ONE HUNDRED YEARS OF CHEMICAL ENGINEERING

CHEMISTS AND CHEMISTRY

A series of books devoted to the examination of the history and development of chemistry from its early emergence as a separate discipline to the present day. The series will describe the personalities, processes, theoretical and technical advances which have shaped our current understanding of chemical science.

ONE HUNDRED YEARS OF CHEMICAL ENGINEERING

From Lewis M. Norton (M.I.T. 1888) to Present

Edited by

NIKOLAOS A. PEPPAS

School of Chemical Engineering, Purdue University,
West Lafayette, Indiana, U.S.A.

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PREFACE

One hundred years ago, in September 1888, Professor Lewis Mills Norton (1855–1893) of the Chemistry Department of the Massachusetts Institute of Technology introduced to the curriculum a course on industrial chemical practice. This was the first structured course in chemical engineering taught in a University. Ten years later, Norton's successor Frank H. Thorpe published the first textbook in chemical engineering, entitled "Outlines of Industrial Chemistry." Over the years, chemical engineering developed from a simple industrial chemical analysis of processes into a mature field.

The volume presented here includes most of the commissioned and contributed papers presented at the American Chemical Society Symposium celebrating the centenary of chemical engineering. The contributions are presented in a logical way, starting first with the history of chemical engineering, followed by analyses of various fields of chemical engineering and concluding with the history of various U.S. and European Departments of Chemical Engineering.

I wish to thank the authors of the contributions/chapters of this volume for their enthusiastic response to my idea of publishing this volume and Dr. Gianni Astarita of the University of Naples, Italy, for his encouragement during the initial stages of this project.

N. A. Peppas
Lafayette, Indiana
November 1988

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Nikolaos A. Peppas

THE ORIGINS OF ACADEMIC CHEMICAL ENGINEERING

1. Chemistry in the Nineteenth Century Germany

The origins of chemical engineering can be linked to the industrial revolution of the 18th and 19th century in Europe and the United States (1-4) and the sociopolitical changes following the 1848 revolution in France and Germany (5-6). No doubt one can claim that chemical engineering was practiced even by the ancient Greeks and Romans when they were making soap or wine, or treating ores in Lavrion or Sicily.

Astarita (7) clarified the importance of Italian scientists of the 15th and 16th century in this development. Davies (8) has stressed previously the influence of 18th century chemistry, physics and mathematics on the development of chemical engineering. But, it was not until the first quarter of the 19th century, especially in England and Germany, that chemical processes in the form of what we now call "unit operations" became the basis of many industries. The production of soap, and wine, the distillation of spirits, the production of sulfuric acid, and the treatment of coal are only a few of a range of processes practiced in those days.

In the beginning of the 19th century, the scientific conditions were such that chemistry flourished in Germany. Prominent among all scientists, Justus von Liebig (1803-1873) may be considered a major force in 19th century chemistry, not only because of his own research but also because of his great gift as an educator (2). Educated in Paris under Joseph Gay-Lussac (1778-1850) and having received a doctorate from the University of Erlangen in 1822, von Liebig established in 1825 a small chemistry laboratory at the University of Giessen, a small town 50 km north of Frankfurt. In the next thirty years, a plethora of students, later famous scientists, would be educated there, including August von Stradonitz Kekule (1829-1896), August W. von Hoffman (1818-1892), C. Adolph Wurtz (1917-1884), and Charles F. Gerhardt (1816-1856).

The two major German Universities of the early 19th century for the study of chemistry were the University of Göttingen and the University of

N. A. Peppas (ed.), One Hundred Years of Chemical Engineering, 1–14.

Heidelberg. At Göttingen, the chemistry laboratories were established by Friedrich Strohmeyer (1775-1835) who was succeeded by Friedrich Wöhler (1800-1882), a student of Leopold Gmelin (1788-1853). The latter was the originator of chemistry at Heidelberg, where he was followed by Robert Bunsen (1811-1899), a student of Strohmeyer.

Thus, in the second quarter of the 19th century, three major chemistry laboratories at the Universities of Giessen, Göttingen and Heidelberg were producing a number of outstanding organic and physical chemists, who would in turn establish laboratories (or "Chairs") elsewhere, including the USA. Here were educated, Ira Remsen (1846-1927, Professor and later President at Johns Hopkins, 1876-1913) and Josiah Cooke (1827-1894, Professor at Harvard University), two of the most prominent U.S. chemists in the third quarter of the 19th century.

What made von Liebig and his students "different" from other chemists was their effort to apply their fundamental discoveries to the development of specific chemical processes and products. The aniline dye process of von Hoffman is only one of many processes developed between 1840 and 1880 in Germany. This trend, however, did not continue past the third quarter of the 19th century. For example, von Liebig moved to a "better Chair" at Munich in 1852, where he became involved in pure, theoretical chemistry.

2. Industrial Changes

The political revolution of February 1848 in France swept eastward across the Rhine, overthrew established authority in Germany, put in power men who had been asking for change and gave central Europe a taste of liberal reform (5,6). One of the main results of these changes was the improvement of work conditions in the industrialized European countries (4). Industrial workers demanded shorter work weeks, higher pay and safe working conditions. This led to a need to revise acceptable industrial processes with an emphasis, albeit primitive, on safer and more efficient methods. Like a phoenix, chemical engineering would emerge from the needs of the mid 19th century.

Despite these developments, education in these areas was not formalized. At best, students obtained some superficial knowledge about these processes in chemistry courses. The operation of distillation columns, filtration units, etc. was taught in "technical" schools, not in Universities. For example, the Technical University of Braunschweig, would soon give such "industrial" courses, but in the eyes of the academic descendents of von Liebig at Göttingen, Heidelberg and Berlin, this was not a "University!"

3. George E. Davis

It was in 1887 that an unknown industrial inspector from Manchester, England, George E. Davis (1850-1906) decided to transfer his vast knowledge from his years of inspecting chemical plants in the industrial region of England to the classroom (9). In the fall of 1887 he gave a series of 12 lectures, later published in the *Chemical Trade Journal*. The material was quite empirical, but it had a definite advantage in that, at last, an individual had put on paper a series of articles on the operation of some of the important chemical processes of those days.

4. The First Chemical Engineering Curriculum

At the end of the 19th century the competition of England, Germany and the United States for industrial chemicals had become rather fierce. It was not surprising then that only one year after Davis' lectures in Manchester, Professor Lewis M. Norton (1855-1893) of the Chemistry Department of M.I.T. started teaching a course in chemical engineering. As Weber (10) notes, the material was taken predominantly from his notes on industrial chemical practice in Germany, which at that time had probably the most advanced chemical process industry in the world.

When Norton died in 1893, Professor Frank H. Thorpe (1864-1932), who had received a B.S. degree from M.I.T. only four years earlier and a doctorate from the University of Heidelberg in 1893, took responsibility for Norton's course and published in 1898 what may be considered to be the first textbook in chemical engineering (11), entitled *Outlines of Industrial Chemistry*. The term "Industrial Chemistry" first appearing in Norton's book to broadly describe industrial processes applied in the production of chemicals would become strongly associated with chemical engineering in the next fifty years. Not until the radical approach to analysis of chemical engineering problems introduced by, among others, R. Neal Amundson and Rutherford Aris in the mid 1950's at the University of Minnesota, and by B. Robert Bird, Warren E. Stewart and Edwin N. Lightfoot at the University of Wisconsin would "industrial

Figure 1: George E. Davis (1850-1906) taught the first chemical engineering course in Manchester, England in 1887.

chemistry" be clearly separated from the main goals of "chemical engineering."

Although Norton and Thorpe were the pioneers of the chemical engineering enthusiasm at M.I.T., it was Arthur A. Noyes and later William H. Walker (1869-1934) who brought to this discipline the respect it should enjoy within the engineering curriculum (12,13). After an M.S. in Chemistry at M.I.T. (1887) and a doctorate at the University of Leipzig with Ostwald (1890), Noyes established the Research Laboratory of Physical Chemistry in 1903. William Walker, who had received his doctorate in 1892 at the University of Göttingen with Otto Wallach (Nobel Prize 1910), saw the importance of such a laboratory in chemical research and established in 1908 the Research Laboratory of Applied Chemistry.

During the same period in England, Davis proceeded with the publication of his *Handbook of Chemical Engineering* in 1901, which was revised and published in a second edition of over 1000 pages in 1904. Davis was responsible for adopting the idea of "unit operations" (especially in the second edition of his book (9)) although the term was coined by Arthur D. Little (7) at M.I.T. much later, in 1915. This was the idea that all chemical processes can be analyzed by dividing them in distinct operations (distillation, extraction, filtration, crystallization, etc.) which are governed by certain principles. More than anything, however, Davis was responsible (9) for coining the term *chemical engineering* to describe this new engineering area addressing problems of the chemical industry.

In the United States, M.I.T. is considered to be the first university to offer a four-year curriculum in chemical engineering (a "course" X in M.I.T.'s parlance), in 1888*. However, as a Department, Chemical Engineering did not become independent until 1920! Until then it was the Division of Applied Chemistry of the Department of Chemistry. In those early days Walker (for whom the most prestigious AIChE Award is named) was the main driving force of the Division, assisted by Warren K. "Doc" Lewis (1882-1975, for whom the prestigious AIChE Teaching Award is named) after his return from the University of Breslau where he

* In recent years many faculty members of Departments of Chemical Engineering have presented detailed or often cursory "histories" of their Departments (see for example the 1968-1986 issues of *Chemical Engineering Education)*. In these articles one finds a persistent effort of many of the authors to prove that their Schools have existed for more than 75 years, in one case since 1853! The truth is that even if an "industrial chemistry" course was taught at a university, this would not constitute acceptance of a chemical engineering curriculum.

Figure 2: Professor Lewis M. Norton (1855-1893) of the Chemistry Department of MIT taught the first chemical engineering course in the United States in 1888.

had studied with Richard Abegg, receiving his doctorate in 1908. Abegg was a student of A.W. von Hoffman. Noyes, after a few more years at M.I.T., would move to Pasadena, California in 1913 to transform what was then Throop College to the world-known California Institute of Technology.

Other Universities followed the examples of M.I.T. The University of Pennsylvania (1894), Tulane University (1894), University of Michigan (1898), and Tufts University (1898) created four-year programs in Chemical Engineering, but always as part of their Chemistry Department.

5. Early Chemical Engineering Courses

The training of chemical engineers was a subject of much debate in the first years of the 20th century. Milton C. Whitaker, a professor of Chemical Engineering at Columbia University and an important contributor to the ChE literature and societal causes expressed his views on the training of chemical engineers (14) as follows: "The chemical engineer works in the organization, operation and management of existing or proposed processes with a view to building up a successful manufacturing industry... His fundamental training in chemistry, physics, mathematics, etc., must be thorough and must be combined with a natural engineering inclination and an acquired knowledge of engineering methods and appliances." He continued by giving a description of the types of courses that should be taught, which he classified as courses for "fundamental training" (chemistry, physics, mathematics), "associated training" (electrical, mechanical, civil and general engineering, and business economics) and "supplementary training" (laboratory and administration courses).

Whitaker's views are presented here with some emphasis because he was a most influential educator and researcher, one of the earliest members of AIChE and its President in 1914. Whitaker, who had studied Chemistry (Ph.D. '02) with Franz Sachs (a student of Siegmund Gabriel at the University of Heidelberg) and received the Perkins medal in 1923, was one of the earliest "true" chemical engineers, who believed in the rapid separation of "industrial chemistry" from "chemical engineering." His views affected his graduate students, prominent among which was Eugene E. Leslie (Ph.D. '15, Columbia University) who taught at the University of Michigan. Leslie along with his students George G. Brown (Ph.D. '24) and Warren L. McCabe (Ph.D. '28) created an excellent Department of Chemical Engineering.

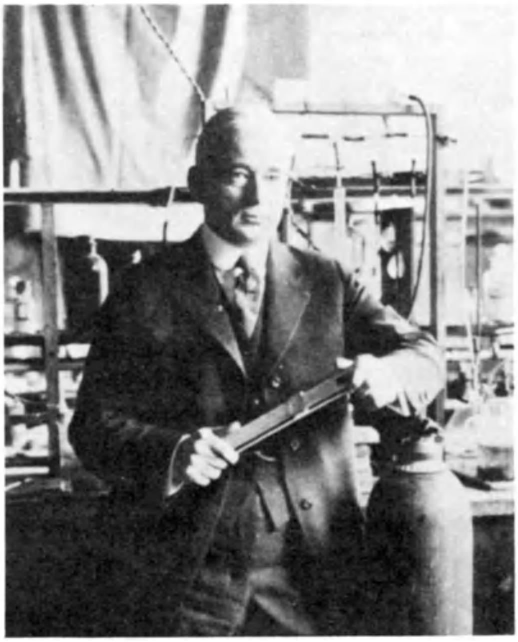

Figure 3: Professor William H. Walker of MIT in 1907.

The establishment of the American Institute of Chemical Engineers (AIChE) in 1908 gave shape to the dreams of the "converted chemists" who were calling themselves "chemical engineers" (15), albeit with major obstacles. For example, Hugo Schweitzer (11) declared in a 1904 ACS meeting: "I am absolutely against the introduction of chemical engineering in the education of chemists." In the same meeting, M.T. Bogert (16), later a colleague of Whitaker, who did not join Columbia until 1907, agreed with Schweitzer saying that progress in "technical chemistry" was achieved in research laboratories by researchers *without* engineering training. In the same meeting Whitaker became the apologist of chemical engineering stating that a chemist was "generally not the man who is capable of transmitting from a laboratory to a factory the ideas which he has developed" because he was not educated "in the engineering branches." With such debates, when AIChE was formed in 1908 it had only 40 members (out of a possible 500 chemical engineers). The number rose to 214 in 1914 when Whitaker was President but it was not until 1926 that AIChE truly became a representative society of chemical engineers.

Olaf A. Hougen (17) of the University of Wisconsin, for example, notes that it was only "from 1888 to 1923 that industrial chemistry was the chief offering of all chemical engineering departments ...," and he continues " in these courses, the sequences of steps in chemical manufacture were described. The approach did not allow much time for discussion in depth of the scientific principles involved." Hougen remarks also that the introduction of unit operations by Walker, Lewis and McAdams of MIT during the 1920's "marked the beginning of the distinctive American system of chemical engineering education." Hougen concludes that the next three decades (1920-50) in the development of the science of chemical engineering "came with the application of physical chemistry to material and energy balances, to thermodynamics, and to rates of chemical reactions in industrial processes."

Robert L. Pigford of the University of Delaware, a deep thinker and analyst of the progress of chemical engineering in the 20th century, who in recent years has been one of the major supporters of an increase in chemistry courses for undergraduate chemical engineers, notes (19) that "an equally important contribution to the role of applied physical chemistry in chemical engineering occurred in 1936 with the book *Industrial Chemical Calculations*" by Hougen and Watson. "Their textbooks had a profound effect upon students in the forties and fifties and thus upon many practicing engineers today."

Meanwhile, the first Ph.D. degrees in chemical engineering were awarded to C.H. Herty and J.L. Keats of MIT in 1924. Soon thereafter the Universities of Michigan and Wisconsin, Columbia and the University of Pennsylvania gave their first Ph.D. degrees in the same area (19).

6. Development of Engineering Science

The development of the field of unit operations, and the subsequent introduction of thermodynamics and chemical kinetics led to further developments of the chemical engineering field.

The year 1955 marked an important change in Engineering education throughout the United States. In May 1952 S.C. Hollister, President of the American Society for Engineering Education (ASEE), appointed a *Committee on Evaluation of Engineering Education* with the goal to evaluate engineering education and suggest new approaches to teaching engineering. When the report of this committee was published on June 15, 1955 a long chapter in the history of engineering education had ended.

The report was only thirty-six pages long. It was polite to the older tradition but firm in its recommendations to the new generation (20).

> The objective in engineering curricula will not be achieved... by repair of patchwork curricula. It requires complete reconstruction of curricula.
>
> Some attention to engineering art and practice is necessary, but its high purpose is to illuminate the engineering science, analysis or design, rather than to teach the art as engineering methodology.
>
> It is the responsibility of the engineer to recognize those new developments in science and technology that have significant potentialities in engineering. Moreover, the rate at which new scientific knowledge will be translated into engineering practice depends, in a large measure, upon the engineer's capacity to understand the new science as it develops.
>
> Fortunately, some things do not change. Reactions, stresses, and deflections will still occur, and they will have to be calculated. Electrical currents and fields will follow unchanging laws. Energy transformation, thermodynamics, and heat flow

> will be as important to the next generation of engineers as to the present one. Solids, fluids, and gases will continue to be handled, and their dynamics and chemical behavior will have to be understood. The special properties of materials as dependent upon their internal structure will be even more important to engineers a generation hence than they are today. *These studies encompass the solid, unshifting foundation of engineering science upon which the engineering curriculum can be built with assurance and conviction* (author's italics).

Gradually the committee built the framework of a scientifically oriented curriculum. According to their recommendation the curriculum should consist of humanistic and social studies (one fifth), mathematics and the basic sciences (one fourth), engineering sciences (one fourth), engineering analysis and design (one fourth), and elective courses (one tenth).

The recommendations of the Hollister report created much discussion throughout the country. The older generation of instructors opposed them vehemently. The younger generation accepted them. For the first time the word *engineering science* was appearing in an official document on engineering education.

7. The Minnesota/Wisconsin Revolution

In the early days of chemical engineering, the teaching of and research in industrial chemistry was the central theme. Around 1920, unit operations became the main focus of chemical engineering research and education and was so until the war. In the 1930's applied thermodynamics also became an important component of academic chemical engineering (21,22).

Two developments that occurred at the University of Minnesota and the University of Wisconsin in the 1950's changed the course of chemical engineering. Five academic researchers would become the leading forces of major changes in chemical engineering education and research. These five educators were Neal R. Amundson, Rutherford Aris, R. Byron Bird, Edwin N. Lightfoot, Jr. and Warren E. Stewart. Their "message" was controversial and much questioned, but it was gradually accepted by both industry and academia.

When Charles A. Mann, the founder of Chemical Engineering at the University of Minnesota died in 1949, the search outside the department for a new head was unsuccessful (23) and Neal R. "Chief" Amundson, who had been made Acting Head in 1949, while still an Associate Professor, became the Head in 1951. Amundson was an educator and researcher with far-reaching insight. Educated both as a chemical engineer and a mathematician (his Ph.D. in 1945 was from the Department of Mathematics), he soon realized that further insight into chemical engineering problems lay in an analysis of chemical processes and phenomena based on fundamental understanding of these problems. Applied mathematics and later the computer would become excellent tools for generalization and solution of various transport and reaction engineering problems. His first steps into this area were taken with some of his early graduate students such as Andreas Acrivos of Stanford University and the late Leon Lapidus of Princeton University. They were followed by a bold attack on a wide range of chemical engineering problems, especially those involving chemical reactor design, with the collaboration of an adventurous young mathematician and a fast learner in chemical engineering, Rutherford Aris, whom Amundson met at Cambridge in 1955. Amundson and Aris became a powerful duo in our profession and the heart of what is considered by many to have been the best chemical engineering graduate program ever, the University of Minnesota of the 1960's and 70's.

At about the same time, a second major educational revolution was occurring at the University of Wisconsin. Professors Bird, Stewart and Lightfoot, collectively known to future generations of students as BSL, prepared a set of notes (in 1957) and eventually a book (in 1960) entitled *Transport Phenomena,* which offered a new approach to the analysis of chemical engineering unit problems. The main lesson of BSL is that there is a strong unifying backbone to apparently different unit operations in the framework of the continuum equations of transport. The necessity for analysis of individual operations or processes does not disappear, but the differential volume and the balance equations become the central theme of this approach.

Thus, in the mid 1960's the major chemical engineering departments in the United States, with a handful of exceptions, were adjusting to the new ideas of our profession. Unit operations had definitely declined and unit processes were almost obsolete (17) as unifying themes for education and research.

8. Interdisciplinary Work

A third revolution, the implications of which would not be felt until the mid 1970's, was also occurring in chemical engineering in the early 1960's. This one did not start from one specific school but was rather initiated by a group of gifted educators and researchers in various universities and industrial government laboratories. These researchers recognized that chemical engineers could contribute significantly to areas outside of the main attention of classical chemical engineering, interdisciplinary areas such as biochemical and biomedical sciences, and polymers. Elmer L. Gaden of Columbia and Arthur E. Humphrey of the University of Pennsylvania in biochemical engineering, Arthur B. Metzner of the University of Delaware and R. Byron Bird in polymer engineering, Edward W. Merrill of M.I.T. in biomedical engineering and Michel Boudart of Stanford and Richard H. Wilhelm of Princeton in catalysis were only some of these researchers.

The changes in educational activities were associated with major changes in research. The National Science Foundation, National Institutes of Health and other federal agencies became a "paradise" for funding of the work of the *nouvelle vague* of chemical engineers, and major contributors to the success of the graduate programs of many Schools.

Thus, at the end of the seventies chemical engineering was an extremely active field of education and research throughout the world.

9. Affiliation of the Author

School of Chemical Engineering
Purdue University
West Lafayette, IN 47907 USA

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D.C. Freshwater

THE DEVELOPMENT OF CHEMICAL ENGINEERING AS SHOWN BY ITS TEXTS

"Just as the arts of tanning and dyeing were practiced long before the scientific principles upon which they depend were known, so also the practice of Chemical Engineering preceded any analysis or exposition of the principles upon which such practice is based." Walker, Lewis and MacAdams(21), Preface to 1st. edition.

1. INTRODUCTION

Chemical Engineering is the newest of the four major engineering disciplines. Civil and Mechanical Engineering for example, both predate it in terms at least of their professional associations by some 100 years. It emerged as a separate discipline somewhat slowly, almost reluctantly between the end of the 19th and the early 20th century but was well established by the late 1920's. This late beginning and prolonged labour tends to conceal the fact that many of what are today regarded as standard unit operations were practiced long before the subject was recognised. This lack of recognition is compounded by the fact that so many histories of technology treat either the development of scientific theories or of mechanical inventions. Those which describe the growth of chemical technology tend to do so on the basis of particular products or groups of products. For example the contents list of volume 3 of Singer's History of Technology(1) shows that it is almost wholly product orientated whilst the same tendency is followed in the last chapter dealing with chemical inventions. One could cite several other examples but without labouring the point it does seem that there has not been much effort towards describing the emergence of unit operations as such except in a very few instances e.g. the first edition of Dickey's book on Filtration(2). In using this product pattern the historians of science have followed the precedent of the chemical industry of the 19th century which was hampered in its development by its failure to recognise that the many products which

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it made all had a number of processes or operations in common which, when studied in the abstract could display rules of general applicability. This was the foundation stone for the building of chemical engineering and unless it is recognised as such then the approach to chemical engineering will be too narrow. This concept was first put into written form by Geo. E. Davis in his Manchester lectures, later published as the First Handbook of Chemical Engineering.(3) However it is not the purpose of this paper to establish or dispute priorities nor to try to explain why this concept which we tend today to regard as self evident took so long to discover. Rather is it the purpose to (a) draw attention to the early practice of certain unit operations as shown in published books and (b) to show how the more modern development of the subject may be traced through text books published in the last 60 years. Books have been taken as the touchstone of this development rather than papers or patents for two reasons. First, the publication of a book implies the existence of a substantial body of knowledge which is codified at least to some extent by being written in book form and published. In other words, books tend to represent existing knowledge (and practice) rather than new discoveries or inventions. The second reason is that books, by their nature are likely to be more widely disseminated and read than are papers or patents and therefore may possibly have a greater influence on the development of a whole subject. Particularly is this likely to be the case in the training of new artisans and professionals.

2. SOME EARLY UNIT OPERATIONS

I shall begin arbitrarily in the early 1500's because this was when one of the most extensive and possibly influential texts of all was published - De Re Metallica by Agricola (Georg Bauer)(4).

This magnificent compilation of technology, of which there is an excellent English translation by Hoover, is sober if not humbling reading for all who think that particle technology with all its ramifications was discovered in modern times. The illustrations are not only works of art but have enough detail that a skilled millwright could make most of the equipment required to carry out operations such as transport of fluids (gases and liquids), size reduction, separation both by size and by species and roasting operations. This book, well known amongst historians of science deserves to be better known and appreciated by chemical engineers. Just one example will be cited to show the extent and modernity of this work - it is the pump which operates by drawing up a series of plugs fixed on an endless belt which passes inside a pipe of slightly larger diameter. This work influenced the performance not only of mining operations but of many solids handling processes for at least three hundred years. In this book, stripped of all the magic and much of the mystery are exposed the basic processing procedures for solids handling. Agricola is not concerned with alchemy nor with pretentious theorising but with the practical ways of extracting and refining metallic ores.

It is interesting that at about the same time another notable work on technology was written - L'Art de Terre by Palissy.(5) The word notable rather than important is used because although Palissy undoubtedly discovered and wrote down much on the technology of ceramics, his works were not in fact well known (in contrast to those of Agricola) and do not appear to have been published until the 19th century. However so effective were they that even then they were able to have an effect on this industry.(6)

The third text which appears to be significant at about this time is the work of Brunschweig (or Braunschweig) Liber de Arte Distillandi de Simplicibus and Liber de Arte Distillandi Compositis 1500-1507.(7) These two volumes, which were to be copied frequently by other writers set out with many illustrations the known practice of distillation at that time and were to serve as the guide for many years into the future. It is hard in these books to recognise much of what we think of today as distillation but their importance is not so much the quaint apparatus as the approach to describing technological apparatus free of magic and in sufficient detail to enable would be practitioners to build the equipment. For further detail on this work the reader is referred to the classic History of Early Distillation by Forbes.(8)

We now come to a remarkable gap in our technological books. There was no book of any note from this time until the nineteenth century as far as chemical technology (and hence chemical engineering) was concerned. It is as though technology and chemical technology in particular stagnated for 200 years. Indeed this is probably an accurate description of the latter since little real progress could be made without adequate theory. Much has been blamed on the phlogiston heresy although McEvoy has pointed out recently that this is too facile a view(9). More important was the lack of a realistic stoichiometry and an atomic and molecular theory. In a useful work, Berry and Williams (10) have presented a table of concurrent events in history including scientific and technological development. It is interesting to see that no notable books in the field of chemical or process technology were published between about 1580 and 1800. This paper is not concerned with theoretical treatises which were essential to the future development of chemical industry. However notice must be taken of Boyle's Sceptical Chymist (11) which did so much to stimulate thought and progress in chemistry and also of the collections of Royal Society publications made by Houghton (12). These together with the publications of Lavoisier, Dalton and many others laid the basis for the chemical revolution described by Partington (6). This is usually associated with the beginning of the industrial revolution but it also had a strong push from the Napoleonic wars. France at this time must be regarded as the leader in chemical processing and especially in that part of it which is peculiarly chemical engineering in nature, namely the physical operation of distillation. This was important not so much for its application to potable spirits but much more for the production of alcohol as an industrial solvent. The stimulus provided by the invention of Cellier Blumenthal (8) was continued by Savalle who, unrecognised by many writers, produced one of the key inventions for modern processing. He introduced the first true automatic controller for a process plant with his steam regulator. It is difficult to overemphasise the importance of this which was patented in 1845. Without it, continuous operation was not conceivable and thus the Coffey still which relied absolutely for its success upon batch operation (since it had no provision for removing fusel oils) and which was so popular was made obsolete (or would have been were it not for the quaint excise laws). Stock (13) has drawn attention to early inventions important to the development of chemical processing but this one of Savalle's not only predates these but is essentially more significant than many later ones. However, this is not a history of chemical engineering invention and it is necessary to return to the main stream of the argument. The middle to late 1800's were marked by a series of books on distillation and on the processing of coal tar which were in their way important precursors of chemical engineering. Foremost amongst these was that of Barbet which summarised the vast strides the French has made in the art of distillation by this time (14). In it is described many distillation techniques which are looked upon as modern at present although the names given to them are not necessarily the same. For example, taking a "heart cut" was practiced long before the petroleum industry was born. The French called it "pasteurisation". When petrochemicals began to be made on a large scale many of the techniques of the early French engineers had to be rediscovered. Simultaneous with this practical development came the seminal work of Sorel (15) published in 1889 on the theory of fractional distillation which solved the stagewise calculation process.

Close in time were published two books by Hausbrand in Germany, the first a textbook on distillation and the second, on evaporation (16,17). These were thorough almost exhausting tomes on the practical techniques of these two operations with numerous tables enabling the performance of actual separations to be selected very easily. No doubt generations of Hausbrand's students had worked laboriously at compiling these by hand calculations. One can still use Hausbrand's tables in his book published in 1893 to determine the number of plates required in an alcohol stripping column to effect a given degree of exhaustion from a given strength of wash and be confident that the answer will correspond to actual experience. His book on evaporators is likewise full of useful practical data including the first (and until very recently) the only published data on the performance of direct contact condensers.

In view of all this activity of which only a relatively small part has been described, it is surprising that chemical engineering did not emerge as a discipline in either France or Germany nor yet in the U.K. where the publication of the first textbook on Chemical Engineering, Geo. E. Davis's handbook took place in 1902 (3). The reasons for this have been concisely and convincingly covered by Guedon (18) and need not be further expounded here. Suffice it to say that despite the clear recognition by Davis of the essential chemical engineering idea and his vigorous prosecution of the name neither his book nor his philosophy made any significant impact on the technical world of his day. The book and its writer have been described by the author in a previous paper (19) and is mentioned here not because of its influence which was miniscule but because it showed more clearly than any of the other texts of the time, the development of the subject as a whole instead of a set of individual operations. Clearly the time was ripe for its emergence and appropriately enough, this happened in the United States, already becoming the technological leader of the world.

3. THE NEW TECHNOLOGY

Naturally, this new branch of engineering did not spring ready armed from the ground but its growth was phenomenally rapid. From the invention and enunciation of the unit operation title by Little (20) to the establishment of schools in the leading universities was but a matter of a few years. Now it is obvious but no less true that to teach a subject requires textbooks and there was a corresponding burgeoning in the publication of books on chemical engineering. Many of these early books became classics and are rightly regarded as so by those who still own first editions or even those old enough to have been taught with their aid. Walker, Lewis and MacAdam's Principles of Chemical Engineering (21) appeared in 1923 the same year that Liddell's 2 vol Handbook of Chemical Engineering was published (22). Although early efforts to start teaching chemical engineering in the U.K. had not succeeded they were revived in the early 1920's albeit on a part-time basis. Norman Swindin, a protege of Davis, wrote a series of monographs on various aspects of chemical engineering to assist in this effort. These interesting again, not so much for their influence as for demonstrating the way in which the subject was spreading. Incidentally his book on Chemical Works Pumping published in 1922 was the first to draw to the attention of chemical engineers, the importance of Reynolds number in fluid transport of chemicals (23). But it is "The Principles" which really set chemical engineering on the path to eminence as an established profession. Not only does it show great perception and power of style, more importantly from the point of view of this paper, it demonstrates the extent to which the subject had attained a recognisable format. Any really great text will make its own contribution to the codification of a subject and this book set the course for chemical engineering. Two quote again from the preface to the first edition:- "In this book we have attempted to recall to the reader's mind those principles of science upon which chemical engineering operations are based and then to develop methods for applying those principles to the solution of such problems as present themselves in chemical engineering practice.

.....so far as is now possible the treatment is mathematically quantitative as well as qualitatively descriptive." It was in the 1920's and 30's that a whole series of significant texts were published, most of them in the U.S.A. Almost all of these were concerned with the physical operations of transport processes and solids processing which presumably reflects the needs and understanding of the role of the chemical engineer at that time. Although the first edition of Hougen and Watson on Chemical Process Principles appeared in 1930 (24) it did little to restore this balance. This is not to say that it was not a significant text, but the chemical engineer charged with designing a chemical reactor at this time would have had to go to the chemical literature for assistance. Theory was well served by Lewis and Randall's book (25) published in 1933 but it was to be more than 20 years before a book dealing specifically with reactor design would appear which would treat of this in Walker's terms i.e. "applying principles of science to the solution of (the) problems in a mathematically quantitative way". It is remarkable but true that as late as the 1950's one could graduate as a chemical engineer without knowing anything about chemical reactor design. Many courses had virtually nothing in their curricula on this topic.

The next year saw the arrival of the first edition of Perry in the dumpy format in which it literally was a handbook (26). To avoid making this a mere catalogue and for ease of reference, Table 1 is a chronological list of books published between 1880 and 1940. It was a rerun in chemical engineering of the great 18th century era of certainty before people like Rousseau introduced doubt. This was not to last however and the first seeds were perhaps sown by the publication of Mathematical Methods in Chemical Engineering by Sherwood and Read (27). Change which is always inevitable but not necessarily good and certainly not comfortable, was about to begin. Naturally the change was gradual and even artificially lengthened by WWII when the emphasis was on production at almost any cost. This experience however was itself responsible for the development and introduction of several significant new developments in the subject which were eventually reflected in both books and teaching. Failures in distillation scale up led to a renewed interest in this which may be seen reflected in books like the 1950 edition of Robinson and Gilliland (28). Similarly problems in design led to Kern's Heat Transfer (29), perhaps the last great chemical engineering text written by a practitioner to be published. Another key book which essentially came out of wartime experiences of the lack of published material and consequent design inadequacies was Denbigh on Chemical Equilibria (30). Finally what I call this transition period was marked by the first signs of what was to burgeon into a particularly fruitful field for academic authors, the first book on what might be described as modern process control by Ceaglske (31).

4. THE CHEMICAL ENGINEERING SCIENTIST

In the last twenty to thirty years a profound change has come over chemical engineering at least as perceived in its text books. Nowadays, as opposed to previous centuries, practically all text books in a subject such as this are written by academics and thanks to the system that we have developed, fewer and fewer of these have any substantial industrial experience. Thus the nature of their work reflects their interests in peculiarly academic directions. Thus chemical engineering books no longer reflect to anything like the extent that they did in the past, the practice of the profession but rather the research interests of the authors. This may seem a harsh criticism but is not meant as such but rather as an observation of the changes that have occurred. These changes are exemplified and indeed may be said to have been partly induced by one famous book, Bird, Stewart and Lightfoot, Transport Phenomena (32). This has since had many imitators but it stands supreme in (a) its precedence in the growing recognition that the old unit operation concept was outdated and (b) in its development of a new intensity of mathematical approach to the subject. This book and its "look-alikes" have almost literally swept the academic world of chemical engineering since the early 1960's and produced a new generation of chemical engineers who are different from anything that has gone before. Whether these are better or worse remains to be seen but it certainly is an extraordinary phenomena that will become part of the future history of the profession. There is perhaps only one other remarkable text book in this time period and that is The Strategy of Process Engineering by Rudd and Watson (33). This is remarkable for several reasons not least of which is its virtual neglect by so many academics. It was the first book to recognise (a) that design was not something picked up by experience but was a formal procedure with its own rules which could not only be learnt by students but could be taught in a rigorous manner and (b) that the chemical engineer needed to know about a whole range of techniques outside the narrow ever more scientific approach of chemical engineering science (sic). Here is a book that truly reflects the practice of the profession in industry far more than any other published in the same time period. Hence in the sense of the theme of this paper it is a very significant book and will be seen as such in the future.

Writing about historical developments tempts one to make predictions about the future but I will try to avoid this and merely draw attention to what I believe to be a very important new development in our subject. This is the topic of Loss Prevention and I am able to include it because there have been several books published by chemical engineers on this in the last ten years. Of these by far the most extensive (and biggest) is the two volume work by Lees (34). These books and this text in particular bring us back to the idea of this paper that the text books of chemical engineering enable us to follow the development of the subject not only in the past but even up to the present time.

I am conscious that I have omitted many excellent and perhaps important books in this review. I also freely admit to allowing a fairly free rein to my prejudices but hopefully this has made it more interesting or even more stimulating to read. I hope no-one will try to draw lessons for the future from it.

Department of Chemical Engineering
Louisiana State University
Baton Rouge, Louisiana 40803-7300, USA

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N.A. Peppas

ACADEMIC CONNECTIONS OF THE 20TH CENTURY U.S. CHEMICAL ENGINEERS: INFLUENCE OF THE 18TH AND 19TH CENTURY SWEDISH, FRENCH AND GERMAN CHEMISTS

1. Introduction

The preparation of academic genealogical charts has been a natural way to crown the retirement celebrations for a distinguished scientist, especially a university professor. It appeared for the first time in Germany during the second half of the 19th century. The academic genealogical tree of Justus von Liebig (1803-1873), the famous German chemist who was professor at the University of Giessen from 1824 to 1852 and then at the University of Munich from 1852 to 1873, is probably the most well-known one, and can be admired at the Liebig Museum in Giessen, Federal Republic of Germany.

In the early days of chemistry, especially organic chemistry, between roughly 1820 and 1895, academic genealogy was a way for proud professors (and proud former students) to show their common roots, their similar research interests and their influence upon the world of chemistry. This was a great period for organic and physical chemistry (1-7), when the students of Jöns Jakob Berzelius, Friedrich Wöhler, Friedrich Strohmeyer, Robert Bunsen, Justus von Liebig, Friedrich Kekulé, August von Hoffman, and later of Adolph von Baeyer, Viktor Meyer, Friedrich Wilhelm Ostwald, Otto Wallach and Hermann von Helmholtz were the leaders of the chemical (and physical in the case of Helmholtz) research and education world.

Probably the most distinguished assembly of chemists in the history of science (8) could be found at the First International Chemical Congress which was held in Karsruhe in the Kingdom of Baden in 1860. Aside from Kekulé, Liebig, Wöhler, Bunsen and von Baeyer, there were also present Jean Baptiste Dumas, Hermann Kopp, Adolph Kolbe, Sir Edward Frankland, Dmitri Mendeleev, Friedrich Beilstein, Lothar Meyer and Charles Friedel, all of them "academically related." It was at this meeting that Stanislao Cannizzaro, a young Italian chemist who was working in Sardinia, and a former assistant of Michel Chevreul in Paris, burst in an

N. A. Peppas (ed.), One Hundred Years of Chemical Engineering, 27–37.

outright support of the "forgotten" atoms/molecules hypothesis of another great Italian chemist, Amedeo Avogadro, who had died four years earlier.

Chemical engineers, especially U.S. engineers, have not been that interested of academic trees, at least not during the days of infancy of our profession. However, in the past twenty years such academic trees have been prepared by the former graduate students of a well-known figure of the profession, especially on the occasion of the termination of his/her service with a university, or on an important anniversary. Such academic genealogical roots are now available for Olaf Hougen of the University of Wisconsin, Neal Amundson of the Universities of Minnesota and Houston, Edward Merrill of MIT, and Stuart Churchill of the Universities of Michigan and Pennsylvania. Other academic trees have been privately circulated among former students and associates.

2. Academic Genealogy and the History of Chemical Engineering

In the present work we have undertaken a long and painstaking effort to rediscover, reexamine and complete the global academic genealogical chart of U.S. (and other) academic chemical engineers. This effort was not triggered by vanity or by an effort to show pride in our common routes, but rather by an effort to discover the influence of other scientific areas on the development of academic chemical engineering. It is then rather interesting to follow the transfer of similar ideas from one professor to his students, and yet to examine the evolution of these ideas as "schools of thought" and groups of philosophical approach to chemical engineering developed during the past 85 years.

When the project of discovery of the academic roots of US ChE professors was completed it became apparent that more than 90% of the current and past academics could be linked together in one academic family.

Figure 1 offers a global view of the natural development of chemical engineering from chemistry, which in turn had sprung from medieval alchemy, medicine and botany. Most of the names appearing in the genealogical charts for the 14th through 17th century were physicians, botanists or early physicists (6-11). From these scientists came in the 18th century the development of strong chemical developments. Finally, these developments led eventually to the creation of chemical engineering, especially after 1880 and predominantly in the United States.

Two main academic lines can be distinguished. These lines include a number of famous scientists that developed a number of schools of thought, especially between 1750 and 1875. Line I (Figure 2) effectively starts with the father of modern chemistry, Antoine Lavoisier, in 1763. During its first 60 years it is a predominantly French line, but after the establishment of the laboratory group of Justus von Liebig in Giessen in 1824 it becomes a German line. Historically, it is known as the French-German academic chart.

Line II (Figure 3) has its origins in a French mathematician and astronomer, Pierre Mauperthuis, and starts roughly around 1724. His greatest student was the Swedish astronomer Anders Celsius, who established a Swedish school of scientists. His other follower was Georges Buffon, a French naturalist, whose books and lectures at the Jardin du Roi of Paris influenced two generations of botanists and indirectly many chemists. Line II is traditionally known as the Swedish-German genealogical chart, sometimes also mentioned as the Swedish-French-German chart.

It is commonly agreed that the most important scientific developments in the last century of the medieval period came from Italy, France and England and were made by physicians and astronomers. Soon thereafter, important scientists from the Scandinavian peninsula and the Netherlands contributed significantly to these fields. Whereas Italian, French and Dutch scientists created schools of academic followers, English scientists worked usually independently. The absence of strong British genealogical charts is observed throughout this analysis, although this does not mean that important English or Scottish scientists do not exist (12-20).

The beginnings of any modern academic genealogy (Figure 1) can be associated with the Flemish anatomist Andreas Vesalius (1514 - 1564) who studied medicine at the Universities of Louvain and Paris and received his medical degree from the University of Padua in 1537. Vesalius is off course the father of modern anatomy. In Paris he had studied under Jean Francois Fernel (1497-1558), a French physician and professor at the University of Paris (1534-1558). Vesalius became professor of medicine at the University of Pavia in 1540 and transferred later to Bologna and Pisa. He was influenced by the writings of Mondino de Luzzi (1275-1326), a famous Italian anatomist of the 14th century, and Miguel Servetus (1511-1553), a Spaniard physician whom he had met in Paris in 1535. The influence of Mondino de Luzzi is the earliest link to the genealogical charts presented here that can be made with some historical credibility. Some well-known 20th century scientists have told me that their academic tree has been traced back to Aristotle. Such a connection may be possible because of the Aristotelian influence on the writings of most "scientists" of the medieval ages, but it is probably a historically unacceptable one.

3. Construction of the Genealogical Charts

For the construction of the genealogical charts shown here, current U.S. (and other) academic researchers and educators were linked to the persons who directed their Ph.D. or similar degrees. This was especially true for the case of degrees issued after 1850. Some well known researchers of the last 135 years did not obtain a doctorate. They were linked according to the professor or professors with whom they performed an important research project as undergraduate students, and to the researcher who had most influenced their early research contributions (e.g. coauthor in their first publications). Such is the case of R. Norris Shreve (1885-1975) who received only a B.S. degree from Harvard University (1906), but who, while at Harvard, did significant research with Latham Clarke, an assistant and former Ph.D. student of Theodore Richards (1868-1928), in fact in Richards' laboratories. A similar situation can be referred to Otto Kowalke, who received his B.S. at the University of Wisconsin (1909), where one of his most influential teachers was Louis Kahlenberg, whereas his mentor was Charles Burgess.

During the past century a number of well-known researchers performed their doctoral thesis independently or *in absentia,* and submitted it to a particular school for approval. This is for example the case of Warren McCabe who performed his doctoral work (1928) mostly at MIT but under the nominal direction of Eugene Leslie of the University of Michigan. Rutherford Aris did his Sc.D. work at the University of Minnesota but submitted to the University of London (1960). No professor is mentioned as an "academic advisor." A few years ago, Aris asked to be linked to Neal Amundson "as his student," a request that is only natural, since Amundson was his mentor in his early years at Minnesota.

In the development of the academic connections of the 19th century researchers it became necessary to recognize some strong associations which became more important that the typical professor/student relation in the development of whole schools of thought. The most classical example is that of two contemporary researchers, Robert Bunsen (1811-1899) and

Gustav Kirchhoff (1824-1877) who, without having any common academic education, became best friends and collaborators as professors of organic chemistry and physics respectively, at the University of Heidelberg for over 30 years (1854-1887). In another interesting case Friedrich Wöhler (1800-1882) received his medical degree in Heidelberg (1823) where he had Leopold Gmelin (1788-1853) as his primary mentor. Yet, soon after his degree in 1823 he went to Uppsala where he worked for seven years (1823-30) as assistant of Berzelius. He became the main spokesman of Berzelius' ideas until he became professor of chemistry at the University of Kassel in 1830 and the University of Göttingen in 1836. Therefore, it is only natural that he be linked to Berzelius as well (21-25).

The cases of Viktor Meyer and Max Bodenstein are also quite interesting. Viktor Meyer (1848-1897) did a doctoral thesis at the University of Heidelberg (1867) on a subject suggested and supervised by Adolf von Baeyer (1835-1917) who at that time was simply an assistant of Bunsen. The "official" supervisors of his thesis were the organic chemist Bunsen, the physicist Kirchhoff and the physical chemist Hermann Kopp (1817-1892). He is therefore linked to all four of them, although in terms of philosophy of research he remained a follower of von Baeyer. Max Bodenstein (1871-1942), often called the father of electrochemistry, did his doctoral work under Viktor Meyer at the University of Heidelberg (1894). For the next eleven years (1895-1906) he became the main assistant of Wilhelm Ostwald, ultimately converted to physical chemistry which he practiced when he became professor in the Universities of Hannover and Berlin. Here he is linked to both Meyer and Ostwald.

Adolph von Baeyer (1835-1917) was another major German chemist, who was somewhat difficult to link to others. His doctoral work was suggested and partially supervised by Friedrich Kekule (1829-1896), who at that time (1856-58) was an assistant of Bunsen at Heidelberg. However, the actual thesis of von Baeyer was submitted to the faculty of the University of Berlin (nominal reader was Eilhardt Mitscherlich) in 1858, and the degree was issued by this last University. Therefore, von Baeyer is linked to Kekulé and Bunsen.

Ernest Gibson presented another rather complicated situation. He started his doctorate with Richard Abegg (1869-1910) at the University of Breslau then in Germany (now Wroclaw in Poland). Yet Abegg died in 1910 and Gibson continued and finished his degree (1911) under the somewhat loose advisorship of Otto Lummer. It is therefore quite clear why some researchers of the genealogical chart of Henry Eyring connect him only to the von Helmholtz tree (Line X, Figure 1), although the Eyring chart should be also connected to that of von Hoffman.

In all the figures of this work, the terms Ph.D. and M.D. are used as abbreviations of a doctorate and a medical degree, although it is quite clear that in non-anglosaxonic countries these degrees were never indicated by these initials. For most of the researchers of the 18th century and the beginning of the 19th century, the necessary linking has been done according to assistantship or lengthy apprenticeship, since a doctorate was not available in most cases.

Connections in the 15th and 16th century were not always possible, although the famous link of Vesalius/Fallopius/Fabricius/Harvey is a true one, all having been medical researchers at the University of Padua in Italy. Other academic links have been established during these two centuries according to the strong influence that one researcher's work and writings had on the research and philosophy of another. Perhaps the best example of this type of linking is the strong influence that the writings of Georg Brandt had on Antoine Lavoisier. Georg Brandt (1694-1768) was a famous Swedish chemist, probably the first true chemist, that was not influenced by the ideas of alchemists of earlier centuries or the unfounded "phlogiston" theory of his contemporary Georg Stahl (1660-1734). Lavoisier (1743-1794) although he never met or studied with Brandt, was much influenced by his writings, more so than by the lectures of his true teachers, the astronomer Nicolas de Lacaille (1713-1762) and the botanist Guillaume Rouelle (1703-1770).

Other connections are discussed in the main text. We have left the well-known genealogical chart (Line XI) of Amundson last to comment on the unusual problem faced with the linking of certain members of this line. Since the academic predecessors of Amundson received their doctorates in mathematics, it was quite difficult to discover their connections (mathematicians do not often identify "major professors," or, if they do, they do not publish with them).

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5. Affiliation of Author

School of Chemical Engineering
Purdue University
West Lafayette, Indiana 47907, USA

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19. J. Macquer, *Dictionnaire de chymie*, Paris, 1778.

20. A. Lavoisier, *Premieres lecons d' analyses*, Paris, 1797.

21. J. von Liebig, *Die Chemie und ihrer Anwendung auf Agrikultur und Physiologie*, Braunschweig, 1840.

22. F. Wöhler, *Grundriss der Chemie*, 1880.

23. H.V. Regnault, *Premiers elements de chimie*, Paris, 1874.

24. R. Bunsen, *Chemische Analyse durch Spektralbeobachtungen*, 1880.

25. H. Kopp, *Geschichte der Chemie*, Braunschweig, 1847.

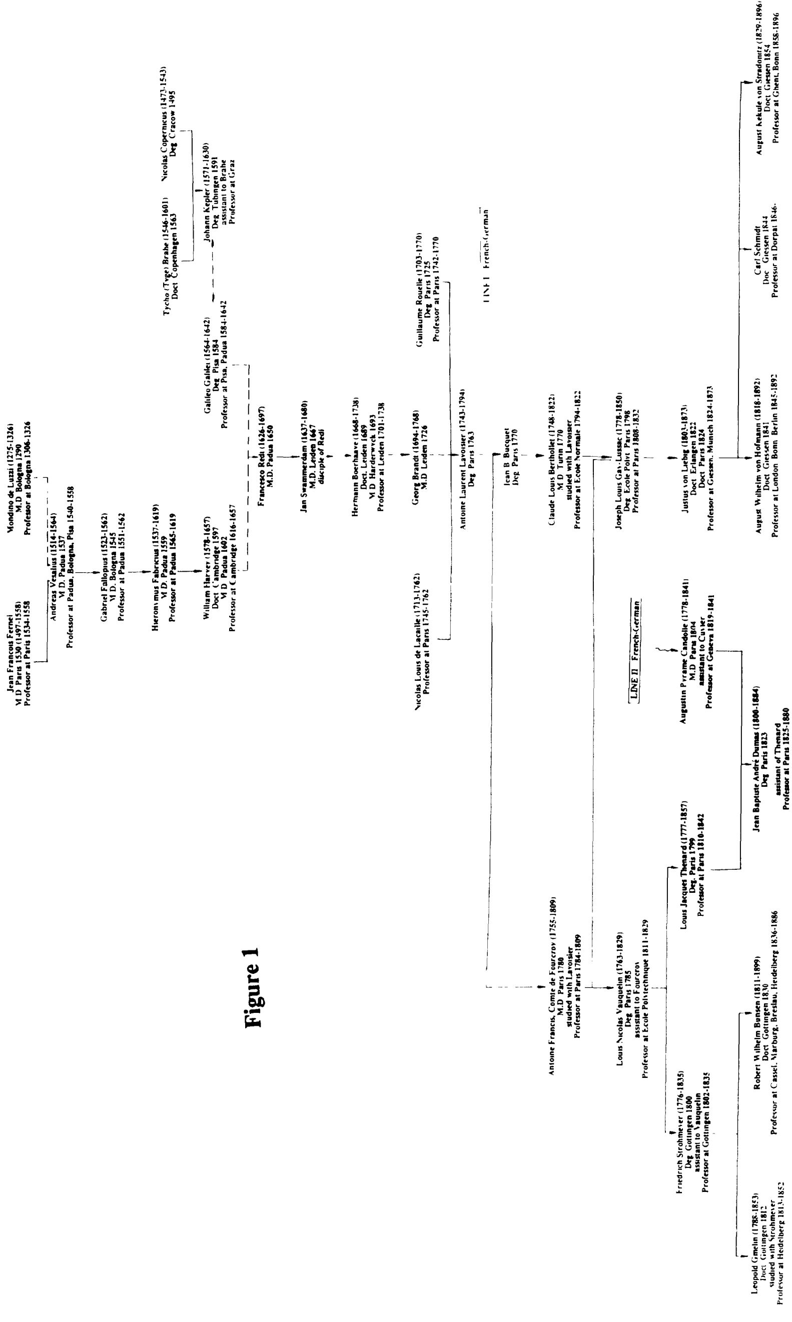

Jean Francois Fernel
M D Paris 1530 (1497-1558)
Professor at Paris 1534-1558
Mondino de Luzzi (1275-1326)
M.D Bologna 1290
Professor at Bologna 1306-1326
Andreas Vesalius (1514-1564)
M D. Padua 1537
Professor at Padua, Bologna, Pisa 1540-1558
Gabriel Fallopius (1523-1562)
M D. Bologna 1545
Professor at Padua 1551-1562
Hieronymus Fabricius (1537-1619)
M D. Padua 1559
Professor at Padua 1565-1619
William Harvey (1578-1657)
Doct Cambridge 1597
M D Padua 1602
Professor at Cambridge 1616-1657
Tycho (Tyge) Brahe (1546-1601)
Doct Copenhagen 1563
Nicolas Copernicus (1473-1543)
Deg Cracow 1495
Galileo Galilei (1564-1642)
Deg Pisa 1584
Professor at Pisa, Padua 1584-1642
Johann Kepler (1571-1630)
Deg Tubingen 1591
assistant to Brahe
Professor at Graz
Francesco Redi (1626-1697)
M.D. Padua 1650
Jan Swammerdam (1637-1680)
M.D. Leiden 1667
disciple of Redi
Hermann Boerhaave (1668-1738)
Doct. Leiden 1689
M D Harderwyck 1693
Professor at Leiden 1701-1738
Nicolas Louis de Lacaille (1713-1762)
Professor at Paris 1745-1762
Georg Brandt (1694-1768)
M.D Leiden 1726
Guillaume Rouelle (1703-1770)
Deg Paris 1725
Professor at Paris 1742-1770
Antoine Laurent Lavoisier (1743-1794)
Deg Paris 1763
LINE I French-German
Jean B Bucquet
Deg Paris 1770
Antoine Francis, Comte de Fourcroy (1755-1809)
M.D Paris 1780
studied with Lavoisier
Professor at Paris 1784-1809
Claude Louis Berthollet (1748-1822)
M D Turin 1770
studied with Lavoisier
Professor at Ecole Normale 1794-1822
Louis Nicolas Vauquelin (1763-1829)
Deg Paris 1785
assistant to Fourcroy
Professor at Ecole Polytechnique 1811-1829
LINE II French-German
Joseph Louis Gay-Lussac (1778-1850)
Deg Ecole Polyt Paris 1798
Professor at Paris 1808-1832
Friedrich Strohmeyer (1776-1835)
Deg Gottingen 1800
assistant to Vauquelin
Professor at Gottingen 1802-1835
Louis Jacques Thenard (1777-1857)
Deg. Paris 1799
Professor at Paris 1810-1842
Augustin Pyrame Candolle (1778-1841)
M.D Paris 1804
assistant to Cuvier
Professor at Geneva 1819-1841
Justus von Liebig (1803-1873)
Doct Erlangen 1822
Doct Paris 1824
Professor at Giessen, Munich 1824-1873
Leopold Gmelin (1788-1853)
Doct Gottingen 1812
studied with Strohmeyer
Professor at Heidelberg 1813-1852
Robert Wilhelm Bunsen (1811-1899)
Doct Gottingen 1830
Professor at Cassel, Marburg, Breslau, Heidelberg 1836-1886
Jean Baptiste André Dumas (1800-1884)
Deg Paris 1823
assistant of Thenard
Professor at Paris 1825-1880
August Wilhelm von Hofmann (1818-1892)
Doct Giessen 1841
Professor at London Bonn Berlin 1845-1892
Carl Schmidt
Doc Giessen 1844
Professor at Dorpat 1846-
August Kekule von Stradonitz (1829-1896)
Doct Giessen 1854
Professor at Ghent, Bonn 1858-1896
Line IV
Line V
Line VI
Line IX
Line VIII
Line VII

Figure 1

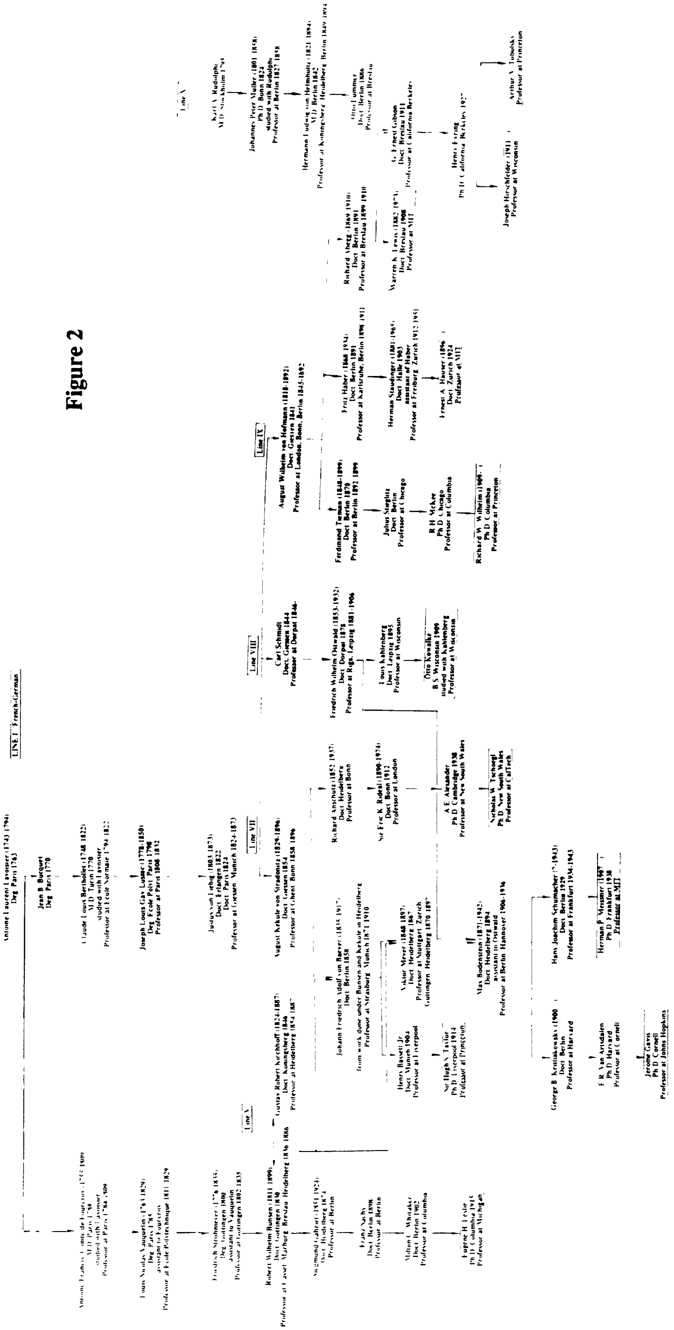


Figure 2

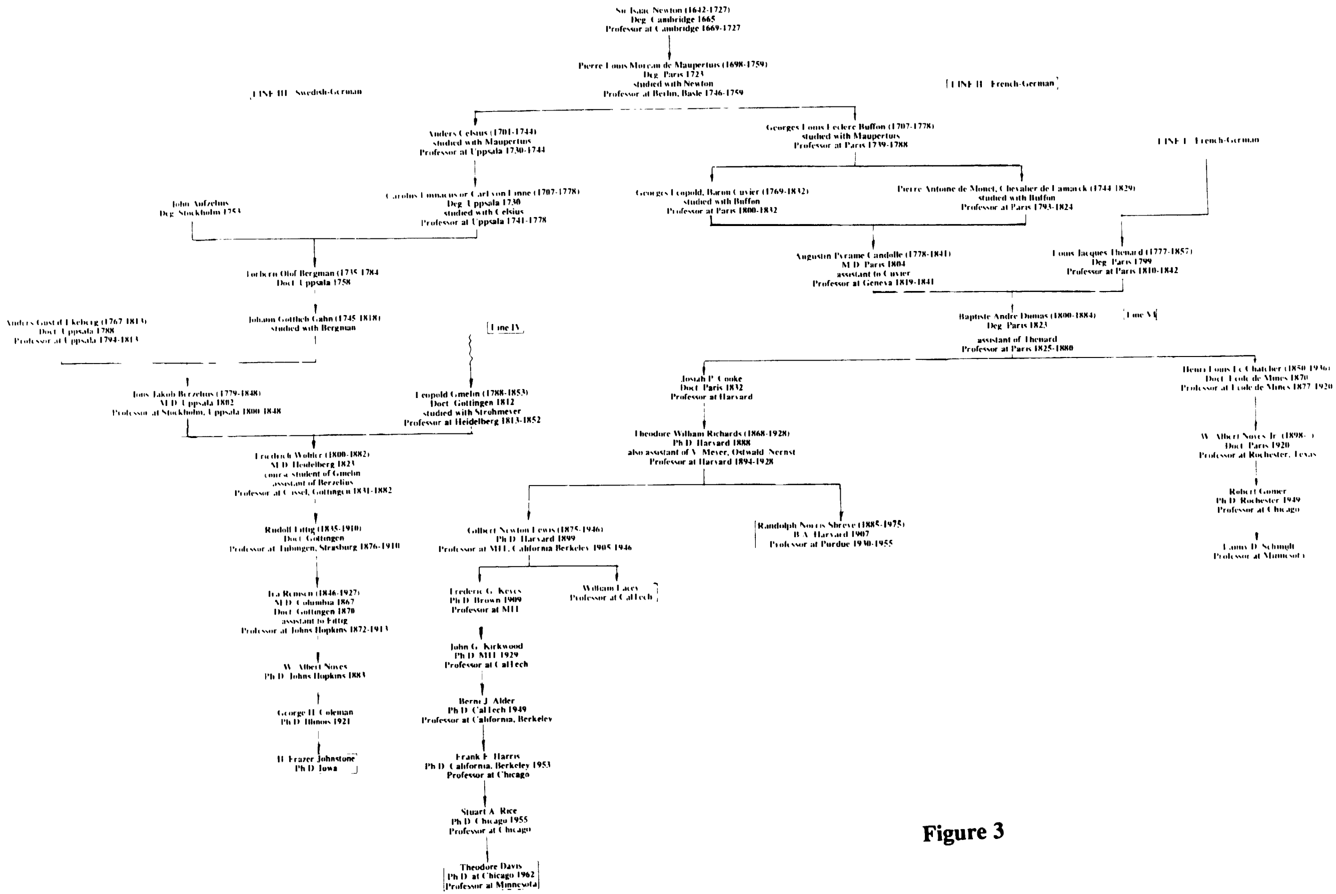

Sir Isaac Newton (1642-1727)
Deg. Cambridge 1665
Professor at Cambridge 1669-1727
Pierre Louis Moreau de Maupertuis (1698-1759)
Deg. Paris 1723
studied with Newton
Professor at Berlin, Basle 1746-1759
LINE III Swedish-German
LINE II French-German
LINE I French-German
Anders Celsius (1701-1744)
studied with Maupertuis
Professor at Uppsala 1730-1744
Georges Louis Leclerc Buffon (1707-1778)
studied with Maupertuis
Professor at Paris 1739-1788
Carolus Linnaeus or Carl von Linne (1707-1778)
Deg. Uppsala 1730
studied with Celsius
Professor at Uppsala 1741-1778
John Afzelius
Deg. Stockholm 1753
Georges Leopold, Baron Cuvier (1769-1832)
studied with Buffon
Professor at Paris 1800-1832
Pierre Antoine de Monet, Chevalier de Lamarck (1744-1829)
studied with Buffon
Professor at Paris 1793-1824
Torbern Olof Bergman (1735-1784)
Doct. Uppsala 1758
Augustin Pyrame Candolle (1778-1841)
M.D. Paris 1804
assistant to Cuvier
Professor at Geneva 1819-1841
Louis Jacques Thenard (1777-1857)
Deg. Paris 1799
Professor at Paris 1810-1842
Johann Gottlieb Gahn (1745-1818)
studied with Bergman
Anders Gustaf Ekeberg (1767-1813)
Doct. Uppsala 1788
Professor at Uppsala 1794-1813
Line IV
Baptiste Andre Dumas (1800-1884)
Deg. Paris 1823
assistant of Thenard
Professor at Paris 1825-1880
Line VI
Jons Jakob Berzelius (1779-1848)
M.D. Uppsala 1802
Professor at Stockholm, Uppsala 1800-1848
Leopold Gmelin (1788-1853)
Doct. Gottingen 1812
studied with Strohmeyer
Professor at Heidelberg 1813-1852
Josiah P. Cooke
Doct. Paris 1832
Professor at Harvard
Henri Louis Le Chatelier (1850-1936)
Doct. Ecole de Mines 1870
Professor at Ecole de Mines 1877-1920
Theodore William Richards (1868-1928)
Ph.D. Harvard 1888
also assistant of V. Meyer, Ostwald, Nernst
Professor at Harvard 1894-1928
W. Albert Noyes Jr. (1898-)
Doct. Paris 1920
Professor at Rochester, Texas
Friedrich Wohler (1800-1882)
M.D. Heidelberg 1823
course student of Gmelin
assistant of Berzelius
Professor at Cassel, Gottingen 1831-1882
Robert Gomer
Ph.D. Rochester 1949
Professor at Chicago
Rudolf Fittig (1835-1910)
Doct. Gottingen
Professor at Tubingen, Strasburg 1876-1910
Gilbert Newton Lewis (1875-1946)
Ph.D. Harvard 1899
Professor at MIT, California Berkeley 1905-1946
Randolph Norris Shreve (1885-1975)
B.A. Harvard 1907
Professor at Purdue 1930-1955
Lanny D. Schmidt
Professor at Minnesota
Frederic G. Keyes
Ph.D. Brown 1909
Professor at MIT
William Lacey
Professor at CalTech
Ira Remsen (1846-1927)
M.D. Columbia 1867
Doct. Gottingen 1870
assistant to Fittig
Professor at Johns Hopkins 1872-1913
John G. Kirkwood
Ph.D. MIT 1929
Professor at CalTech
W. Albert Noyes
Ph.D. Johns Hopkins 1883
Berni J. Alder
Ph.D. CalTech 1949
Professor at California, Berkeley
George H. Coleman
Ph.D. Illinois 1921
H. Frazer Johnstone
Ph.D. Iowa
Frank F. Harris
Ph.D. California, Berkeley 1953
Professor at Chicago
Stuart A. Rice
Ph.D. Chicago 1955
Professor at Chicago
Theodore Davis
Ph.D. at Chicago 1962
Professor at Minnesota

Figure 3

J. Bridgwater

HISTORY OF A RESEARCH JOURNAL, CHEMICAL ENGINEERING SCIENCE

ABSTRACT

A significant part of the high quality academic journal market has become controlled by private publishing houses. Within chemical engineering the pace and quality have been set by Chemical Engineering Science. The subject area was identified as important around 1950 and the journal started publication in 1951. The forces leading to its formation and the policies followed are traced; how these have related to its achievements is appraised. Key features in the early phase can be identified from the little early documentation that survives. A penetrating assessment of the market by the publisher is clear, put into action by the selection of enterprising individuals to run the journal who were prepared to act authoritatively and who maintained the highest academic standards.

1. INTRODUCTION

Commercial houses have been surprisingly successful in the publication of journals of high research quality. One journal falling into this class is *Chemical Engineering Science*, published by Pergamon Press. It is perhaps surprising that the professional scientific and engineering societies have allowed such events to happen since they should have the more direct access to the demands of their communities and to the changes in science and technology. However, in *Chemical Engineering Science* Pergamon Press saw a need and established a new style in the early 1950s which was later copied by both other commercial publishers and professional societies. This style has held it in the absolute forefront internationally to this day. The impact of information technology on the publication of scholarly work has yet to be felt but it would seem that the commercial publishers, each of whom is responsible for many journals, should enjoy a substantial advantage. It will be interesting to see what the next decade brings.

2. EARLY DAYS

As Executive Editor I have been gradually accumulating

N. A. Peppas (ed.), One Hundred Years of Chemical Engineering, 39–46.

information about the founding of *Chemical Engineering Science*. In the beginning there was no Executive Editor and my predecessor, Peter Danckwerts, was no believer in keeping old files. Recently some of the information was published in a Festschrift (Robert Maxwell and Pergamon Press, Pergamon Press, 1988) presented to Robert Maxwell on the occasion of 40 years existence of Pergamon Press and reprinted in the Journal (J Bridgwater, Chem Engng Sci 1988 43 (6) iii) and here this is elaborated.

Pergamon Press was formed from Butterworths and Springer in 1951. Springer was busy re-establishing itself after the Second World War and Butterworths, apparently under Government influence earlier, was developing a publication policy to strengthen British academia as there was considerable concern about American domination. Robert Maxwell bought out the other interests and, as part of the separation of activities in 1951, three journals were brought into the newly founded Pergamon Press and a policy of developing new periodicals was instituted. *Chemical Engineering Science* was the Press's first new venture and Volume 1, Number 1 appeared in October 1951.

The articles published in this issue were:

"Rapid calculation of plate number and reflux ratio in batch distillation" by F J Zuiderweg;

"The statistical interpretation of thermodynamic concepts" by M B Donald;

"Continuous filtration. Calculation of cake impurity and liquid yield" by H Mondria;

"On the 'viscosity' of a bed of fluidised solids" by H Kramers; and

"Studies on fluidization. 1. The critical mass velocity" by C van Heerden, A P P Nobel and D W van Krevelen.

Of these five, four have titles that would not cause surprise today. The exception is the article by Professor Donald which, on examination, appears a little unusual even by the standards of 1951. There was also a survey article in French by Professor Cathala discussing the development of chemical engineering and the role of Europe within it; this article is mentioned below.

Apart from Professor Donald's contribution from the UK, all the others were from The Netherlands. The first volume was completed with the sixth part in December 1952 and workers in the UK and The Netherlands were almost entirely responsible; there were no contributions whatsoever from outside Europe.

The original Editorial Board was comprised of:

J Cathala (Toulouse)
M B Donald (London)
F Giordani (Naples)
A Guyer (Zurich)
W L de Keyser (Brussels)
D W van Krevelen (Geleen)
S G Terjesen (Trondheim)

It was further supported by an Advisory Board which had its membership drawn as follows:

France (4)
United Kingdom (3)
Belgium (2)
Netherlands (2)
Switzerland (2)
Australia (1)
Denmark (1)
Finland (1)
Italy (1)
Norway (1)
Sweden (1)

The only person from outside Western Europe was from Australia!

The need to be less parochial was soon recognised and American editors were appointed. During sabbatical leave at Cambridge University in 1954-55 as a Fulbright Scholar, Professor N R Amundson met Dr Paul Rosbaud, the Pergamon Director who had taken a close interest in *Chemical Engineering Science* since its inception. Subsequently Professor Amundson became American editor in 1956 and established the journal in the USA, setting high standards and soon handling very large numbers of manuscripts. The journal is much in his debt.

3. ROSBAUD

My discussions with individuals and such correspondence as I have been able to unearth serves to emphasise the key role of Dr Rosbaud in terms of academic policy of the journal. The original idea appears to have been Rosbaud's with the initial academic liaison being carried out under the name of Professor Donald of University College, London. However Professor Donald never worked as a principal editor. Dr Rosbaud provided the real drive. He had considerable editorial talent and had previously worked for Butterworths and Springer. During the Second World War he was, as a German, a spy for Britain in Berlin code-named 'The Griffin'. His story is told in the book of that name by Arnold Kramish (Houghton Miflin Co., Boston, Mass. 1986).

Sven Terjesen, who was on the Editorial Board from 1951 to 1983, has sent me copies of some early letters. It is clear that Rosbaud was taking responsibility for choosing editors and ensuring that high standards were applied. For example on 9 September 1953, Rosbaud wrote to Terjesen:

> "It is perhaps a good sign for the journal when somebody belonging to one of the big Industrial Research Laboratories told me the other day that he and his collaborators are a bit reluctant to send in papers because they think their work does not come up to the high scientific standard which is required in our journal ... I am not prepared to lower the scientific standard to publish papers which would fit better into other journals which are not as ambitious as ours".

Rosbaud left Pergamon in the mid-1950s and the need for a focus eventually led to the appointment of an Executive Editor and P V Danckwerts held this post from 1958 to 1982. However, the Editors continued - and still continue - to operate in a sovereign fashion, merely reporting what they had done to the Executive Editor's office. The idea of a community of senior scholars of the subject promoting the dissemination of knowledge through the journal has thus stood the test of time well. The man providing this structure for *Chemical Engineering Science* was indeed Rosbaud.

4. OPERATION WITH PERGAMON

Danckwerts ran the Editorial Board in a diffuse way and minutes are only available on the files of one meeting and even then the attendance was far from complete. The editors now meet regularly on a 3-yearly basis supplemented by informal contacts at technical meetings. The Executive Editor is responsible for overall organisation and maintains central records on activities but individual Editors continue to assume full responsibility for decisions on the manuscripts sent to them.

The very first issue mentions the possibility of submitting review articles. This was only taken up by the journal in 1981 and we now (August 1988) stand at number 28 in the series. These are seen as particularly relevant by the editors in consolidating prior research papers and defining the fertile areas of chemical engineering research. Despite the long initiation time, this forum has shown a very successful growth.

Pergamon Press has provided professional support in publishing; they have always respected the value of academic peer review and publications practices. Indeed I consider that the journal has been very much less subject to pressure than many associated with professional engineering societies. The balance between support and interference can be a fine one; it is one the Press seems to grasp properly.

5. RESEARCH ACHIEVEMENTS

I wrote to the present and former Editors to solicit their views about which articles published in *Chemical Engineering Science* they thought significant. Such responses of course were substantially subjective - one Editor being quite clear that he was responsible for two of the three major articles! There was, however, a remarkable unanimity concerning what was significant in the early years up to 1960. These were:

- The applications of physics to chemical engineering particularly from the Dutch school. Kramers and van Krevelen are seen as key contributors.

- P V Danckwerts, Continuous flow systems. Distribution of residence times, Chem Engng Sci, 1953, 2, 1.

- R Aris, On shape factors for irregular particles - I. The steady state problem. Diffusion and reaction, Chem Engng Sci, 1957, 6, 262.

- R Aris and N R Amundson, An analysis of chemical reactor stability and control - I. The possibility of local control, with perfect or imperfect control mechanisms, Chem Engng Sci, 1958, 7, 121.

The responses also mentioned what they felt to be some of the key factors that had helped the journal. These included "inculcation amongst researchers of the role of mathematics (even 'severe' mathematics)" to quote one respondent, the existence of true chemical contributions, processing of papers in a flexible rather than a hidebound fashion, and a willingness to allow more than one cultural approach.

6. MAXWELL INITIATIVES

Mr Robert Maxwell has taken a positive interest in *Chemical Engineering Science* and has encouraged the Editors to be forward looking. It is heartening that through his interest Pergamon has recently made two contributions to the chemical engineering community.

Firstly, the Danckwerts-Maxwell Prize was endowed at the University of Cambridge to encourage research in the Department of Chemical Engineering, Professor Danckwerts' former department. It is awarded annually for the best PhD dissertation.

Secondly, in association with The Institution of Chemical Engineers, the Press founded the annual Danckwerts Memorial Lectures, the purpose being to acknowledge ".... the recognition of the contribution made by P V Danckwerts in pursuit of scholarship in *Chemical Engineering Science* for 30 years. The field of the lecture shall be appropriate to the aims and scope of *Chemical Engineering Science;* the purpose shall be to invite as lecturer an international authority on some aspect within the aims and scope of the journal. It is anticipated that the lecture will become an important and continuing part of the academic life of the international chemical engineering community" (From the minutes of the meeting held on 6 September 1985 to discuss the founding of the Lecture.)

The first lecturer was Neal Amundson who spoke on "P V Danckwerts - his research career and its significance" (Chem Engng Sci, 1986, 41, 1947). The second lecture was given by M M Sharma, a former editor of the journal, whose topic was "Chemical engineering science in India - needs, opportunities and challenges" (Chem Engng Sci, 1987, 42, 2497). The third lecturer was Octave Levenspiel whose lecture was entitled "Chemical engineering's grand adventure" and was published as Chem Engng Sci, 1988, 43, 1427.

7. THE PAST AND THE FUTURE

In the very first article of the journal, Professor Cathala of Toulouse presented a historical development of chemical engineering and saw *Chemical Engineering Science* rather as a medium for European workers to publish their results in their own languages. In due course there arose a general acceptance of English although the alternative title *Genie Chimique* was only removed from the cover in the early 1980s.

Professor Cathala remarked in his summary (Chem Engng Sci, 1951, 1, 1). "If chemical engineering is not yet recognised everywhere in Europe as an independent technology, the great number of technologists who contribute every day to the success of chemical industry, are in fact behaving as Chemical Engineers. Like MOLIEREs Bourgeois Gentilhomme, who wrote prose without knowing it, they practise a new technology while ignoring its real name. It is always necessary to know something of the grammar to speak a language well. The coming generation of technologists enlisted by the industry every year, can no longer ignore the principles of a science that will teach them how to conceive, calculate, draw, build and operate the equipment by which any kind of chemical reaction may be carried out on an industrial scale".

Cathala's latter remarks continue to apply. Information technology is transforming the practice of chemical engineering and most countries have programmes of work aiming to harness new materials and biotechnological products. There is a need to suppress pollution, to address the need of reducing energy usage, to produce energy and chemicals in ways that prevent harm to the environment, and to improve safety. The need for chemical engineering is as great as ever and many new research arenas are opening.

8. CONCLUSION

What have been the keys to success?. I propose three. First of all, Rosbaud identified a clear market need, anticipating other publishers and professional societies. Secondly, the international editorial board with editors acting independently each in his own sphere has given a diversity of approach and avoided cosiness. Thirdly, the quality of published work has been of paramount importance.

School of Chemical Engineering
University of Birmingham
PO Box 363
Birmingham B15 2TT
England

Stephen Whitaker

THE DEVELOPMENT OF FLUID MECHANICS IN CHEMICAL ENGINEERING

ABSTRACT

The nominal objective of this article is to provide a survey of the development of fluid mechanics in chemical engineering from 1888 to the centennial year of 1988; however, the events that occurred in 1960 prevent any survey written at this time to go beyond the year of 1960. In that year, the text entitled **Transport Phenomena** was produced by R.B. Bird, W.E. Stewart and E.N. Lightfoot, and, in a more subtle manner, the chemical engineering community was introduced to **The Classical Field Theories** by C. Truesdell and W. Noll. The first was a freeway network of new paths to follow, while the second was a tome assembled much along the lines of a Roman aqueduct. Coupled with the publication of the English version of **Boundary Layer Theory** by H. Schlichting in 1955, these works provided chemical engineering researchers and teachers with a boundless domain for new studies. About the period between 1960 and 1988, I can only say that it would be best to delay any comments until a later date. Given this situation, one might suppose that our survey would begin in 1888; however, in order to place the chemical engineering achievements within the U.S.A. in perspective, we will begin our study in the middle of the eighteenth century. From the work of Euler, we will follow the development of fluid mechanics up to 1879, when Sir Horace Lamb's **Treatise on the Mathematical Theory of the Motion of Fluids** was published. In this way we will know what was available in 1888 when the new discipline of chemical engineering began to emerge. We will close this article with some predictions for the future which suggest that fluid mechanics will eventually

N. A. Peppas (ed.), One Hundred Years of Chemical Engineering, 47–109.

play a central pedagogical role in chemical engineering education.

1. Prologue

While physicists uniformly cite Newton's laws as *completing* the formulation of classical or Newtonian Mechanics, Truesdell (Chap. II, 1968) takes the point of view that Newton *began* the formulation of classical mechanics. In his view, the end of that formulation came with the publication of Lagrange's work, **Méchanique Analitique**, in 1788. The names associated with the period between Newton and Lagrange are Bernoulli, Leibnitz, Huygens, Hooke, D'Alembert and others, but it was Euler who made the greatest contributions to organizing Newtonian mechanics. Euler represented Newton's ideas in terms of two laws of mechanics which we state as

I. The time rate of change of the linear momentum of a body equals the force acting on the body.

II. The time rate of change of the angular momentum (moment of momentum) of a body equals the torque acting on the body.

It is understood that the distances and velocities associated with these two laws are determined relative to an *inertial frame* and that the torque and angular momentum are measured relative to the same fixed point. It is important to note that an inertial frame is a frame in which these laws hold, thus, it must be found by experiment. In his study of the motion of Mars about the sun, Newton found that the stars provided a satisfactory inertial frame. For many engineering problems, a frame fixed relative to the earth can be used as an inertial frame; however, this is not the case for large scale meteorological phenomena for which the rotation of the earth produces an acceleration referred to as the Coriolis force (Dutton, 1976).

In addition to providing a concise statement of the laws of mechanics, Euler postulated that these laws hold not only for distinct bodies, but also for any arbitrary body that one might imagine as being cut out of a distinct body. By *distinct body*, we mean something like the planet Mars, the Rock of Gibralter, or a baseball. The idea of applying the laws of mechanics to any arbitrary part of a distinct body was a novel suggestion in Euler's time. Today, every engineering student applies this concept in a statics course, where it is used to isolate what is known as a *free body*. Truesdell (page 193, 1986) refers to this now well-established concept as the *Euler cut principle*. With this concept in mind, the laws of mechanics and the principle of conservation of mass can be expressed as

$$\frac{d}{dt}\int_{\mathcal{V}_m(t)} \rho \, dV = 0 \tag{1-1}$$

$$\frac{d}{dt}\int_{\mathcal{V}_m(t)} \rho \mathbf{v} \, dV = \int_{\mathcal{V}_m(t)} \rho \mathbf{b} \, dV + \int_{\mathcal{A}_m(t)} \mathbf{t}_{(\mathbf{n})} \, dA \tag{1-2}$$

$$\frac{d}{dt}\int_{\mathcal{V}_m(t)} \mathbf{r} \times \rho \mathbf{v} \, dV = \int_{\mathcal{V}_m(t)} \mathbf{r} \times \rho \mathbf{b} \, dV + \int_{\mathcal{A}_m(t)} \mathbf{r} \times \mathbf{t}_{(\mathbf{n})} \, dA \tag{1-3}$$

The *concepts* that are introduced here must not be overlooked, and we list them as

a) The concept of a moving, deforming body occupying a region in space designated by $\mathcal{V}_m(t)$.

b) The concept of a continuum described by field variables such as the density, ρ.

c) The concept of a stress vector, $\mathbf{t}_{(\mathbf{n})}$, describing the vector force per unit area acting on an imaginary surface (or Eulerian cut) having an outwardly directed unit normal vector, $\mathbf{n}$.

We could summarize Eqs. 1-1 through 1-3 by saying that they introduced the concepts of *kinematics* and *stress*. More than half a century would elapse before the concept of stress would be presented in a modern framework by Cauchy, and it would require a slightly longer period of time before a constitutive equation would be developed leading to the Navier-Stokes equations. In the century between Euler and Stokes, the basic ideas associated with *kinematics*, *stress* and *constitutive relations* were formulated. Two centuries later, these same concepts represent the building blocks of fluid mechanics. Before we comment on the development of these concepts, we need to examine how Eqs. 1-1 through 1-3 compare with Newton's three laws of mechanics.

Newton's three axioms can be stated as (Truesdell, page 88, 1968)

I. Every body continues in its state of rest, or of uniform motion straight ahead, unless it be compelled to change that state by forces impressed upon it.

II. The change of motion is proportional to the motive force impressed, and it takes place along the right line in which the force is impressed.

III. To an action there is always a contrary and equal reaction; or, the mutual actions of two bodies upon each other are always directed to contrary parts.

To see the correspondence between Euler's point of view and that of Newton, we restrict our discussion to mass point mechanics and consider the isolated particle illustrated in Fig. 1-1. The mass of this particle is m_1 and Euler's first law requires

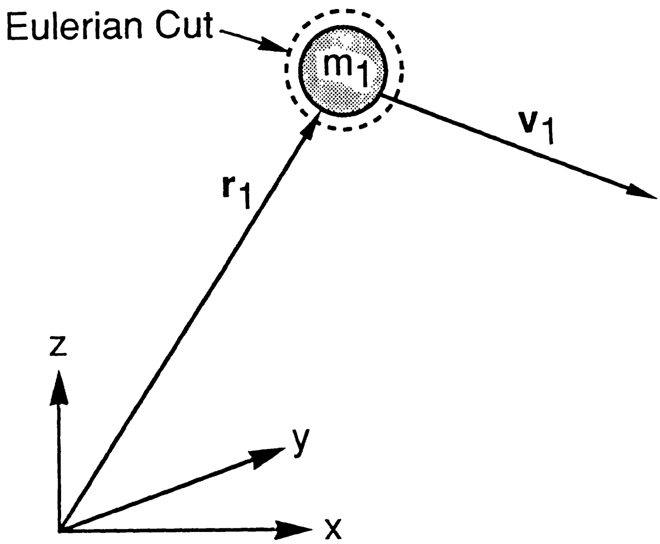
$$\frac{d}{dt}(m_1 \mathbf{v}_1) = 0 \tag{1-4}$$

From this it follows that

$$m_1 \mathbf{v}_1 = \text{constant vector} \tag{1-5}$$

and here we see that Newton's first law is nothing more than a special case of Euler's first law. Since there are no torques acting on the particle shown in Fig. 1-1, Euler's second law

Figure 1-1
An Isolated Body Not Acted Upon by Any Force



requires that the time rate of change of angular momentum is zero. This means that Eq. 1-3 leads to

$$\frac{d}{dt}(\mathbf{r}_1 \times m_1 \mathbf{v}_1) = 0 \tag{1-6}$$

and we can carry out the differentiation to obtain

$$\left(\frac{d\mathbf{r}_1}{dt}\right) \times m_1\mathbf{v}_1 \; + \; \mathbf{r}_1 \times \left[\frac{d}{dt}(m_1\mathbf{v}_1)\right] \; = \; 0 \tag{1-7}$$

The velocity of the particle is given by

$$\mathbf{v}_1 = \frac{d\mathbf{r}_1}{dt} \tag{1-8}$$

so that Eq. 1-7 takes the form

$$\mathbf{v}_1 \times m_1\mathbf{v}_1 \; + \; \mathbf{r}_1 \times \left[\frac{d}{dt}(m_1\mathbf{v}_1)\right] \; = \; 0 \tag{1-9}$$

Since the cross product of a vector with itself is zero, we see that Eq. 1-9 reduces to

$$\mathbf{r}_1 \times \left[\frac{d}{dt}(m_1\mathbf{v}_1)\right] \; = \; 0 \tag{1-10}$$

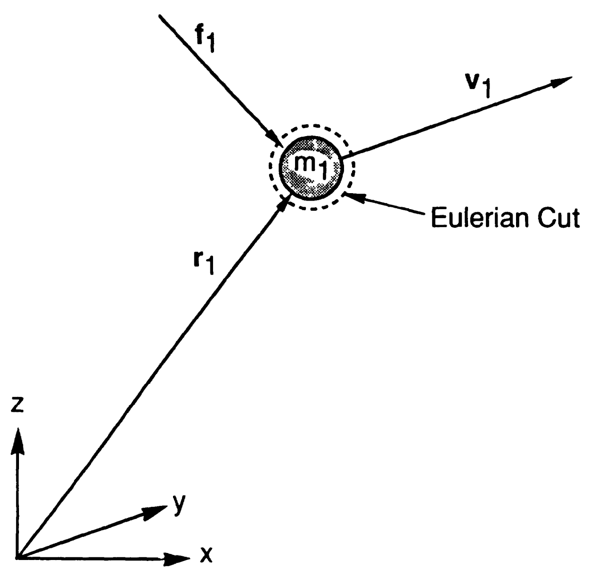
At this point, we note that the location of the coordinate system shown in Fig. 1-1 is arbitrary, thus the position vector $\mathbf{r}_1$ is arbitrary and Eq. 1-10 requires that

$$\frac{d}{dt}(m_1\mathbf{v}_1) \; = \; 0 \tag{1-11}$$

Here we see that Euler's second law has provided *no new information* concerning the motion of the particle illustrated in Fig.1-1.

In order to examine Newton's second law in terms of Euler's laws of mechanics, we consider a particle acted upon by a force $\mathbf{f}_1$ as illustrated in Fig. 1-2. For this case, Euler's first law

Figure 1-2
Particle Acted Upon by a Force



clearly takes the form

$$\frac{d}{dt}(m_1\mathbf{v}_1) = \mathbf{f}_1 \tag{1-12}$$

This is undoubtedly the meaning that Newton wished to convey with his statement of the second law, and indeed this is the representation given in every undergraduate physics text. Application of Euler's second law to the process illustrated in Fig. 1-2 yields

$$\frac{d}{dt}(\mathbf{r}_1 \times m_1\mathbf{v}_1) = \mathbf{r}_1 \times \mathbf{f}_1 \tag{1-13}$$

On the basis of Eqs. 1-6 through 1-10 we can put this result in the form

$$\mathbf{r}_1 \times \left[\frac{d}{dt}(m_1\mathbf{v}_1) - \mathbf{f}_1\right] = 0 \tag{1-14}$$

and since $\mathbf{r}_1$ is arbitrary, we find that Euler's second law reduces to

$$\frac{d}{dt}(m_1\mathbf{v}_1) = \mathbf{f}_1 \tag{1-15}$$

Here we again find that Euler's second law has provided *no new information* concerning the motion of a single particle.
We concluded this study with an examination of Newton's third law, and to do so we consider the two-particle system illustrated in Fig. 1-3. We begin by applying Euler's first law to the isolated two-particle system identified by Eulerian Cut I. Since there is no external force acting on the two-particle system, we can use Euler's first law to obtain the relation

$$\frac{d}{dt}(m_1\mathbf{v}_1 + m_2\mathbf{v}_2) = 0 \tag{1-16}$$

The second and third cuts illustrated in Fig. 1-3 provide the following results

$$\frac{d}{dt}(m_1\mathbf{v}_1) = \mathbf{f}_1 \tag{1-17}$$

$$\frac{d}{dt}(m_2\mathbf{v}_2) = \mathbf{f}_2 \tag{1-18}$$

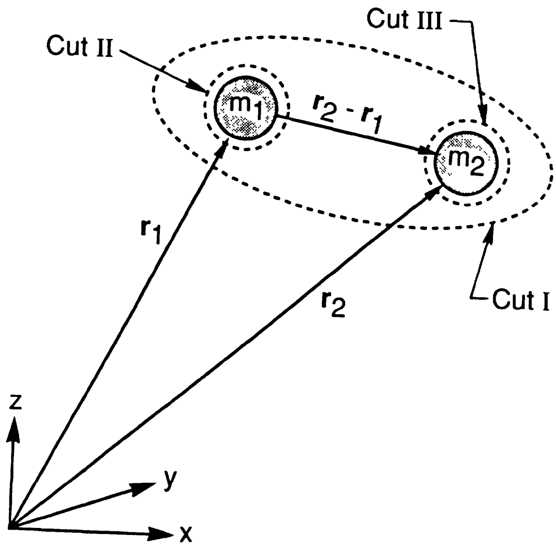
If we add Eqs. 1-17 and 1-18 and compare the result with Eq. 1-16, we see that the sum of the interaction forces is zero:

$$\mathbf{f}_1 + \mathbf{f}_2 = 0 \tag{1-19}$$

This can be arranged in the form

$$\mathbf{f}_1 = - \mathbf{f}_2 \tag{1-20}$$

Figure 1-3
Isolated Interacting Particles



in order to express the "action-reaction" statement of Newton's third law.

At this point, we have shown that Euler's first law contains all the results available in Newton's three laws. In addition, we have found that Euler's second law provides *no new information* concerning the processes illustrated in Figs. 1-1 and 1-2. It might seem that Euler's second law is devoid of content for mass-point mechanics; however, application of Eq. 1-3 to the Eulerian Cut I illustrated in Fig. 1-3 will indeed provide some new information. Since there are no external torques acting on the two-particle system, Euler's second law yields

$$\frac{d}{dt}\left(\mathbf{r}_1 \times m_1\mathbf{v}_1 + \mathbf{r}_2 \times m_2\mathbf{v}_2\right) = 0 \tag{1-21}$$

Carrying out the differentiation and following Eqs. 1-6 through 1-10 leads to

$$\mathbf{r}_1 \times \frac{d}{dt}(m_1\mathbf{v}_1) + \mathbf{r}_2 \times \frac{d}{dt}(m_2\mathbf{v}_2) = 0 \tag{1-22}$$

Use of Eqs. 1-17 and 1-18, along with the result given by Eq 1-20, allows us to express Eq. 1-22 in the form

$$(\mathbf{r}_2 - \mathbf{r}_1) \times \mathbf{f}_2 = 0 \tag{1-23}$$

There are three possible ways in which this relation can be satisfied and we list them as:

1. $\mathbf{r}_2 - \mathbf{r}_1 = 0$
2. $\mathbf{f}_2 = 0$
3. $(\mathbf{r}_2 - \mathbf{r}_1)$ and $\mathbf{f}_2$ are parallel

Since the first two possibilities can not be generally true, we conclude that the interaction force between two particles must be parallel to the vector $\mathbf{r}_2 - \mathbf{r}_1$. We express this result as

$$\mathbf{f}_2 = \alpha(\mathbf{r}_2 - \mathbf{r}_1) \tag{1-24}$$

where α is some scalar parameter of the particle-particle interaction force law. Equation 1-24 indicates that the interaction force between two particles must act along the line of centers, i.e., it is a *central force.*

Here we have found that for the case of mass points, Euler's second law does nothing more than place a constraint on the type of force that can exist between two particles. In most applications of Newton's laws, one tacitly assumes that the force between particles lies along the line of centers and this is precisely what Newton assumed when he analyzed the motion of the planets around the sun. The *central force law* is usually avoided in the statement of Newton's three laws, and in fact it is not always true. For example, if the force between the two particles shown in Fig. 1-3 is a gravitational force, Eq. 1-24 can be strictly true only if the particles are not moving. Since the gravitational force between the two particles is propagated at the *speed of light*, this force will not act along the line of centers when the two particles are moving relative to each other. It should not be surprising that the importance of this effect depends on v^2/c^2 where v is the relative particle velocity and c is the speed of light. When v^2/c^2 is small compared to one, the central force law illustrated by Eq. 1-24 is an excellent approximation. Under these circumstances, the mechanical problem is considered to be Newtonian, classical, or non-relativistic.

At this point we are in a position to understand why physicists resolutely adhere to Newton's three laws of mechanics while engineers always adopt some form of Euler's two laws. The physicist, with an overriding interest in the motion of particles, finds it convenient to tacitly accept the central force law in the discussion of non-relativistic mechanics since this idea is easily altered when relativistic problems are encountered. If the physicist were to adopt Euler's two axioms of mechanics, the second axiom would require alteration when relativistic problems arise. Engineers, on the other hand, are immersed in the study of continua and Euler's laws for linear and angular momentum are perfectly suited to their purposes which rarely include relativistic effects.

Governing Differential Equations

To obtain the differential form of Eq. 1-1, we consider a transformation from the spatial coordinates **r** to a reference coordinate system **R**. This leads to

$$\frac{d}{dt}\int_{\mathcal{V}_m(t)} \rho(\mathbf{r},t)\, dV = \frac{d}{dt}\int_{\mathcal{V}_m(t=0)} \rho(\mathbf{R},t)\, J\, dV_0 = 0 \qquad (1\text{-}25)$$

Here we have used

$$dV = J dV_0 \tag{1-26}$$

where J is the Jacobian of the transformation

$$\mathbf{r} = \mathbf{r}(\mathbf{R}, t) \tag{1-27}$$

One can interchange differentiation and integration in the second term of Eq. 1-25 in order to obtain

$$\frac{d}{dt}\int_{\mathcal{V}_m(t)} \rho(\mathbf{r},t)\, dV = \int_{\mathcal{V}_m(t=0)} \left[\left(\frac{D\rho}{Dt}\right)J + \rho\left(\frac{DJ}{Dt}\right)\right] dV_0 = 0 \tag{1-28}$$

In this result, the *material derivative* is used and it is identified explicitly as

$$\left.\frac{d\rho}{dt}\right|_{\mathbf{R}} = \frac{D\rho}{Dt} = \frac{\partial\rho}{\partial t} + \mathbf{v}\cdot\nabla\rho \tag{1-29}$$

The partial derivative used in this representation is given by

$$\left.\frac{d\rho}{dt}\right|_{\mathbf{r}} = \frac{\partial\rho}{\partial t} \tag{1-30}$$

Use of Eq. 1-26 allows us to express Eq. 1-28 as

$$\frac{d}{dt}\int_{\mathcal{V}_m(t)} \rho\, dV = \int_{\mathcal{V}_m(t)} \left[\frac{D\rho}{Dt} + \rho\left(\frac{1}{J}\,\frac{DJ}{Dt}\right)\right] dV = 0 \tag{1-31}$$

Serrin (page 131, 1959) has attributed the result

$$\frac{1}{J}\frac{DJ}{Dt} = \nabla\cdot\mathbf{v} \tag{1-32}$$

to Euler and Truesdell (page 50, 1954) refers to it as *Euler's expansion formula.* When used in Eq. 1-31 along with Eq. 1-29, we obtain

$$\frac{d}{dt}\int_{\mathcal{V}_m(t)} \rho \, dV = \int_{\mathcal{V}_m(t)} \left[\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v})\right] dV = 0 \tag{1-33}$$

and from this result the continuity equation follows

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0 \tag{1-34}$$

Rouse and Ince (page 104, 1963) attribute this form of the continuity equation to Euler and they identify the year as 1755. The derivation given here rests upon the kinematical theorem

$$\frac{d}{dt}\int_{\mathcal{V}_m(t)} \psi dV = \int_{\mathcal{V}_m(t)} \left[\frac{\partial \psi}{\partial t} + \nabla \cdot (\mathbf{v}\psi)\right] dV = 0 \tag{1-35}$$

which is generally known as the *Reynolds transport theorem* (Truesdell, page 53, 1954). This result is valid for ψ being a tensor of any order and when $\psi = \rho\Omega$. Serrin (page 133, 1959) obtains

$$\frac{d}{dt}\int_{\mathcal{V}_m(t)} \rho\Omega \, dV = \frac{d}{dt}\int_{\mathcal{V}_m(t)} \rho \frac{D\Omega}{Dt} dV \tag{1-36}$$

This result is sometimes known as the special form of the Reynolds transport theorem (Whitaker, Sec 3.4, 1968).
We now turn our attention to Euler's first law, given by Eq. 1-2, and use Eq. 1-36 to obtain

$$\int_{\mathcal{V}_m(t)} \rho \frac{D\mathbf{v}}{Dt} dV = \int_{\mathcal{V}_m(t)} \rho \mathbf{b} \, dV + \int_{\mathcal{A}_m(t)} \mathbf{t}_{(\mathbf{n})} \, dA \tag{1-37}$$

To extract a governing differential equation from this result one must transform the area integral of $\mathbf{t}_{(\mathbf{n})}$ to a volume integral. The best that Euler could do was to express the stress vector as

$$\mathbf{t}_{(\mathbf{n})} = -\mathbf{n}p \tag{1-38}$$

and this allows Eq. 1-37 to be written as

$$\int_{\mathcal{V}_m(t)} \left[\rho\frac{D\mathbf{v}}{Dt} - \rho\mathbf{b} + \nabla p\right] dV = 0 \tag{1-39}$$

The resulting differential equations

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v}\cdot\nabla\mathbf{v}\right) = -\nabla p + \rho\mathbf{b} \tag{1-40}$$

are often referred to as *Euler's equations.* It seems clear that Euler knew that Eq. 1-38 could not be generally correct, for the tangential stress that a flowing fluid exerted on a solid could not be explained by Eq. 1-38. While Euler had posed the question of internal stress in terms of his formulation of the laws of mechanics and his cut principle, he was unable to unravel the complex concept of stress.

Bernoulli's Equation

In the engineering literature, one finds references to Bernoulli's equation, the "working" Bernoulli equation, the "modified" Bernoulli equation, the "extended" Bernoulli equation, et cetera. Because of the existence of numerous variations on this theme, it is of some interest to know what role Johann Bernoulli (*père*) and Daniel Bernoulli (*fils*) played in the development of this theorem. Through the efforts of Hunter Rouse, Johann Bernoulli's **Hydraulica** and Daniel Bernoulli's **Hydrodynamica** have been translated by Carmody and Kobus (1968). In the preface to that edition, one is surprised to find the observation by Rouse that " the word is gradually spreading that the theorem bearing his name (Daniel) is nowhere to be found in his habitually cited **Hydrodynamica**." After that revelation, one should not be surprised to find the comment "These he (Leonhard Euler) finally integrated for specific conditions, thereby first deriving in a rigorous manner what is now known as Bernoulli's equation."

In order to place in proper perspective what is generally referred to as Bernoulli's equation, we ignore Eq. 1-40 and move ahead to the Navier-Stokes equations

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v}\right) = -\nabla p + \rho \mathbf{g} + \mu \nabla^2 \mathbf{v} \tag{1-41}$$

To keep matters as simple as possible, we have restricted our discussion to flows for which variations in the density can be neglected. The quasi-steady form of Eq. 1-41 can be used when

$$\rho \frac{\partial \mathbf{v}}{\partial t} << \mu \nabla^2 \mathbf{v} \tag{1-42}$$

and viscous effects can be neglected by imposing the inequality

$$\mu \nabla^2 \mathbf{v} << \rho \mathbf{v} \cdot \nabla \mathbf{v} \tag{1-43}$$

The constraints associated with these inequalities are given by (Whitaker, 1988)

$$\frac{\upsilon t^*}{L_\mu^2} >> 1, \quad \mathrm{Re}\frac{L_\mu}{L_\rho} >> 1 \tag{1-44}$$

Here t^* is a characteristic time, L_μ is the viscous length, and L_ρ is the inertial length. When small causes give rise to small effects (Birkhoff, page 4, 1960), we can use Eqs. 1-44 to arrive at

$$\rho \mathbf{v} \cdot \nabla \mathbf{v} = -\nabla p + \rho \mathbf{g} \tag{1-45}$$

The gravity vector can be expressed as the gradient of a scalar

$$\mathbf{g} = -\nabla \varphi \tag{1-46}$$

and this allows us to express the steady form of Euler's equations as

$$\rho \mathbf{v} \cdot \nabla \mathbf{v} = - \nabla (p + \rho\varphi) \tag{1-47}$$

We obtain Bernoulli's equation by forming the scalar product of Eq. 1-47 with a unit tangent vector to a streamline. We designate this unit vector by λ and note that it is defined by

$$\lambda = \mathbf{v}/v \tag{1-48}$$

where v is the magnitude of the velocity vector, $\mathbf{v}$. Forming the scalar product of λ with Eq. 1-47 leads to

$$\lambda \cdot \left[\rho v \lambda \cdot \nabla \mathbf{v}\right] = - \lambda \cdot \nabla (p + \rho\varphi) \tag{1-49}$$

Making use of the directional derivative yields

$$\lambda \cdot \left[\rho v \frac{d\mathbf{v}}{ds}\right] = - \frac{d}{ds}(p + \rho\varphi) \tag{1-50}$$

in which s represents the arclength along the streamline determined by λ. The left hand side of Eq. 1-50 can be expressed as

$$\lambda \cdot \left[\rho v \frac{d\mathbf{v}}{ds}\right] = \rho \mathbf{v} \cdot \frac{d\mathbf{v}}{ds} = \rho \frac{d}{ds}(\frac{1}{2} v^2) \tag{1-51}$$

and since we are ignoring variations in the density this result takes the form

$$\lambda \cdot \left[\rho v \frac{d\mathbf{v}}{ds}\right] = \frac{d}{ds}(\frac{1}{2} \rho v^2) \tag{1-52}$$

Here we see that the component of Eq. 1-47 *tangent to a streamline* is given by

$$\frac{d}{ds}(\frac{1}{2} \rho v^2 + p + \rho\varphi) = 0 \tag{1-53}$$

The integrated form of this result can be expressed as

$$\frac{1}{2}\rho v^2 + p + \rho\varphi = C \tag{1-54}$$

where the constant of integration, C, is associated with a particular streamline.

Since the units of each term in Eq. 1-47 are (force/volume), integration of that equation along a streamline leads to an equation having the units of (force × distance/volume) or (energy/volume). Because of this, there is a tendency to think of Bernoulli's equation as an *energy equation*, and one can arrive at this result by energy considerations (Milne-Thompson, page 8, 1960). However, it is best to think of Eq. 1-54 precisely in terms of the derivation presented here, i.e., it is the integrated form of the component of Eq. 1-47 tangent to a streamline.

Cauchy's Equations

Euler completed most of his studies of mechanics by 1766; however, it was not until 1822 that the concept of stress was described in modern form. On the basis of Eq. 1-2, Cauchy first proved two lemmas concerning the stress vector which are given by

$$\mathbf{t}_{(\mathbf{n})} = -\,\mathbf{t}_{(-\mathbf{n})} \tag{1-55}$$

$$\mathbf{t}_{(\mathbf{n})} = \mathbf{n}\cdot\mathbf{T} \tag{1-56}$$

in which $\mathbf{T}$ is the stress tensor. Use of the second of these in Eq. 1-2 yields

$$\frac{d}{dt}\int_{\mathcal{V}_m(t)} \rho\mathbf{v}\,dV = \int_{\mathcal{V}_m(t)} \rho\mathbf{b}\,dV + \int_{\mathcal{A}_m(t)} \mathbf{n}\cdot\mathbf{T}\,dA \tag{1-57}$$

and from here the special form of the Reynolds transport theorem and the divergence theorem provides

$$\int_{\mathcal{V}_m(t)} \left(\rho \frac{D\mathbf{v}}{Dt} - \rho\mathbf{b} - \nabla \cdot \mathbf{T} \right) dV = 0 \tag{1-58}$$

The usual assumptions concerning continuity lead to Cauchy's first equation

$$\rho \frac{D\mathbf{v}}{Dt} = \rho\mathbf{b} + \nabla \cdot \mathbf{T} \tag{1-59}$$

and a similar analysis of Eq. 1-3 gives Cauchy's second equation

$$\mathbf{T} = \mathbf{T}^T \tag{1-60}$$

This latter constraint on the stress tensor is the continuum analog of the central force condition given by Eq. 1-24 for mass points.

About the same time that Cauchy was putting the concept of stress in order, Louis Navier was presenting his derivation of Eq. 1-41 to the Académie des Sciences (Rouse and Ince, page 194, 1957). Navier's extension of Euler's representation of the stress vector was based on an assumption about the force between molecules in relative motion. His results were rederived by Poisson and extended by Saint-Venant to include the viscous contribution to the normal stresses. In 1845, Sir George Stokes provided a derivation that is generally repeated in modern treatments (Aris, Sec. 5.21, 1962), and it is for this reason that the equations in question are referred to as the Navier-Stokes equations. Stokes' analysis has been presented by Serrin (Sec 59, 1959), and for a compressible, isotropic, linear fluid, one finds a stress tensor given by

$$\mathbf{T} = -p\mathbf{I} + 2\mu\mathbf{D} + (\kappa - \frac{2}{3}\mu)(\nabla \cdot \mathbf{v})\mathbf{I} \tag{1-61}$$

Here μ and κ represent the coefficients of shear and bulk viscosity, and $\mathbf{D}$ represents the rate of deformation tensor given by

$$\mathbf{D} = \frac{1}{2}(\nabla \mathbf{v} + \nabla \mathbf{v}^T) \tag{1-62}$$

In writing Eq. 1-61, one imposes the constraint of local thermodynamic equilibrium (DeGroat and Mazur, 1962) so that the pressure is defined as

$$p = \rho^2 \left(\frac{\partial e}{\partial \rho}\right)_s \tag{1-63}$$

Here, e is the internal energy per unit mass and s is the entropy per unit mass. Use of Eqs. 1-61 and 1-62 in Eq. 1-59, and neglecting variations in μ and κ, leads to the following set of equations for the velocity and density

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v}\right) = -\nabla p + \rho \mathbf{b} + \mu \nabla^2 \mathbf{v} + (\kappa + \frac{1}{3}\mu) \nabla (\nabla \cdot \mathbf{v}) \tag{1-64}$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0 \tag{1-65}$$

The general solution of flow problems requires a thermal equation of state (Callen, Chap. 2, 1985)

$$p = p(\rho, T) \tag{1-66}$$

and an equation for the temperature (Whitaker, Chap. 5, 1982). If one is willing to impose the approximation that the density is a constant (Whitaker, 1988) Eqs. 1-63 and 1-64 reduce to

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v}\right) = -\nabla p + \rho \mathbf{g} + \mu \nabla^2 \mathbf{v} \tag{1-67}$$

$$\nabla \cdot \mathbf{v} = 0 \tag{1-68}$$

Here, the general body force vector **b** has been replaced with the gravity vector **g** in order to recapture the form given earlier by Eq. 1-41. With the approximation of a constant density, one finds that the velocity vector and pressure are completely determined by Eqs. 1-67 and 1-68 and the equation of state given by Eq. 1-66 is therefore not satisfied. This is a situation in which Eq. 1-66 is replaced by

$$\rho = \text{constant} \tag{1-69}$$

If this is a good approximation, the pressure field determined by Eqs. 1-67 and 1-68 will be in good agreement with experimental values. If Eq. 1-69 is *not* a good approximation, the calculated pressure field will be in poor agreement with experimental values.

Before leaving this brief discussion of Stokes' contribution to the development of the Navier-Stokes equations, we need to point out that his ideas about fluid behavior were more general than the result indicated by Eq. 1-61 would indicate. In fact, he defined what is now known as a Stokesian fluid (Aris, Sec. 5.21, 1962) in terms of the following four postulates:

1. The stress tensor $\mathbf{T}$ is a continuous function of the deformation tensor $\mathbf{D}$ and is independent of all other kinematical quantities.

2. The fluid is homogeneous, that is, $\mathbf{T}$ does not depend explicitly on the position $\mathbf{r}$.

3. The fluid is isotropic.

4. When $\mathbf{D} = 0$, $\mathbf{T}$ reduces to $-p\mathbf{I}$.

If one also imposes the constraint that $\mathbf{T}$ is a linear function of $\mathbf{D}$, the Newtonian fluid, represented by Eq. 1-61, is obtained. At this point, we have seen that 100 years was required for the concepts of *kinematics*, *stress*, and *constitutive relations* to be developed. It was Euler who provided a precise statement of the non-relativistic laws of mechanics, introduced the cut principle and the concept of stress, and developed important results concerning the kinematics of continua. This was done primarily in the period between 1750 and 1766. In 1822, Cauchy placed the concept of stress on a modern basis and in

1845, Stokes provided the same service for the formulation of constitutive relations.

Shortly before Stokes was putting the finishing touches on the Navier-Stokes equations, experiments were done that would prove to be exceptionally valuable; both from the point of view of providing an experimental verification of the Navier-Stokes equations and from a purely empirical point of view. In 1839, Hagen described a series of experiments on laminar flow in capillary tubes, and in 1841, Poiseuille published his own independent studies of this problem. Poiseuille's more accurate results could be expressed as (Rouse and Ince, page 160, 1957)

$$Q = \frac{\pi D^4}{128\mu}\left(\frac{\Delta p}{L}\right) \tag{1-70}$$

Here, Q represents the volumetric flow rate, D the tube diameter, and L the tube length. Rouse and Ince (1957) suggest that Stokes was not aware of the data of Hagen and Poiseuille and it remained for Franz Neumann and Eduard Hagenback to independently derive Eq. 1-70 from the Navier-Stokes equations in the years 1858-1860.

In the second half of the 19th century there were numerous experimental studies and many of these are described by Rouse and Ince (Chap XI, 1957). From a theoretical point of view, the great achievement of this period was the work of Maxwell (1867) who provided a kinetic theory version of the Navier-Stokes equations. Much of what was known about the theory of fluid motion in 1879 was compiled in Lamb's **Treatise on the Mathematical Theory of the Motion of Fluids,** and a decade latter a similar treatise entitled **Hydrodynamics** was produced by Basset (1888). Both of these works are largely devoted to the motion of perfect fluids, but toward the end of each volume one can find discussions of what was known about the flow of viscous fluids at the time.

2. Speculation

Since I have not read the literature prior to 1888 I cannot say for certain anything about the status of the *macroscopic balances* associated with the continuity equation and Cauchy's first equation. If the following developments are not in the literature, they certainly could have been since all of the concepts and mathematical tools required were available prior to 1888.

Mass

The derivation of the macroscopic mass balance begins with Eq. 1-1 and moves directly to Eq. 1-34. We consider an arbitrary moving control volume designated by $\mathcal{V}_a(t)$ and we integrate Eq. 1-34 over this volume to obtain

$$\int_{\mathcal{V}_a(t)} \left[\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) \right] dV = 0 \tag{2-1}$$

The normal component of the velocity of $\mathcal{V}_a(t)$ is denoted by $\mathbf{w} \cdot \mathbf{n}$, and for this moving deforming control volume there exists a kinematical theorem known as the *general transport theorem.* This can be expressed as

$$\frac{d}{dt} \int_{\mathcal{V}_a(t)} \psi dV = \int_{\mathcal{V}_a(t)} \left(\frac{\partial \psi}{\partial t} \right) dV + \int_{\mathcal{A}_a(t)} \psi \mathbf{w} \cdot \mathbf{n} dA \tag{2-2}$$

Use of this result along with the divergence theorem allows us to write Eq. 2-1 in the form

$$\frac{d}{dt} \int_{\mathcal{V}_a(t)} \rho \, dV + \int_{\mathcal{A}_a(t)} \rho \, (\mathbf{v} - \mathbf{w}) \cdot \mathbf{n} \, dA = 0 \tag{2-3}$$

The first term in this result represents the rate of accumulation of mass within the control volume while the second term represents the net rate at which mass leaves the control volume. Rouse and Ince (1957) have commented extensively on what they refer to as the *continuity principle*, and while Eq. 2-3 does not appear in their discussion it is clear that the physical concepts associated with Eq. 2-3 were understood prior to 1888. An example is the analysis of flood waves published by Dupiut in 1848 (Rouse and Ince, page 168, 1957).

Momentum

To obtain the linear momentum balance, one proceeds from Eq. 1-2 to Eq. 1-59 and uses the continuity equation to obtain the conservative form on the left hand side leading to

$$\frac{\partial}{\partial t}(\rho \mathbf{v}) + \nabla \cdot (\rho \mathbf{v}\,\mathbf{v}) = \rho \mathbf{b} + \nabla \cdot \mathbf{T} \tag{2-4}$$

Integration over $\mathcal{V}_a(t)$ and use of the general transport theorem gives the macroscopic momentum balance

$$\frac{d}{dt}\int_{\mathcal{V}_a(t)} \rho \mathbf{v}\, dV + \int_{\mathcal{A}_a(t)} \rho \mathbf{v}\,(\mathbf{v} - \mathbf{w}) \cdot \mathbf{n}\, dA = \int_{\mathcal{V}_a(t)} \rho \mathbf{b}\, dV + \int_{\mathcal{A}_a(t)} \mathbf{t}_{(\mathbf{n})} dA \tag{2-5}$$

Whether this completely general form of the linear momentum balance was available to the hydraulicians of the nineteenth century remains a question. However, it is certain that the fixed control volume, steady flow form of Eq. 2-5 was in use. As an example we note that Rouse and Ince (page 168, 1957) cite the work of Bresse who correctly analyzed the hydraulic jump and the equation for gradually varied flow in an open channel.

Mechanical Energy

Scalar problems are often easier to solve than the associated vector problem, and the scalar analog of Eq. 2-5 is known as the macroscopic mechanical energy balance. One begins the derivation of this useful result by forming the scalar product of Eq. 1-59 with the velocity vector to obtain

$$\rho\mathbf{v}\cdot\frac{D\mathbf{v}}{Dt} = \rho\mathbf{v}\cdot\mathbf{b} + (\nabla\cdot\mathbf{T})\cdot\mathbf{v} \tag{2-6}$$

It is easy to show that

$$\mathbf{v}\cdot\frac{D\mathbf{v}}{Dt} = \frac{D}{Dt}\left(\frac{1}{2}v^2\right) \tag{2-7}$$

and a bit more difficult to prove

$$(\nabla\cdot\mathbf{T})\cdot\mathbf{v} = \nabla\cdot(\mathbf{T}\cdot\mathbf{v}) - \mathbf{T}:\nabla\mathbf{v} \tag{2-8}$$

Use of these results in Eq. 2-6 leads to an energy equation

$$\rho\frac{D}{Dt}\left(\frac{1}{2}v^2\right) = \rho\mathbf{v}\cdot\mathbf{b} + \nabla\cdot(\mathbf{T}\cdot\mathbf{v}) - \mathbf{T}:\nabla\mathbf{v} \tag{2-9}$$

We should remember that each term in Eq. 1-59 has the units of (force/volume), thus multiplication by the velocity leads to an energy equation having the units of (force × distance/volume × time). It is convenient to arrange the left hand side of Eq. 2-9 in a conservative form, and we begin by expanding the left hand side to obtain

$$\rho\left[\frac{\partial}{\partial t}\left(\frac{1}{2}v^2\right) + \mathbf{v}\cdot\nabla\left(\frac{1}{2}v^2\right)\right] = \rho\mathbf{v}\cdot\mathbf{b} + \nabla\cdot(\mathbf{T}\cdot\mathbf{v}) - \mathbf{T}:\nabla\mathbf{v} \tag{2-10}$$

Use of Eq. 1-34 allows us to write

$$\frac{1}{2}v^2\left[\frac{\partial\rho}{\partial t} + \nabla\cdot(\rho\mathbf{v})\right] = 0 \tag{2-11}$$

and when this is added to Eq. 2-10 we obtain a conservative form for the left hand side

$$\frac{\partial}{\partial t}\left(\frac{1}{2}\rho v^2\right) + \nabla\cdot\left(\frac{1}{2}\rho v^2\mathbf{v}\right) = \rho\mathbf{v}\cdot\mathbf{b} + \nabla\cdot(\mathbf{T}\cdot\mathbf{v}) - \mathbf{T}:\nabla\mathbf{v} \tag{2-12}$$

Decomposition of the stress tensor according to

$$\mathbf{T} = -p\mathbf{I} + \boldsymbol{\tau} \tag{2-13}$$

yields the following version of our energy equation

$$\frac{\partial}{\partial t}\left(\frac{1}{2}\rho v^2\right) + \nabla\cdot\left(\frac{1}{2}\rho v^2 \mathbf{v}\right) = \rho\mathbf{v}\cdot\mathbf{b} + \nabla\cdot(\mathbf{T}\cdot\mathbf{v}) + p\nabla\cdot\mathbf{v} - \boldsymbol{\tau}:\nabla\mathbf{v} \tag{2-14}$$

The last term in this result is referred to as the *viscous dissipation* and Lamb (1879) has given an explicit representation for $\boldsymbol{\tau}:\nabla\mathbf{v}$ for an incompressible, Newtonian fluid.

If we integrate Eq. 2-14 over a *fixed control volume*, $\mathcal{V}$, The divergence theorem allows us to arrange the result as

$$\frac{d}{dt}\int_{\mathcal{V}}\frac{1}{2}\rho v^2\, dV + \int_{\mathcal{A}}\frac{1}{2}\rho v^2\,\mathbf{v}\cdot\mathbf{n}\, dA = \int_{\mathcal{V}}\rho\mathbf{v}\cdot\mathbf{b}\, dV + \int_{\mathcal{A}}\mathbf{t}_{(\mathbf{n})}\cdot\mathbf{v}\, dA + \int_{\mathcal{A}}p\nabla\cdot\mathbf{n}\, dV - \int_{\mathcal{V}}\boldsymbol{\tau}:\nabla\mathbf{v}\, dV \tag{2-15}$$

This result is identical to that given by Basset (page 253, Vol 2, 1888) thus we know that it was available to chemical engineers in 1888. Although Basset took the time to derive this form of the macroscopic mechanical energy balance, I am not able to find the macroscopic momentum balance in his two volume treatise. However, the elements of the macroscopic momentum balance are evident in Basset's treatment of shallow water waves, which is essentially identical to that given by Lamb (1879).

While a complete derivation of Eq. 2-15 was given by Basset, no examples of its application were given and a little thought will indicate that there are two serious limitations in this form of the mechanical energy balance. To begin with, the first term on the right hand side of Eq. 2-15 will be very difficult to evaluate since the integral involves the knowledge of the velocity field everywhere in the control volume. In addition, the use of a fixed control volume precludes the possibility of treating systems in which *shaft work* is non-zero.

We can eliminate the first difficulty by returning to Eq. 2-9 and restricting our analysis to systems in which the body force can be represented as the gradient of a scalar

$$\mathbf{b} = - \nabla\varphi \tag{2-16}$$

Making use of the type of kinematics that was available in Euler's time, we write

$$\rho \frac{D\varphi}{Dt} = \rho \frac{\partial\varphi}{\partial t} + \rho\mathbf{v} \cdot \nabla\varphi \tag{2-17}$$

If the body force potential function is *independent of time*, we have

$$\rho\mathbf{v} \cdot \mathbf{b} = - \rho \frac{D\varphi}{Dt} \tag{2-18}$$

This situation most often occurs when **b** is the gravity vector **g**, and use of Eq. 2-18 in Eq. 2-9 leads to

$$\rho \frac{D}{Dt} (\frac{1}{2} v^2 + \varphi) = \nabla \cdot (\mathbf{T} \cdot \mathbf{v}) - \mathbf{T} : \nabla\mathbf{v} \tag{2-19}$$

From here one follows Eqs. 2-9 through 2.14 to arrive at

$$\frac{\partial}{\partial t} (\frac{1}{2} \rho v^2 + \rho\varphi) + \nabla \cdot \left[(\frac{1}{2} \rho v^2 + \rho\varphi) \mathbf{v} \right] = \nabla \cdot (\mathbf{T} \cdot \mathbf{v}) + p\nabla \cdot \mathbf{v} - \tau : \nabla\mathbf{v} \tag{2-20}$$

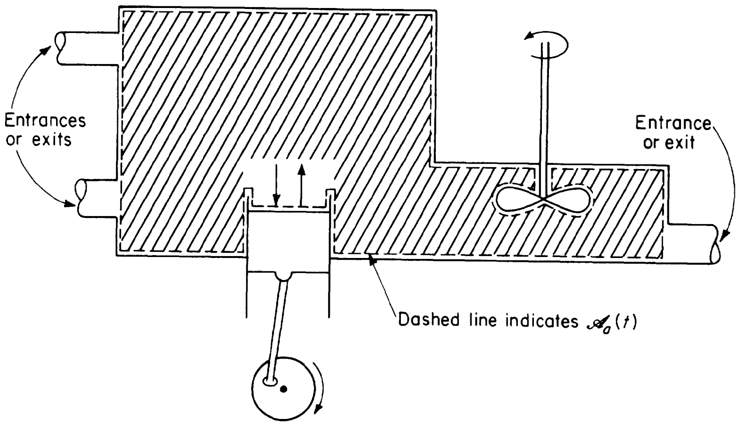
Rather than integrate this form of our mechanical energy equation over a fixed control volume, we perform the integration over an arbitrary moving control volume, $\mathcal{V}_a(t)$. An example of this type of control volume is shown in Fig. 2-1, and the integration leads to

$$\frac{d}{dt}\int_{\mathcal{V}_a(t)} \left(\frac{1}{2}\rho v^2 + \rho\varphi\right) dV + \int_{\mathcal{A}_a(t)} \left(\frac{1}{2}\rho v^2 + \rho\varphi\right)(\mathbf{v} - \mathbf{w}) \cdot \mathbf{n}\, dA = \int_{\mathcal{A}_a(t)} \mathbf{t}_{(\mathbf{n})} \cdot \mathbf{v}\, dA$$

$$+ \int_{\mathcal{V}_a(t)} p\nabla \cdot \mathbf{v}\, dV - \int_{\mathcal{V}_a(t)} \tau : \nabla\mathbf{v}\, dV \qquad (2\text{-}21)$$

The surface area of this arbitrary, moving control volume can often be represented in the following special form

Figure 2-1
A Moving Control Volume



$$\mathcal{A}_a(t) = \begin{array}{ll} A_e(t) & \text{area of entrances and exits} \\ +A_s(t) & \text{area of solid moving surfaces} \\ +A_S & \text{area of solid fixed surfaces} \end{array} \qquad (2\text{-}22)$$

Since $(\mathbf{v} - \mathbf{w}) \cdot \mathbf{n}$ is zero over $A_s(t)$ and A_s we can simplify Eq. 2-21 to

$$\frac{d}{dt}\int_{\mathcal{V}_a(t)} \left(\frac{1}{2}\rho v^2 + \rho\varphi\right) dV + \int_{A_e(t)} \left(\frac{1}{2}\rho v^2 + \rho\varphi\right)(\mathbf{v} - \mathbf{w}) \cdot \mathbf{n}\, dA = \int_{A_s(t)} \mathbf{t}_{(\mathbf{n})} \cdot \mathbf{v}\, dA$$

$$+ \int_{A_e(t)} \mathbf{t}_{(\mathbf{n})} \cdot \mathbf{v}\, dA + \int_{\mathcal{V}_a(t)} p\nabla \cdot \mathbf{v}\, dV - \int_{\mathcal{V}_a(t)} \tau : \nabla\mathbf{v}\, dV \qquad (2\text{-}23)$$

The four terms on the right hand side of this result can be identified as the shaft work, the flow work, the reversible work and the irreversible work (viscous dissipation). The shaft work is a very important quantity in many practical problems and it can only be included in the analysis by means of a moving control volume. In addition, the use of the kinematical relation given by Eq. 2-18 has allowed us to represent the rate of work done by the body force $\mathbf{b}$ in terms of an accumulation and flux of potential energy. It should be clear that the concepts of *kinematics* and *stress* are essential elements of the derivation that led originally from Eq. 1-2 to the macroscopic mechanical energy balance given by Eq. 2-23.

To complete our discussion of macroscopic balances and to lay the groundwork for some of the discussion in the next section, we need to add the total energy equation to our array of tools for solving fluid flow problems. The axiomatic form of the first law of thermodynamics that is analogous to Eqs. 1-1 through 1-3 can be expressed as

$$\frac{d}{dt}\int_{\mathcal{V}_m(t)} \left(\rho e + \frac{1}{2}\rho v^2 + \rho\varphi\right) dV = -\int_{\mathcal{A}_m(t)} \left(\mathbf{q} + \mathbf{q}^R\right) \cdot \mathbf{n}\, dA + \int_{\mathcal{A}_m(t)} \mathbf{t}_{(\mathbf{n})} \cdot \mathbf{v}\, dA \qquad (2\text{-}24)$$

provided φ is independent of time (see Sec. 4). Here e represents the internal energy per unit mass and it is assumed to be a unique function of the local thermodynamic state (DeGroat and Mazur, page 23, 1962). In Eq. 2-24 we have used $\mathbf{q}$ to represent the usual conductive heat flux vector and $\mathbf{q}^R$ to represent the radiant energy heat flux vector, and the governing differential equation associated with Eq. 2-24 is given by

$$\frac{\partial}{\partial t}\left(\rho e + \frac{1}{2}\rho v^2 + \rho\varphi\right) + \left[\nabla \cdot \left(\rho e + \frac{1}{2}\rho v^2 + \rho\varphi\right)\mathbf{v}\right]$$

$$= -\nabla \cdot \left(\mathbf{q} + \mathbf{q}^R\right) + \nabla \cdot (\mathbf{T}\cdot\mathbf{v}) \qquad (2\text{-}25)$$

Integration over an arbitrary moving control volume, $\mathcal{V}_a(t)$, and use of the representation given by Eq. 2-22 leads to the general macroscopic total energy balance.

$$\frac{d}{dt}\int_{\mathcal{V}_a(t)}\left(\rho e + \frac{1}{2}\rho v^2 + \rho\varphi\right)dV + \int_{A_e(t)}\left(\rho e + \frac{1}{2}\rho v^2 + \rho\varphi\right)(\mathbf{v}-\mathbf{w})\cdot\mathbf{n}dA$$

$$= -\int_{\mathcal{A}_a(t)}\left(\mathbf{q} + \mathbf{q}^R\right)\cdot\mathbf{n}dA + \int_{A_s(t)}\mathbf{t}_{(\mathbf{n})}\cdot\mathbf{v}dA + \int_{A_e(t)}\mathbf{t}_{(\mathbf{n})}\cdot\mathbf{v}dA$$

(2-26)

The last two terms in this result represent the shaft work and flow work respectively, and the existence of a number of common terms in Eq. 2-26 and Eq. 2-23 has led to considerable confusion. This will be discussed in the next section.

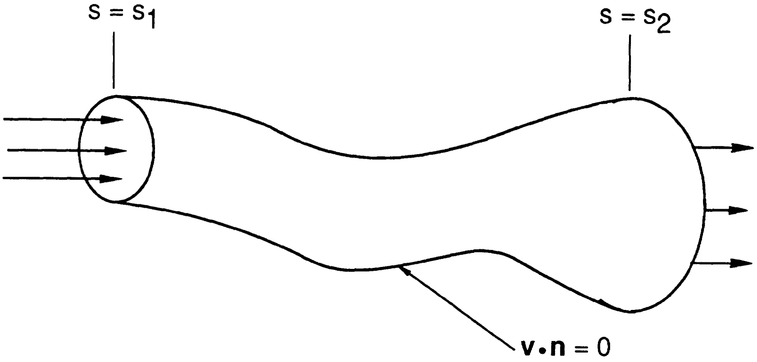
Before moving on to the chemical engineering contributions to fluid mechanics, it is of some interest to apply Eq. 2-23 to a steady, incompressible flow in terms of the stream tube illustrated in Fig. 2-2. For this particular situation, Eq. 2-21 takes the form

$$\int_{\mathcal{A}}\left(\frac{1}{2}\rho v^2 + \rho\varphi\right)\mathbf{v}\cdot\mathbf{n}dA = \int_{\mathcal{A}}\mathbf{t}_{(\mathbf{n})}\cdot\mathbf{v}dA - \int_{\mathcal{V}}\tau : \nabla\mathbf{v}dV \qquad (2\text{-}27)$$

Here we have neglected the reversible work term since $\nabla \cdot \mathbf{v}$ is set equal to zero, and $\mathcal{V}_a(t)$ and $A_e(t)$, have been replaced with $\mathcal{V}$ and A since the control volume is fixed in space. Neglecting all *viscous effects* is consistent with

$$\mathbf{t}_{(\mathbf{n})} = -\mathbf{n}p \quad , \quad \boldsymbol{\tau} : \nabla \mathbf{v} = 0 \tag{2-28}$$

Figure 2-2
Steady, Incompressible Flow in a Stream Tube



thus Eq. 2-24 reduces to

$$\int_{A_1} \left(\frac{1}{2}\rho v^2 + \rho\varphi\right)\mathbf{v}\cdot\mathbf{n}\, dA + \int_{A_2} \left(\frac{1}{2}\rho v^2 + \rho\varphi\right)\mathbf{v}\cdot\mathbf{n}\, dA = -\int_{A_1} p\mathbf{v}\cdot\mathbf{n}\, dA$$

$$-\int_{A_2} p\mathbf{v}\cdot\mathbf{n}\, dA \tag{2-29}$$

Here we have made use of $\mathbf{v}\cdot\mathbf{n} = 0$ on the bounding surface of the stream tube. A little thought will indicate that Eq. 2-26 can be expressed as

$$\int_A \left(\frac{1}{2}\rho v^2 + \rho\varphi + p\right)\mathbf{v}\cdot\mathbf{n}\, dA = \{\text{constant along a stream tube}\} \tag{2-30}$$

where A is any cross-sectional area of the stream tube. Since the macroscopic mass balance for this particular situation requires

$$\int_A \mathbf{v}\cdot\mathbf{n}\, dA = \{\text{constant along a stream tube}\} \tag{2-31}$$

we can let A tend to zero to obtain Bernoulli's equation

$$\frac{1}{2}\rho v^2 + \rho\varphi + p = \{\text{constant along a stream tube}\} \tag{2-32}$$

Here we see that the macroscopic mechanical energy equation contains Bernoulli's equation as a *very special case*. It is for this reason that there is a tendency to confuse the situation and refer to Eq. 2-23 as the "working" Bernoulli equation, or the "extended" Bernoulli equation, etc. This is a mistake. One should think of Bernoulli's equation as the integrated form of the component of the Navier-Stokes equations tangent to a streamline when the constraints indicated by Eq. 1-44 are valid. One should think of the macroscopic mechanical energy balance as the macroscopic mechanical energy balance.

While the Navier-Stokes equations and Bernoulli's equation, along with the macroscopic mass and linear momentum balances, were clearly available prior to 1888, it seems likely that the general macroscopic mechanical energy balance was not. Nevertheless, the fixed control volume version was in print in Basset's treatise and the extension to the general form required only the kinematics that were available in Euler's time.

3. DEVELOPMENTS IN CHEMICAL ENGINEERING

In this section the development of fluid mechanics within chemical engineering is traced from 1888 to 1960. My examination of the literature has not been thorough, thus the contribution of individual players may not be accurately portrayed; however, I hope that I have captured the flavor of the game. One could describe my study as disorganized browsing with the idea of locating the first applications of the principles that were established during the period from 1750 to 1888. It seems highly probable that I have not located the *very first application*, but the sequence of events should be reasonably close to the truth.

The first fluid mechanics paper that I encountered was entitled "The Torsion Viscosimeter." It was authored by O.S. Doolittle (1893) and his opening comment referred to the importance of the coefficient of viscosity in the following manner:

> "The viscosity of an oil is recognized today by both the producer and the consumer as the most valuable measure of its lubricating power, and yet we find no uniformity whatsoever in the manner of measurement of this essential property."

Doolittle's torsional viscosimeter was essentially a damped, oscillating Couette viscometer, and Doolittle chose as the *unit of viscosity* the "number of degrees of retardation between the first and second complete arcs." There is no mention in this paper of the Hagen-Poiseuille law, the Navier-Stokes equations, the treatise of Lamb (1879) or the work of Basset (1888), and it would appear that Doolittle was unaware of the studies of fluid mechanics carried out in the previous century and half. Nearly two decades later, Gillet (1909) began his paper entitled "Analysis and Friction Tests of Lubricating Greases" with the comment:

> "'grease is grease' seems to be the attitude of most makers and users of that lubricant. The following work was undertaken in an attempt to determine the relation,

> if any, between composition and lubricating value of the typical greases on the market today."

The *lubricating value* was determined by a Legler consistometer, which seemed to be little more than a measurement of the time required for a standard rod to sink a standard distance into a standard cup of the grease under consideration. Even though the theoretical relation between the viscosity of a fluid and its lubricating characteristics appeared to be unknown to these early workers, the importance of this physical property was most certainly appreciated. For example, consider the words of Mabery (1910):

> "Next to the conservation of the world's fuel supply, there is probably no subject of greater importance in the manufacturing world than the control of waste power caused by imperfect lubrication and needless friction."

One year later, we find Rogers and Sabin (1911) defining the viscosity by

> "The index of viscosity may be defined as the force required to produce a given shear in a given time."

Obviously, the work of Stokes (1845) was unknown to Rogers and Sabin; however, in the same year we find the work of Bingham and White (1911) in which a capillary tube viscometer is described. They remark that "....the well known formula of Poiseuille for the flow of a liquid through a capillary tube may be written as"

$$\frac{8\ell V}{\pi r^4 t} = \frac{P}{H} \tag{3-1}$$

Here V is the "rate of transpiration" (in fact V is the total volume of flow passing through the capillary tube in a time t), ℓ is the length of the capillary tube, r is the radius, and H is the coefficient of viscosity. Bingham and White refer to the earlier work of Thorpe and Roger [Z. physik Chem., 63, 619 (1908)] with the comment that they "....have already shown that the horizontal tube method of Poiseuille may be used for measuring viscosities...." In the following year, White (1912) described the use of a Ostwald-type viscometer for which the coefficient of viscosity, η, was given by

$$\eta = \frac{\pi r^4 pt}{8v\ell} - \frac{vd}{8\pi t\ell} \qquad (3\text{-}2)$$

The first term on the right hand side of this expression obviously represents the Hagen-Poiseuille law, while the second term (referred to as a kinetic energy correction) represents the influence of the entrance region. Equation 3-2 can be found in many subsequent papers on the use of capillary tube viscometers in which a transient flow process is utilized; however, I was never able to locate a derivation of the kinetic energy correction term.

While the lubricating power of liquids was of obvious importance to many of the early workers, general problems of fluid mechanics were also appreciated by some. For example, in a paper entitled "The Adaptation of the Centrifugal Pump to Chemical Problems" Wheeler (1912) states:

> "It has always seemed to me that the machine which is most used in chemical engineering is the one for moving liquids form one place to another."

Wheeler notes that " we can calculate the speed from the law of falling bodies, $V = \sqrt{2gh}$ . . . ."; however, no mention is made of the mechanical energy balance as a tool for the interpretation of pump efficiencies. At the same time that Wheeler was discussing the centrifugal pump, Almy and Lewis (1912) were presenting their work on filters which was entitled "Factors Determining the Capacity of a Filter Press." They were guided in their work by Lamb's description of Poiseuille's result for flow in a capillary tube. This suggested that the flow rate through a filter should be inversely proportional to the viscosity; however, their experimental-empirical approach led them to conclude just the opposite. Flow through compressible filter cakes represents a very challenging mechanical problem; but it is now reasonably well-established (Whitaker, 1986) that Darcy's law applies in its traditional form. However, the permeability tensor is a function of the fluid viscosity, the fluid velocity, and the mechanical characteristics of the filter cake. Because of this, it is very difficult to understand the process from a purely experimental point of view.

While there was some interest in general fluid mechanical problems in this era, most of the research effort was directed toward the measurement of the viscosity of a wide range of fluids. While the capillary tube viscometer was known by some, its use was not appreciated by all, leading Twining to lament:

> "....yet we can hardly expect to obtain consistent results with viscosimeters many of which, stripped of all external equipage, are fundamentally dependent on little more than a hole in a can."

Twining's work was based on the effort by White (1912) and the viscosity was determined by the use of Eq. 3-2 which Twining refers to as Poiseuille's equation.

The measurement of the coefficient of viscosity was the dominant theme in the fluid mechanics literature up to 1916, and in that year McIlhiney (1916) publicized the suggestion by Deeley and Parr (1913) that "the unit of viscosity in C.G.S. units should be called the poise in honor of Poiseuille." Clearly the experimental studies of Poiseuille were known and appreciated in 1916, and much of this appears to be due to the description of laminar flow in a capillary tube that was available in Lamb's **Hydrodynamics.** The Navier-Stokes equations were also available in that treatise, but their utility was not so evident. In the year 1916, research in fluid mechanics began to move beyond the confines of measuring the viscosity, and it was in that year that Prof. W.K. Lewis published a paper entitled "The Flow of Viscous Liquids Through Pipes." This experimental work was a pressure drop-flow rate study in which dye studies were also used to observe the turbulent fluid motion. Lewis noted that "....at the walls of the container there is always a *film of liquid* which is retarded by the friction of the solid surface." This observation most probably was the harbinger of the *film concept* which played such an important role in the interpretation of heat and mass transfer rates. The experimental measurements were presented as a log-log plot of the volumetric flow rate versus the pressure drop, thus Lewis was unaware of the dimensional analysis put forth by Blasius (1911) several years earlier. While Lewis issued the universal complaint that "....the experimental error was great owing to inadequate equipment...," he was able to identify the laminar regime, the turbulent regime, and a definite transition regime between these two extremes. He summarized his results with predictions for the pressure drop given by

$$P = \frac{8\mu\ell v}{gr^2} \quad , \qquad \text{laminar} \tag{3-3}$$

$$P = f\left(\frac{\rho v^2 \ell}{gr}\right) \quad , \qquad \text{turbulent} \tag{3-4}$$

and indicated that the v^2 dependence in Eq. 3-4 was an approximation. Lewis' experiments were done with water and to obtain a friction factor for some other fluid, he suggested that one find f_{H_2O} at the same velocity and pipe size and then use

$$f = \left(0.955 + 0.045 \frac{\mu}{\mu_{H_2O}}\right) f_{H_2O} \tag{3-5}$$

Obviously the concepts of dimensional analysis were missing here, but they were soon to become widely known.

In the year following Lewis' study of pipe flow, Shepard (1917) published a paper on the falling ball viscometer. In that work, he referred to the analysis of Stokes, thus potentially placing the chemical engineering community in the United States in contact with the great founding works ranging from Euler to Stokes. In 1922 the problem of flow in pipes was reinvestigated by Wilson, McAdams and Seltzer (1922) and in this case the concepts of dimensional analysis were indeed available. The experimental results were presented in terms of the friction factor as a function of the Reynolds number, and the influence of pipe-wall roughness was identified but not quantified. References to Lamb (1879), Reynolds (1883), and Stokes (1850) helped to establish a connection with the work of the 19th century. About the use of the Reynolds number as a correlating parameter, the authors remarked that "....these important results have received surprisingly little attention in this country." It would appear that " keeping up with the literature" is an ever present problem. When the technological transfer of information is inefficient there is a *delay time* caused by the slow rate of transfer. When the technological transfer of information is efficient, there is a *delay time* caused by the fact that we are inundated by information. Perhaps there is a universal delay time to which we must become accustomed.

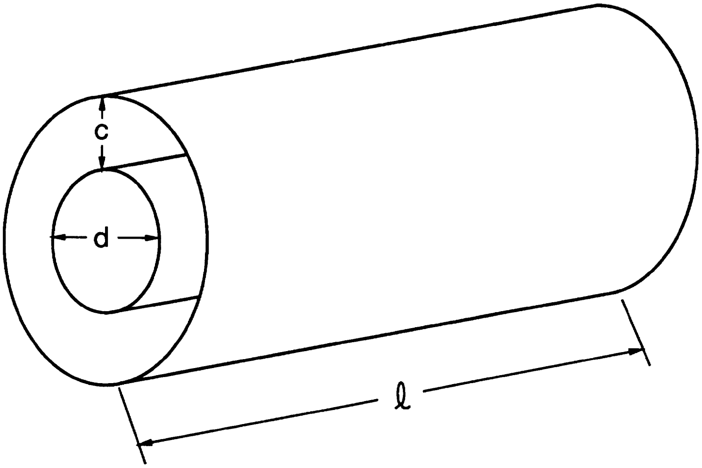
The advent of dimensional analysis suddenly changed the flavor of experimental studies from site specific efforts to generalized experimental programs in which a limited number of experiments might yield a broadly applicable empirical relation. In the same year that Wilson, McAdams and Seltzer were presenting their pipe flow studies, Wilson and Barnard (1922) published the first two parts of a three part study on the mechanism of lubrication. Part three of this study was published two years later by Barnard, Meyers and Forrest (1924). This third paper dealt with the lubrication of a journal bearing and was thus a prime candidate for an analysis using the Navier-Stokes equations. Instead one finds only dimensional analysis, the origin of which is attributed to Hershy [J. Wash. Acad. Sci., 4, No. 19 (1914)]. The system under investigation is illustrated in Fig. 3-1, and the ill-defined coefficient of friction was expressed as

$$f = \text{function}\left(\frac{zn}{p}, \frac{c}{d}, \frac{\ell}{d}, S, M, O\right) \tag{3-6}$$

In this result, z is the viscosity, n is the revolutions per minute, p is the load on the bearing divided by the projected area, and c, d, and ℓ are the lengths illustrated in Fig. 3-1. One should note that the Reynolds number is absent from Eq. 3-6. The parameter S was described by the authors as the "surface conditions - composition, smoothness, et cetera."

Although the surface roughness was not quantified in terms of a dimensionless parameter, the authors must be applauded for warning their readers that this effect needed to be considered. Along the same lines, the symbol M was used to suggest that the "method of supplying the lubricant" might generate a dimensionless parameter of importance. About the symbol O in Eq. 3-6, the authors state that "The 'oiliness' is defined as that property of lubricants by virtue of which one fluid gives lower coefficients of friction than another fluid of the same viscosity." On the basis of the work of Wilson, McAdams and Seltzer (1922), it is difficult to see how the Reynolds number could have been omitted from Eq. 3-6, and it would appear that its omission is the origin of the "oiliness

Figure 3-1
Journal Bearing



factor" if one is dealing only with Newtonian fluids.

In 1923 the first comprehensive chemical engineering text, entitled **Principles of Chemical Engineering** by Walker, Lewis and McAdams, was published. This book was an enormous pedagogical effort which touched upon virtually everything that was chemical engineering in 1923. It begins with *stoichiometry* and ends with *drying* , while *crushing and grinding* and a host of other subjects are located in between. Sixty-five years later stoichiometry is still a crucial element of chemical engineering (Aris, 1965), drying remains as an unsolved problem (Whitaker, 1977), and the *mechanical problems* associated with crushing and grinding are still in their infancy.

After the opening chapter on stoichiometry and a brief commentary on the *film concept* first advanced by Lewis in 1916, Walker, Lewis and McAdams present their treatment of the flow of fluids with:

> "The principles underlying the analysis of every problem of fluid flow are, first, the *conservation of matter*; second, the *conservation of energy*; and third, the *laws of fluid friction.*"

This set of priorities is dramatically different from the set that emerged from the 19th century, i.e., *kinematics, stress,* and *constitutive relations.* The approach taken in this initial pedagogical formulation of chemical engineering principles is with us today in the form of a philosophy that a wide variety of fluid flow problems can be understood via the first law of thermodynamics. After developing the one inlet-one outlet, steady form of the total energy equation given by Eq. 2-26, the authors move on to the mechanical energy balance. Here the contortions of a later period were avoided and a direct approach was taken. The authors wanted the mechanical energy equation in their tool kit, but they did not know how to derive this powerful result. They *began* to solve the problem in the following manner:

> "For steady flow of essentially incompressible fluids under conditions where *friction is negligible*, in the *absence of external work effects* it is found experimentally that there is little error in an energy balance involving only the terms for the mechanical forms of energy."

It is not exactly clear what the authors had in mind here, but it would seem to be Bernoulli's equation given earlier by Eq. 1-54. However, the restrictions of noncompressible fluids, negligible friction, and no external work had to be removed in order to arrive at the desired result. The line of attack at this point was quite direct, the authors simply *added the desired terms* in order "to balance the equation". The result was the one entrance-one exit, steady form of Eq. 2-23 and the authors incorrectly identified it as Bernoulli's equation.

According to Bertrand Russel, this type of approach should be avoided, and his thoughts on the matter are:

> "The habit of simply assuming results, once one is persuaded that they are true, rather than trying to prove them, has all the advantages of thievery over honest toil."

Russel's criticism is really much too mild since the tradition of accepting results without proof can have disastrous consequences when complex problems are encountered outside of the classroom. In that arena one is likely to encounter many persuasions that certain results are TRUE. Under some circumstances, considerable pressure can be brought to bear on individuals to convince them that results which are *unsupportable* are in fact *true*. If *persuasion* rather than *proof* has been a classroom technique in an engineer's formative years, what can we expect when push comes to shove in the marketplace?

In the years following 1923, research papers dealt with the measurement of viscosity as a function of concentration, temperature, and pressure, along with a variety of experimental studies based on dimensional analysis. A classic example of special interest is the three part series by A.P. Colburn and co-workers. The titles of the three papers are:

> "Heat Transfer and Pressure Drop in Empty and Packed Tubes"
>
> I. Heat Transfer in Packed Tubes, Colburn (1931)
> II. Pressure Drop in Packed Tubes, Chilton and Colburn (1931)
> III. Relationship Between Heat Transfer and Pressure Drop, Colburn and King (1931)

The first two studies were typical of the era - extensive experimental work fortified with dimensional analysis; however, the third paper by Colburn and King opened a new area of inquiry. The question was this: Did an analogy exist between heat transfer and momentum transfer? On the basis of the Navier-Stokes equations and the thermal energy equation (Whitaker, Sec 5.5, 1977), one would say NO. The source of this response is simple: the velocity is a *vector* and the temperature is a *scalar*. One need go no further than the mathematical foundations of fluid mechanics and heat transfer, but the chemical engineering community did indeed go further and an extensive search for *analogies* was underway.

One of the first studies of two-phase flow was presented in 1935 by O'Brien and Gosline in a paper entitled "Velocity of Large Bubbles in Vertical Tubes." The process was certainly susceptible to approximate analysis, but the style of investigation was similar to many others of this period, i.e., experiments and dimensional analysis. O'Brien and Gosline expressed the latter as

$$\mathcal{F}\left(\frac{g r_A}{v^2}, \frac{2 v r_A \rho_1}{\mu_1}, \frac{\rho_1 r_A v^2}{T_s}, \frac{2 r_A}{d}, \frac{P_A}{P}, \frac{\mu_1}{\mu_o}, \frac{\rho_o}{\rho_1}, C_p, C_v\right) = 0 \tag{3-7}$$

where the parameters are defined by

ρ = density
g = weight per unit mass
r_A = radius of bubble
v = velocity
P_A = atmospheric pressure
P = pressure
T_s = surface tension
d = tube diameter
μ = viscosity

The subscripts 1 and 0 refer to the liquid and gas respectively, and C_p and C_v represent the constant pressure and constant volume heat capacities. While the latter are not dimensionless, O'Brien and Gosline were concerned about simultaneous heat and mass transfer affecting the bubble motion and they included C_p and C_v in Eq. 3-7 to warn the reader of this possibility. The style here is obviously identical to that found in Eq. 3-6, and it indicates that the authors were willing to identify both what they knew and what they did not know.

In 1939 Thomas H. Chilton presented the Chandler Lecture which was entitled Engineering in the Service of Chemistry. In his opening comments one finds

> "Researchers in theoretical and organic chemistry, each paving the way for the others, have demanded for the adaptation to practical use what we now call the 'chemical engineer'."

The paragraph headings in a section entitled Principles of Chemical Engineering give an indication of Chilton's thoughts about the discipline, and we list them in order as

UNIT OPERATIONS
FLUID FLOW PROBLEMS
TURBULENT FLOW
MASS TRANSFER
PROBLEMS TO BE SOLVED
NOMENCLATURE

About UNIT OPERATIONS Chilton noted that "...it is the principles underlying these unit operations that are important." It would appear from this comment that Chilton had in mind something akin to *transport phenomena*, a point of view that was to fully emerge some 20 years later. In the section on PROBLEMS TO BE SOLVED one finds a reference to *biochemical products* which were to become the rage 40 years hence, and under NOMENCLATURE Chilton remarks that "...*any* consistent set of units may be used." I wonder if he could foresee that *every* consistent set of units would be used, in addition to a variety of *inconsistent* sets. While employed at DuPont from 1958 to 1961 I used to see Tom Chilton occasionally, but in the classic "small world encounter" our last meeting was on the streets of Cuzco, Peru. I was heading toward a mountain and he was heading toward Machu Picchu and our conversation consisted of little more than "Have a good trip".

The work of Lapple and Sheppard (1940) on particle trajectories seems to be one of the first chemical engineering studies in which one comes face-to-face with Newton's laws which appeared in the form

$$M \frac{dv}{dt} = -F_x \tag{3-8a}$$

$$M \frac{du}{dt} = M_g \left(\frac{\rho_s - \rho}{\rho} \right) - F_y \tag{3-8b}$$

While Lapple was laying the groundwork for his book entitled **Fluid and Particle Dynamics** (published by Delaware Press in 1951), others were busy at work with experiments and dimensional analysis. Piret, Mann and Wall (1940) studied the problem of pressure drop and liquid holdup in a packed tower, and Sarchet and Colburn (1940) completed a study on the economic pipe size for the transportation of fluids. A *nomograph* was produced for the optimum pipe diameter, and the decade of the nomograph began as literally hundreds were produced during the next ten years.

The advent of World War II in December 1941 slowed the presentation of research results, and the commercialization of I&EC in 1944 made browsing less productive. A paper by Stoker (1946) entitled "Methods of Producing Uniform Velocity Distributions" caught my eye because of its use of Bernoulli's equation. Stoker identified the following equation

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} \tag{3-9}$$

as "Bernoulli's equation along any given flow line", and went on to say that it is permissible to write this result as

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + K \frac{v_2^2}{2g} \tag{3-10}$$

where K is a loss coefficient. The style here is clearly based on the treatment in **Principles of Chemical Engineering** by Walker, Lewis and McAdams, i.e. persuasion is an acceptable substitute for proof.

The decade of the fifties began a more serious examination of turbulent transport phenomena, and this exploration was opened with Sherwood's (1950) famous paper entitled "Heat Transfer, Mass Transfer and Fluid Friction: Relationships in Turbulent Flow". In this work the viscous sublayer (observed by Lewis in 1916) was quantified in terms of the ubiquitous v^+ - y^+ representation, and descriptions of the buffer zone and the turbulent core were given. In research, the quest for turbulent transport coefficients had begun and analogies were in the wind. In teaching, the decade opened with **Unit Operations** by George Granger Brown & Associates. This text left stoichiometry and thermodynamics to **Chemical Process Principles** by Hougen and Watson (1947) and divided the rest of chemical engineering into the following four parts:

I. Solids
II. Fluids
III. Separation by Mass Transfer: The Ideal Stage Concept.
IV. Energy and Mass Transfer Rates

Like **Chemical Engineering Principles** (Walker, Lewis and McAdams, 1923), this was a massive, skillfully organized (there were eleven Associates) effort that is a prize to own today if for nothing more than the illustrations. At U.C. Berkeley there was a sense of excitement and awe among the undergraduates as they surveyed the material they would ingest in a year-long sequence of two courses. The attack on Part II was led by Prof. C.W. Tobias and I remember with great clarity the day that we encountered what was identified as THE FLOW EQUATION. The treatment was based on the first law of thermodynamics and the one inlet - one outlet version of the control volume shown in Fig. 2-1. The batchified process of "one pound in and one pound out" was analyzed, and in a miracle of kinematic wizardry the first law of thermodynamics for a *body* was transformed into the first law of thermodynamics for a *control volume*. This can be expressed as

$$\Delta H + \Delta PE + \Delta KE = Q - W \qquad (3\text{-}11)$$

which is Eq. 54a in Chapter 12 of **Unit Operations** and Eq. 2 in Chapter III of **Principles of Chemical Engineering**. The proof of this result is suggested by Eqs. 2-24 through 2-26 and the details are given elsewhere (Whitaker, Sec. 10.1, 1968). Rather than follow the pragmatic approach used in **Principles of Chemical Engineering** and declare the mechanical energy balance an experimental verity, Brown & Associates introduced the concept of "lost work" which allowed them to transform the above relation to

$$\frac{\Delta P}{\rho} + \Delta\left(\frac{v^2}{2g_c}\right) + \frac{g}{g_c}\Delta Z = -\overline{w} - \ell\overline{w} \tag{3-12}$$

Here, $\bar{w}$ represents the shaft work per unit mass of flowing fluid, $\ell\bar{w}$ represents the "lost work" per unit mass of flowing fluid, and the appearance of the conversion factor, g_c, suggests an uncertainty about how units enter into a precise description of the laws of physics (Hurley and Garrod, page 1, 1978). Prof. Tobias was (and is) an expert on thermodynamics; however, the thermodynamics that led to the concept of "lost work" were indeed lost on him and his assessment of the development was: "What the h--- is lost work? Work is work, work isn't lost!" As a teacher, Prof. Tobias was "live theater," providing superb explanations of what he knew and succinct commentary on what he did not understand. It was an exciting educational adventure where front row seats were always in demand.

I was never able to comprehend the development of THE FLOW EQUATION in **Unit Operations**, since the analysis of the entropy and the internal energy *required* the use of the mechanical energy equation (Whitaker, Sec. 10.1, 1968). Under these circumstances, one must use in the proof precisely that result which one hopes to prove, thus the development represents a *persuasion*, rather than a *proof*. Be that as it may, variations of this route are in use today [Welty, Wicks and Wilson, page 212, 1984] as a convenient detour around the concepts of *kinematics* and *stress*.

While kinematics and stress were being *avoided* in the teaching of fluid mechanics, they were being *joined* elsewhere, and the search for turbulent constitutive equations (Page, et al, 1952) and nonlinear fluid constitutive equations (Hedstrom, 1952) was on the rise. These two areas came together in the work of Metzner and Reed (1955), and one year later Prof. Tom Hanratty (1956) initiated his studies of turbulent transport phenomena with papers entitled "Heat Transfer Through a Homogeneous, Isotropic Turbulent Field" and "Turbulent exchange of Mass and Momentum with a Boundary." A year later Lynn, Corcoran and Sage (1957) presented their work on turbulent transport in a paper entitled "Material Transport in Turbulent Gas Streams: Radial Diffusion in a Turbulent Duct." All of these studies represented a search for turbulent transport coefficients that could be used with the traditional molecular constitutive equations such as Newton's law of viscosity, Fourier's law of heat conduction, and Fick's law of diffusion. There was no mention of *closure* by means of the turbulent kinetic energy equation put forth by Prandtl (1945), and the k- ε model for closure (Jones and Launder, 1972) was more than a decade into the future.

Progress in research was accompanied by frustration in the classroom, and in 1956, Harding Bliss, then editor of the AIChE Journal, took issue with the development of the macroscopic mechanical balance. In an editorial entitled "Derivation of the Mechanical Energy Balance: A Plea for Simplicity" Prof. Bliss wrote

> "The writer, as a teacher of thermodynamics, must take exception to the ways in which this equation is derived in several chemical engineering texts."

and then added

> "It seems highly questionable to introduce the first law of thermodynamics in the batch form...."

Bliss' criticism seems to be aimed directly at the approach used by Brown and Associates in **Unit Operations,** and as an alternative he suggests that we should start with Bernoulli's equation which he listed as

$$d(KE) + dZ + vdp = 0 \tag{3-13}$$

The lack of any viscous dissipation is taken care of with the statement: "We merely make it work by adding a term for friction so that it becomes after integration"

$$\Delta KE + \Delta Z + \int v dp + \sum F = 0 \tag{3-14}$$

With the comment that "Only one step remains," the shaft work is also added in order to arrive at

$$\Delta KE + \Delta Z + \int v dp + \sum F = W'_{sh} \tag{3-15}$$

Bliss closes his editorial with the comment

> "It is believed that this derivation is simpler and a closer approach to the truth of the matter than those usually offered."

It seems clear that Bliss, like Tobias several years earlier, felt uncomfortable with the entropy arguments that led from the first law of thermodynamics to the macroscopic mechanical energy balance. The route from the former to the latter is indeed possible, but hidden along the way is the mechanical energy equation, thus making the entire development circular. Neither Bliss nor Tobias could provide a proof, but both sensed that something was amiss. Tobias' reaction was the *succinct disclaimer*, while Bliss ignored the admonition of Bertrand Russel and sought a *persuasion*. Those who learned from these two great teachers would agree that it could not have been otherwise.

As if in answer to Bliss' editorial, Prof. Bird (1957) provided a detailed derivation of the macroscopic balances for mass, momentum and mechanical energy. These were presented for an arbitrary moving control volume, and thus captured in a rigorous manner all of the details that had been added by persuasion over the previous years. One might think that this would have ended the confusion about the macroscopic mechanical energy balance, but this has not been the case and a precise understanding of this result seems to be the exception rather than the rule.

As I browsed through the literature, I kept an eye open for a published version of the Navier-Stokes equations. I wondered who would feel comfortable beginning a special study from a general point of view. In 1957, Happel and Brenner began their study entitled "Viscous Flow in

Multiparticle Systems: Motion of Spheres and a Fluid in a Cylindrical Tube" with the set of equations

$$0 = -\nabla P + \mu\nabla^2\mathbf{v} \tag{3-16}$$

$$0 = \nabla\cdot\mathbf{v} \tag{3-17}$$

and a year later Schechter and Isbin (1958) presented a solution for a natural convection boundary layer problem described by

$$\rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = g(\rho_\infty - \rho) + \mu\left(\frac{\partial^2 u}{\partial y^2}\right) \tag{3-18}$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{3-19}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\left(\frac{\partial^2 T}{\partial y^2}\right) \tag{3-20}$$

A similarity transformation was used to extract the following pair of ordinary differential equations from Eqs. 3-18 through 3-20

$$Z''' + 3ZZ'' - 2(Z')^2 + \eta + S_1\eta^2 + S_2\eta^3 = 0 \tag{3-21}$$

$$\eta'' + 3\mathrm{Pr}\,\eta' = 0 \tag{3-22}$$

These were solved using analogue computers, and the technique was new enough so that the wiring diagram was included in their paper. In this era of supercomputers (no doubt ultra-supercomputers will soon follow), it is difficult to imagine the excitement that was associated with solutions of Eqs. 3-21 and 3-22 obtained by resistors, capacitors and amplifiers properly wired together. In 1958, Acrivos analyzed a similar problem described by

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \pm\left(\frac{Gr}{Re^2}\right)\theta \sin\varepsilon + U\frac{\partial^2 u}{\partial y^2} \tag{3-23}$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{3-24}$$

$$u\frac{\partial \Theta}{\partial x} + v\frac{\partial \Theta}{\partial y} = \frac{1}{Pr}\left(\frac{\partial^2 \Theta}{\partial y^2}\right) \tag{3-25}$$

In order to avoid the use of computers, Acrivos applied the von Kármán-Pohlhausen method described by Schlichting (1955). In 1959 Sternling and Scriven began their study of interfacial turbulence with the following set of equations

$$\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v}\cdot\nabla\mathbf{v} = -\frac{1}{\rho}\nabla P + \upsilon\nabla^2\mathbf{v} \tag{3-26}$$

$$\frac{\partial c}{\partial t} + \mathbf{v}\cdot\nabla c = \mathcal{D}\nabla^2 c \tag{3-27}$$

that were coupled by the interfacial transport equations for mass and momentum. This work initiated an explosion in the study of interfacial phenomena and it signalled the beginning of an era when the Navier-Stokes equations represented an acceptable manner of communicating information about fluid mechanical phenomena within the chemical engineering community. Navier, Poisson, Saint-Venant and Stokes would have been pleased.

The year 1960 brought **Transport Phenomena** as perhaps predicted by Tom Chilton in 1939, and the **The Classical Field Theories** as perhaps ordained by Leonhard Euler in 1750. The wide-ranging treatment of heat, mass and momentum transfer by Bird, Stewart and Lightfoot signalled a new era in chemical engineering research and teaching, but the basic concepts of *kinematics*, *stress* and *constitutive relations* still remained to be placed in their proper perspective.

4. EPILOGUE

While I dare not attempt to comment on the vast contributions made by chemical engineers between 1960 and 1988, I have no fear in proposing the pedagogical role of fluid mechanics in the future of chemical engineering education. In the previous three sections we have seen that the basic concepts of fluid mechanics, *kinematics* , *stress* and *constitutive relations* were essentially ignored by the chemical engineering community for over 100 years. Almost overnight this situation changed as chemical engineers realized that progress could be made by studying rheology, turbulence, boundary layer theory, interfacial waves, lubrication theory, etc. And progress was indeed made. But would it not also be *progress* to understand basic concepts well? Consider the first two axioms of thermodynamics for single component systems (Whitaker, 1989)

$$\text{I.}\quad \frac{d}{dt}\int_{\mathcal{V}_m(t)}\left(\rho e+\frac{1}{2}\rho v^2\right)dV = -\int_{\mathcal{A}_m(t)}\left(\mathbf{q}+\mathbf{q}^R\right)\cdot\mathbf{n}\,dA+\int_{\mathcal{V}_m(t)}\rho\mathbf{v}\cdot\mathbf{b}\,dV + \int_{\mathcal{A}_m(t)}\mathbf{t}_{(\mathbf{n})}\cdot\mathbf{v}\,dA \qquad (4\text{-}1)$$

$$\text{II.}\quad e = e(s,\rho) \qquad (4\text{-}2)$$

Here e is the internal energy per unit mass, and s is the entropy per unit mass. The first axiom indicates that the rate of change of internal and kinetic energy of a body is caused by the heat that is supplied to the body and the work that is done on the body. The second axiom indicates that the internal energy is a function of the local state of the system.

Is it possible that the physical content of Eq. 4-1 can be clearly understood in the absence of a knowledge of kinematics and stress? I think not. Some might be annoyed at the lack of a potential energy term on the left hand side of Eq. 4-1; however, kinematics can take care of this problem. If the potential energy function φ is independent of time, one can use the kinematical relation expressed by Eq. 1-36 and the kinematical relation expressed by Eq. 2-18 to arrive at

$$\frac{d}{dt}\int_{\mathcal{V}_m(t)} \rho\varphi \, dV = -\int_{\mathcal{V}_m(t)} \rho\mathbf{v}\cdot\mathbf{b}\, dV \tag{4-3}$$

This can be used to write Eq. 4-1 in the form

$$\frac{d}{dt}\int_{\mathcal{V}_m(t)} \left(\rho e + \frac{1}{2}\rho v^2 + \rho\varphi\right) dV = -\int_{\mathcal{A}_m(t)} \left(\mathbf{q} + \mathbf{q}^R\right)\cdot\mathbf{n}\, dA + \int_{\mathcal{A}_m(t)} \mathbf{t}_{(\mathbf{n})}\cdot\mathbf{v}\, dA \tag{4-4}$$

If one cannot *derive* Eq. 4-4 from Eq. 4-1 given that φ is independent of time, there is another route that is available, i.e., propose Eq. 4-4 as an axiom. But instead let us apply *kinematics* to what is generally true in order to derive what is true when φ is independent of time. If one integrates Eq. 4-4 between two times, the result can be arranged in a form often seen in thermodynamics texts

$$\Delta U + \Delta PE + \Delta KE = Q - W$$

This is usually identified as the first law for closed systems.

Given Eq. 4-4 for a body, one can ask how it is to be used to solve problems associated with the control volume shown in Fig. 2-1. Clearly we need a macroscopic balance form of Eq. 4-4. The traditional approach avoids systems such as the one illustrated in Fig 2-1. Instead, a *one entrance-one exit* system is considered along with the batch process described by (the citation here is virtually any current text on thermodynamics)

one pound goes in and one pound goes out

After considering this process for awhile, one deduces an open system form of the first law that is generally expressed as

$$\Delta H + \Delta PE + \Delta KE = Q - W$$

The student is often left with the impression that the difference between open systems and closed systems is simply the replacement of the internal energy, U, by the enthalpy, H. In addition, the student may leave this brief encounter with bodies and control volumes with the idea that the *kinematics* required to accomplish the transformation consists of nothing more than a sketch on a piece of paper. If we want our students to believe this type of development, then we want them to believe in the tooth fairy. And if we want them to believe in the tooth fairy, what happens when they come face-to-face with a tough problem? Instead of dealing with *one entrance-one exit* systems in which "a pound goes in and a pound goes out," let us use *kinematics* and the concepts of *stress* to derive the differential equation associated with Eq. 4-4 (Whitaker, Sec. 10.1, 1968)

$$\frac{\partial}{\partial t}(\rho e + \frac{1}{2}\rho v^2 + \rho\varphi) + \nabla \cdot \left[(\rho e + \frac{1}{2}\rho v^2 + \rho\varphi)\,\mathbf{v}\right]$$

$$= -\nabla \cdot (\mathbf{q} + \mathbf{q}^R) + \nabla \cdot (\mathbf{T} \cdot \mathbf{v}) \tag{4-5}$$

Now let us use the same *concepts* to derive the general macroscopic total energy balance

$$\frac{d}{dt}\int_{V_a(t)} (\rho e + \frac{1}{2}\rho v^2 + \rho\varphi)\, dV + \int_{A_a(t)} (\rho e + \frac{1}{2}\rho v^2 + \rho\varphi)(\mathbf{v} - \mathbf{w}) \cdot \mathbf{n}\, dA$$

$$= -\int_{A_a(t)} (\mathbf{q} + \mathbf{q}^R) \cdot \mathbf{n}\, dA + \int_{A_a(t)} \mathbf{t}_{(\mathbf{n})} \cdot \mathbf{v}\, dA \tag{4-6}$$

Elsewhere (Whitaker, Sec. 10.1, 1968) it is shown that for a steady process with one entrance and one exit, Eq. 4-6 can be expressed as

$$\Delta\,(h + \frac{1}{2}v^2 + \varphi) = \frac{\dot{Q} + \dot{W}}{\dot{m}} \tag{4-7}$$

Here $\dot{Q}$ represents the rate at which heat is transferred to the fluid in the control volume, and $\dot{W}$ represents the rate at which work is done on the fluid in the control volume by solid moving surfaces, i.e., the *shaft work*. If life were restricted to steady process with one entrance and one exit, and it is not, one could ask what we have gained by coming to grips with the complex concepts of kinematics and stress en route to Eq. 4-7. That we have understood the concepts of stress and kinematics is really not very important. What is important is that we have by-passed the tooth fairy.

Prediction: Fluid mechanics will eventually become a prerequisite for the study of thermodynamics.

The time-table for this prediction is uncertain, but the final result is inevitable.

Let us move on to the subject of binary mass transfer and consider the two diffusion processes illustrated in Fig. 4-1. The process shown in Fig 4-1a is standard fare for chemical engineering students. They begin with the species continuity equation

$$\frac{\partial c_A}{\partial t} + \nabla \cdot \mathbf{N}_A = R_A \tag{4-8}$$

which quickly reduces to

$$N_{Az} = \text{constant} \tag{4-9}$$

Fick's law

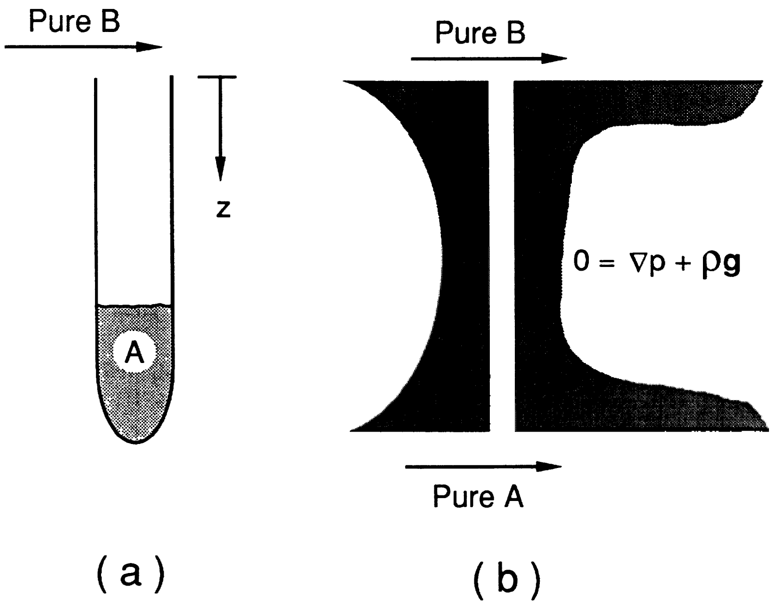
$$\mathbf{N}_A = x_A (\mathbf{N}_A + \mathbf{N}_B) - c\mathcal{D}_{AB} \nabla x_A \tag{4-10}$$

and the plausible simplification

$$\mathbf{N}_B = 0 \tag{4-11}$$

leads one to the well-known solution for the concentration profile, the molar flux of species A, and the position of the gas-liquid interface.

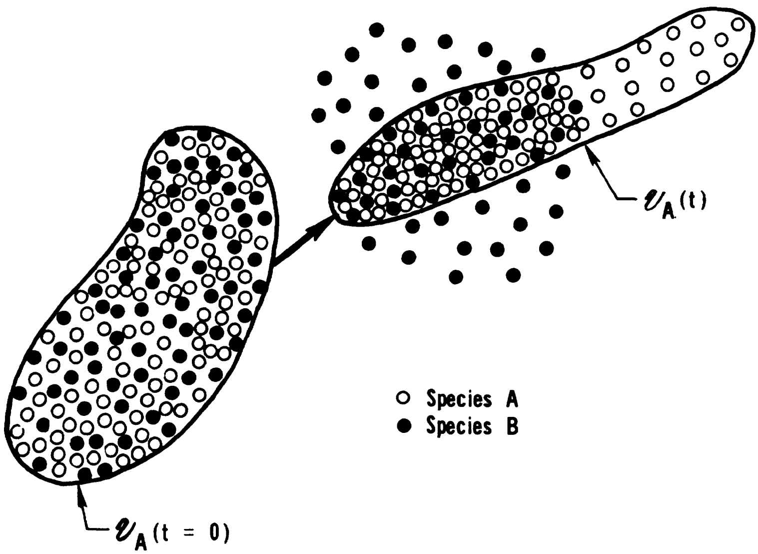
Figure 4-1
Binary Diffusion Processes



After these results have been obtained, it is instructive to ask students to compute the *mass average velocity* (Whitaker, 1967). When this is done, two questions become apparent: (1) How is it that one can compute the mass average velocity without using the Navier-Stokes equations or the macroscopic momentum balance? and (2) What happened to the no-slip condition? Few realize that the no-slip condition is an approximation that fails in this case, and fewer still understand that Eqs. 4-10 and 4-11 represent the two independent *species momentum equations* that are required in order to solve the *mechanics problem* associated with this diffusion process.

While virtually *all* chemical engineers can solve the problem illustrated in Fig. 4-1a, virtually *none* can solve the equally simple (apparently) problem shown in Fig. 4-1b. The difficulty results from the fact that few persons look upon these two processes as problems of a *mechanical nature*. This situation can be remedied by searching for the origin of Eq. 4-10. One begins with the concept of a *species body* illustrated in Fig. 4-2, and

Figure 4-2
Species Body



states two axioms for the mass of multicomponent systems as

$$\text{I.} \qquad \frac{d}{dt}\int_{\mathcal{V}_A(t)} \rho_A \, dV = \int_{\mathcal{V}_A(t)} r_A \, dV \tag{4-12}$$

II. $$\sum_{A=1}^{A=N} r_A = 0 \tag{4-13}$$

The kinematics of Euler allow one to extract the species continuity equation from Eq. 4-12, and this is given by

$$\frac{\partial \rho_A}{\partial t} + \nabla \cdot (\rho_A \mathbf{v}_A) = r_A \tag{4-14}$$

It is a matter of definitions to obtain Eq. 4-8 from this result; however, it is best to contemplate Eq. 4-14 in its original state. In this state it should be clear that quantum mechanical considerations will provide a chemical kinetic constitutive equation for r_A, and it should be clear that Eq. 4-14 represents the governing differential equation for ρ_A.

In order to solve Eq. 4-14 we need to know r_A and $\mathbf{v}_A$, and since velocities are determined by the laws of mechanics we need the laws of mechanics for multicomponent systems. These can be expressed as (Whitaker, 1987)

I. $$\frac{d}{dt}\int_{\mathcal{V}_A(t)} \rho_A \mathbf{v}_A \, dV = \int_{\mathcal{V}_A(t)} \rho_A \mathbf{b}_A \, dV + \int_{\mathcal{A}_A(t)} \mathbf{t}_A \, dA$$

$$+ \int_{\mathcal{V}_A(t)} \sum_{B=1}^{B=N} \mathbf{P}_{AB} \, dV + \int_{\mathcal{V}_A(t)} r_A \mathbf{v}_A^* \, dV \tag{4-15}$$

II. $$\frac{d}{dt}\int_{\mathcal{V}_A(t)} \mathbf{r} \times \rho_A \mathbf{v}_A \, dV = \int_{\mathcal{V}_A(t)} \mathbf{r} \times \rho_A \mathbf{b}_A \, dV + \int_{\mathcal{A}_A(t)} \mathbf{r} \times \mathbf{t}_A \, dA$$

$$+ \int_{\mathcal{V}_A(t)} \mathbf{r} \times \sum_{B=1}^{B=N} \mathbf{P}_{AB} \, dV + \int_{\mathcal{V}_A(t)} \mathbf{r} \times r_A \mathbf{v}_A^* \, dV \tag{4-16}$$

III. $$\sum_{A=1}^{A=N} \sum_{B=1}^{B=N} \mathbf{P}_{AB} = 0 \tag{4-17}$$

IV. $$\sum_{A=1}^{A=N} r_A \mathbf{v}_A^* = 0 \tag{4-18}$$

It is tedious to show that Eq. 4-16 yields only the symmetry condition for the species stress tensor

$$\mathbf{T}_A = \mathbf{T}_A^T \tag{4-19}$$

More effort is required to demonstrate that for a binary system, the two independent linear momentum equations represented by Eq. 4-15 are solved (approximately) by Eqs. 4-10 and 4-11. This means that Eq. 4-10 represents a *special form* of Eq. 4-15, while Eq. 4-11 represents a plausible constraint that *supercedes* the use of Eq. 4-15 for species B. For the process shown in Fig. 4-1b, the trivial form given by Eq. 4-11 is not applicable and one must work harder to get a solution to this mechanical problem. The details are given by Jackson (1977) and a variation of that discussion has been presented by Whitaker (1987).

The key point to be made here is that a true understanding of the world's two simplest diffusion processes is based upon the laws of mechanics for multicomponent systems.

Prediction: The mechanics of multicomponent systems will eventually become a prerequisite for the study of mass transfer.

Only time will tell how long it will take us to accept the knowledge of the 19^{th} century and place our studies of thermodynamics and mass transfer on a modern basis.

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Department of Chemical Engineering
University of California
Davis, California 95616, USA

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H. Janeschitz-Kriegl

CHANGING VIEW ON THE CLASSICAL STEFAN PROBLEM

ABSTRACT. In 1891 Stefan calculated the growth of polar ice with the aid of a method proposed by Neumann in 1860. This calculation forms the starting point for activities in the field of moving boundary value problems. Although a phase transition (crystallization) is assumed as the reason for the solidification - notice the accepted role of the latent heat - the concept of "nucleation" has rarely been applied so far. It is only with the increasing importance of relatively slowly crystallizing polymeric materials that supercooling was recognized as a point for the mathematical treatment of molding processes. But this causes a change of view on the subject. So far, basic treatments of transport phenomena have been avoiding molding processes, despite their technological importance. Apparently, these processes seem too difficult for beginners. In the present paper, however, it will be shown that one can give a useful classification of crystallization phenomena without relying on too complicated calculation methods.

1) Introduction

In his famous work on the growth and the melting of the ice layer on the polar sea (1, 2, 3) Stefan formulated a widespread engineering problem at Vienna University roughly at the time when Lewis Mills Morton started his first lecture course on chemical engineering at the Massachusetts Institute of Technology. Unconsciously Stefan used the mathematical formulations previously given by Neumann (4).

For the purpose Stefan assumed that the sea is represented by the half infinite space. In the most simple version of the treatment, the surface temperature of the water is assumed to jump at zero time to a constant value below the freezing point. As a consequence, a solidified layer of ice starts growing.

The following boundary conditions are assumed at the moving boundary between ice and water:

a) <u>The usual heat balance:</u> The heat conducted out

N. A. Peppas (ed.), One Hundred Years of Chemical Engineering, 111–124.

of the boundary (into the formed layer of ice) must be equal to the heat conducted into the boundary (from the water) augmented by the latent heat of crystallization released in the boundary. Clearly, the latter amount of heat is proportional to the growth speed of the layer.

b) The temperature at the moving boundary is assumed to be equal to the equilibrium melting point of water.

Obviously, because of condition b) this treatment must be characterized as a quasi-equilibrium treatment. It can only hold for a sufficiently slow process. However, by the application of this approach one obtains the so-called "square-root-law" for the time dependence of the layer thickness. But this law has an infinite slope at zero time. In other words, it does not represent a slow process initially. An estimate of the error made in this way cannot be given without the introduction of the physical conceptions of nucleation and supercooling. This fact has been overlooked at the time.

The quasi-equilibrium situations treated along the lines promoted by Neumann, Stefan and their successors become particularly obvious, if e.g. the crystallization from a solution is treated. As, in general, the crystalline phase of the solvent does not contain the solute, the concentration of the latter component continuously increases in the liquid phase during the growth of the solidified layer. This causes a melting point depression according to thermodynamics. One has a problem in which the temperature of the crystallization front is no longer constant. In addition to the diffusion of heat also a diffusion of the solute had to be treated simultaneously. In spite of this clear non-equilibrium situation the equilibrium melting point depression depending on the local concentration was used in the boundary condition so far.

It appears that problems which have been solved along these lines are manifold: Melting and solidification of alloys in metal casting, the occurrence of "mushy" regions in (binary) systems of compositions deviating from the eutectic composition etc. See e.g. the beautiful book by John Crank (5), where only occasionally an exception is made from the lines sketched so far in the introduction.

However, the absolute necessity for a change in the view on the Stefan problem, as announced in the title, was recognized only very recently when the solidification of polymeric materials by crystallization was examined more closely. In fact, polymers are known for being notoriously slow in approaching equilibrium. With polymers we are confronted with the consequences of delayed nucleation and serious supercooling. (In fact, the key word "nucleation" cannot be found in several well-known reviews concerning traditional moving boundary problems.)

In the context of this meeting which is devoted to the recollection of the beginnings of engineering education and to the progress of this education, the present introduction cannot be concluded without the remark that also the "changed view" on the Stefan problem can find its precipitate in elementary textbooks on transport phenomena where only the Neumann solution was presented so far, if heat transfer accompanied by a phase change was discussed at all. This will be demonstrated in Section 4.

2) Experimental evidence

Even for one-component metal systems (pure metals) delay by nucleation becomes obvious from the work of Ruddle (6) on metal castings. From Fig.1 one can conclude that the delay in solidified layer growth must be due to nucleation prob-

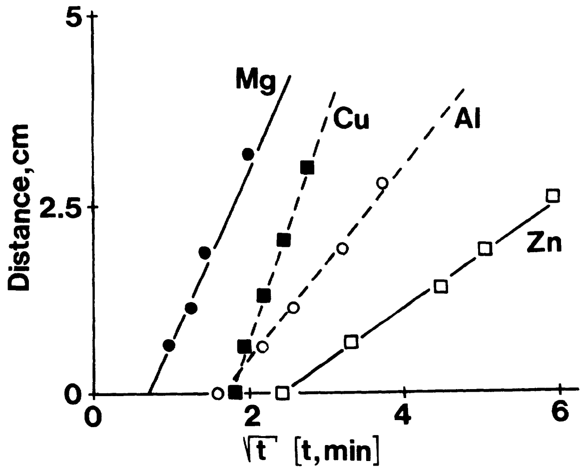

Fig. 1 Rates of skin formation in pure aluminium, copper, magnesium and zinc, according to ref. 6

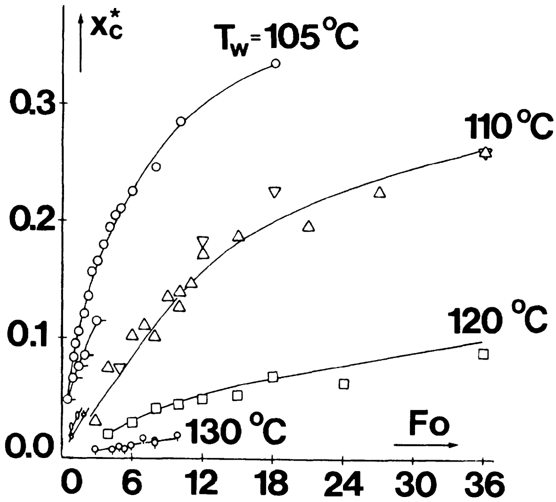

Fig.2 Reduced location of crystallization front versus dimensionless contact times (Fourier numbers) for the wall temperatures indicated near the curves with unchanged bulk temperature of 180°C for an industrial polypropylene, according to ref.7. The short pieces of lines near the origin belong to T_W = 100°C (o-), 95°C (▸) and 90°C (ȯ). A farther growth was inhibited by diffuse nucleation in the bulk of the melt. Sample thickness ≃ 0,7 mm.

lems at the mold wall. It can be seen from the temperature-time diagrams monitored at various distances from the mold wall that supercooling occurs only close to this wall.

With polypropylenes, however, it could be shown (7, 8) that the initial growth speed is finite and equals the linear growth speed of spherulites at temperatures corresponding with the indicated wall temperatures (See Fig.2 and 3). To explain this facts theoretically (9), one has to release boundary condition b), as quoted in the introduction: The temperature at this boundary must be allowed to at-

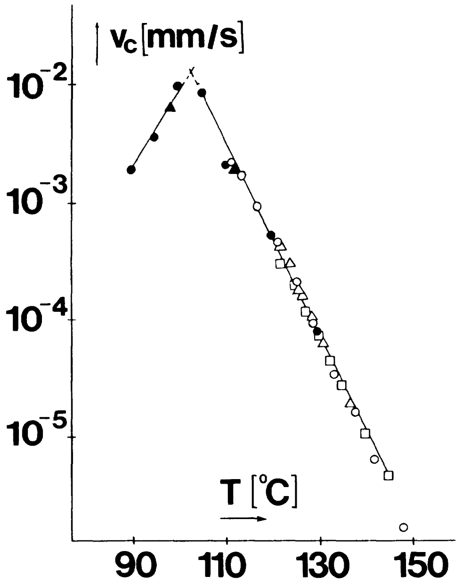

Fig.3 Initial growth speed of crystallization fronts as a function of wall temperature for two industrial polypropylenes (● ... M = 290 000, ▲ ... M = 160 000) according to ref.8. For comparison: ○ ... M = 500 000, □ ... M = 50 000 spherulite growth, refs. 26) and 12), △ ... zone crystallization, ref. 27).

tain values below the melting point. In addition, the growth speed (dx_c/dt) occurring in boundary condition a) is assumed to be a unique function of the temperature (Fig.3) at the boundary. This is in contrast to Stefan, where this speed adjusts itself to the interplay between heat release by crystallization and heat removal by conduction. By assuming (dx /dt) as a function of local temperature one acknowledges the influence of secondary nucleation to which the growth speed is related.

However, for polymers this layer growth is a very slow process. From a principal point the mere fact that the boundary becomes supercooled, is of greater importance: As a consequence, the melt in front of the boundary becomes supercooled as well. This means that dispersed primary nucleation can occur in the bulk of the fluid. (In Stefan's approach this possibility is excluded by definition: The bulk of the fluid is always at or above the melting point.) This brings about that, with a sufficient degree of supercooling of the mold wall, only the diffuse primary nucleation will be of importance: No perceptible layer will be formed anymore at the wall.

3) Theoretical Considerations on Nucleation

A new field had to be entered. Existing theories mainly described the so-called isothermal nucleation and growth. Heat transfer considerations had not yet been applied. It was tacitly assumed that the investigated slice of polymer was so thin that a quench to a certain level of supercooling could be carried out in such a short time that virtually no nucleation and crystal growth would occur within this time span. So everything which contributed to the formation of the crystalline texture was thought to occur under "isothermal conditions" at the chosen level of supercooling. As is well-known, with dispersed primary nucleation one obtains a spherulithic structure in polymers.

In the well-known theories by Avrami (10) and by Tobin (11) several steps are taken in account, as there are: the activation of (primary) nuclei, their growth with time, impingment of spherulites and even the loss of potential nucleation sites where these sites were swamped by already growing spherulites. These considerations lead to expressions for the degree of crystallization as a function of time. These expressions are the result of a simple integration over the time or the solution of an integral equation over the time. In accordance with properly carried out experiments (see Fig.4) one obtains S-shaped curves (12) according to both treatments. At zero time (and zero degree of crystallinity) there is a horizontal initial slope. After some time the crystallization rate rises steeply. Finally, the curves level off at the obtainable degree of crystallization. Near the point of inflexion the slope is so steep that one can consider the time of half conversion as an induction time τ_i.

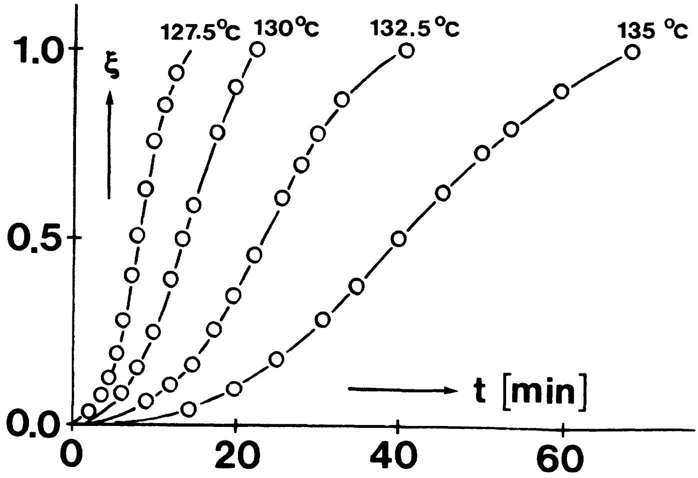

Fig.4 Degree of crystallization versus time for several crystallization temperatures indicated near the curves (isothermal experiments) for a polypropylene (M_w =50 000) according ref.12.

Difficulties arise, when these models must be applied to non-isothermal conditions governed by the equation of heat conduction. For the purpose, Nakamura et al.(13) introduced a temperature dependent integrand into one of Avrami's integrals. A more useful approach was given by Malkin et al. (14), who were able to replace Avrami's integral by a differential equation inspired by chemical reaction kinetics. Finally, Schneider, Berger and Köppl (cooperating with the author in a national research program), after having worked some time along similar lines as Malkin et al. (15), were able to show that Avrami's and Tobin's expressions could exactly be replaced by sets of differential equations ("rate equations") (16, 17). In this form, these models can be used in (numerical) solutions of the complete heat transfer problem. A serious complication is that experiments, as tried out so far, are not sufficiently sensitive to the details of the model. As a consequence, there is a lack of data for these calculations.

4) A Qualitative Guiding Principle

As shown by Astarita and Kenny in a paper which appeared only recently (18)*), a useful application can be made of dimensionless numbers also in this area of engineering. These authors define a Deborah number

$$De = \tau_i \, a/L^2 \qquad (1)$$

where τ_i is the induction time - say - at the temperature T_w of the quenched surface (interface between polymer melt and vessel wall), a is the heat diffusivity of the polymer melt and L is the layer thickness of the polymer. In this expression L^2/a gives the time needed for thermal equilibration with the vessel wall, when no phase change occurs in the melt, viz. when only the heat $c\,(T_i - T_w)$ is conducted to this wall per unit mass of the polymer, with c being its specific heat and T_i its initial temperature. Another dimensionless number is the Stefan number defined by

$$St = H \,/\, c(T_i - T_w) \qquad (2)$$

where H is the latent heat of crystallization per unit of mass. This is the factor, by which the time (L^2/a) must be multiplied in order to obtain the time of thermal equilibration if <u>essentially</u> the latent heat must be removed from the polymer. However, as St is not much larger than unity in most situations of polymer processing (in contrast to metallurgy), the "sensitive" heat $c(T_i - T_w)$ which must also be removed by conduction, cannot be disregarded against H. So the time needed for thermal equilibration with phase change reads:

*Preprint known to the author already for some time.

$$\tau_s = (L^2/a)(1 + St) \tag{3}$$

For a crystallizing polymer eq.(1) must therefore be replaced by

$$De^* = \tau_i/\tau_s \tag{4}$$

Astarita and Kenny disregarded $c(T_i - T_w)$ against H and used the reciprocal value of De*, viz. St/De as a criterion for the question whether the material in a slab of thickness L crystallizes due to the (almost simultaneous) formation of a great number of small crystallites (spherulites) (St/De << 1) or crystallizes in a zone moving from the wall into the melt (St/De >> 1). Astarita and Kenny kindly proposed to name this critical number after the present author. When this number increases, the mentioned zone more and more resembles a real crystallization front. In principle, however, as has been pointed out by Berger and Schneider (15), it remains a zone, as nucleation occurs homogeneously in the bulk of the fluid.

For illustration we may look on Fig. 5 (19). In this figure the growth of the thickness x_c of the layer (between the center of the moving zone and the wall) is demonstrated as a function of time t for a high density polyethylene (melting point 143°C). Initial temperature of the melt was always 170°C. Several temperatures T_w of the quenched vessel wall are indicated near the curves. In order to evaluate the effective time $\hat{t}_o$ of delay for the square-root-law ($x_c \propto \sqrt{t - \hat{t}_o}$) which eventually must hold for sufficiently long times (when the temperature gradients become small enough), x_c^2 is plotted versus t. In these plots the delay of the crystallization is clearly observable even for this polymer, which is well-known as the one with the fastest rate of crystallization. The straight parts of the curves indicate the time ranges where the square-root-law holds. By extrapolation to $x_c = 0$ the $\hat{t}_o$-values are obtained. However, one may observe that the curves are considerably non-linear near their starting points, the latter being identified with the respective induction times τ_i at the wall temperatures.

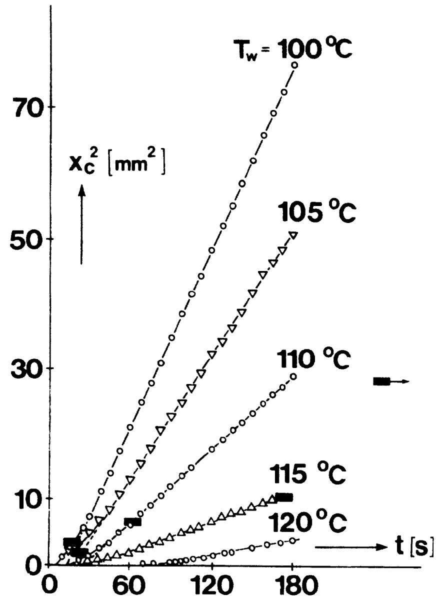

Fig.5 Square of distance of crystallization zone from the wall vs. time for several wall temperatures indicated near the curves, for a high density polyethylene according to unpublished work by E. Ratajski. Horizontal bars indicate positions of L^2 according to eq.5.

Assuming that the values of τ_i/τ_s are permitted to be at most one tenth for the observation of a moving zone, one can calculate the corresponding values of L^2 according to:

$$L^2 = 10\ \tau_i\ a/(1 + St) \tag{5}$$

Tentatively, these values are indicated on the x_c^2-axis of Fig.5 by horizontal bars for the respective T_W-values. For the purpose, the τ_i-values are estimated from the figure. The thermal data of the polyethylene melt are gathered in Table 1. Purposely, no difference is made between data for the solid and the liquid state.

By the introduction of the bars the figure becomes self-explanatory. (For T_W = 100 and 105°C the accuracy of τ_i is extremely poor. For T_W =120°C the bar would be at 27,5 mm^2). The straight parts of the curves for T_W = 110, 105 and 100°C have slopes corresponding with the ones calculated according to the classical theory of Stefan and Neumann (22, 23). The corresponding slopes of the curves for T_W = 120 and 115°C, however, are lower than those predicted by the classical theory, which points to their transitional character. One may expect that most of the other crystallizable polymers will only show this latter behavior.

5) Shear Influence

As is well-known, the rate of nucleation is enhanced by the application of a deformation to the polymer melt (24). But only recently, a theory of shear induced crystallization could be developed (25). This type of crystallization causes highly oriented boundary layers in injection molded articles (cf.ref. 8). Shear induction is an elastico-viscous relaxation phenomenon. So far, however, this perception did not contribute to a simplification of the situation. The main problem is as everywhere in this field: A lack of experimental data for the model parameters, as there are: Critical shear rate $\dot{\gamma}_a$ for the activation of shear induced crystallization, effective relaxation time τ of the melt and induction time $\tau_{i,\infty}$ at infinite (i.e. large enough) rate of shear. For all these parameters also their temperature and molecular weight dependences should be known.

Conclusions

The classical approach to heat transfer problems complicated by the occurrence of phase changes is, from the point of view of thermodynamics, a quasi-equilibrium treatment. It has been used by Stefan in 1889 for the description of the growth of polar ice, and has, since that time, become very popular in many fields of technology, in particular in metal casting (many component systems, alloys). In general, however, one has underestimated the influences of the delayed adjustment to equilibrium (nucleation, crystallization kinetics). For the description of the solidification of semi-crystalline polymers, the classical approach can no longer be advocated. In this respect, many new aspects have been elaborated only recently. Some of them are useful also in elementary textbooks on transport phenomena.

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Table 1

Physical Data for HDPE-Melt

a	=	$1{,}24 \cdot 10^{-7}$ m^2 s^{-1}	
c	=	2,73 kJ/kgK	ref. 20)
ρ	=	760 kg m^3	
H	=	208 kJ/kg	ref. 21)

Johannes-Kepler-Universitaet Linz
Institut für Chemie
Altenberger Strasse 69
A-4040 Linz
AUSTRIA

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N.A. Peppas and R.S. Harland

UNIT PROCESSES AGAINST UNIT OPERATIONS: THE EDUCATIONAL FIGHTS OF THE THIRTIES

1. Introduction

Chemical Engineering started as a discipline concerned with the education of engineers who would work in chemical plants. Yet, in the early days of the development of this field, industrial chemistry was the most "acceptable" method of education of students.

The training of chemical engineers was a subject of much debate in the early part of the 20th century. Milton C. Whitaker, a professor of Chemical Engineering at Columbia University and an important contributor to the ChE literature and societal causes, expressed his views (1) on the training of chemical engineers as follows: "The chemical engineer works in the organization, operation and management of existing or proposed processes with a view to building up a successful manufacturing industry... His fundamental training in chemistry, physics, mathematics, etc., must be thorough and must be combined with a natural engineering inclination and an acquired knowledge of engineering methods and appliances." He continued by giving a description of the types of courses that should be taught, which he classified as courses for "fundamental training" (chemistry, physics, mathematics), "associated training" (electrical, mechanical, civil and general engineering, and business economics) and "supplementary training" (laboratory and administration courses).

The establishment of the American Institute of Chemical Engineers (AIChE) in 1908 gave shape to the dreams of the "converted chemists" who were calling themselves "chemical engineers" (2), albeit with major obstacles. For example, Hugo Schweitzer (3) declared in a 1904 ACS meeting: "I am absolutely against the introduction of chemical engineering in the education of chemists." In the same meeting, M.T. Bogert (3), later a colleague of Whitaker, who did not join Columbia until 1907, agreed with Schweitzer saying that progress in "technical chemistry" was achieved in research laboratories by researchers *without* engineering training. In the same meeting Whitaker became the apologist of chemical engineering stating that a chemist was "generally not the man

N. A. Peppas (ed.), One Hundred Years of Chemical Engineering, 125–142.

who is capable of transmitting from a laboratory to a factory the ideas which he has developed" because he was not educated "in the engineering branches."

An example of a typical chemical engineering curriculum required during the first quarter of the 20th century is shown in Table 1. This is the ChE curriculum of Purdue University for the year 1923-24. It includes a plethora of chemistry-oriented courses, with some thermodynamics and elements of chemical engineering introduced in the senior year.

2. The Development of Unit Processes and R. Norris Shreve

The main proponent of teaching industrial chemistry in U.S. Chemical Engineering Departments in the second quarter of the 20th century became R. Norris Shreve, a professor of chemical engineering at Purdue University.

R. Norris Shreve was born in St. Louis, Missouri on March 9, 1885. He attended a private grade school and the Ferguson High School, from which he graduated in 1902. He got a job at the Mallinckrodt Chemical Works Company "washing dishes", and was taught chemistry by Charles Luedeking and William Lamar. He learned how to manipulate laboratory equipment and make laboratory analyses. Luedeking was so impressed that he asked the company to approve a petition and lend him money to study chemistry.

Indeed, Shreve arrived in Cambridge, Massachusetts in September 1904, having been admitted to Harvard University after taking special examinations at St. Louis. At Harvard he had a brilliant scholastic career, graduating with an A.B. *summa cum laude* in only three years (1907), a record that remained in Harvard's history for more than 40 years. While at Harvard, Shreve became very interested in research. He was fortunate enough to work in the laboratories of Theodore W. Richards (1914 Nobel Prize), under the supervision of Richards and Latham Clarke, a young instructor.

At the end of his undergraduate studies, Shreve was offered a fellowship for graduate work with Theodore Richards, but Edward Mallinckrodt, Jr. (1878-1967), then President of Mallinckrodt Chemical Works, persuaded him to return to St. Louis. He became an assistant chemist in the alkaloidal department, with W. Lamar in charge, and he was involved in the development and study of the properties of alkaloids, and later photographic chemicals.

Table 1
ChE Plan of Study for the 1923-1924 Academic Year at Purdue University

		Freshman Year	
	First Semester		Second Semester
(3 1/3)	General Chemistry 1a	(3 1/3)	General Chemistry 2a
(3)	English Composition 1	(3)	Argumentation 7a
(3)	Elem. German for Engr. 51 or Int. German for Engr. 51a	(3)	Elem. German for Engr. 52 or Int. German for Engr. 52a
(5)	Coll. Alg., Trig., Anal. Geom. 1	(5)	Coll. Alg., Trig., Anal. Geom. 2
(2)	Mechanical Drawing 11	(2)	Mechanical Drawing 12
(1 2/3)	Military Training 1	(1 2/3)	Military Training 2
(2)	Shop Work 22a, 24 or 25	(2)	Shop Work 22a, 24 or 25
(20)		(20)	
		Sophomore Year	
(4)	Qualitative Analysis 103	(2)	Sanitary Biol. of Water & Sewage 5
(3)	Expository Writing 31	(4)	Qualitative Analysis 104
(3)	Int. German for Chem. Engr. 55 or Adv. Germ. for Chem. Engr. 155a	(3)	Int. Germ. for Chem. Engr. 56 or Adv. Germ for Chem. Engr. 156a
(1 2/3)	Military Training 3	(3)	Hist. of Eur since 1870 1
(4)	General Physics 1	(5)	Diff & Int. Calculus 4
(2/3)	Surveying 4	(1 2/3)	Military Training 4
(5)	Diff. & Int. Calculus 3	(4)	General Physics 2
(21 1/3)		(22 2/3)	
		Junior Year	
(4)	Applied Mechanics 1	(4)	Applied Mechanics 2
(4)	Quantitative Analysis 105	(4)	Quantitative Analysis 106
(5)	Organic Chemistry 107	(5)	Organic Chemistry 108
(3)	Power Plants & Transmissions 21	(3)	Thermodynamics 38
(1)	Technical Literature 123	(1)	Mech. Laboratory 78
(2/3)	Testing Materials 31	(17)	
(17 2/3)			
		Options	
		Choice must be made of one of the following groups:	
		(Military)	
(3 2/3)	Military Training 5	(3 2/3)	Military Training 6
		(General)	
(3)	Adv. Germ. for Chem. Engr. 157	(3)	Elementary Economics 1
(3)	Mineralogy 107		
		Senior Year	
(2)	Elements of Chem. Engr. 101	(2)	Elem. of Chem. Engr. 102
(2)	Appl. Thermochem. & Thermophys. 103	(2)	Appl. Thermochem. & Thermophys. 104
(3)	Theor. Physical Chemistry 117	(3)	Theor. Physical Chem. 118
(4)	Electrical Engineering 9	(4)	Elec. Engineering 10
(3)	Elec. Meas. 6a or Radiation & Pyrometry 112	(2 2/3)	Radiation & Pyrometry 112 or Electrical Measurement 6a
(14)		(13 2/3)	
		Options	
		Choice must be made of one of the following groups:	
		(Military)	
(3 2/3)	Military Training 7	(3 2/3)	Military Training 8
(3)	Elementary Economics 1	(3)	Engineering Administration 3
		(Engineering)	
(2)	Machine Design 61	(3)	Engineering Administration 3
(3)	Principles of Metallurgy 105	(3)	Principles of Metallurgy 106
		(Chemical)	
(5)	Applied Analysis 109	(5)	Applied Analysis 110

In 1911, he followed Lamar to Newark, New Jersey, where he worked for his newly established company, Lamar Chemical Works, in competition with Mallinckrodt. This company did not do very well financially and it was soon abandoned by Lamar. Shreve decided to take over the company because "... as the younger and 'less expensive' man, (I) should stick to the ship and see if I could save it." (6). Suddenly a brilliant industrial career began.

At the age of 28 in 1913, Shreve had made the company again profitable. In 1914, while at Lamar, he also started the Shreve Chemical Company. In 1915 he abandoned Lamar Chemical Works, and as president of his own company (at the age of 30) he became associated with Marden, Orth and Hastings of New York. He designed, built and operated a two million dollar plant for production of ammonium nitrate in Newark, New Jersey, along the Passaic River. This dye plant was very profitable, but it was absorbed in 1918 by Calco Chemical Company. That same year, Shreve produced his first book on *Dyes Classified by Intermediates* and started his long correspondence with A.E. Chichibabin, a famous Russian chemist of the Moscow Institute of Chemistry, who had already published many articles on the chemistry on nitrogen-containing heterocyclic compounds, including pyridine and its derivatives.

Shreve stayed with Calco from 1918 to 1919 (the company was eventually bought by American Cyanamid). In 1919 Shreve made the big decision to abandon industry and start working as an independent consultant. At age 34 he opened a technical office in the same building with the Chemists' Club of New York, on 52 East 41st Street. Through his association with the Chemists' Club, he was able to find many serious clients and embark on a most successful career as a consultant.

From 1919 to 1930 his consulting work included the production of potash from the greensand beds of Texas which was done for Eastern Potash Corp., soda ash from the alkali lake deposits for Inyo Chemical Co., medicinal dyes for Roosevelt Chemical Co., and antiseptics and dyes for Mallinckrodt. The breadth of his activities in those years is immense. During that period he wrote his second book, a 690-page *Greensand Bibliography* published in 1930 by the U.S. Bureau of Mines.

In 1923 he embarked on another industrial adventure by forming the company Ammonite Co., Inc. and becoming its President and chief stockholder. Ammonite was formed to utilize the results of his research as well as the research of Chichibabin in Russia to produce various types of nitrogen-based explosives. Unfortunately, a major explosion in that company led to its dissolution in 1926. In 1928, while consulting for

Mallinckrodt he was asked to go to Europe, where, among others, he finally visited Professor Chichibabin.

He came to Purdue University in the summer of 1930, keeping some of his industrial consulting "to help augment the small salary that Purdue was then paying." (6). He was appointed an Associate Professor, and became a Full Professor in 1931.

When he arrived at Purdue, one of his first tasks was to start the graduate program in Chemical Engineering. However, equipment was scarce and he needed funds. He approached his former clients. Mallinckrodt first (4) and many other companies began supporting his students in exchange for the rights to the patents produced.

Within a short time after his appointment in the faculty, Shreve had developed very specific ideas about chemical engineering. In 1931 this research field was defined by him as organic chemical technology (5). In 1969 he stated (6) that "my job was to develop the applications of chemistry to industry and that's what we call chemical engineering." He believed in industrial experience and had a very high respect for professors who had a balanced background. To Henry J. Ramey, Jr., a former doctoral student of his who was contemplating accepting an offer from Texas A & M University, he wrote (7): "It *always* pleases me when any of our boys goes into teaching particularly after they have had industrial experience. There are too many teachers of engineering who think all they need to do is sit in a corner and push a slide rule or run a computer. Both of these instruments are necessary and more so every day, but the work of a chemical engineering professor is to teach students how to run the chemical industry of the United States and they need industrial experience."

3. Unit Processes and Shreve's Philosophy

Shreve's educational philosophy was the outcome of his close contacts with industry and of his strong interactions with the German educational system. Very early in his career, he adapted the idea of teaching industrial processes as a method of presenting chemical engineering to his students. His research became equally chemistry-oriented.

For example, in the Purdue curriculum Shreve introduced two courses in the area of organic chemical technology, ChE 126 to 129, which after 1935 were increased to eight courses. In the early days

Figure 1: Professor R.N. Shreve is considered the originator of the philosophy of unit processes in the United States. He is shown here in a 1937 photograph.

Shreve's courses were descriptive representations of current industrial processes. For example, courses ChE 126 to 129 (see Table 2) included descriptions of "processes for the manufacture of paper, soap, glycerine, rayon, starch, paints, varnishes, lacquers, explosives, resins, celluloid, leather, insecticides, and rubber."

After 1935 a major change occurred in Shreve's educational philosophy. This change was the result of imitation of the new ideas applied by Clifton Lovell in unit operations (8). Clifton Lovell was the colleague of Shreve at Purdue that had the more "engineering-oriented" ideas about chemical engineering. A firm believer of teaching and research in unit operations, heat and mass transfer, and separation processes, he became the antagonist of Shreve's ideas at Purdue. Unfortunately, he died relatively young in 1948, and his impact in chemical engineering was never recognized. First, Shreve believed (6) that the students had to have well equipped laboratories to understand the various industrial processes. Then in 1935 he started presenting the idea that industrial chemistry could be classified according to a series of "unit processes" such as alkylation, nitration, oxidation and sulfonation.

Shreve wrote many articles on this subject and based his classification on older ideas put forward by German organic chemists in the 1920's. He was especially concerned with the progress of unit operations at the expense of industrial chemistry in major Schools such as M.I.T., University of Michigan and University of Wisconsin and he had considerable, and somewhat heated, discussions with the main proponent of unit operations at Purdue, Clifton Lovell. In a 1938 position paper, ironically entitled *Unit Operations* and corrected with pencil by Shreve to *Unit Processes,* he writes:

> Chemical engineering instruction as now practiced has in general two specific divisions: Unit Operations and Unit Processes. The distinction between these two has been to place physical procedures under Unit Operations and those involving chemical change under Unit Processes. This is a very useful, but not an ironclad, division. The study of both Unit Operations and Unit Processes is essential to a thorough training in chemical engineering, in that the chemical industry is based upon both types of change.

Shreve's ideas were soon adopted by other Schools which instituted at least one course in unit processes. Unfortunately, the subject of unit processes *per se* was a rather dry one, requiring an endless description of processes and operating conditions, so that even excellent lecturers, such

Table 2
ChE Plan of Study for the 1936-1937 Academic Year at Purdue University

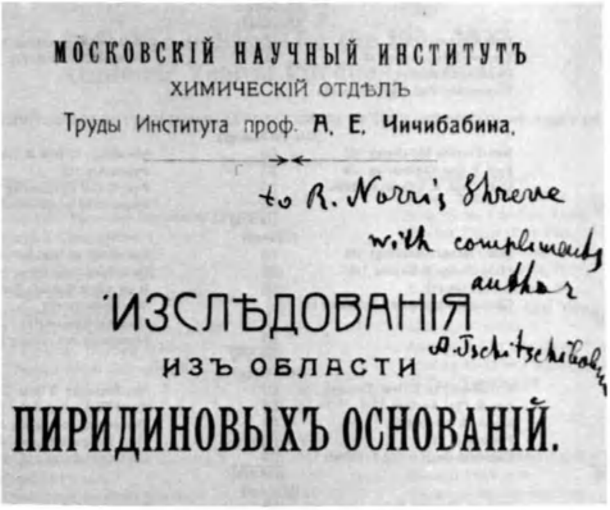
	Freshman Year		
	First Semester		Second Semester
(4)	General Chemistry 1 or	(4 or 3)	Chem. Engr. Met. 30 or
	Synthetic Inorganic Chemistry 1a		Gen. chem. 2 or Syn. Inorg. Chemistry 2a
(3)	English Composition 1	(3)	English Essay 10 or Prin. of Speech 14
(2)	Engineering Drawing 11		or Intr. to the Drama 19
(0)	Engineering Lectures 1	(2)	Engineering Drawing 12
(5)	Trig., Coll. Alg., Anal. Geom. 1	(0)	Engineering Lectures 2
(1 2/3)	Military Training 1	(5)	Trig., Coll. Alg., Anal. Geom. 2
(2)	Founding, Pattern Making 32-33	(1 2/3)	Military Training 2
	or Forging, Welding & Heat	(2)	Surveying 6 or Founding, Pattern
	Treating 34, or Surveying 6		Making 32-33 or Forging, Welding
(17 2/3)			& Heat Treating 34
		(17 2/3 or 16 2/3)	
	Sophomore Year		
(4)	Differential & Integral Calculus 3	(4)	Differential & Integral Calculus 4
(4)	General Physics 1	(4)	General Physics 2
(4)	Qualitative Analysis 3 or 3a	(3 or 4)	Chemical Equilibrium 4 or
(3)	Elementary German 41		Quantitative Analysis 105
(3)	English Essay 10, or Prin. of Spch.	(3)	Elementary German 42
	14 or Expository Writing 31	(4)	Applied Mechanics 1
(1 2/3)	Military Training 3	(1 2/3)	Military Training 4
(19 2/3)		(19 2/3 or 20 2/3)	
	Junior Year (Required)		
(4)	Applied Mechanics 1	(3)	Thermodynamics 30
(4)	Theor. Physical Chemistry 117	(4)	Theor. Physical Chemistry 118
(4)	Quantitative Analysis 105	(4)	Applied Mechanics 2
	TO THESE BASIC COURSES MUST BE ADDED THE FOLLOWING FOR THE RESPECTIVE OPTIONS:		
	(Gas Technology)		
(4)	Organic Chemistry 107	(4)	Organic Chemistry 108
(4)	Fuel & Gas Engineering 120	(4)	Gas Engineering 121
(20)		(2)	Elementary Unit Operations 134
		(21)	
	(General)		
(4)	Organic Chemistry 107	(2)	Elementary Unit Operations 134
(3)	Elementary Economics 1	(4)	Organic Chemistry 108
(2/3)	Testing Materials 31	(3)	Mineralogy 107
(18 2/3 or 19 2/3)		(20)	
	(Metallurgy)		
(3)	Non-Ferrous Metallurgy 110	(3)	Metallurgy of Iron & Steels 123
(2)	Mineralogy of Ores 107a	(2)	Gas, Fuels & Lubricants 100a
(2)	Ore Dressing 119	(1)	Metals & Alloys 109c
(2)	Elementary Unit Operations 134	(3)	Metallurgical Laboratory 131
(20 or 21)		(20)	
	(Military)		
(4)	Organic Chemistry 107	(4)	Organic Chemistry 108
(2/3)	Testing Materials 31	(2)	Elementary Unit Operations 134
(3 2/3)	Military Training 5	(3 2/3)	Military Training 6
(20 1/3)		(20 2/3)	
	(Organic Technology)		
(4)	Organic Chemistry 107	(4)	Organic Chemistry 108
(3)	Inorganic & Organic Technology &	(3)	Inorganic and Organic Technology
	Stoichiometry 128		& Stoichiometry 129
(1)	Chemical Literature 123	(2)	Elementary Unit Operations 134
(19 or 20)		(20)	

Senior Year
(Required)

(3)	Unit Operations 137	(3 2/3)	Electrical Engineering 20
(3 2/3)	Electrical Engineering 19	(3)	Physical Chemistry 118
(3)	Physical Chemistry 117		
(2)	Elementary Unit Operations 134		

TO THESE BASIC COURSES MUST BE ADDED THE FOLLOWING FOR THE RESPECTIVE OPTIONS.

		(Gas Technology)	
(3)	Non-Ferrous Metallurgy 105	(3)	Metallurgy of Iron & Steel 106
(4)	Fuel & Gas Engineering 120	(2)	Pyrometry 112
(2)	Gas, Fuels, & Lubricants 109a	(4)	Fuel & Gas Engineering 121
(20 2/3)		(3)	Engineering Administration 103
		(18 2/3)	
		(General)	
(3)	Non-Ferrous Metallurgy 105	(3)	Metallurgy of Iron & Steel 106
(2)	Plant Design & Layout 116	(3)	Unit Operations 138
(2)	Pyrometry 112	(3)	Inorganic & Organic Technology & Stoichiometry 128
(1)	Chemical Engineering Problems 111		
(19 2/3)		(1)	Chemical Engineering Problems 111
		(3)	Elementary Accounting 104
		(19 2/3)	
		(Metallurgy)	
(3)	Metallography & Heat Treating 113	(2)	Metallography & Heat Treating 132
(2)	Gas & Fuel Analysis 109a	(3)	X-ray Technology 146
(1)	Metals & Alloys 109c	(3)	Elementary Accounting 104
(2)	Pyrometry 112	(2)	Plant Design & Layout 116
(1)	Chemical Engineering Problems 111	(2)	Electrometallurgy 117
(20 2/3)		(18 2/3)	
		(Military)	
(3 2/3)	Military Training 7	(2)	Pyrometry 112
(3)	Elementary Economics 1	(3 2/3)	Military Training 8
(1)	Chemical Engineering Problems 111	(3)	Elementary Accounting 104
(19 1/3)		(3)	Unit Operations 138
		(18 1/3)	
		(Organic Technology)	
(3)	Unit Processes in Organic Technology 126	(3)	Unit Processes in Organic Technology 127
(2)	Plant Design & Layout 116	(3)	Unit Operations 138
(3)	Elementary Economics 1	(2)	Pyrometry 112
(1)	Chemical Engineering Problems 111	(1)	Chemical Engineering Problems 111
(20 2/3)		(3)	Metallography 133
		(18 2/3)	



МОСКОВСКІЙ НАУЧНЫЙ ИНСТИТУТЪ
ХИМИЧЕСКІЙ ОТДѢЛЪ
Труды Института проф. А. Е. Чичибабина.

to R. Norris Shreve
with compliments
author
A. Tschitschibabin

ИЗСЛѢДОВАНІЯ
ИЗЪ ОБЛАСТИ
ПИРИДИНОВЫХЪ ОСНОВАНІЙ.

Figure 2: Autographed copy of Prof. A.E. Chichibabin's works on *Pyridine Bases* sent to R.N. Shreve in 1919.

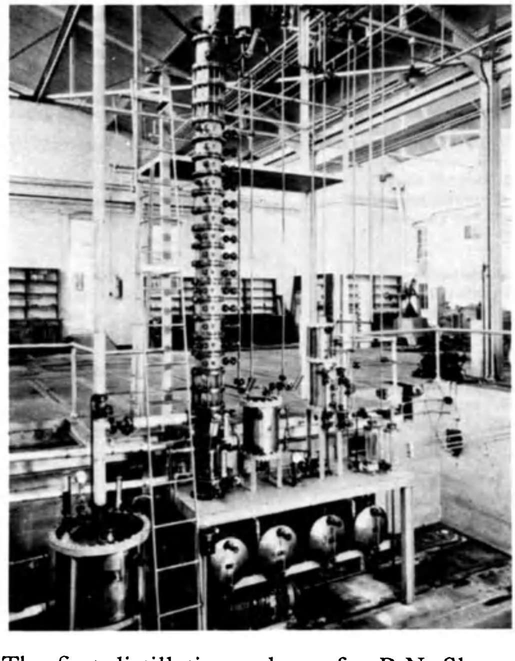


Figure 3: The first distillation column for R.N. Shreve's research in March 1933.

as Shreve, could not pay justice to the subject. The older generations of ChE students recall with awe the various required courses they had to take in unit processes during their undergraduate years, courses which were facitiously baptized "Flowsheet 101" or "Making chemicals from water, earth, fire and naval stores."

4. Debate

Surprisingly enough "industrial chemistry" was also attacked by engineers working in industry such as Albert B. Newman (1948 president of AIChE) who in 1938 was writing (9):

> The forward-looking administrator of a chemical engineering course is thoroughly convinced that major emphasis should be given to elementary and advanced fundamentals and that the teaching of descriptive and factual material should be only illustrative of these fundamentals. He knows the absurdity of trying to teach students the minute details of a wide variety of industrial processes, knowing very well that such details can be learned more quickly, accurately and effectively in the industry itself. The teaching of descriptive and factual material should be only illustrative of fundamentals. *The modern employer does not engage a graduating student because the student can describe for his employer how his product is made* (authors' italics).

To counterbalance these views one may use a large number of letters written by leaders in industry to various faculty members during the period 1934-40 and kept in the Archives of the School of Chemical Engineering at Purdue University. It seems that major industries were very supportive of Purdue's educational and research philosophy, their leaders often taking a polemic, aggressive attitude, fighting a crusade-like war. I believe that just one such letter (10) will show the tone of discussions about chemical engineering during the 1930's.

> While I am on the subject may I suggest that each year you try turning out a few good industrial chemists. I don't mean (the) so called chemical engineers who have spent most of their time on strains and stresses of steel and other rot that they don't need, I mean men who can look at a formula and give it a name, who know the principal reactions for the replacement of groups in the organic molecule... We are greatly disturbed over the variety (of) guinea pig chemists, that call themselves engineers as well, that we have to employ.

This letter gives us an opportunity to comment on the unfortunate misunderstandings that plagued chemical engineers until around 1940 in the USA and as late as 1955 in most German- and French-speaking Europe. Unfortunately, many chemists of the early and middle period of the 20th century had the impression that chemical engineers were nothing more than "chemists working in industry" and that the "chemical engineering curriculum" could be equalled with a "chemistry curriculum" containing one or two extra courses in "industrial chemistry." This problem was further complicated by the words used for *chemist* and *chemical engineer* in other languages. For example, the corresponding expressions in French are *chimiste* and *ingenieur chimiste,* in Italian *chimico* and *ingegnere chimico* and in Greek *chimikos* and *chimikos michanikos,* where the words *chimiste, chimico* and *chimikos* are used as nouns and adjectives, respectively.

Amidst these criticisms and praises, Shreve and most of his supporters remained quite serene, continuing their work with the conviction that what they were offering in terms of "finished product" (i.e., undergraduate and graduate students) was needed by industry. In fact, in the early days (1930-38), rarely did Shreve even use the word "chemical engineering." For him (5) "this field of *Organic Technology* (authors' italics) is a wide and varied one, which employs many chemical engineers, and is based upon much research. Its object is the making of products of ever increasing importance in our economic life." Later, he was writing (11) to an official of Dow Chemical Co. "Here at this University we quite regularly cooperate with industry in carrying out researches in conjunction with the staff and with our students ... Such work is done in a very modest way or extensively, depending upon the value of the project ... Arrangements can be made to patent results...."

Probably the most open critic of this educational approach was R.L. Pigford of the University of Delaware, who in 1976 wrote (12):

> Thus, chemical engineering curricula developed before 1950 in many schools as a two-part subject with applied physics and unsophisticated mathematics undergirding the unit operations and with applied physical chemistry nearly the only component derived from chemistry. Although chemical engineering students studied organic chemistry alongside chemistry students, instruction in chemical engineering departments seldom was affected by inorganic and organic chemistry directly. Most students and faculty members were fascinated with the mathematical analysis of process problems, not by the invention of processes incorporating new chemistry.

There were exceptions, to be sure. At Purdue, R.N. Shreve wrote a well-known book in which an attempt was made to categorize organic and inorganic reactions into groups as had been done with the unit operations. The absence of quantitative, theoretical treatments made the subject seem too much like "memory work" for most students. Thus, many students had to learn from their industrial practice of engineering that, without some appreciation of chemical properties and phenomena, they were ill prepared to deal with some of the innovative problems instead of the textbook problems.

5. Modernization of the Philosophy of Unit Processes

Shreve presented an interesting analysis of his educational philosophy in an unpublished article (13) entitled *Some Observations Regarding Chemical Engineering,* written on December 5, 1938 and discovered in his files in the special collections of the Purdue library. Here we reproduce major portions of it, since it sheds light into the directions of Purdue ChE in the 1930's and 1940's.

> Chemical Engineering is the youngest of the important branches of engineering. In the last twenty-five years it has evolved out of chemistry in a somewhat similar manner as was the growth of electrical engineering out of physics at a much earlier time. Twenty-five or thirty years ago the field now covered by chemical engineering was that of applied chemistry and also, to a certain extent, mechanical engineering. In those days the chemical changes (now recognized as unit processes) and the physical changes (now recognized as unit operations) were carried on in a rudimentary way by those who had training in the field of chemistry. In 1906, as a student at Harvard, I attended lectures by W.H. Walker in what was then called industrial chemistry but which was the start of Walker's conception of unit operations, brought to fruition in the book by Walker, Lewis and McAdams on this subject.
>
> Probably one of the quickest changes that has ever taken place in the field of applied science has been the growth of chemical engineering during this period. We really have a lusty infant that we are playing with and it seems to me that it is up to a number of us as to whether the growth takes place in a limited manner or in a broad field. We can either confine chemical

Figure 4: Synthetic rubber production in the Unit Processes laboratory of Purdue University in June 1944.

Figure 5: A 1941 photograph of the Unit Operation laboratory at Purdue University.

engineering, as is done by a number of older men in the AIChE, and have it embrace only the physical changes, or those recognized as unit operations, or we can go to the limit and bring within the field of chemical engineering those that are dealing with the application of chemistry to industry. Such a breadth of chemical engineering would be analogous to the fields now covered in their own particular scope by electrical engineering, civil engineering or mechanical engineering. The recent tendency seems to be to broaden our engineering fields rather than to narrow them.

Before we begin to examine a typical definition such as this applied to chemical engineering let us first ask what is left to chemistry. This will cover certainly the theoretical fields of inorganic, organic, analytical and physical chemistry. Indeed this is the type of teaching and research confined to such institutions as Harvard and Princeton. It is true of the *teaching* of chemistry here at Purdue, but it is only partly true of the research work here. Particularly under the leadership of Professor Haas much of *applied* chemistry has been investigated. I would say that strictly speaking some of the research, though none of the teaching, carried on in the department of chemistry really belongs within our fields, but on the other hand, Purdue is serving industry better with more and more work in the applied field, and rather than discourage any such work on the part of chemistry, I would encourage it.

A broad view of chemical engineering would be to so train men that they enter into the chemical industry able to carry out the following:

1. Design of equipment for carrying on chemical changes.
2. Supervision of equipment and men producing chemicals and allied products.
3. The research and development of new products, or the improvement of old processes. Already in the organic chemical industries there is being spent for research $4.30 from every $100 of sales.
4. The sale of chemicals. This involves in our modern chemical industry the servicing of such sales; indeed the large majority of chemical firms now refuse to hire for salesmen anyone without a technical background.
5. Executive work in chemical fields.

Table 3
ChE Plan of Study for the 1950-1951 Academic Year at Purdue University

	Freshman Year		
	First Semester		Second Semester
(4)	General Chemistry 1 or 17	(4)	General Chemistry 2 or 18
(3)	English Composition 1 or 32	(3)	Gr. American Books 4, Reading in Informal Essay 10, Intr. to Poetry 20, Intr. to Fiction 27 or Principles of Speech 14
(2)	Engineering Drawing 11	(2)	Engineering Drawing 12
(0)	Engineering Lectures 1	(5)	Analytical Geometry 2 or Elem. Engineering Math. 32
(5)	Algebra & Trigonometry 1 or Elem. Engineering Math. 31	(2 1/3-3)	Military Training
(2-3)	Military Training	(2)	Plane Surveying 6 or Welding & Heat Treating 34 or Casting 36
(2/3)	Personal Living		
(2)	Welding & Heat Treating 34 or Casting 36 or Plane Surveying 6		
(18 2/3-19)		(18 1/3-19)	
	Sophomore Year		
(2 or 3)	Chem. Eng. Calculations 40 or Principles of Economics 1	(3 or 2)	Principles of Economics 1 or Chem. Eng. Calculations 40
(4)	Qualitative Analysis 26	(4)	Quantitative Analysis 27
(4)	Calculus 3	(4)	Calculus 4
(4 1/3)	General Physics 1	(4 1/3)	General Physics 2
(3)	Principles of Speech 14, Great American Books 4, Readings in Informal Essay 10, Intr. to Poetry 20 or Intr. to Fiction 27	(3)	Expository Writing 31
(2 1/3-3)	Military Training	(2/3)	Professional Problems 0
		(2 1/3-3)	Military Training
(19 2/3-21 1/3)		(22 to 20 1/3)	
	Junior Year		
(5)	Statics & Kinetics 21	(3)	Mech. of Materials 23
(4)	Organic Chemistry 151	(4)	Organic Chemistry 152
(4)	Physical Chemistry 173	(4)	Physical Chemistry 174
(3)	Unit Operations 137	(3)	Unit Operations 138
(3)	Elements of Democracy 30 or International Relations 109	(4)	Elementary Metallurgy 2
(19)		(18)	
	Summer Sessions		
(2)	Unit Operations 139		
(2)	Unit Operations 140		
(3)	Europe Since 1914 (1) or U S. in World Affairs (5)		
(3)	Psychology 74		
(10)			
	Senior Year		
(3 2/3)	Direct Currents 19	(3 2/3)	Alternating Currents 20
(3)	Engineering Instrumentation 155 or Technical Elective	(1)	Chemical Literature 113
(3)	Elementary Heat Power 29	(3)	Chem. Eng. Thermodynamics 10
(3)	Chemical Process Industries 128	(3)	Chemical Process Industries 129
(3)	Technical Elective	(3)	Technical Elective or Engineering Instrumentation 155
(3)	Non-Technical Elective	(3)	Non-Technical Elective
(18 2/3)		(16 2/3)	

> Here at Purdue University we are apparently going to continue to have a large school, so we shall 'produce' a considerable number of chemical engineers. We have to 'sell' these students in the prevailing market just as though we were dealing with a manufactured product. Therefore, it is particularly necessary for us to broaden the fields into which our graduates can enter. We should prepare for (1) design, (2) production, (3) research, (4) sales and (5) management. Research is a field in which I see a large potential avenue if we do not neglect our chemical aspects. How much better for developing a new process in the laboratory and carrying it through into the factory is a man trained in unit operations, unit processes, and theoretical chemistry, than one schooled in theoretical chemistry only!

The educational system of Shreve remained acceptable by many Universities. For example, even the 1950-51 curriculum of Purdue University included several organic chemical technology courses (see Table 3). But, analyzing the text presented in the previous two pages, we can now conclude that for the originator of the idea of "unit processes", this field was an expression of his disagreement with the physical approach of unit operations. Clearly, what Shreve was attempting to express through his "unit processes" was the idea of chemical reaction engineering. Unfortunately, his message was lost in the long descriptive details of the educational material that he and his followers were presenting to students.

6. Affiliation of Authors

School of Chemical Engineering
Purdue University
West Lafayette, IN 47907, USA

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H. Kramers

CHEMICAL ENGINEERING IN THE NETHERLANDS 1935-1965

1. The pre-war years

The integral concept of chemical engineering aimed at rational design and operation of chemical processes was in the first half of this century mainly an Anglo-American affair. Since the introduction of the first chemical engineering curriculum at MIT it became the fourth large engineering discipline in the Engineering Departments of the universities on the North American continent, and also to some extent in Great Britain.
Before the second world war this trend had little impact on the universities on the continent of Europe. The first to be influenced were rather the more practice-oriented technical colleges with their relatively short curricula aimed at supporting functions in industry. At the science oriented academic level the need for the special training of chemical engineers was not felt, and for instance in Germany with its important chemical industry (mainly I.G. Farben), it was held that chemists and mechanical engineers together could cope with the requirements of this branch of industrial activity - which they actually did with great success.

In pre-war Netherlands, industry in general was not very much developed, and in particular the chemical industry was in an infant stage, as compared to the present situation. The main process industries were Shell (at the time called "Bataafsche Petroleum Maatschappij"; oil refining), Unilever (oils and fats), DSM (formerly called "Dutch State Mines"; coke, gas and coal chemicals, fertilizers) and AKU (semi-synthetic fibers). These companies, together with a string of minor chemical firms, recruited for their needs chemists trained at one of the 6 general universities in the country and chemical

N. A. Peppas (ed.), One Hundred Years of Chemical Engineering, 143–152.

technologists from the Technical University of Delft (TUD).
In the chemistry curricula of the general universities, courses on technical matters and industrial applications were non-existent. If a student after graduation went to industry, this was often considered as an unintended spin-off. On the other hand, the department of Chemical Technology of TUD, in existence since 1902, was meant to provide for industrial chemists. Its curriculum offered a rather limited preparation in mathematics and physics, but a very solid base in the various branches of chemistry. In the later years of the 5-year study, all students took a major course in chemical technology, since 1926 taught by professor H.I. Waterman. In the course of time, his lectures evolved from an encyclopedic description of the various kinds of chemical industry towards a more systematic treatment of reaction types as used in industry. Waterman had many connections with chemical industry, and with colleagues throughout Europe. He also was well aware of the overseas situation in chemical engineering education. Foreseeing the great potential developments in the chemical industry, he recognized in an early stage the desirability of introducing chemical engineering unit operations and design aspects into the chemical technology curriculum. However, the introduction was delayed until after 1945[1)].

In the same period, a new engineering discipline was founded at the TUD in 1930, that of technical physics. The purpose of this new department was to train engineering oriented physicists for the development and design of instruments and other light equipment. On the basis of much mathematics, mechanics and physics, but hardly any chemistry, its curriculum could spread into many different directions during the last 2 years of the study. In 1934 this department set up an optional course

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1) Waterman's teaching and research have been of the greatest importance to the Dutch chemical industry. He continued his activities until 1959, with an interruption from 1941 to 1945 due to the German occupation of the country.

on physical operations in the process industries, called "physical technology". It was given on a part-time basis by professor W.J.D. van Dijck, who at that time was research coordinator at Shell. Van Dijck - a physicist by origin - was in his field rather an inventor than a research scientist; during his active career he wrote only a few publications, but he held more than 100 patents. His lectures on physical technology were extremely lucid and excellently documented. They were also attended by many of Waterman's students. With these exercises in process engineering and equipment, such students on graduation had become comparable to the overseas chemical engineer - although with a bias towards technical chemical research rather than design work.

2. Post-war developments in education

From spring 1941 until mid 1945 the TUD, like all universities, ceased to function properly. For the chemical industry, the 15 year period after the war was not only one of reconstruction, but also of considerable expansion. Shell extended into more refining and oil-based chemicals, DSM switched to oil-based chemistry, and AKU started producing synthetic fibers. Some smaller chemical enterprises grew rapidly, like the Royal Dutch Salt Company, which among others built a large soda ash plant in the North. World-wide operating companies (Esso, Gulf, Texas, Mobil and British Petroleum) opened big oil refineries in the surroundings of Rotterdam and Amsterdam, and subsidiaries of ICI, DuPont, Dow Chemical and Hoechst started sizable operations along the North Sea coast. The need for chemically trained scientists and engineers could be expected to grow very fast.
In anticipation, in 1946 Shell gave a grant of 2 million guilders - at that time a considerable amount of money - to the TUD. One half of this amount was to be spent for the extension of Waterman's semi-technical facilities, and the other half on the founding of a new building with equipment for research and pilot plant operation in physical technology. Concurrently, in the latter field, the university had to provide for a professorship and the necessary staff. In 1947 the author of this paper was appointed to this chair, which he held until 1963. As a rather unique feature, this nomination involved the staff

membership of both the department of Technical Physics and that of Chemical Technology. At about the same time, professor P.M. Heertjes was appointed in the latter department in order to teach chemical engineering operations.

It was soon decided to split up the teaching of the by now "classical" unit operations into two parts: physical transport phenomena and physical separation methods. The argument for a basic course in transport phenomena was that, although general physics courses may cover initial notions on fluid flow, heat conduction and diffusion, a further elaboration of rates of transfer of momentum, heat and matter for engineering purposes would be essential; and that not only for the process industries[2)]. This approach seems to have been rather novel at that time. It has now been adopted at many universities, and its most extensive elaboration is to be found in the well known textbook "Transport Phenomena" initiated by professor R.B. Bird, who in 1958 spent a semester at TUD (1). At a later date, professor W.J. Beek published a book on the same subject, based on his lectures at TUD, where he held the chair of physical technology from 1963 until 1969 (2).

Coming back to the picture of the early 50's: courses on equipment for the process industry were given in the department of Mechanical Engineering by professor E.F. Boon from 1948 to 1959, and subsequently by professor F.C.A.A. van Berkel. Both also held a nomination in the department of Chemical Technology. In this way, all basic courses in the area of chemical engineering were available. although distributed over three departments.

These courses have been listed in the diagram below, which also indicates the possibilities to follow them for students of the 3 departments involved.

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2) This idea can be traced back to the studies by Dr. A. Klinkenberg within Shell. He recalled it in the final paper of ref. (4).

Basic Course	For students of the department of :		
	Chemical Technology	Technical Physics	Mechanical Eng.
transport phenomena (Kramers)	obligatory	obligatory	optional
separations methods (Heertjes)	obligatory	optional	optional
chem. technology (Waterman)	obligatory	---	optional
process eng. practice (Heertjes)	optional	---	---
process equipment (Boon)	optional	---	obligatory

In this diagram the term "obligatory" means that all students of the corresponding department had to follow the course indicated. In the later years of their study there was much opportunity for differentiation, hence the term "optional". The diagram does not show a number of other, more specialized courses, which could be chosen as well. The choice was closely related to the area of activity of the M.Sc. thesis supervisor.

Within the "chemical engineering education cluster", as described above, there was much cooperation between the various teaching and research units. Often common seminars were held, and in the laboratories there was a certain degree of mixing between students from the different departments, and thus with different backgrounds: a useful preparation for practice in industry, also from the human point of view.

3. R&D cooperation, national and international

During the first 20 years after the war, the atmosphere for doing research at the university was very favorable. The students could spend most of their final year on a research subject as a key-stone of their education. The "cluster" also had currently a population of around 30 Ph.D. students. Both graduate and post-graduate research gave rise to a rapidly increasing flow of publications.
In research matters there also was strong interaction between the TUD and industry. The most prominent industrial R&D centers in this respect were the Shell Laboratory in Amsterdam and the DSM Central Laboratory in Geleen, in the South of the country. One of the directors at the Shell Laboratory was Dr. J.C. Vlugter, one of Waterman's former collaborators, who was a great animator of chemical engineering research both within his company and at the TUD. He was founder and first chairman of the Chemical Engineering Section of the Royal Institution of Engineers, and co-founder of the European Federation of Chemical Engineering. In 1959 he joined the faculty of the Chemical Engineering department of TUD to succeed professor Waterman[3)]. The DSM Laboratory was directed by professor D.W. van Krevelen, a university chemist, who also had spent several years with Waterman in Delft. He was able to combine management with active research, from 1940 to 1960 mainly on chemical engineering topics (3). From 1953 on he also was a part-time professor at TUD.
The lively contacts between university and industry enabled us to play an influential role on the continent of Europe, in particular with respect to the two following issues.

Already by the end of the 40's, the problem arose that for the more sophisticated publications on chemical engineering topics there were insufficient outlets in

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3) However, a few years later he was asked to set up the third technical university in the East of the country. There he also founded the Chemical Technology department, which he brought to a level of notable quality.

Europe. At the same time Dr. Paul Rosbaud was scouting for new scientific journals on behalf of Pergamon Press Ltd. This situation led to the creation of a new journal: "Chemical Engineering Science". It was, among others, enabled by a commitment from the Dutch side to provide for at least one third of the papers during a starting period of several years. The founders' meeting in 1950 was attended by Van Krevelen, together with Cathala (Toulouse), Donald (London) and Guyer (Zuerich). The first number was issued in 1951. Since then, with Danckwerts (Cambridge) as editor-in-chief for many years, this journal has become widely accepted.

The other international issue with a strong Dutch participation concerns the European Federation of Chemical Engineering. Vlugter was for many years a member of its Supervisory Committee. He was champion for setting up international working groups on the different aspects of chemical engineering. Some of these were chaired and others manned by younger Dutch chemical engineers, mainly from industry, who in the course of time became well-known in their fields. On the subject of one of these working groups, "Chemical Reaction Engineering" (at that time a novel concept) some more comment is given below.

4. Chemical Reaction Engineering

It can be said that during the first half of the century in the chemical engineering unit operations the interplay between physico-chemical equilibria and physical transport rates had generally become to be understood and systematized to the extent that reliable predictions on the performance of equipment were feasible. However, a more systematic approach to the prediction of overall rates of chemical conversion ("macrokinetics") as a combined result of purely chemical "microkinetics" and transport rates was still due to come. Van Krevelen coined this broad field of investigation "chemical reaction engineering", the great actual interest of which was soon recognized. With the support of the European Federation working group, two related national associations decided to organize one or more international meetings on the subject. Thus, 3 symposia on "Chemical Reaction Engineering" were held in Amsterdam in 1957, 1960 and 1964 (4, 5, 6). In particular the first symposium can be regarded as a historic event, and its syllabus[4)] is worthwhile quoting:

> "Chemical reaction engineering is a part of engineering in general. It is a new branch of science which is still in the development stage./ It aims at controlling the chemical conversions on a technical scale and will ultimately lead to appropriate and successful reactor design./ An important part is played by various factors, such as flow phenomena, mass and heat transfer, and reaction kinetics. It will be clear that in the first place it is necessary to know these factors separately./ Yet this knowledge in itself is insufficient. The development of chemical conversions on a technical scale can only be understood from the relation and interaction between the above mentioned factors./ This relation and interaction will be the main theme of this symposium."

At these 3 symposia a total of 73 papers was presented. Although 30 of them were from Dutch origin (Shell, DSM and 2 technical universities), it is believed that they had their impact on the European scene. From the start a network of active participants developed, to which belonged Danckwerts and Denbigh (UK), Wicke, Schoenemann and Hofmann (W.Germany), Letort and Le Goff (France), and Jottrand and Froment (Belgium). The subject of chemical reaction engineering was also treated in special courses, initially at the TUD. From these, a textbook resulted in 1963 on the design and operation of chemical reactors (7), of which a revised second edition appeared recently (8). The first edition was soon followed by Denbigh's text on the theory of chemical reactors (9).

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4) Formulated by professor K. Rietema, editor of the proceedings, ex-Shell and at that time teaching physical technology at the (second) Technical University, Eindhoven.

5. Concluding remark

As has been alluded to in passing, in the period under consideration two new technical universities were established; in 1952 in Eindhoven and in 1960 in Twente, both having fairly large chemical technology departments. Furthermore, at the general universities of Groningen and Amsterdam chemical technology curricula were set up. The educational programs at these institutions have moved towards the Anglo-American pattern, probably more so than in the adjoining countries. However, as compared to e.g. the United States graduates in chemical engineering, the Dutch had more preparation in chemistry and more inclination towards research, whereas their immediate aptitude for process engineering and design was relatively less. Since in general the basis in the Dutch education system is rather broad, most graduates in chemical technology (alongside with engineering physicists and mechanical engineers, who drifted towards chemical engineering) have appeared to adapt readily to chemical engineering practice.

Rozenbos 5a, Rheden, the Netherlands

R.A. Mashelkar and J.V. Rajan

CHEMICAL ENGINEERING DEVELOPMENTS IN INDIA

INTRODUCTION

Chemical Engineering is a dynamic discipline and it has been evolving continuously since the days of craft innovations of prehistoric times. Chemical engineering has played an important role in the development of chemical industry, which, in turn, has played a key role in the matters of providing the essential human needs such as food, clothing, shelter, etc. to the mankind. In India too this industry continues to play a major role in practically all the national endeavours. It was the foresight of the Late Dr. H.L. Roy, who introduced chemical engineering in the curriculum of the then Bengal National College, the nucleus of the present Jadavpur University, as early as 1921. Interestingly, then the discipline of chemical engineering was still in its infancy even in the developed countries of the West. From this early start chemical engineering evolved in tune with the needs of the nation and today the Indian chemical engineering community faces challenges, which can be converted into great opportunities.

On the world scene, we have recently witnessed a great change of emphasis from homogeneous materials to composites, from commodity chemicals to specialities, from synthesis to formulations, from process concerns to product emphasis, from cost competition to quality competition and so on. The perceptions of chemical engineering in India have been somewhat different, as we shall show later. Indeed science and technology in prehistoric times in India had a character and flavour of its own and in pre-vedic times it was leading the rest of the world in many areas of medicine, materials, etc. It could neither keep this lead nor maintain a position of its own for a variety of reasons and while tracing the history of chemical engineering in India, we believe, it is logical to begin precisely with these times.

N. A. Peppas (ed.), One Hundred Years of Chemical Engineering, 153–222.

1. SCIENCE AND TECHNOLOGY THROUGH MIDDLE AGES

We shall begin our survey of the past by tracing the evolution of science and technology in the pre-Renaissance middle ages (say BC 700 - AD 1500). The technology of the far East at that time was very much ahead of the West and exports of products and technology to Europe were largely from the East [1]. European civilization derived its rich scientific heritage from the ancient world through its remarkable faculty for assimilation - from Islam, India and China. But unlike the East, veneration of past accomplishments was not a hindrance for new initatives. Natural resources, social systems and the questioning spirit were the corner-stones for structuring the edifice of philosophical inquiries. European civilization progressively became "so widespread in its roots, so eclectic in its borrowings, so ready to embrace the exotic" ...... while the more ancient civilizations have "tended to be strongly xenophobic and have resisted confession of inferiority in any aspect, technological or otherwise". Europe certainly stuck firmly to its religion and philosophy but in the processes of manufacture and natural science it readily adopted whatever seemed useful and expedient. Among the states in Europe however, the liberal ideas and revolution in thought that made chemistry as a formal science were of French origin.

When the scientist-philosophers began to understand the molecules, the metamorphosis of alchemy to chemistry commenced, rather slowly but steadily. Although the early European philosophers were adept at explaining natural phenomena, the artisans of that time knew nothing beyond their inherited practices or empirical methods impliedly imbibed from the then advanced civilizations of the East, including India and China. They were innocent of theories to explain their practices. The realization that science and crafts were the products of natural phenomena and a knowledge of nature gave the power to control its forces, had to await the dawn of 17th century. Empirical practices were the pre-cursors of engineering principles and their integration with science during the 16th and 17th centuries marked the transition from empiricism to engineering techniques. Leonard's rigorous analysis of the problems of dynamics, later enriched by the works of Galileo, Huygens, Newton, Torricelli and Pascal gave the scientific framework to problems of engineering. The Renaissance scientists and others who followed (from Francis Bacon to Descartes) believed that science must ultimately guide the craftsmen and only a science-based technology would shape the future course of civilization.

The double-link between science and technology was mutually inclusive and rightly so as we now know. The era of Industrial Revolution (1750-1850) profoundly changed the pattern of civilization first in Britain, then in continental Europe and in the North American continent and ultimately in much of the rest of the world.[2] Britain was the workshop of the world until 1850, when her supremacy was seriously challenged by North America and countries of Europe. The transition from empiricism to experimental purism as a basis for technology was generally evident in all branches of technology, but more so in chemical industry. To demystify ancient technologies and facilitate the shift from craft mysteries to science as a basis for technology, the Royal Society, in the mid-17th century sponsored and published studies on "Histories of Nature, Arts or Works" which provided for the first time scientific descriptions of craft technologies (some of whose roots incidentally could be traced to the Orient, e.g. vegetable dyes) as they were practised in the 17th century. Industrial progress then was overwhelmingly dependant on empirical inventions or innovations of craftsmen rather than systematic scientific research, whose ascendancy was to come two centuries later. The small scale art of concoctions, stewings and fusions continued, but were gradually transformed into carefully controlled activities of enterprise. Medieval Europe's technical developments during the 13th-16th centuries which were products of assimilation of arts and crafts of the East were supplanted by the creative philosophies of European science during the 16th-17th centuries. Thus came about the birth of the chemical industry which had at its core the engineering principles and practices refined by the scientific theories then extant. But the unending quest to know the science behind the changes in the chemical and physical properties of raw materials fashioned chemical engineering around physical unit operations and chemical unit processes. So a logical assumption - indeed it seems well-nigh an inevitable conclusion - is that the basic discoveries gave the scientific back-up for systematising engineering theories, principles and practices which transformed the discoveries into industrial enterprises.[3] Nevertheless, we also know that for several engineering problems, there are no ready made science-based solutions. Empirical methods were developed long before the discovery of scientific principles, e.g. production of metals and alloys prior to the modern conception of chemical elements and smelting processes.

To reiterate, requirements of industry were the motivational force up to a point in history for imparting necessary impetus, purpose and direction to the then nascent chemical engineering practices to evolve and bridge the interface between chemistry and industry. The present day chemical industry truly reflects the maturity of the discipline with an exclusive store of literature and an expanding band of dedicated practitioners possessing heterogeneous expertise.

After the birth of modern science and industrialism (1500-1750 AD) Western Europe drew on world's raw materials and primary products and exported manufactured wares. By the end of the 19th century Europe held almost all the rest of the world in technological bondage. Greater use of power and machinery, application of knowledge of natural sciences to industrial practices gave a definite edge to produce "more goods, more cheaply" than the countries of the orient. The technological superiority of the East over the West during the classical eras was reversed. European traders in course of time did the rest and the countries of the orient had to suffer not only economic, but administrative and political subjugation as well. This then is a synoptic capsulation of the origin of chemical engineering in general. The mystical practices and empirical guesses of the East were assimilated by the West in its own crafts, and later refined to become the progenitor of industry in Europe and America. However to know about the vintage "chemical enginering" practices of the East, say specifically India, we must delve deep into the past perhaps starting from Mohenjodaro to the medieval India.

2. ERA OF EMPIRICISM - MOHENJODARO TO MEDIEVAL INDIA (BC 2500 - AD 800)

In the orient the then scientifically advanced civilizations were India and China. Some five to six thousand years in the distant past, when Europe and America have had their dark ages, India was producing chemicals and cutleries, silks and seagoing vessels, dyes and damascus steel, metal wares, glass, ceramics, phytal drugs and perfumeries, gold ornaments, iron copper and metal alloys. The Indian intelligentsia, steeped as they were in ritualism and religious dogmas, were probing the mysteries of the cosmos and propounding theories and principles in astronomy, physics, chemistry, medicine, mathematics and cosmogony just as the Renaissance men, very much later in history, rediscovered their intellectual power in the context of christianity.[4] Unit operations and unit processes were very much in evidence in the production of textile dyes, therapeutics of Ayurveda, organic and inorganic pigments and colours used in the painting of murals and frescoes. Sound empirical knowledge of chemistry, thermodynamics, and design engineering techniques for heat and mass transfer could be discerned in the manufacturing practices followed by the ancients in respect of copper, iron, bronze, zinc, mercury, gold and silver mining, ornaments, hand tools and armaments, glass and ceramics. Indus valley civili ation produced glazed pottery. Glass industry came into being during BC 1000-700. Black polished works found in excavations testifies to the standard of technological skills acquired for firing under both oxidising and reducing conditions to impart desired colours. Sound engineering principles have been exemplified in the production of high temperature fired ceramics and glass wares.

The artisans of that time were not writers of manuals, but archaeological finds (BC 2500), the extant scriptural and secular literature of the Vedic, Buddhist, Jaina and Dravidian schools of thought (BC 1600 - 300), the literary works of the Greeks of Asia Minor (Scylax, Hecataeus, Herodotus and Ctesias - BC 600-300), reports on Alexander's Indian Expedition by Nearchus, Onisicritus, Aristobulus and Clitarchus (BC 320-200), accounts of Greek ambassadors sent out from Syria and Egypt (Megasthenes, 300 BC; Eratosthenes, BC 276-195; Apollodorus of Artemita, BC 200-100; Alexander Polyhistor, BC 105-40; Strabo, BC 63-19 AD; Diodorus, BC 60-36) and Pliny's Natural History (70 AD) provide enough material to infer the status of science and engineering in ancient India.[5] Among the Vedas proper, Atharva Veda (BC 1000-800) deals with a variety of themes, one of which relates to diseases and therapeutics. The later Ayurveda texts of Charaka, and Susruta (80-350 AD) are far more detailed and give explicit methods and procedures to be followed in the production of therapeutics from different sources. The Arthasastra (BC 400) of Kautilya contains chapters on gemnology, mining and metallurgical operations, minting coins, ocean mining, salt manufacture botanical species suitable for forests, medicinal plants, weights and measures, measurement of space and time based on astronomical parameters, meteorology, sanitation and public health, clues for spotting minerals and metals on the basis of exudations or oozes, and so on.[6]

During 2500-1500 BC, closed pottery kilns generating temperatures of 700-800°C were developed to smelt copper ores to make implements for daily use. It was also during this period that dyed cotton fabrics were used. The period covering the Vedic pre-Buddhist era to 800 AD saw the emergence of mining of ores like copper, iron, gold, silver and lesser metals. The history of empirical science, engineering and technology of the period spanning Indus Valley Civilization to medieval era (BC 2500 - AD 1500) is too voluminous to be abridged in a manuscript on developments in chemical engineering. Yet it is within these pages of history that we get glimpses of ancient engineering practices. So, as a compromise we have tried to be selective in the choice of examples for highlighting chemical engineering craft practices embedded in chemistry, medicine and metallurgy. A fascinating account of the development in ancient Indian Science and Technology can, however, be found elsewhere.[7]

3. CHEMICAL OPERATIONS AND EQUIPMENT

Chemistry in ancient India was largely restriced to making medicines,[8] dyes, glass, alkalies, acids and their metallic salts. The chemistry of the Tantrik period (800-1300 AD) contained in their Siddha philosophy was largely devoted to the elixir of life and similar themes of alchemical importance. Buddhist

Nagarjuna's treatise Rasaratanakara was the precursor of several other treatises on rasas (minerals). Nagarjuna's work deals with the purification of sulphur, calamine, silver, mercury, etc. The other texts dealing with chemical substances are : Rasarnava, Sarvesvararasayana, Dhatuvada, Rasahridaya (of Govinda), Rasendrachudamani (of Somadeva), Rasaprakasasudhakara (of Yasodhara), Rasachintamani (of Madanantadeva), Rasakalpa and Rasa-ratnasamuchchaya (1300 AD). All these works deal with the extraction, purification, sublimation, distillation and chemical processing of substances, the apparatus and equipment used and related topics. Somadeva's Rasendrachudamani gives a concise description of apparatus needed for chemical processing as well as the materials of construction of these apparatus. What follows are a few selected examples of processes, equipment and design engineering practices of this ancient era.

3.1 Dyes and Dyeing

A piece of dyed cotton found in the ruins of Mohenjodaro (BC 2500) proved the ancient Indians' knowledge of dyes and dyeing. Magasthenes, the Greek Ambassador (300 BC), writes of the richness and bright colours of the garments worn by Indians. In St. Jerome's (400 AD) Latin translation of the Bible, Job's Wisdom is expressed "as enduring as the colours of India." During the reign of Jehangir more that 400 tints were produced through a judicious blend of colours and varying process additives (mordants). During Aurengazeb's time the number came down to 150 and at the turn of the 19th century, there were only 60 tints. Common sources for these natural colours were turmeric for yellow, pistachio galls for red, the bark and root of Indian mulberry for dark red, root of Indian madder for brilliant red, coral jasmine for orange, Larkspur flowers for light yellow, the insect pigment cochineal for crimson, saffron for bright yellow, indigo for blue and purple, indigo and coral jasmine for green and iron filings for black.

The process of extraction of natural colours from tubers, roots, leaves or flowers consisted of collection, washing, drying, pulverising, soaking, decanting of liquid, boiling, evaporation and caking. Ancient dyes needed a mordant to fix them to the fibres/fabrics.

Alum and a variety of metallic salt earths and natural organic materials containing acids and/or alkali were used. The Harappa and later Indians used various plants and household substances, e.g. alum, buffalo milk, sour coconut, palm juice, butter milk, castor oil, wood ashes, salt, vinegar, plant roots, barks, myrobalans, rhinds of pomegranate and dungs of cow, sheep and goat to fix the dye and enhance fastness properties. By varying the mordant constituents, concentration and soaking time, hundreds of subtle shades were created.

3.2 Painting

The art of painting is well codified as early as 600 BC. Theoretical and operational aspects of painting frescoes and murals are described in treatises like Shadanga (Six Limbs) and Chitralakshna. Ancient cave paintings dating back to BC 200 found at Ajanta are colours of vegetable origin but inorganic pigments like ruddle (red ochre), haematite (red and brown peroxides of iron) and ochre have also been employed. Engineering operations involved in Ajanta murals are : even surfacing of rock walls, preparation of plaster cement from materials such as earth, paddy husk, pulverized rock, fibre and gum for coating the surfaced rock walls, preparation of a finely ground lime paste and use of metal reflectors for lighting the dark reaches of the caves in preference to oil fired torches to prevent soot deposits on the paintings. Some unit operations viz. pulverizing, mixing, blending and drying can be inferred in the preparation of paints.

3.3 Chemical Processes

Potassium carbonate (Susruta's Process) "Cut the plants, burn them, boil the ashes with water in an iron pan and then filter through cloth, folded several times. The clean solution is rich in potassium carbonate."

Caustic Alkali (Sustra's Process) "Burn strongly several kinds of limestones and shells, add water, mix the slaked lime with lixiviated liquid, and boil and stir with an iron ladle."

3.4 Chemical Reactors and Processing Equipment

The apparatus and equipment used by the alchemists and artisans in the ancient past were baked clay pots, bamboo, and metallic vessels made of iron and copper and surgical instruments made of steel. Indigenous medicine makers in rural India even now continue their inherited traditional manufacturing practices. The units appear to have been so designed as to meet the objectives of functional facility, cost effectiveness and operational flexibility.

Dola Yantram (Fig.1)

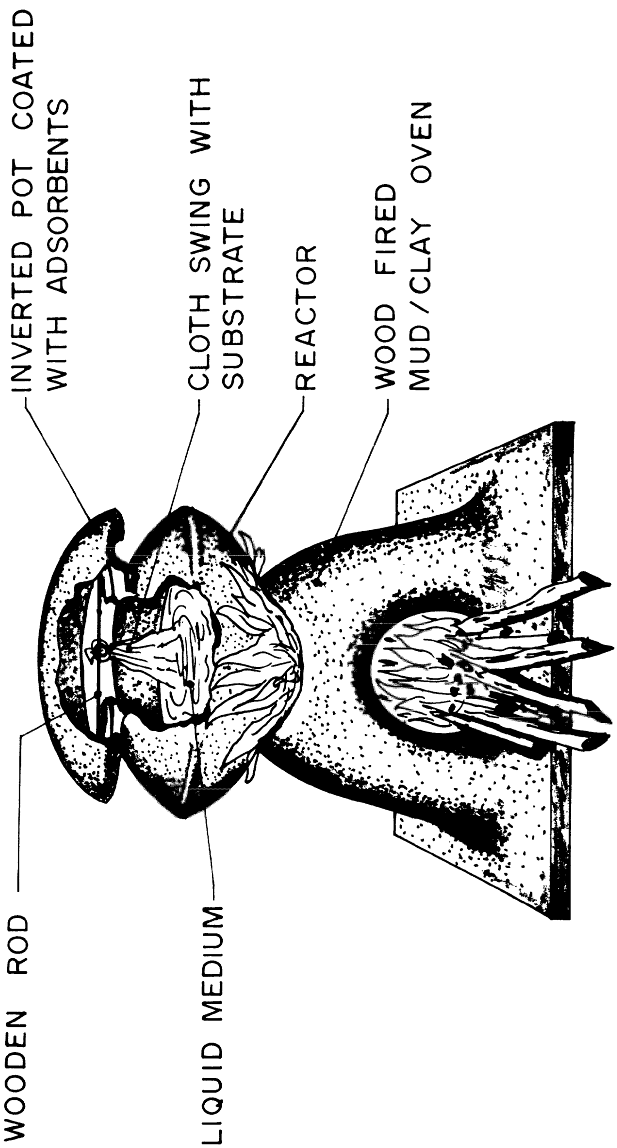
The terms 'dola' (swing) and 'yantram' (apparatus) literally mean an apparatus with a swing. Within the swing is placed the material to be extracted. The apparatus is a pot used for alchemical extraction, the pot being filled with a liquid and the extractant enclosed in a pouch tied to a rod placed on the mouth of the pot and suspended into the liquid. The liquid is allowed to boil while a second pot is inverted over the first to trap within steam vapours. The boiling liquid apparently imparts momentum to the pouch to swing.

Adhaspatana Yantram (Fig.2)

The term 'adhas' means 'down' and 'patana' means 'fall'. In this unit inverted pot is smeared/filled with the material. Within its neck is a molecular sieve like diaphram. The inverted vessel is inserted into the neck of the receiver, which remains buried. The bottom vessel contains water or any other liquid. Heat is applied from the top. The vapours filter down and condense with the liquid.

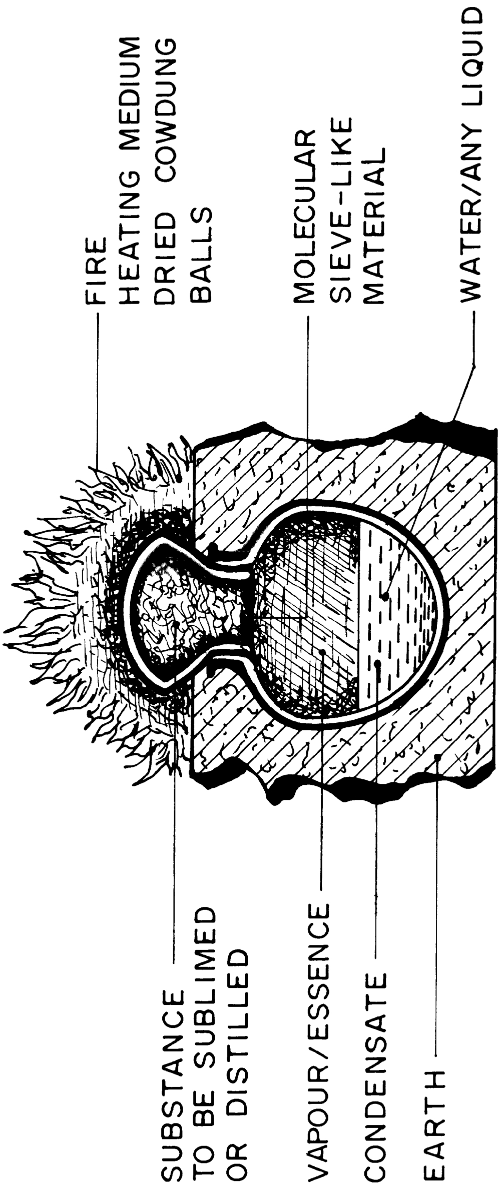
Tiryakpatana Yantram (Fig. 3)

"Tiryak" means 'cone' or 'angle'. The sublimed/ distilled product passes through a bamboo tube angled into another receiver vessel. The mouth of the vessels and joints are luted with clay. The receiver is kept cooled.



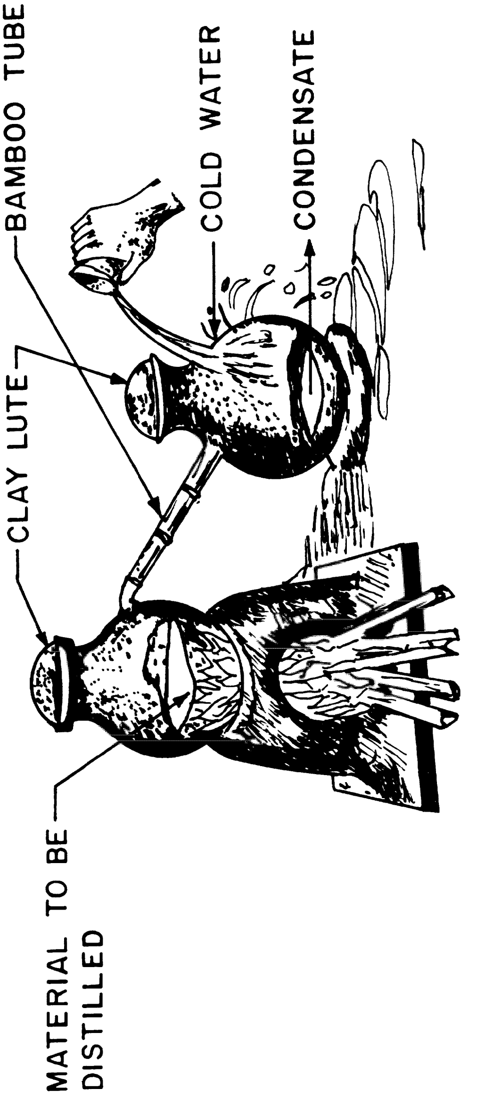
DOLA YANTRAM EXTRACTION UNIT

FIG.1



ADHASPATANA YANTRAM

FIG.2



TIRYAKPATANA YANTRAM

FIG.3

Valuka Yantram (Fig. 4)

"Valuka" means sand. This is a sand bath apparatus used to produce mercuric compounds. A long-necked glass flask is wrapped with several folds of cloth smeared with clay and sun-dried. Three-fourth's length of the flask is buried in a sand-packed pot. An inverted pot having an adsorbing/absorbing medium is placed on the rim of the sand-packed pot and luted with clay. Heat is applied till a straw placed on the top gets burnt (evidently indicative of the reaction time).

Khosthi Yantram (Fig. 5)

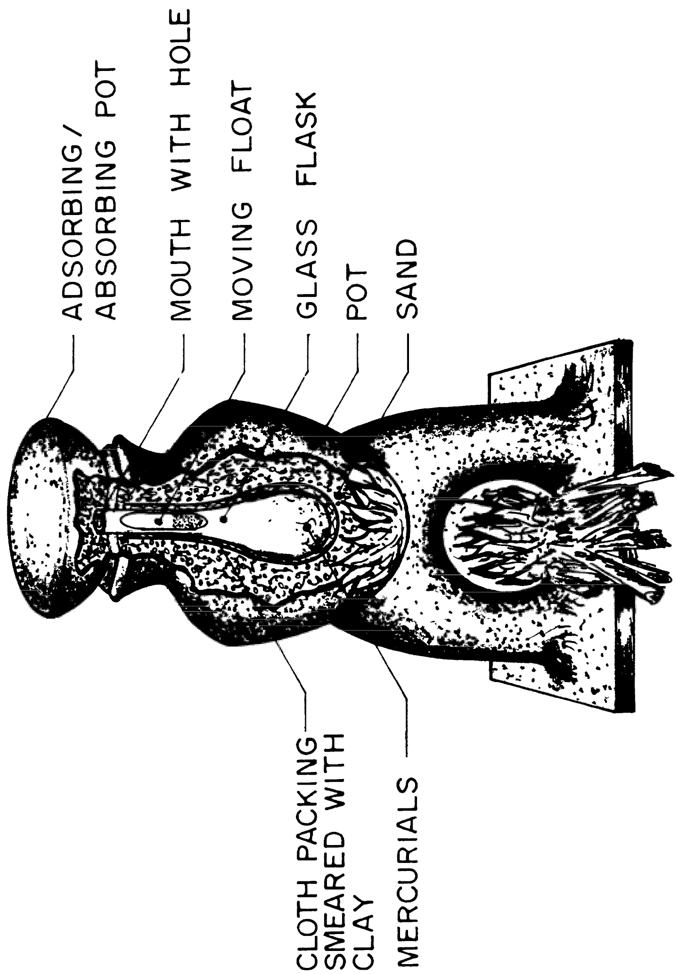
"Khosthi" stands for bellows and the unit is used for zinc extraction from calamine, which after pulverization and mixing with additives (lac, treacle, white mustard, myrobalan and borax), is boiled in milk and clarified butter, made into balls, placed in a crucible and strongly heated, the crucible resting inverted on a pot with a perforated top and containing water where the zinc vapours get condensed.

4. MATERIALS ENGINEERING

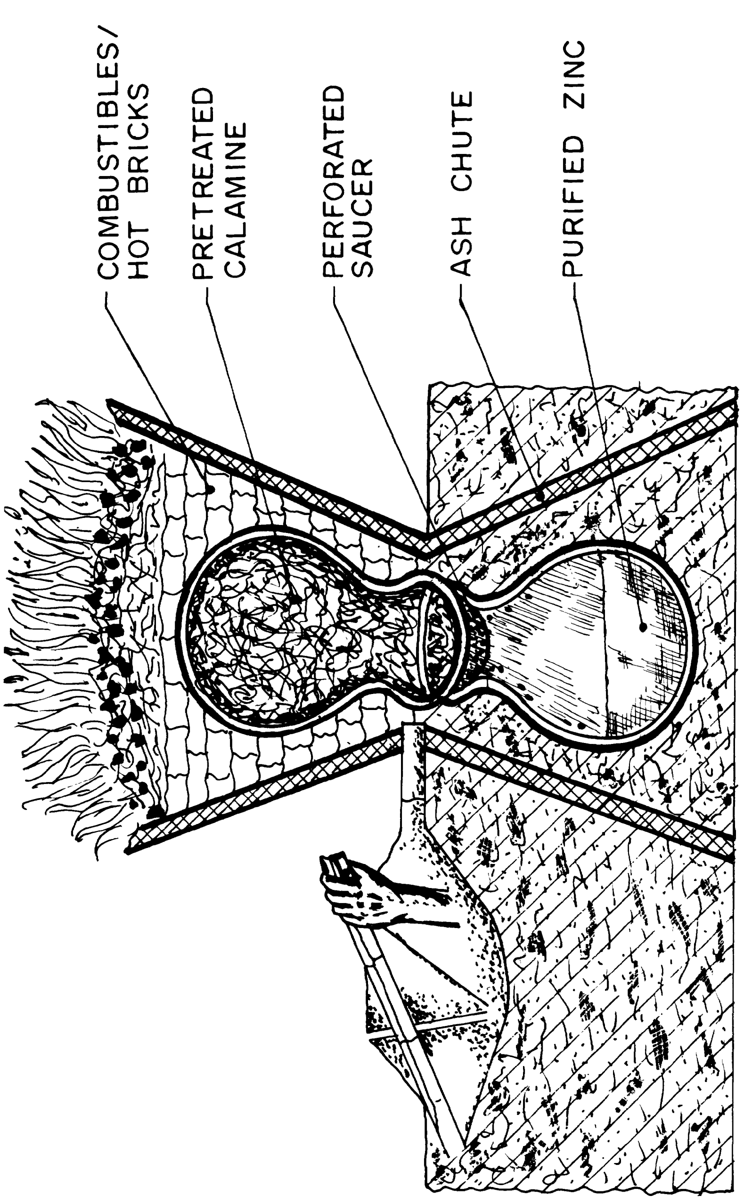
Processing of ferrous and non-ferrous metals

It is now commonly accepted that chemical engineers will have a major role to play in materials engineering. However, India appeared to be fairly advanced in the materials field a few centuries ago. It is a recorded fact that during 1660-1670, India exported to Western Europe nearly 6.5 tons of 'Wootz Steel' in small lumps of unspecified size made by the native crucible process in the Deccan. The famous Damascus Swords were made from this Indian steel, deemed then to be a high technology and an advanced material.

According to Yajurveda (BC 700-300), iron (shyam ayas) was used from 1000 BC, and apparently sara loha (steel) came on the scene around 500 BC.[9] The well known iron pillar at Mehrauli at Delhi, made of a single piece of iron and weighing approximately 6 tons, stands testimony to the metallurgical expertise of medieval era, which could not be matched by even the best iron founders of the west until about 1800 AD. The pillar



VALUKA YANTRAM
MERCURIC COMPOUNDS REACTOR
FIG.4



KOSHTHI APPARATUS (ZINC EXTRACTION UNIT)

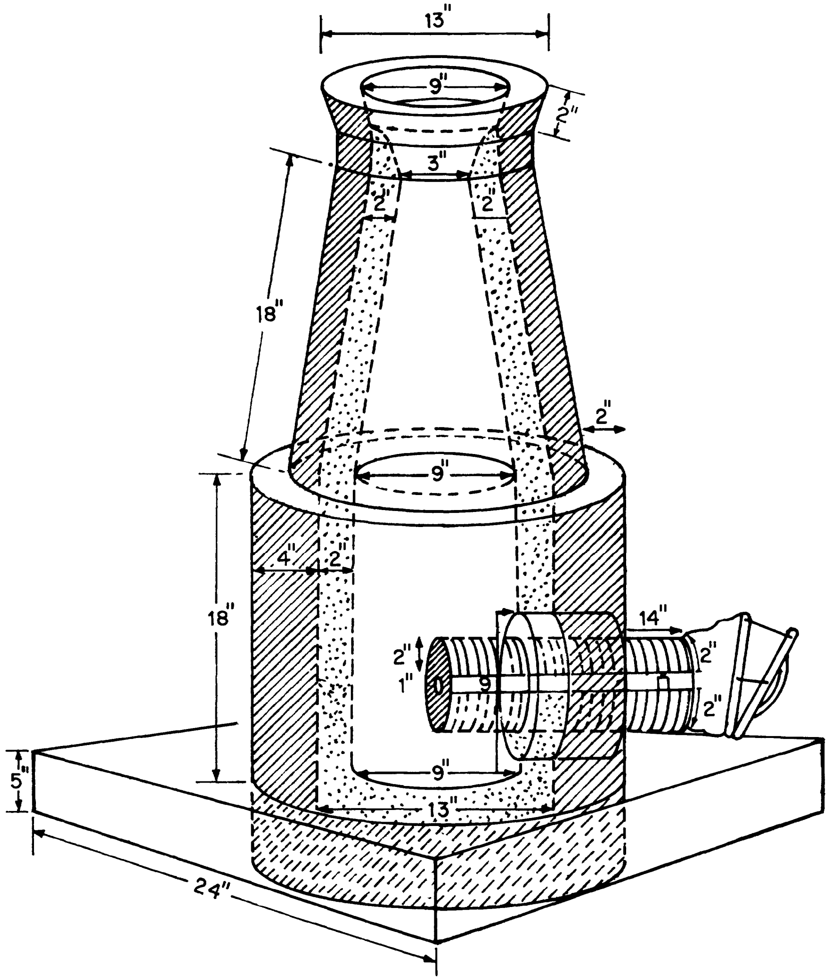
FIG. 5

is chemically pure iron (specific gravity 7.81) consisting of : iron 99.720%, carbon 0.080%, silicon 0.046%, sulphur 0.006%, phosphorus 0.114%, and no manganese. The process of making the pillar might have been the welding together of iron blooms (wrought iron weighing 80 lb each produced in a primitve blast furnace) in successive lumps. Kautilya's Arthsastra (BC 400) contains detailed instructions on iron smelting.[6] A sketch of iron furnace of South India is shown in Fig. 6

The Seraks (lay Jains) were probably the first (300 BC) to have mined and smelted copper. The process in brief was : "crushing and pulverizing copper ore on stone anvil with a heavy hammer, mixing with cow dung to make ore balls and roasting in a primitive blast furnace."[9]

A typical design of a furnace may be of interest. The blast furnace pit located in a circular hut of sand floor was of 12-15 inches in diameter and 2 or 3 inches deep. Pit was coated with a fine sand and ashes to prevent metal adhesion to sides and bottom. Two clay nozzles or tuyeres were placed on opposite sides of this hollow and a third between them. The nozzles were then connected by moist clay, and a circular rim of mud, a few inches in height, was raised, on which three annular vessels of fire clay were placed to form the body of the furnace. Bellows made of goat skins with a nozzle were operated by family members. The charge consisted of roasted ore, charcoal and iron slag to act as flux), which was smelted for 9-10 hours, the slag was then drawn off, and the smelted copper removed later for further refining in an open furnace and casting into bars. Artist's impression of a copper reducing furnace is given in Fig. 7 A schematic of a copper smelter is given in Fig. 8

Zinc smelting activity in India has been traced to 100 BC which continued till the first quarter of the 19th century.[10-11] Archaeological brass finds in Taxila dating back to 400 BC showed on analysis that the alloy was a product of fusion of copper and metallic zinc.[10] Recent excavations at Zawar, Rajasthan, of old sphalerite (zinc sulphide ore) mines revealed, on radiocarbon assay of timber supports found at a depth of 100 meters, that the mining activity went back to BC 120 to AD 30 and the possiblity that it might as well go back



IRON FURNACE OF
SOUTH INDIA

FIG. 6

FIG. 7: COPPER REDUCING FURNACE

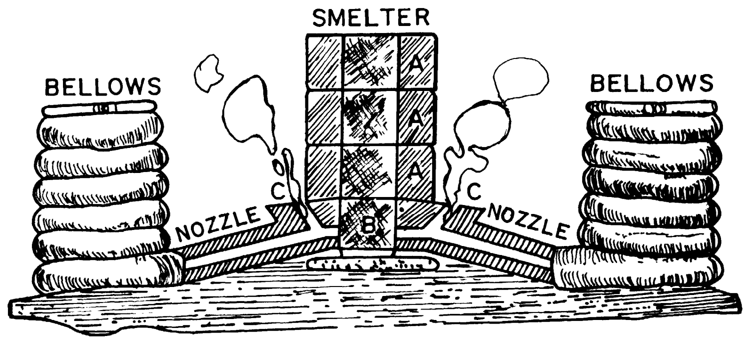


FIG.8: COPPER SMELTER SCHEMAT-KHETRI

A: SMELTER MADE OF THREE SEPARATE ANNULAR PARTS PLACED ONE UPON THE OTHER-EXTERIOR DIAMETER OF EACH PART 15", HEIGHT 9", THICKNESS 3"

B: CHAMBER FOR BURNING CHARCOAL

C: OPENING FOR STOKING FIRE-BEING PLUGGED WITH CLAY AFTER STOKING to 300 BC cannot be discounted. Rasarnava and specifically, Rasaratnasamuchchaya, gives the know-how for zinc extraction in the following words : "Rub calamine with turmeric, the chebulic myrobalans, resin, the salts, soot, borax. Fill the inside of the crucible with the above mixture and dry it in the sun. Close its mouth with a perforated saucer (Khoshti apparatus). A vessel filled with water is embedded in the ground, over which the above vessel charged with the mixture is inverted, which is again heated by means of a charcoal fire. The operation is stopped when the flame issuing from the mass changes from blue to white. The essence of the metal which drops into the water and has the lustre of tin is to be collected." This account when compared with the design of zinc smelter at Zawar brings into focus the evolving phenomenon of technological upgradation.

This furnace (Fig. 9) consists of a "condensation" chamber (65 x 65 x 20 cm) at the bottom and a firing chamber at the top. Zinc vapour is condensed into fine zinc metal powder. The composite perforated terracotta plate made in four equal segments of 35 cm^2 each, 4 cm thick, with a large hole surrounded by smaller perforations, supported on a ledge on three sides of the furnace walls with a solid terracotta pillar is placed at the junction of the four segments. The furnace probably had a curved roof with chimney type of vents, which served the dual purpose of outlet for hot gases and inlet for fuel. The retorts used were small, cylindrical and made of clay, tapered and pointed at one end and luted to a cone shaped clay funnel with a condensation tube at the other end. Absence of sulphur in the spent charge shows that the sphalerite was preroasted at 900-950°C to obtain zinc oxide. Salt was also added (as mentioned in the 14th century Rasaratnasamuchchaya) in the smelting charge to facilitate sintering of dolomite and maintain it within the retorts in a porus open texture as well as to plug the micropores in the thin clay retort wall by the reaction of salt vapours with silica and alumina present. The design of the smelter and processing of zinc ore show not only a mastery on materials and process engineering skill, but also a depth of knowledge in chemistry acquired empirically by the Indians of the bygone era.

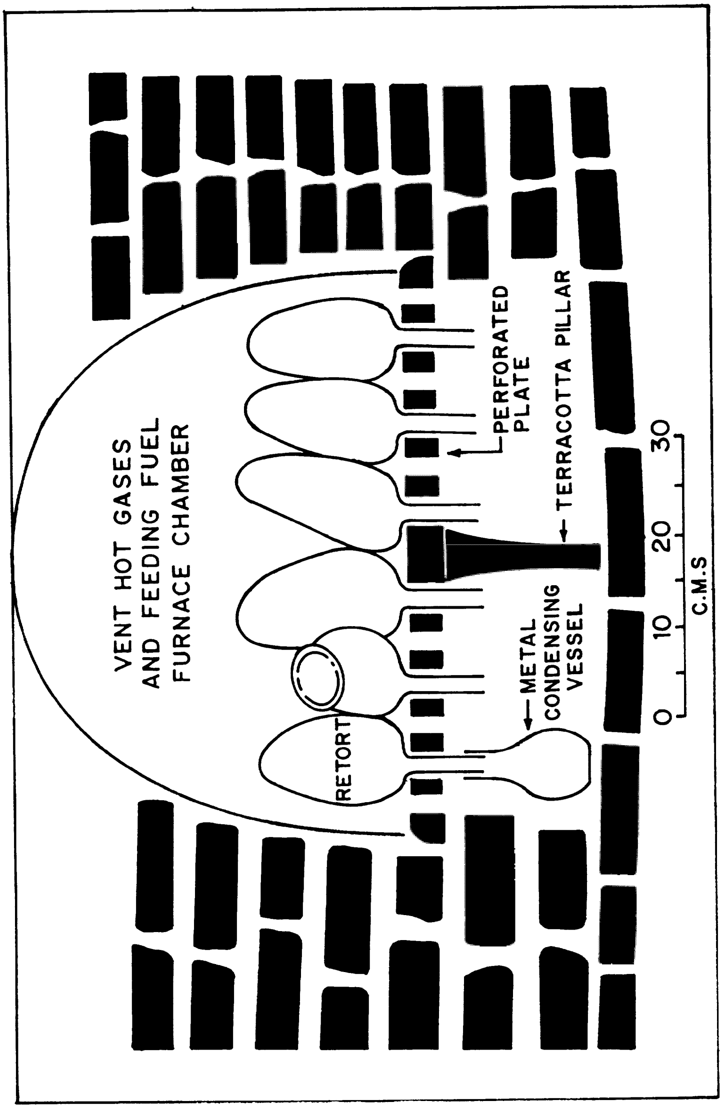


FIG.9: ZINC DISTILLATION FURNACE-ZAWAR CROSS SECTION

5. CHEMICAL ENGINEERING PRACTICE IN MEDICINE

The earliest reference to disease and medicine in the Indian scriptures goes back to the Rigveda (BC 1500) physicians, Asvins, who come closest to the medicine man of many primitive cultures. The next reference appears in the Jaina and Buddhist scriptures which talk of phytal and inorganic chemical cures for human and animal ailments. Buddhist monks and nuns were probably the first (300 BC) to organize hospitals to treat patients. Arthasastra envisages a corps of physicians to care for the war wounded with drugs bandages and other equipment and a staff of veterinarians attached to the military to care for battle horses and elephants. Emperor Ashoka's philanthropic activity included propagation of medicinal plants, founding hospitals for men and animals, and regulation of animal slaughter. Islam brought to India the therapeutic uses of mercury and other metals, opium, and diagnosis through pulse. The Greek classification of materia medica, medicine and healing, was suitably adapted by Indian practitioners.

Charaka (80-180 AD) wrote his monumental Charaka Samhita when he was court physician to Kanishka, but his original work has been lost.[12] Several redactions of the work however exist. The treatise lists medicinal susbtances of animal origin (177), plant origin (341), and mineral origin (64), apart from cereals and legumes, natural waters, sugarcane derivatives and honey, milk and milk products, vegetables, oils, etc. of medicinal value. Susruta Samhita is the work of Susruta (c 350 AD), and the available Samhita is believed to be redacted by the Buddhist monk Vasubhandu.[13] Susruta Samhita is more of a treatise on surgery (hernia, cataract and plastic surgery) than on medicine. Skin graft for a torn ear and rhinoplasty techniques were perfected by Susruta. He has also designed several surgical instruments. The ancients had adopted ingeneous engineering practices in medicine for drying, pulverizing, mixing, steaming, vapourising, condensing, distilling etc. They have designed ingenious equipment having functional flexibility.

6. THE ERA OF TRANSITION

The examples cited in the foregoing testify to the existence of a technologically advanced society in India till about the medieval era. Leading centres of learning at Taxila, Nalanda, Sarnath, Amaravati, Banares, Kanchi, Ujjain, Odantapura, Vikramshila, Somapura and Jagadhala were imparting knowledge in different branches of sciences util they were destroyed by dynastic wars and invasions from abroad. Yet the work culture and craft experience continued to survive with the patronage of the rich or the royalty. The advent of European traders and missionaries, who brought with them the fruits of Renaissance and Industrial Revolution led to a progressive decline of indigenous enterprise and craft innovations in India.

Abatement of dynastic wars and alien invasions, witnessed during the medieval period beginning from about 700 AD, brought forth a reassertion of Indian wisdom in the fields of metaphysics, astronomy and mathematics with a perceptible transition from ritualistic orthodoxy to realistic heterodoxy.[14] The reawakening, however was more philosophical in content and stayed confined to the higher social class orders with little influence or craft technology. The latter depended as ever on the innate skills and inventiveness of the artisans, which flourished without any serious external competitive challenge. Craft engineering practices became more systematized as exemplified by improved processing procedures adopted in the production of sugar, salt, fertilizer, large scale extraction of indigo, paper technology and pyrotechniques. Process schemats relating to the later medieval era (AD 1200-19th century) not only throw light on the continuously evolving craft practices, but provide more depth of detail that was lacking in the aphoristic description of methods and procedures found in ancient literature of the prechristian eras.

7. CHEMICAL PROCESSES OF MEDIEVAL ERA (AD 800-1947) - SOME EXAMPLES

We will give a quick summary of certain chemical processes practised by the ancient Indians to indicate the extent to which they had acquired a mastery over a number of chemical processes and physical operations.

Indigo process[15] : Indigo and fabrics dyed with indigo have been major items of export to Europe and other countries since ancient times. The commercial scale production dates back to AD 1607 following upgradation of craft practices. The details of the process schemat show the skills in liquid and solids handling and designing in the case of Indigo dyes. Mordanting methods and processing procedures for extraction of other natural colours remained more or less similar inspite of the European influence that was creeping in.

Saltpetre (Potassium nitrate) : Salpetre (potassium nitrate) appears in the form of thin white efflorescence on the surface of old mud heaps, mud walls, lanes and walls of villages and towns and other solid waste dumps.[16] In the remote past, ash from wood and/or cow dung and nitrified manure were scattered over the soil to effloresce. Subsequently a number of operations involving leaching, sedimentation, evaporation, crystallization, etc. led to a process for the production of potassium nitrate. Until 1860, India was the monopoly supplier of this chemical to the world.

Sugar (from Saccharum officinarum is one of the earliest agrobased organic chemicals produced in India.[17] Vedic scriptures[18] (BC 1500) mention two liquors made from sugarcane : "Sidhu" from care juice and "gandi" from molasses. The term Saccharum is etymologically related to Sanskrit word Sarkara (sugar). Nearchus (c 325 BC) accompanying Alexander the Great described sugarcane as a honey producing grass without the help of bees.[19]

The Greek and Roman authors (Theophrastus and Paulus Egineta, late 7th century AD) called it "honey which comes from bamboo" and as "Indian salt". The processing of cane to make sugar in the past involved manual and/or animal power, the operations consisting of washing, crushing, filtering, boiling, clarifying and crystallizing. The equipment used were simple viz. stone or wooden mortars or iron rollers for crushing, open mud pots/pans for boiling, cloth lined conical bamboo cane baskets for juice clarification and open pans for crystallization.

Salt processing : Salt is known since prevedic times and is certainly as ancient as human civilization. Susruta mentions four kinds of salts which correspond to rock salt, sea salt, lake salt and earth salt. Arthsastra gives an outline of salt manufacture which was supervised by "Lavanadhyaksa". Alexander is reported to have noticed Indian mountains containing salt. Abandoned rock salt mines of ancient vintage exist even now. Salt was obtained by lixiviating salt earth or pulverized salt rock. The operations involved included outcrop mining, pulverizing, hydrolysis, filtration and crystallization. Effluent was separated for alternative uses as manure and asphalt. Solar evaporation of brine of natural springs was done in large masonry evaporation pans. Salt has also been produced by boiling the mother liquor left after the removal of saltpetre (KNO_3) crystals. Solar evaporation was more common in the case of sea water or sub soil brine.

The examples cited in the foregoing pertaining to the chemical area are typical of the all-round advancement of craft innovations in other fields of enterprise as well, viz. metallurgy, production of machine tools and hand tools, painting and sculpture, architecture, wood engineering, jewellery and so on. Indeed Indian artisans had by the middle ages, developed a copious formulary in pyrotechniques for over a score of fire works. By 11th century AD, paper technology was well developed, although the ancient art of paper making stood its ground for quite some time. Jaina scriptures (BC 500) speak of "Kagad" or "Kadgal" referring to paper.[20] According to Nearchus (BC 325), Indians made paper by beating cotton fabrics. Megasthenes (BC 311-306) reports that paper has been in use for writing horoscopes and almanacs. The ancient art of paper production travelled along with Buddhist missionaries to the East and West and returned to India around AD 1000. Thus, to a large extent, craft expertise and quality helped to mitigate and successfully hold out against the power-driven technology push of Europe till about the beginning of 18th century, when the Europeans began to acquire decisive political and administrative control over the social and economic affairs of Indians.

8. THE GREAT DECLINE

India had her golden eras right from the classical age extending till about 12th-15th century AD. Later the creative contributions of Indians regressed essentially because of endogenous social contraints like caste system, lack of collaborative integration among productive classes - among the artisans, craftsmen and the literate sections - rigid class-conscious professionalism, the proverbially weak status, both economically and socially, of the artisans and craftsmen in the social milieu and the progressive drying up of patronage of the royalty or rich enterpreneurs, including wealthy merchants and traders . The scientist philosophers were more concerned with their metaphysical commentaries and the craftsmen and artisans became almost destitutes, slowly getting devalued in the social structure. Their creative spirit could not be sustained and it was not long before decadence reared its head. India could have drawn inspiration from the renascent Europe or from the developments leading to Industrial Revolution to arrest the slide, but the philosophic thinkers (scientists) and innovators let events overtake them till the Europeans introduced western science, engineering and technology in India[21]. In addition there were exogenous compulsions that came into play with the advent of foreigners, starting intially with the Portugese and then the Dutch and the British, who made secure their political supremacy by 1767. Britain mainly wanted to maintain the momentum of Industrial Revolution, use basic raw materials for its industry and ensure a protected market for the British industry. This had an obvious impact on the indigenous innovative expertise and the growth of craft inventions. During this period however, an educational infrastructure was built. The task of tracing the developments of chemical engineering in India will not be complete unless a brief reference is made to the preindependent status of general education, science and technology. This will enable us to establish a clear relationship with the evolution of chemical engineering studies in the earlier decades of the twentieth century.

9. STATUS OF EDUCATION - 1547-1947 AND AFTER

European naturalists, doctors, engineers and technicians also migrated to India along with the trading enterprises. The 17th and 18th centuries saw visits of jesuits and other missionaries, who propagated, alongside religion, their learnings in European astronomy, mathematics, geography, natural history and life sciences.

9.1 Science Studies

Garcia de Orta (1479-1570), the earliest Portugese physician-botanist to settle down in Goa, wrote a monograh in 1565 on the local plants and fruits entitled "Colloquies dos Simples e drogos de Cousas medicinais da India". The European employees of trading companies and missionaries were responsible for some of the major studies of Indian flora and fauna, mineral resources, geographic (cartographic) and climatic characteristics.

An outstanding event of scientific significance, again engineered by European intellectuals in India, is the founding of a learned society - the "Asiatick Society" on January 15, 1784, under the Presidentship of Robert Charles, Second Judge of Supreme Court. The Society[21] was later called "The Asiatic Society of Bengal" and rechristened in 1936 as "The Royal Asiatic Society of Bengal".

In 1829 a few Indians were also elected to the membership of the Society. The investigations of the members in different branches of natural history of India resulted in the accumulation of materials, curios, coins, plant specimen, minerals that called for the establishment of a museum in 1814, which received statutory recognition in 1866. Then came the organisation of several other learned societies and institutions to nurture and consolidate the growing interest in matters concerning science and technology[22]. (See table(1) for details)

Education at schools, colleges and universities and scientific investigations by the members of the learned societies were proceeding side by side from the late 18th century. India also derived the benefit of the scientific and technologicl activities of the then leading nations in Europe, viz. France and Germany through Britain by virtue of the direct economic, political and educational ties, which India had with the latter. While the common Indians remained untouched by these

TABLE 1

ESTABLISHMENT OF LEARNED SOCIETIES AND INSTITUTIONS - SOME LANDMARKS (1784-1947)

Asiatick Society at Calcutta	1784
Indian Museum, Calcutta	1814-1866
Society for Promotion of Education (Bombay, Surat, Thana and Broach)	1815
Indian Association for the Cultivation of Science, Calcutta	1876
Imperial Forest School, Dehra Dun	1878-81
Imperial Agricultural Research Institute	1903
National Council of Education, Calcutta	1906
Society for the Promotion of Technical Education in Bengal	1906
Indian Research Fund Association for Medical Research	1911
Indian Institute of Science, Bangalore	1911
Indian Science Congress Association, Calcutta (First Session)	1914
Institution of Engineers (Received Royal Charter in 1935)	1920
Council of Scientific and Industrial Research, New Delhi	1942

happenings around, Indian intellectuals were progressively drawn into the mainstream of scientific studies relating to natural sciences, physical sciences and mathematics. During the whole of 19th century and a slightly more than the first quarter of 20th century, trends on the impact of modern science and technology in India were discernible. The first few decades, particularly of 20th century, saw renewed efforts in building up a sound infrastructure for teaching and research in modern science. This brief discussion on science studies and general education up to the early 20th century overtly skirts the topic on developments in engineering education and practices and more specifically, chemical engineering, to which we shall now revert.

9.2 Engineering Education-General

The British government had taken up during the later half of the 19th century a variety of engineering investigations connected with hydrology, navigation, construction of bridges, canal works, locks, regulators and devices needed in dam systems, construction of light houses, water supply and drainage. Both the civil and military requirements for trained engineering manpower could not be fully met through importation of expertise from Britain. The rulers had few options but to involve the "natives" and impart necessary training and education. The 1888 Government Resolution explicitly recognized the importance of technical education for training adequate number of technicians for industrial employment. Government's policy encouraged employment of foreign technicians even in well developed industries like cotton, jute and coal, there had been other pressures, like the Swadeshi Movement of Bengal, the parallel developments in the fields of general education which augmented the availability of literate Indians who could manage ad hoc engineering innovations under Indian conditions and the Educational Code and Universities Act of Lord Cruzon in 1940 which gave the much needed unitary and centralized character to the system of education - all of which have helped the spread of engineering education among Indians. Lord Curzon firmly believed not only in the education of many, but also in the co-ordination of technical education with industrial development. He also visualized that qualified Indian engineers and technical men would in time replace the Europeans in Indian industry. Much before the enactment of Curzon's code, however, there were in existence several schools, colleges, and industrial technical institutions imparting engineering knowledge and training in industrial techniques. A list of the engineering and technical institutions (1794-1946) is given in table 2. Many of these institutions offered licentiatship till 1880, and later also conducted degree courses.

10. CHEMICAL ENGINEERING IN PREINDEPENDENT INDIA - THE BEGINNING

The origin of chemical engineering in European countries may have been shrouded in mystery. But it is not so in the case of India, because we do not have to speculate on the point of time or the causative factors that transformed craft empiricism into concepts of engineering precision. The continuity that we could trace in Europe on the transition from empricial practices to the puristic ideals of Renaissance may not be evident in the case of India, because these developments bypassed the countries of the orient. When the fruits of science came to India, they were harbingers of colonial domination; to buttress its economic and political ambitions and to effectively asphyxiate the already declining empirical expertise. What India received from Europe in the sphere of education, science, technology and enterprise during the 18th and 19th centuries were mere transplantations of advances achieved abroad. The schools, colleges, universities, industrial training schools and technical institutes were replicates of foreign institutions. Thus the evolution of chemical engineering in India in the early decades of 20th century followed the British or other foreign patterns of education.

Earlier we had referred to Lord Curzon's Educational Code and Universities Act. it was also Curzon unintentionally though, who had triggered the developments that ultimately fashioned the chemical engineering studies in India. His act of partitioning Bengal led to an intensification of Swadeshi movement in Bengal[23]. The leading intellectuals of the day constituted the National Council of Education on 11 March, 1906 and organised the Bengal National School and College (BNC)

TABLE 2

ENGINEERING SCHOOLS, COLLEGES AND INDUSTRIAL TECHNICAL INSTITUTES (1794-1946)

Survey School, Madras - Taught and trained apprentices; course duration 1½ years - Subjects : algebra, mensuration, building construction, surveying, plane drawings, etc.	1794
Engineering Institution in Bombay by Elphinstone	1821
Madras Industrial School of Ordnance Artifices	1840
Roorkee Engineering College (affiliated in 1864 to Calcutta University)	1847-1853
School of Industrial Arts at Madras, started by Hunter	1850
School of Industry, Madras, Organized by Hunter	1851
Engineering School at Poona - To educate subordinate officers in PWD; became a College in 1856 affiliated to Bombay University.	1854
College of Engineering in Madras - affiliated in 1877 to Madras University. Emerged since 1880 as one of the best engineering institutions in the country	1855-1859
Engineering College at Calcutta - Affiliated to Calcutta University; in 1880 shifted to Sibpur - conducted courses in Civil Engineering	1856
Imperial Forest School, Dehra Dun	1878-1881
School of Industry at Ratnagiri and at Byculla in Bombay Presidency	1879
Survey School at Calcutta	1879

Victoria Jubilee Technical Institute, Bombay with courses in electrical, mechanical and textile engineering	1887
Industrial Schools at Gorakhpur and Banaras	....
School of Engineering at Bankipur, Bihar	1896
Bengal Technical Institute founded by Sir Tarak Nath Palit	1906

on 8 August 1906 to impart literary, scientific and technical education to Indians on national lines and under national control. The Bengal Technical Institute (BTI) was founded to fulfil similar objectives by Palit on 25 July 1906. Popular enthusiasm of nationalism in education, however, did not last long and both BNC and BTI were amalgamated in 1910. The BTI conducted primary and secondary courses of 3 and 3½ years duration. Subjects of study at the primary level were : arithmetic, algebra, geometry, physics, chemistry, elements of drawing, English and practical training in mechanical and electrical fitting, carpentry, drawing and surveying. Courses taught at the secondary stage included mechanical engineering, electrical engineering, industrial chemistry, etc. besides courses in mathematics, physics, chemistry and English. Secondary course became of 4 years duration from 1911. In the same year was set up in the distant Bangalore another institution for science, technology and engineering studies - the Indian Institute of Science. At the BTI, the study content of industrial chemistry was revised by an expert committee and, after approval of Acharya Profulla Chandra Roy in 1921, this section metamorphasised into "Chemical Engineering". India thus appears to have stolen a march over Britain in formalizing the study of "chemical engineering" at a higher level some 25 years before the Department of Petroleum Engineering in Birmingham University was named as the Department of "Chemical Engineering" in 1946. The Battersea Polytechnic (now the University of Surrey) however was conducting a course as early as 1914 on "chemical engineering" dealing more explicitly with unit operations than detailed in Davis' Handbook published in 1901.[24]

The early christening of chemical engineering in India was probably due to American influence, because the Professor in charge of the department at BTI, Hira Lal Roy, had his degree in chemistry from Harvard in 1913 and the degree of Dr. Ing in 1923 from Germany. His associate, Baneshwar Das, had his B.S. in Chemical Engineering from Illinois. Thus the progenitors of chemical engineering in India were foreign trained. This foreign legacy has somehow remained a continuing phenomenon in all spheres of chemical engineering activity, whether they be educational or industry or even research (with some isolated exceptions). In 1924 BTI came to Jadavpur campus and was renamed as the College of Engineering and Technology in 1928.[23] BTI has been the predecessor of Jadavpur University and the forerunner of a number of other technical schools, university faculties and departments and research laboratories that came on the scene prior to Independence. These institutions also, in due course, had organized courses of study or undertaken research problems in chemical engineering topics of special relevance to the Indian conditions.

In table 3 we have provided a list of Institutions that offered courses of study in applied and industrial chemistry as well as chemical engineering in preindependent India.

The history of faculty development and course content of chemical engineering offered by institutions provide a fascinating study. For instance, discovery of mineral oil and petroleum refining gave a big boost to unit operations in US. Olaf Hougen, in his Bicentennial Lecture on Chemical Engineering History, admirably captures the decisive push from the emerging US Chemical Industry that influenced the changing pattern of course studies.[25] The conceptual basis of Davis analysis of British chemical process industry gained acceptance and the University Birmingham started a degree course in mining in 1907 and the syllabus of 1910-11 included unit operations like crushing, conveying, pumping, hydraulic separations, fluid flow, and so on. Thermodynamics, material and energy balances, reaction kinetics, etc. became newer fields of study during 1920-30 when continuous operation of chemical processes gained in importance. Chemical engineering is thus a product of industry, born to subserve industrial needs. It has "no reason for existence at all except in relation to industry."

The Indian situtation is in sharp contrast to the above picture. The beginning of chemical engineering has to be traced to a handful of intellectuals who visualised its importance in the context of an independent and economically strong India in the not too distant future. They had before them the examples of France, Germany, and US which had become technologically stronger and possessed a distinct edge over Britain in terms of chemical output. Technical courses in India were modelled on the lines of Germany, UK and the US and the text books for the subjects of study were also of foreign origin. The

TABLE 3

INSTITUTIONS OFFERING COURSES OF STUDY IN APPLIED CHEMISTRY/INDUSTRIAL CHEMISTRY/CHEMICAL ENGINEERING IN PREINDEPENDENT INDIA

Bengal Technical Institute (shifted to Jadavpur in 1924 and renamed as College of Engineeering and Technology, Bengal in 1928 (Jadavpur College); statutory recognition received in 1955	1906
Indian Institute of Science, Bangalore (started with General Chemistry, Applied Chemistry and Electrical Technology)	1909-1911
Harcourt Butler Technological Institute (HBTI), Kanpur started as a college of Oil Technology and a few other subjects	1920
Royal Institute of Science - Formally opened in 1924 and renamed as Institute of Science in 1950	1920-1924
Department of Chemical Technology, Bombay University (started with textile chemistry and chemical engineering)	1934
Andhra University College of Engineering, Waltair - Studies on chemical engineering initiated in 1945 "as specialization" at M.Sc. level	1933
Imperial Institute of Sugar Technology, Kanpur (formed by taking over the Sugar technology section of HBTI, Kanpur; name changed to Indian Institute of Sugar Technology after 1947 and renamed as National Sugar Institute)	1936
Drug Research Laboratory, established by Jammu & Kashmir State; taken over by CSIR in 1957 and renamed as Regional Research Laboratory, Jammu	1941

Lakshminarayan Institute of Technology, Nagpur (to impart training in B.Tech. (Chem. Engg.), M.Tech. in chemical engineering and chemical technology and B.Sc. (Tech) in oil technology	1942
A.C. College of Technology, Madras	1944
Central Laboratories for Scientific and Industrial Research, Hyderabad (Taken over by CSIR in 1956 and renamed as Regional Research Laboratory, Hyderabad)	1944
Bengal Immunity Research Institute, (Chemical Engineering as relevant to drugs and pharmaceutical research)	1947

course content of chemical engineering faculties in India closely followed their contemporaries abroad.

BTI's Chemical Engineering course at the time of introduction included mathematics, physics, chemistry, history and economics, drawing and workshop, mechanics, electrical engineering, heat engines and metallurgy, fuels, qualitative and quantitative analysis, industrial chemistry, chemical engineering unit operations, technology of oils and fats and soap technology. Courses were under constant review and changes introduced ostensibly to maintain parity with international trends but also to serve other requirements such as broad basing course content, meeting the recommendations of academic and professional expert committees, University Grants Commission and other Government agencies.

Progressive developments continued to occur. Thus a four year diploma in chemical engineering for matriculates (1921), five year course (1930), four year course with admission limited to Inter Science students (1941), master's degree chemical engineering course (1951), five year degree course open to higher secondary students with pass marks in science (1961), Ph.D. in engineering (1966) and a four year course open to students who had done ten years of secondary and two years of higher secondary school (1968) were some of the important landmarks.

In more specific terms, in BTI, the mid-forties saw the introduction of subjects like, strength of materials, industrial and chemical engineering calculations and design engineering. The 1950 modification of courses included : thermodynamics, unit operations, applied kinetics and electives like food technology along with technology of oils and fats. The seventies witnessed the introduction of process instrumentation and control, chemical plant design and project engineering and the withdrawal of electives viz. technology of food, oils and fat which were merged with Industrial Chemistry/Chemical Technology. More stress was laid on applied kinetics, reactor design and electrochemistry. Post graduate diploma course in polymer engineering and furnace technology was introduced. During the eighties, the courses were again modified with the introduction of chemical engineering, mathematics, numerical analysis, computer programming, etc. The contents of the unit operation course were revised and segmented into fluid mechanics, heat transfer, separation processes and mechanical operations.

The Department of Chemical Technology of the Bombay University (BUDCT), which came into being in 1934 had a full fledged chemical engineering section, but the main attraction to the students then was textile chemistry because of immediate career opportunities in Bombay. Efforts of pioneers like GP Kane in the early years had helped the Chemical Engineering Section of BUDCT to get over a variety of teething problems in its faculty development programmes in different branches of chemical technology. The chemical engineering section at University Department of Chemical Technology has continued to modernise the courses in keeping with the modern trends and developments in chemical engineering and technology. It is instructive to see the way the courses had undergone changes over the years keeping in tune with the demands of the industry.[26] Table 4 gives the chronological development of courses at the Department of Chemical Technology.

Andhra University College of Engineering established in 1933 offered graduate and post graduate courses in sugar technology and chemical technology with electives such as pharmacy, electrochemical technology, petroleum refinery engineering and chemical engineering. The chronological development of activities at this institute is shown in table 5.

The famous Indian Institute of Science, Bangalore is primarily a research institute today. It started offering courses leading to various degrees at different points of time for various reasons; the research bias, however, continues. The courses in Chemical Engineering had their beginnings in what was known then as the Department of General Chemistry. The motivating reason was to meet the man-power requirements of the growing chemical industry as well as to contribute towards the war effort. The emphasis at this stage, however, was still on research. Thus a student, working for the research conferment of the Associate of Indian Institute of Science (A.I.I.Sc.) would, after satisfying the requirements for this degree, get the Diploma of Indian Institute of Science (D.I.I.Sc.) also for the successful completion of course work in Chemical Engineering. In other words, initially only a package of D.I.I.Sc. - A.I.I.Sc. could be obtained by the student.

TABLE 4

DEVELOPMENT OF COURSES IN CHEMICAL ENGINEERING AND TECHNOLOGY, BOMBAY UNIVERSITY, DEPARTMENT OF CHEMICAL TECHNOLOGY.

1934	Two years Post B.Sc. courses : B.Sc. (Tech) course in Textile Chemistry and Chemical Engineering
1943	B.Sc. (Tech) courses in other branches : Pharmaceuticals and fine chemicals; foods & drugs; intermediates and dyes; oils, fats and waxes; plastics paints and varnishes
1948	B.Sc.(Tech) Technology of Plastics and B.Sc.(Tech) Technology of paints and pigments and varnishes instead of B.Sc.(Tech) technology of plastics, paints, varnishes
1949	B.Sc.(Tech) in chemistry of food drugs redesignated as technology of foods
1951	B.Chem.Engg. - Four year post inter science course replaces B.Sc. (Tech) in chemical engineering in line with the changing pattern of CE course in the country.
1958	B.Pharm - Three years post - inter science course introduced
1964	Centre of advanced study in textile fibres and dyes, which was renamed as Centre of advanced study in applied chemistry in 1965
1965	M.Pharm. & Ph.D. courses introduced
1965	Three year B.Sc.(Tech) course replaces two year B.Sc.(Tech) course in line with changing trends in academic circles
1966	Two year M.Sc.(Tech) partly by papers and partly by research replaces M.Sc.(Tech) course by research only

TABLE 5

DEVELOPMENT OF COURSES IN CHEMICAL ENGINEERING AND TECHNOLOGY (ANDHRA UNIVERSITY COLLEGE OF ENGINEERING - DEPARTMENT OF CHEMICAL ENGINEERING)

1933	B.Sc. (Hons.) Sugar Technology
1933	D.Sc. by research; changed to Ph.D. from 1969
1935	M.Sc. by research
1938	B.Sc. (Hons.) Chemical technology (electives: sugar technology, pharmacy, electrochemical technology, petroleum refinery engineering)
1939	M.Sc. (Sugar Technology)
1945	M.Sc. (Sugar technology, electrochemical technology, chemical engineering)
1951	B.Sc. (Hons.) Pharmacy
1954	M.Sc. (Ore dressing), changed to M.Tech. (Mineral process engineering) from 1983 onwards
1958	B.Tech. (chemical engineering with different electives)
1962	M.Sc.(Tech.) chemical engineering - four semester with different electives
1969	Ph.D. by research and D.Sc. reserved for post-doctoral research
1983	M.Tech. Three semesters with specialization in chemical reaction engineering, corrosion engineering, electrochemical engineering, energy engineering, mineral process engineering, petroleum refinery engineering, process dynamics and control

In 1951, the Chemical Engineering Section got a separate status as the Department of Chemical Technology and Chemical Engineering. At this time, D.I.I.Sc. and A.I.I.Sc. were separated and the students could obtain the two degrees independently. The D.I.I.Sc. degree was conferred after successful completion of two years' of course work. The postgraduate nature of the Institute was maintained by requiring a B.Sc. degree as admission criteria. The A.I.I.Sc. continued to be a research conferment. The separation was carried out in view of the fact that under the prevailing conditions the man-power then required by the Indian industry did not need any training for conducting research.

As Chemical Engineering courses were started in many Indian universities in the fifties, the D.I.I.Sc. in Chemical Engineering was stopped in 1959 in keeping with the Institute's policy of concentrating on research and teaching at higher (post graduate) level. The changes in syllabus for D.I.I.Sc. during the period 1943 to 1959 did not follow any set pattern. Deletions and additions were being carried out almost every year, the primary motivation being the desire to include various facets of the rapidly growing discipline. In 1959 the Institute changed the names of the degrees from D.I.I.Sc. to B.E. and A.I.I.Sc. to M.Sc. (Engg.)

Harcourt Butler Technological Institute (H.B.T.I.) at Kanpur was set up in 1921 on the recommendation of Holland Industrial Commission of 1907 which inter alia recommended that an institution for technological training research and advice be set up at Kanpur. Ever since its foundation in 1921 these have been the three primary objectives of H.B.T.I. The development of chemical engineering at HBTI was closely linked towards technology.

In the early stages this institution imparted training in oil and paints, leather and sugar technology. However, a separate institution for leather was now developed into a full fledged Leather Institute. Sugar technology was separated around 1937 and given over to the Imperial Council of Agricultural Research and this has now developed into National Sugar Institute which is the only major Institution of its kind in the country.

While all the Technological courses run by HBTI had chemical engineering and other engineering input appropriate to the times, a formal course in chemical engineering was started only in 1954 as a post B.Sc. two year diploma course i.e. A.H.B.T.I. in Chemical Engineering. This developed into a four year B.Sc. (Chemical Engineering) degree course from 1958. In 1964 five post B.Sc. three year undergraduate Chemical Technology courses in Biochemical Engineering, Food Technology, Oil Technology, Paints Technology and Plastics Technology were started. Introduction of these undergraduate courses has had considerable impact on the structure and organisation of Chemical Engineering course.

In the fifties a number of Institutes named as Indian Institute of Technology (IIT) were established in different parts of the country of which the first was IIT, Kharagpur. IIT, Bombay was established in 1958 and had a B.Tech. course of five year duration with 10 semesters. Subsequently emphasis on continuous evaluation on semester based instruction, emphasis on tutorials, seminars etc. was introduced. IIT, Kanpur was established in 1959 and the academic programme commenced in 1960 in the temporary shelter provided by HBTI. For a decade (1962-72) IIT, Kanpur had an educational collaborative programme with a consortium of nine US Universities, which helped to implant the US educational culture of engineering science at Kanpur. Similar collaborations existed between IIT (Delhi) and UK, IIT (Madras) and West Germany, etc.

Several institutions devoted to chemical engineering studies that came into existence prior to 1947 were offering courses and training in different branches of chemical technology involving considerable chemical engineering inputs. Faculty improvement and course content changes were common features in all these institutions as well. It is not our intention to give case-by-case study of each institution and the brief resume on a few selected centres of chemical engineering learning from four different regions of India typify the overall situation of chemical engineering education in the preindependent India. These changes were influenced considerably by the changing demands of the profession and society.

A striking feature of the data on faculty development, especially during the preindependent period, is the large variety in respect of course duration, minimum qualification for admission (e.g. matriculation, I.Sc. or B.Sc.) and different nomenclature for degrees for similar courses. Chemical Engineering was offered as a subject of study in some institutions as a constituent of degree courses in applied chemistry; or 2-year post-B.Sc. course; or a 3 or 4-years of study after intermediate science; or a 5-year course after matriculation. Nomenclature of degrees too varied viz. B.Sc. (Industrial Chemistry), M.Sc. (Applied Chemistry), B.Sc. (Hons.) Tech., B.Tech., B.Sc. (Tech.), B.Chem.Eng. and so on. To impart uniformity in course content and duration and to secure an easily identifiable nomenclature for the degrees to be awarded to chemical engineering graduates, the All-India Council of Technical Education (AICTE) in the late forties proposed a model 4 year course after Inter Science for the first degree in chemical engineering. Government financial support to existing and new institutions was made contingent upon their acceptance of the model syllabus both in respect of duration and general content without in any way infringing upon the autonomy of the universities and equivalent institutions to frame their own courses of study. This proposal was accepted and in course of time a uniform pattern emerged.

11. DEVELOPMENTS IN CHEMICAL ENGINEERING - POST - INDEPENDENT INDIA 1947-1987

Although chemical engineering education in India is quite old, the real development of chemical engineering science took place in sixties and onwards. This can be analysed along three distinct lines: academic chemical engineering as taught and investigated in educational institutions; chemical engineering research as carried out at higher centres of learning and chemical engineering as practised or used by the chemical industry. These developments proceeded almost on mutually exclusive dimensions with minimal convergence or interaction; the sole exception being the basic education serving as the feeder of manpower for chemical engineering research and chemical industry. The reasons were obvious. Educational curricula, research and industry in India evolved to a large extent as a consequence of transplantation, with appropriate modifications, of advances taking place elsewhere in these fields and the interfacial demarcation is more real than apparent.

Now for a minor digression. Prior to 1947 the outturn of chemical engineering graduates was about 180, but not all of them could find job satisfaction or remunerative careers, because the broad range of industries requiring their professional services had not come into existence in India. The second World War indirectly helped some of the preindependent chemical engineering institutions like Department of Chemical Technology of University of Bombay to establish and consolidate collaborative work with industry, but such instances were rare till the late seventies. Yet another offshoot of the war was that Britain had perforce to encourage small scale production facilities for military stores, chemicals, explosives, etc. in India. With the escalation of war to the Far East in 1941 and the consequent blocking of seaways due to enemy action more production units for chemical and allied products had to be established. The chemical engineers found opportunities to improvise and develop processes for chemicals and chemical engineering education received a fresh boost. After independence and for a decade thereafter industrial progress was gradual but gathered momentum in the late sixties that gave justification for enhanced acceleration of facilities for chemical engineering education.

12. POSTGRADUATE EDUCATION IN CHEMICAL ENGINEERING

During the quarter century preceding independence (1922-1947), modest number of academic institutions imparting teaching and training in applied chemistry, chemical technology and chemical engineering at the first degree and post graduate levels came into existence. In the overall scheme of chemical engineering education, chemical technology has to remain an integral component because of the economic imperatives of certain process technologies. This did happen as is evident from sugar technology in different parts of India, technology of dyes in the western region, edible oil technology of the south or technology of coal in the East. In fact the growth of petrochemical industry in and around Baroda in the state of Gujarat prompted the M.S. University of Baroda to organise undergraduate and postgraduate chemical engineering courses in petrochemicals and polymer technology from 1963.

The chemical engineering education in India continued to undergo progressive changes both in content and areas of emphasis. From courses in industrial chemistry to start with, it had progressed on to unit operations and in course of time became broadbased to include material and energy balances, thermodynamics and process control, applied reaction kinetics and process design, transport phenomena, process dynamics, process engineering, computer applications as well as interdisciplinary study areas like biotechnology, energy engineering, environment, materials and management. These changes in the syllabus of study occurred over a period of time and after a good deal of deliberations by various expert committees.

The rationale for the development of graduate curricula flowed from the nature of chemical engineering discipline in which the "four rate processes of heat, mass and momentum transfer and of chemical change were combined with conservation equations and the laws of thermodynamics to provide an understanding of the phenomena taking place in process equipment and process plant (analysis), which formed the basis for dimensioning of equipment and plant (synthesis) in a way that yielded competitive products under safe conditions without harming the environment (engineering)". Reference was already made to the subjects of study for undergraduate CE course and the efforts of the All-India Council on Technical Education to bring some uniformity in course content and duration. In 1978 two centres were established - one each at Indian Institute of Technology and University of Roorkee - to develop chemical engineering curriculum. Recommendations of both the groups, which combined the considered opinions of persons from the areas of teaching, research and industry were debated in detail and a consensus evolved. The Ministry of Education and Culture in 1981 published the model curriculum and its frame work for the first degree course in chemical engineering comprises eight semesters. From this the first two are common to all branches of engineering. The curriculum consists of two courses in physics, one in chemistry and four in mathematics as core subjects of study for all engineers, plus two additional courses in chemistry for chemical engineers.

A number of postgraduate studies essentially aimed at advancing the chemical engineering knowledge beyond the undergraduate study or specialisation in some specific areas have been coming up in India and they have been carefully scrutinised over the years. The first formal M.Tech. course was offered by Indian Institute of Technology, Kharagpur, which was the first among the five IITs established in India. A standing committee called Postgraduate Development Committee was appointed in 1953 by the AICTE to frame postgraduate courses and research in technical institutions. This was followed in 1959 by another committee under the chairmanship of Professor M.S. Thacker, which made a comprehensive study of postgraduate engineering education. A number of recommendations were made in 1961. Some salient features were as follows : 1) two types of postgraduate courses - a postgraduate diploma course of one year duration of immediate relevance to industry, e.g. combustion technology, furnace technology, cellulose technology etc. and a two-year Masters degree course could be offered (2) course content should include, inter alia, mathematical studies; materials science and technology and instrumentation; (3) project work could be research-oriented or design-oriented; (4) Masters degree should be a must for doing Ph.D. in engineering; and (5) in certain specific fields, M.E./M.Tech. courses may be made available to Masters degree holders in the appropriate branches of science. These recommendations greatly influenced the growth and development of postgraduate education since 1961. The 1971 review of postgraduate programmes of study and research by Professor Chandrakant ensured closer collaboration amongst academic institutions, industry and the laboratories of Council of Scientific and Industrial Research.

The Nayudamma Committee reviewed the progress made in postgraduate education and research in engineering and technology in 1978. The major recommendations of this review were : (1) M.Tech./M.E. programmes should be of two year duration having three semesters - two of course work in the first year and one of dissertation and viva in the second year; (2) holding an All-India Graduate Aptitude Test in Engineering twice a year to ensure selection of only meritorious and motivated students; (3) courses of study should ensure participation of industry, be need-based and of national relevance; (4) curriculum should have 30-50% core area subjects; 50-70% optional area subjects, and dissertation should be on live problems and/or emerging areas; and (5) project/dissertation work should preferably be joint projects with industry. The Committee also recommended encouragement of sponsorship of candidates by industry and government organizations; tax rebates to industry on contributions to postgraduate education and research in engineering and technology; monitoring of academic research at all levels as to their socioeconomic relevance; and efforts to inculcate the culture of sponsored research at engineering faculties. The three semester course has been implemented from 1983. The structure for the curricula and syllabi for the first degree and postgraduate courses have been reviewed and reformed periodically at the national level with a view to building up a technical manpower pool that can feed the growing needs of the industry, teaching and research. However there have been concerns expressed from time to time pointing to a certain mismatch in the mix of skills and degree of specialization required to subserve the Indian developmental needs. Further the educational infrastructure already created has also not been fully utilized. The average outturn of M.Techs in chemical engineering is only 50-60% of the intake capacity of postgraduate institutions and in the case of Ph.Ds it is only 30%. There are continued efforts to identify national goals of engineering education and determine their priorities for basic engineering education in the coming decades. A survey has been made by a joint AICTE and UGC study group on national tasks, professional skills and professional attitudes. The Activity Analysis Cell of the Department of Chemical Engineering, Andhra University, Waltair, has analysed the range of professional chemical engineering activities to ascertain the needs and skills required of personnel at various levels and their characteristics so as to formulate appropriate skill generating systems including drafting appropriate curricula. So, the process continues and we have not heard the last word in respect of the study content of postgraduate courses in India.

The purpose of chemical engineering education in India today is to make available a trained cadre of professionals to efficiently man the chemical process and allied industries, to carry out advanced research of relevance and to foster academic excellence in teaching institutions. The chemical engineering faculties and fraternity have stood up to the challenges and tackled them, if we may say so with a certain amount of legitimate pride, successfully. A major reason for the success is the augmentation of education , training and research facilities in chemical engineering. Prior to 1947 there were about a dozen institutions, from where some two hundred graduates passed out. The Indian Institute of Chemical Engineers came into being in 1947, whose current membership exceeds 4000. This represents only about 12-15% of the total number of chemical engineers in the country. Associateship examinations are held according to prescribed syllabi. The number of academic institutions offering courses and training has gone upto about 40 and their annual outturn is about 1800 chemical engineering graduates; about 200 to 250 M.Techs and about 50 to 60 Ph.Ds. Amongst the premier institutions offering training and education in chemical engineering are university departments, institutes of technology and regional engineering colleges.

13. ACADEMIC RESEARCH IN CHEMICAL ENGINEERING

The origin of chemical engineering research should indeed go back to the beginning of chemical engineering in this country, since the importance of research in chemical engineering education and industrial development was recognized ever since its inception. Some of the early research papers in late fifties related to binary and ternary vapour-liquid equilibria[27], applied thermodyanmics[28], hydrodynamics in packed liquid extraction columns[29], etc. and were indeed published in reputed journals such as Chemical Engineering Science. However, major research contributions, which have made a lasting impact on the profession at large, started appearing only in early or mid sixties.

Over the past two decades, the quality and net impact of chemical engineering research, excepting a few schools of excellence, has left much to be desired. In many cases the trends in research were closely dictated by those in USA or Europe. However, irrespective of the intrinsic intellectual challenge or the industrial relevance, research was undertaken in such mundane areas of vapour-liquid equilibria, kinetics of known systems, factors affecting minimum fluidization velocity, dimensionless correlations of empirical nature for correlating heat or mass transfer data, etc. There have been a few schools, who have distinguished themselves in academic chemical engineering research over the past two to three decades, especially in the areas of mass transfer with chemical reaction, fluid dynamics, especially with reference to bubble drop phenomena, biochemical engineering, chemical reaction engineering, fluidisation, polymer engineering, etc. We will provide a somewhat elaborate description of the work done in these centres, while at the same time mentioning some of the other very good work done in other institutes. The three schools we will focus on are those in Department of Chemical Technology of University of Bombay, Indian Institute of Science, Bangalore and National Chemical Laboratory in Pune.

One of the schools in chemical engineering which has made a major impact is the one at Department of Chemical Technology in University of Bombay. The level of research in this Department was low until Professor M.M. Sharma joined the department in 1964. Over the past 24 years, he has brought in an excellent culture of high level research in the department. A fascinating account of his experience of building up this school in this department against many odds is given in his H.L. Roy Memorial lecture[30] entitled 'The Joy of Teaching and Research in University; Some Personal Experiences'. This paper gives an insight into the development of a school of excellence by a commited chemical engineer, who fought the system, worked on a 'zero budget', and made a major impact on the world scene.

In early years, in gas-liquid reactions new theories for complicated reaction systems were developed so were new techniques developed allowing the kinetics of extremely fast reactions to be studied. One of the main contributions was the development of new systems which would conform to a particular regime of mass transfer with reaction and thereby enable the determination of transport coefficients as well as interfacial areas by chemical methods. In liquid-liquid reactions this group did a pioneering work in that the chemical method of measurement of interfacial areas in liquid-liquid systems was introduced.[31] A new theory to take into account the influence of sparingly soluble fine particles in a system conforming to the instantaneous reaction regime was developed,[32] verified experimentally and got a widespread acceptance, internationally.

Impressive contributions have been made in this school in the area of engineering analysis and design of gas-liquid and liquid-liquid contactors. Some novel separation strategies for close boiling acidic/basic mixtures by dissociative extraction were developed just as hydrotropic efforts were utilised to carry out separation of close boiling substances.

One of the recent themes pursued by this group is that of development of novel strategies for process intensification involving two or three phase systems. These include addition of a microphase in the form of fine solid catalyst particles, an immiscible phase, etc. What is remarkable is that not only a dramatic enhancement in transport rates (sometimes even by two to three orders of magnitude) has been demonstrated but also that sound models based on mechanistic considerations have been proposed and verified.[34,35]

A major feature of the work from this school has been the close linkage between the theory and practice. This has led to intellectually stimulating work in areas which are of direct industrial relevance. A case in point is the development of novel methods to recover toxic chemicals from waste streams including phenolic materials.

The chemical engineering school at National Chemical Laboratory (NCL) has grown under the leadership of Dr. L.K. Doraiswamy since the very inception of the laboratory over 35 years ago. He certainly was the first chemical engineer, who placed research from an Indian school in a firm way on the world map. He joined NCL after finishing his Ph.D. in Wisconsin under Prof. Olaf Hougen. His contributions in early sixties were in the area of applied thermodyanmics. His group contribution methods for the estimation of thermodynamic properties made a major impact and his papers have been cited in a number of books in the area.[36] Similarly the Reddy-Doraiswamy equation for estimating diffusivities can be cited as an interesting case of an often cited equation coming during the early stages of development of chemical engineering, when such equations were sought by chemical engineers for process design calculations.[37]

The major impact the school from NCL has made is undoubtedly in the area of chemical reaction engineering. A special feature was the integrated approach that was used, including basic kinetics and catalysis, internal and external field problems, as well as practical reactor design for the industry. Excellent contributions in gas-solid catalytic and non-catalytic reactions, multiplicity and instability, stochastic modelling, etc. have emerged from this school.

Some of the major contributions to research were the design of an experimental reactor for obtaining kinetic data, a comprehensive analysis of the role of regimes of control in the analysis of catalytic reactions, studies of influence of role of catalyst fouling, validity of kinetic modelling through independent determination of kinetic adsorption parameters, investigation of fundamental nature of adsorption, a self consistent strategy for determining the mode of adsorption, etc.[38-40] An interesting feature of the work from this group was a remarkable combination of analysis and experiments. Many novel experimental findings emerged for the first time. For instance, the concept of an expanding core model[41] in gas-solid reactions (the so called "rotten-apple" model) is a case in point. The most recent contributions are in the area of stochastic modelling, where the shortcomings of the conventional macroscopic methods of modelling in chemical reaction engineering were noticed and new strategies and methodologies of 'microscopic' analysis proposed, which have brought in some unusual features also. The work in surface science has been equally innovative. A novel concept of feed back of active centres as a possible reason for non-unique behaviour, <u>a priori</u> instability on surfaces, etc. are other notable findings. Similarly interesting contributions in fluidised bed reactors, catalyst dilution, etc. have also appeared.[42,43]

During the past decade or so, the school in polymer science and engineering that was established in the chemical engineering division has made useful contributions in the area of transport phenomena in non-Newtonian fluids, analysis of polymerisation reactors, polymer processing and polymer crystallization behaviour. A notable feature again has been the blend of theory and practice in most of this work.

It is worth recording that the first two books to be published by international publishers were in the area of Chemical Reaction Engineering and they were from National Chemical Laboratory and Department of Chemical Technology of University of Bombay. One of them is by Ramchandran and Chaudhari[44] on 'Three Phase Catalytic Reactors' and the other is by Doraiswamy and Sharma[45] on 'Hetrogeneous Reactions' published in two volumes.

The chemical engineering department of Indian Institute of Science in Bangalore is one where sustained contributions in Chemical Engineering Science have been made. Some outstanding work has been done by Prof. Kumar and his coworkers in the area of bubble and drop formation in gas-liquid and liquid-liquid systems, bubble formation in fluidised beds, drainage and reaction in foam beds, permeation through foam films, drop coalescence and breakage in turbulent stirred dispersions, etc. An interesting feature of the work from this school has been equal emphasis on analysis through modelling and simple but effective experimentation to verify these models.

One of the major contributions from this group has been the development of a unified model, which could explain both bubble and drop formation through a single set of equations.[46] This model has been tested for a variety of systems. It has been modified to take into account the complexities, drainage between bubbles, etc. New models have been developed for the prediction of drop and bubble sizes in complex situtations like sieve plates, sintered disks, etc. The model has been also extended to predict pneumatic atomisation, nucleate boiling, etc.

The work on foam bed contactors, which is extremely fundamental in nature, has been endowed with sound physics and has led to rational analysis and design procedures for foam bed contactors. The models developed are capable of predicting liquid hold-up in both semi-batch and cocurrent foam columns, by assigning separate roles to the nearby vertical and nearly horizontal plateau borders, and also by taking surface mobility into account during drainage through plateau borders and films.[47,48]

The work on coalescence and breakage from this school considers the simultaneous effects of surface tension and flow in the drop and predicts the maximum stable drop size in a stirred vessel as a function of various operating parameters.[49] The previous models overpredicted the maximum drop size.

There are isolated pockets of excellence in many schools of chemical engineering around the country. These include thermodynamics, modelling and simulation in IIT (Bombay), fluidisation and chemical reaction engineering in IIT (Madras), mixing in IIT (Kharagpur), biochemical engineering in IIT (Delhi), transport phenomena in Banaras Hindu University, etc.

One of the very good schools of chemical engineering is in IIT (Kanpur). Right from early days a scholarly tradition of publication with accent on rigourous mathematical analysis has been prevalent in this school. In fact some of the fine papers on mathematical analysis came from this school. The main areas of investigation over the years have been energy engineering, reaction engineering, catalysis, polymer engineering, etc. Polymer reactor modelling and simulation is undoubtedly one of the area of strength and the recent book on 'Step Growth Polymerisation' of Gupta and Kumar[50] which has been published by an international publisher, is a testimony to the high quality and acceptability of the work in this specific area. Due to want of space, it is not possible to give an elaborate account of academic research in all the schools.

14. CHEMICAL ENGINEERING IN INDIAN CHEMICAL INDUSTRY

14.1 Background and Status of Industry

The Indian Chemical Industry can trace its origin to 1890 when an Englishman put up a soap factory at Meerut or even earlier to 1825 when crude oil was struck in Assam. But the progress has been painfully slow till the 1960s, when it gathered momentum. Early chemical engineers found opportunities in the 1940s to organize small scale production of chemicals like sodium bichromate, sodium sulphide and sodium hypochlorite because of constraints imposed by second world war. German surrender in 1945 gave access to a wealth of scientific, technical and engineering data on chemical processes and plants that were considered to be decades ahead of the knowledge held by the Allies. BIOS and FIAT reports became the bible of chemical technologists and engineers the world over. Indeed the organic fine chemicals, intermediates and dyes segments of the Indian Chemical Industry derived considerable mileage from the exposure of German intellectual property.

After the war, when India became free, the national government inherited an agrarian economy that was largely defunct. Capital goods and machine building industry were totally absent. Economic surplus and savings were appropriated by the colonial state, foreign capitalists, native landlords and money lenders, who did not invest them in industry or agriculture. The nation was surviving on imports for meeting vital defence and strategic needs. Developmental planning became imperative to infuse some signs of life in the stagnant economy. An Industrial Policy Resolution was adopted in 1956, which envisaged State dominance in several core sectors. Government had also to play a prominent role in institution building for various scientific and technological disciplines so as to ensure a steady supply of qualified scientists and engineers to serve industry, teaching and research. Planned efforts towards self-reliance provided the needed impetus for industrial development in general and for chemical industry in particular. Table 6 gives the chronology of events in the history of Indian Chemical Industry.

In the true sense of the word, the chemical industry in India is a late starter and is barely thirty years old. Petroleum refineries were established in 1954. Initially the sugar industry provided a surplus of molasses, whose disposal used to be an acute problem. Through a policy decision of the Government of India, cheap ethyl alcohol, based on throwaway price of molasses, provided the base for synthetic organic chemical industry. Small capacity plants for polyethylene, polystyrene, synthetic rubber, acetic acid, etc. were installed from late fifties to late sixties.[51-53] Most of the plants were based on technology acquired from overseas. Lately, in the generation of indigenous know-how, particularly for speciality chemicals required for dyestuffs, drugs, and pesticides industries, India has had some remarkable success. Prices of chemicals, plastics, synthetic fibres, synthetic rubber, etc. have been influenced by the high cost of raw materials and imposts of several levies and duties; the free market prices have been affected by the import duty. Of late, the Government has enunciated the welcome policy of economic size of plants for basic chemicals, polymers, elastomers, fibres, formulation of drugs and pesticides, etc.

TABLE 6

INDIAN CHEMICAL INDUSTRY - SIGNIFICANT LANDMARKS

Item	Year of Introduction
Soap	1889
Paints	1902
Drugs	1902
Nitric Acid	1904
Sulphuric Acid	1907
Rubber	1920
Coaltar chemicals	1922
Ammonia/Ammonium Sulphate	1938
Dyes and intermediates	1940
Sodium carbonate/Sodium hydroxide	1940
Sulphuric acid (Chamber process)	1940
Drugs and pharmaceuticals	1947
Sulphuric acid (Contact process)	1948
Man-made fibers (viscose rayon)	1950
Pesticides	1952
Textile auxiliaries	1952
Thermoplastics and thermosets	1957
Polystyrene	1957
Polyethylene	1959
Polyvinylchloride	1962
Polyamides	1962
Elastomers (synthetic)	1963
Polyester fibre	1965
High density polyethylene	1968
Nitrile rubber	1976
ABS	1977

Acrylic fibre/polypropylene	1978
PMMA	1979
PET/PBT	1982
VAM	1981-82
Silicon	1986
PTFE	1987

As regards indigenous resources for chemical industry in India a substantial amount of offshore and onshore oil and natural gas is available; latter equivalent to about 40 million tpa of crude oil. There is no indigenous sulphur. The forest resources are limited and have to be assiduously preserved and expanded. There has been a major denudation of forests.

The chemical industry in general is characterized by certain features in respect of structure and range of investment, pattern of enterprise and ownership, government control over production, pricing, distribution and foreign technical collaboration, and existence of large, medium and small scale sectors, etc. Both government and private enterprises operate in some of the major segments of the chemical industry. State domination can be seen in capital intensive strategic sectors like petrochemicals and fertilizers, while private initiative and enterprise are predominant in respect of acids and alkalies, dyes and intermediates, drugs and pharmaceuticals, agrochemicals, paints and resins, oils and fats, alcohol-based organics, polymers, elastomers, man-made fibres, chemical plant fabrication,project engineering, & instruments.

14.2 Project Engineering

There is a strong in house chemical engineering infrastructure today in India that has facilitated adaption, assimilation and improvement of indigenous or imported technology package. The culture of project engineering grew in India since the sixties. A number of project engineering consultants and project engineering companies, depending upon the nature of technology, took up design engineering, construction, installation and commissioning of chemical plants. Multinational firms were very active in this area to start with and indigenous units started off as subcontractors. After gaining experience and expertise, a number of Indian project engineering firms came on the scene. Some of the multinational project engineering units got progressively Indianised to enhance their reach or areas of operation. The project engineering firms handled all types of technologies, whether indigenous or imported, and also offered turnkey plants with process and performance guarantees. The Government of India also took steps to organize large scale project engineering enterprises in the public sector to take care of adaptation and implementation of sophisticated technologies in the area of oil refining, fertilizers, petrochemicals and downstream products.

Today, we have a number of project engineering companies in both private and public sector, some of them are quite large in size. For instance, Engineers India Limited (EIL), which is a leading public sector project engineering company has over 2500 engineers, out of which 500 are highly qualified chemical engineers with expertise ranging from design operations to software development. EIL offers process design and basic engineering services based on its own know-how, licensor's know-how or know-how jointly developed with research laboratories or operating companies.

Similarly two major public sector project engineering firms, very active in the construction of fertilizer and allied plants, may be mentioned. They were set up by the Government in the sixties to foster self reliance in the fertilizer sector: one is FACT Engineering and Design Organization (FEDO), a unit of Fertilizers and Allied Chemicals Travancore Ltd. (FACT) and the other, Projects and Development India Ltd. (PDIL), as a unit of Fertilizer Corporation of India. FEDO was allocated the areas of ammonia and phosphatic fertilizers, and PDI /FCI the area of urea and nitrogenous fertilizers so that both the organizations could play a complementary role.

These companies have developed international collaborations and have rendered engineering and consultancy services outside India. For instance, FEDO has rendered such services to Tanzania, Zambia, Brazil and Austria. These companies have developed over the years a strong and internationally competitive project engineering culture and systems for design, engineering, procurement, construction, planning, cost control and project management of high professional standards. Similarly, FACT's Engineering Works (FEW) has diversified into production of special equipment for chemicals and petrochemicals, offshore drilling platforms, highpressure valves and cryogenic storages.

Project enginering contributions of other firms are equally impressive. Companies such as Davy Power Gas India (DPGI), who came to India in 1946 to build a fertilizer plant at Sindri, have had an impressive record of accomplishments in the chemical and allied sectors for clients in India and abroad. Humphreys and Glasgow who started the operations in 1962 moved from medium to small scale producers in early sixties to the high tonnage areas of fertilizers and petrochemicals in seventies. Kinetics Technology, an affiliate of KTI (Netherlands), Dalal Consultants and Engineers, etc. are examples of other project engineering companies, who began operations in early seventies, and who have served the indutry well in subsequent years.

Irrespective of the emergence of a strong project engineering culture in India, it must be emphasised that in the area of transfer of indigenous technology, development of basic engineering packages, etc., the group of industries have not played as 'major' a role as they should have barring of course, a few exceptions. In coming years, as India seeks a strong indigenous base of its own, it is imperative that these lacunae are eliminated.

14.3 Chemical Plant Fabrication

In the brief survey of project engineering capability and its role in the chemical sector, we have also cited examples of chemical plants and apparatus being designed and fabricated by project engineering firms. In fact the chemical plant fabrication in India started with the fabrication of ordinary tanks. The industry can now fabricate almost all the major items of equipment for petrochemicals, fertilizers and other segments of the chemical industry. More than 80% of the plant and equipment needs of nuclear fuel processing and nuclear power plants can be met indigenously. Reactors, pressure vessels, heat exchangers, distillation columns that can withstand high temperatures and pressures are produced within India. Materials of construction used include carbon steel, alloy steel, aluminium and other nonferrous metals. Modern welding techniques and non-destructive testing procedures have been applied extensively. Ancillary equipment like pumps, valves, compressors and instruments of standard or specific dimensions are produced in the country. Imports of plant and equipment, however, continue in certain strategic cases or when tied to know-how import.

Over the past thirty years, India has developed the capacity to design, fabricate, construct, operate and export contact sulphuric plants, soda ash and caustic soda plants. The industry can offer complete know-how package for oil exploration, petroleum refining, medium-size petroleum down stream products, sugar production, basic drugs and pharmaceuticals, R&D consultancy, organising infrastructural facilities and pilot plants for the production of small volume chemical products, process, plant and machinery for pulp and paper, turn-key plant for man-made fibres, dyes and intermediates, etc. The engineering and design capability extends to fertilizers and agrochemicals as well. Fertilizer plants using different feedstocks (coal based, synthesis gas, natural gas or fuel oil) can be indigenously fabricated now for export.

14.4 R&D in Indian Chemical Industry

The R&D base of Indian chemical industry, although reasonably good in certain sectors, is not really powerful. In early years, there was little opportunity for Indian scientists and engineers to demonstrate their capabilities due to the very large import of know-how from aborad for a variety of technologies. However, in mid-seventies the situtation changed somewhat and indigenous development started gaining roots. The foreign collaborations, however, continue to increase. In forty years after independence, the total number of foreign collaborations approved in the country amounted to over 11,000, of which around 8000 involved foreign technical participation, but not all of them were in the chemical sector. During 1980-85, the number of agreements in certain sectors of chemical technology (chemicals, synthetic fibres, glass and ceramics), excluding drugs and pharmaceuticals, amounted to 495. The policy liberalization in the 1980s has been lapped up by all chemical manufacturers, big or small, privately or publicly owned with predictable side-effects like repetititve imports of similar technologies, inhibition of domestic or in-house R&D initiatives, import of obsolete technologies, etc. Foreign collaboration _per se_ has been a mixed blessing; it has certainly helped in bridging decades of technology gap and coming nearer to the industrialized countries of the West. However, those innovative instincts that are responsible for technological advances have been certainly missing in a large measure in the Indian chemical industry. Chemical industry's preeminence in the nation's economy, its sustained growth and everwidening product spectrum, despite its none-too-strong research base, are in some way dependent upon the vastness of the Indian market, the protectionist policies pursued and the liberalization of imports of technology pacakges through collaborative arrangements.

The expenditure on inhouse R&D in industry is as low as 0.7% of sales turnover, in comparison to 2 to 3% in advanced countries. Paradoxically, there is a better R&D culture in medium and small size organisations than that in big industrial houses and over the years in some of these organisations very innovative developments combining good chemistry with modern chemical engineering have taken place. Some of the notable examples cited in Prof. Sharma's Danckwerts Memorial Lecture[54] include an agrochemical isoproturon made without the use of phosgene well before the Bhopal disaster, cypermethric acid, which is a new generation synthetic pyrethroid, ephedrine, a drug on whose technology there is a dominance of one company in the world, etc. These certainly represent interesting examples of innovative developments, but what is heartening to see is that there is an increasing interaction between the national laboratories and the industry which have started showing interesting results. A few examples of this may be in order.

National Chemical Laboratory in Pune has had an impressive record of accomplishments[55] Starting from technologies for organic intermediates, pesticides, etc. in early seventies today major breakthroughs in high tech catalysts of interest in petrochemicals have opened up the possibilities of reverse transfer of technology to the western world. The learning process of process development and technology transfer helped along by the culture of involvement of a project engineering company has matured today into a well developed strategy for technologies of a variety of types and sizes.

Regional Research Laboratory in Hyderabad, has had an impressive record of transfer of technologies in pesticides, drugs, etc. Indian Institute of Petroleum, established in 1960 is credited with the largest indigenously developed technology of aromatics extraction. Similarly useful contributions have been made by other CSIR laboratories such as Central Salt and Marine Chemicals Research Institute at Bhavnagar, Central Food Technological Research Institute at Mysore, etc. Chemical engineers have certainly played an important role in all these developments.

15. CHALLENGES AND OPPORTUNITIES

Chemical industry in India will continue to play a dominant role. This industry's share in India's gross industrial output went up from 8% in 1970-71 to 40% in 1983-84. High annual growth rate, as much as 18%, was the special characteristic of the chemical industry until 1976-77, which declined to 6.7% in 1977-78, but recovery was swift and has been on the upswing since then with the segmental growth rate being in the range of 10-25%.

It is generally agreed that the chemical industry is directly concerned with basic human needs, such as, food, health, clothing, and shelter. These needs are governed by the demographic dynamics of the nation, policy orientations, as well as certain unpredictable natural phenomena. For instance, if the monsoon fails for two or more successive seasons (as often happens in India), the production of cereals, pulses, oil seeds and other crops will be seriously affected. So would be purchasing power of the vast rural and urban middle class in India. The impact will be felt in fertilizers, food processing, agrochemicals, and other sectors. Dyes sector depends on the textile industry for its growth, whose fortunes are linked to the clothing needs of the population, buying power of the rural poor and so on. Malnutrition and the safeguards against endemic, epidemic and other tropical diseases will influence the developments in the drug and pharmaceutical sector. Government policies will as ever remain a potent instrument in regulating the growth and stability of the industry.

The perspectives of the chemical industry in India need not necessarily follow the pattern in USA, Western Europe, etc. For instance the nitrogenous fertilizer industry in India will have to necessarily grow in a big way unlike the situation in the developed countries, where this industry is already stagnant, if not on the decline. Indeed the percentage of hydrocarbons dedicated to fertilizers in India will be around 20%, the highest in the world. The investment in the chemical industry during the next 15 years will be around $ 60 billion, out of which more than 30% investment will be in the fertilizer sector. The pressure on land is severe and displacement of cotton crop with food crops may become increasingly important leading to greater emphasis on synthetic fibres, particularly polyesters. The problem of housing is acute and backlog runs to more than 30 million houses. The challenges faced by chemical engineers in India will therefore be related to these facts of the growth of Industry. Research and Development will undoubtedly play a very significant role in this context.

A comment therefore on the present state of research in chemical engineering is in order. Research thrives on innovative young students. What have been the incentives for young chemical engineers to take up a research career in India ? A large number of scholarships are available today for those students who pass the Graduate Aptitude Test in engineering conducted by the Ministry of Human Resources Development. However, there are not enough takers for these scholarships. Similarly, although there is an excellent system of generous support through University Grants Commission, Department of Science and Technology, Council of Scientific and Industrial Research pursue Masters and Doctoral degree programmes, it has not been possible to attract the best students because of migration of a substantial number of very good students to the USA and also due to the fact that the job opportunities in India for Masters and Ph.D. degree holders are not attractive. In addition, many schools in India have not been able to attract the best talent due to problems of leadership, bureaucratic procedures, absence of facilities comparable to those in the western world, lack of stimulating environment for research and indeed lack of culture of research in some schools. However, there are signs to indicate that this situation may be changing as more and more young chemical engineers are getting attracted to research and hopefully we will see a reversal of brain drain in not too distant a future.

India's role in technology development/export in the late nineties, could indeed be a major one. For instance, India can be a leading fertilizer manufacturer in the world, provided appropriate inputs in R&D are made. India can acquire a leading position covering all types of nitrogenous and phosphatic fertilizers, from preparation of project reports to supply of technology, erection of plants to running of plants on contract basis, in any location in the world. A large reservoir of trained personnel in various sectors, accustomed to working under adverse and hostile conditions, is a special asset. Developing countries in Africa, South East Asia, etc. can benefit from the Indian experience. Thus from technology to running plants, India and China may well emerge as serious contenders on world scene.

Similar examples can be cited in other areas such as synthetic fibres, speciality chemicals, software development, etc. The needs, opportunities and challenges before the chemical engineering community in India have been aptly summarised recently.[54] In every single national endeavour, the chemical engineering community can play a major role. It needs to be seen if the enormous challenges posed in this vast country will be converted into opportunities for growth and prosperity by Indian chemical engineering community. The present indications are that this community will certainly rise to the ocassion and meet the challenges with determination and dedication.

ACKNOWLEDGEMENT

An elaborate questionnaire was prepared by the authors and sent to over 100 institutes, public and private sector chemcial manufacturers, project engineering companies and chemical plant manufacturers in India. The response received from all the individuals and companies to our request was simply overwhelming. The present paper has used the information collected from these sources rather extensively. It is impossible to catalogue the names of all those who responded. We could, however, like to place so willingly on record our grateful thanks to all those, who responded.

R.A. Mashelkar and J.V. Rajan
National Chemical Laboratory
PUNE : 411 008, INDIA

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Peter N. Rowe and Anthony R. Burgess

CHEMICAL ENGINEERING AT UNIVERSITY COLLEGE LONDON

Abstract

The first professorship in chemical engineering in Britain (believed to be the first in Europe) was established at UCL in 1923. It was founded in memory of Sir William Ramsay and a thriving department has been active there ever since. The paper describes the early history of the department - research activities, course syllabus and the severe disruption caused by the war of 1939-45. Accelerated growth in the post-war years included a major development of biochemical engineering which began in the early 1950s and the establishment of vigorous research groups in crystallisation, combustion kinetics and fluidisation. The present status and direction is briefly reviewed.

Amongst the first professorial appointments made by University College shortly after it was founded as the University of London (Figure 1) in 1826 was a professor of engineering, the first in England and amongst the first in Europe. It is difficult to believe that this new liberal university was the first to be established in England since the Middle Ages when Oxford and Cambridge were founded. Not only did it break the stranglehold of the Church of England on higher education, but it also sought to extend the field of study beyond moral and political philosophy to "those sciences which consist in the examination of the laws and properties of material objects". These were the days of rapid development in modern engineering but the subject was not then adequately organised for effective teaching and many thought it inappropriate as a university subject. (That view has even been heard from liberal arts professors during the nineteen eighties!) Nonetheless engineering survived at UCL and towards the end of the 19th century the College had established strong

N. A. Peppas (ed.), One Hundred Years of Chemical Engineering, 223–236.

departments of Civil (notably Public Health Engineering), Mechanical and Electrical Engineering. It was in this last department that John Ambrose Fleming made the first thermionic valve. Fleming and Alexander Graham Bell, contempories and fellow students at UCL, have probably contributed more to the development of telecommunications and modern electronics than anyone before or since. UCL was therefore a fitting place for the first UK chair of chemical engineering.

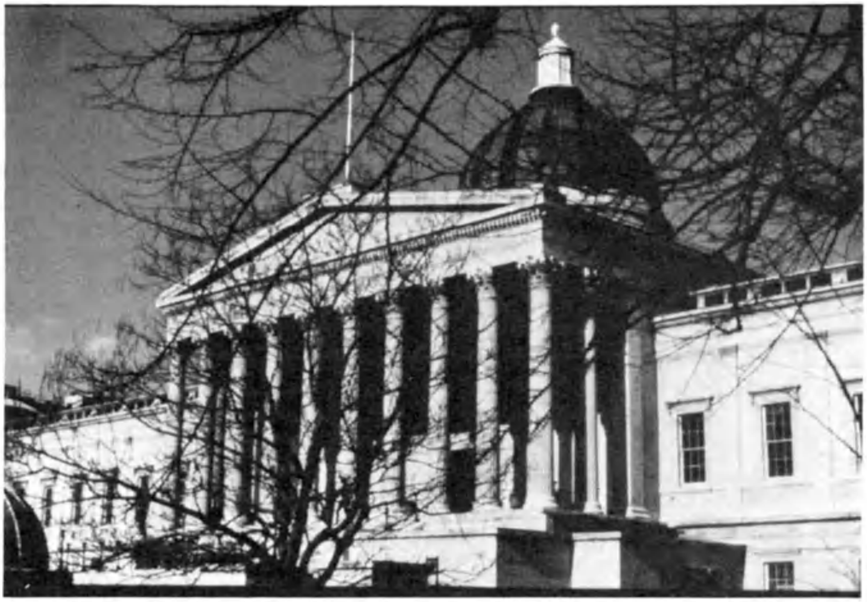

Figure 1: The portico of University College London, virtually unchanged since the College was opened in 1828 as the University of London. The neo-Grecian design is considered to be the finest work of William Wilkins who subsequently designed the National Gallery in Trafalgar Square a few years later.

Sir William Ramsay (Figure 2) was first a professor at the University of Glasgow before coming to University College London as Professor of Chemistry in 1887, a position he held until retirement in 1913. He is widely known for his discovery of the noble gases for which he was awarded the

Nobel Prize for Chemistry in 1904 and which earned him a deserved reputation as a meticulous and thorough experimental scientist whose attention to detail and the precision of measurement led to his famous discoveries. His interest in industrial chemistry and large-scale manufacture is far less widely known but was perhaps an equal interest with him. In 1878 the UCL department had started a course in industrial chemistry under Graham that we would today call chemical engineering. It was abandoned in 1885 presumably through lack of demand but also probably through lack of interested and experienced teachers to teach it. In spite of the successful development of engineering studies at UCL, such applied subjects were still barely considered respectable amongst English academics of the last century, although Ramsay made unsuccessful attempts to reinstate it.

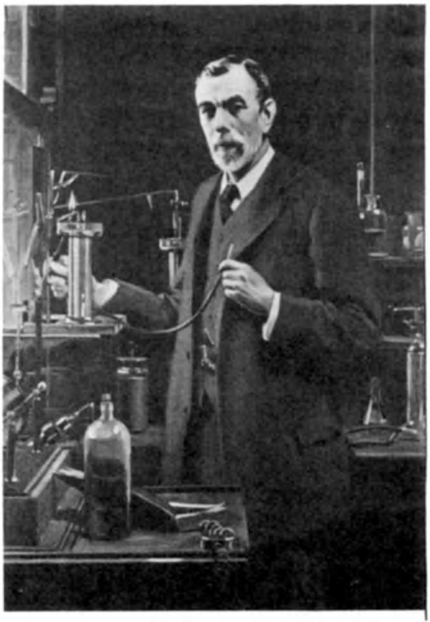

Figure 2: Sir William Ramsay, FRS, Professor of Chemistry at UCL, 1887–1913.

Figure 3: Professor E.C. Williams, the first holder of the Ramsay Memorial Chair in Chemical Engineering at UCL, 1923–1928.

The first World War of 1914-18 brought brutal realisation of England's weakness in industrial chemistry at which Germany was much superior. Ramsay was brought from retirement particularly to advise on atmospheric nitrogen fixation and on the Haber process to obtain nitric acid for the manufacture of explosives, areas in which he made significant contributions (much of this concealed by war-time secrecy) until his untimely death in 1916. After the war former colleagues of Ramsay from both Glasgow and London set out to raise funds with which to establish some memorial to the great man. Unusual for such ventures, the fund raisers were embarrassed by the generosity of industry's response and raised £50,000, an exceptional sum for those days (1923) and the equivalent of £1.2M today ($2.2M). It was evident that Ramsay's interest in and contributions to the chemical process industries was appreciated by those who knew and made use of it.

The trustees of the memorial fund used £23,000 to establish the international Ramsay Fellowships which continue to prosper today and, largely through the urgings of Professor F.G. Donnan, Ramsay's successor as professor of chemistry, £27,000 to found at UCL the Ramsay Memorial Chair, the first professorship in chemical engineering to be established in Britain (and probably in Europe). Surely Sir William would have approved most warmly of this fitting tribute. In 1923 the first Ramsay Professor, E.C. Williams (Figure 3), was appointed and an independent department established.

Williams established a thriving postgraduate course and an active research group but numbers were small, about six students a year. After five years he left to become Director of the Royal Dutch Shell Petroleum Group's Research Laboratories at Berkeley, California and was succeeded by W.E. Gibbs in 1928. By this time the professor had one full-time lecturer (J.P. Mullen) to assist him, a laboratory steward (R.S. Potter) and the occasional help of an honorary assistant. In 1932 this small group was able to move from cramped quarters in the chemistry department to a newly built laboratory in adjacent Gordon Street (Figure 5) and the session 1932/33 started with a further lecturer (M.B. Donald) and a total of 32 students. Figure 4 is a reproduction of the UCL "Calendar" of 1931/32 which describes the chemical engineering courses of the time. Amongst the students of this period was P.C. Carman (of flow through porous media fame), F.E. Warner (to become a leading UK consultant and President of I.Chem.E.) and R. Edgeworth Johnstone (to become first professor of chemical engineering at Nottingham University). The visionary and sterling work of W.E. Gibbs in consolidating and developing a strong and well-organised department was sadly ended by his death in January 1934 at the tragically early age of 45. Gibbs was succeeded in 1934 by H.E. Watson who had been a research assistant to Ramsay and from 1916 professor at the Indian Institute of Science in Bangalore.

A parallel development was meanwhile taking place at Imperial College, a sister college within the federation that now comprises London University. Chemical engineering there was growing within the department of chemical technology which had a strong research interest in combustion and related topics. Watson's first few years as Ramsay Professor were much occupied with the planning of what was to be a four-year undergraduate course to run at each of the two London colleges, IC and UCL, and the first undergraduate entry was taken in October 1937. Unhappily the outbreak of war in 1939 disrupted this pioneering course but a few students graduated from an abbreviated course in 1940. University College suffered aerial bombardment in 1940 which did severe damage and the hard-won Ramsay Laboratory of Chemical Engineering received a direct hit in 1941 which totally demolished it and most of the department's records (Figure 7). By then the College had been evacuated, students dispersed, staff enlisted for war service and organised chemical engineering teaching was more or less suspended throughout the UK.

CHEMICAL ENGINEERING.

Ramsay Professor: W. E. GIBBS, D.Sc., M.I.Chem.E.
Lecturers: J. P. MULLEN, M.Eng., M.I.Chem.E.
M. B. DONALD, M.Sc., A.R.C.Sc.

The Ramsay Laboratory of Chemical Engineering has been instituted with the object of providing postgraduate training to students who have already taken a Special Degree in Chemistry or Engineering, with a view to their taking positions in chemical industry where skill in the scientific design and operation of processes and plant is essential.

Figure 4: A reproduction from the UCL "Calendar" of 1931/32 describing the postgraduate course in Chemical Engineering offered to chemists and engineers.

There are considerable openings in industry for men trained in the development of processes from the scale of the research laboratory to industrial factory operation.

The efficient design of chemical plant and processes for economic commercial operation rests mainly upon a correct application of economic, physical, physical chemical and engineering principles, which principles are not peculiar to any one industry, but common to all.

In view of the rapid advances which take place in chemical manufacturing methods, it is considered that a University training should aim at giving a student the fundamentals of plant design and operation rather than the technology of a particular industry. The obtaining of Chemical Engineering data and the use of such data in the design of plants form an important part of the work of the Department. In this way the student is fitted to take his place in any of the chemical or allied industries, equipped with a broad outlook on the economic. engineering and scientific aspects of his profession. The Department is in close touch with many industrial factories where the student can obtain factory experience.

Students who have passed creditably through the Department are, under the regulations of the Institution, exempted from the examination for the Associate Membership of the Institution of Chemical Engineers.

Professor Gibbs will be glad to give advice to students wishing to take Courses in Chemical Engineering.

The Course extends over two Sessions.

A College Diploma in Chemical Engineering may be obtained by students who have spent not less than three terms in the Department. The Diploma will be awarded on the results of an examination.

FIRST YEAR*

A1. (Professor Gibbs.) Industrial Chemical Calculations.
First Term: Tuesday at 9.30.

A 2. (Professor Gibbs and Mr. Mullen.) Heat Transmission and the Dynamics of Fluids.
First Term: Monday and Friday at 9.30.

A 3. (Mr. Mullen.) Principles of Mechanical and Structural Engineering.
First Term: Thursday at 10.30.

A 4. (Mr. Mullen.) Production and Distribution of Energy in Works.
Second Term: Monday at 9.30 and Thursday at 10.30.

A 5. (Professor Gibbs.) The Design and Operation of Unit Types of Chemical Plants.
Second and Third Terms: Tuesday and Friday at 9.30.

A 6. (Mr. Mullen.) Materials of Construction.
Third Term: Monday at 9.30 and Thursday at 10.30.

* For Syllabus and other particulars of these courses, see separate pamphlet.

Figure 4 (continued)

DRAWING OFFICE.

It is not intended to train expert draughtsmen, but sufficient practice will be given to enable the Student to read drawings and to express himself intelligently in the form of engineering drawings.

Monday, 10.30 to 1, and Wednesday, 9.30 to 1.

LABORATORIES.

The Laboratories, including that for large scale experimental work, will be open to Students at all times during University hours. A short course will be given during the first term of the first Session illustrating the laws of heat transfer, the dynamics of liquids and gases and the standard control methods and measurements employed on industrial processes. Particular attention will be paid to fuel and gas analysis, and control methods of combustion processes.

The bulk of the work of the laboratory, however, will be of a research character, consisting of the investigation of processes with a view to large scale development and the investigation of the theory of mechanism and efficiency of operation of specific unit types of operation, such as are calculated to lead to improved methods in the design and operation of industrial plant and process.

The Student will be expected to present a thesis upon the work carried out.

WORKSHOP PRACTICE.

A course in workshop practice will be arranged for Students who desire it, and all Students, so far as facilities allow, will be given every opportunity to use the workshop at other times, upon the condition that unreasonable damage to tools or machines is made good at his own expense.

Fees for Workshop Course: £1 11*s*. 6*d*.

SECOND YEAR.

This will be devoted entirely, with the exception of occasional lectures on special topics, to original research under the supervision of the Professor or other members of the staff. The work may be carried out in the laboratories, or when circumstances require it, wholly or partly at industrial works.

Special lectures will be arranged dealing with the lay-out of plants and factories, factory administration and industrial economics.

WORKS PRACTICE.

Arrangements will be made wherever possible, for selected Students only to obtain experience of actual works practice and of the investigation of chemical engineering problems on the manufacturing scale. The period so spent will normally be from four to six months during the third term and long vacation of the first session. The Student will present a report on the work done in the form of a thesis, though the question of the publication of such thesis must be governed by the wishes of the firm providing facilities for the work.

Figure 4 (continued)

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COMPOSITION FEE
(for full Course): Session, 30 guineas; Term, 11 guineas.

RESEARCH FEES: Registration 1½ guineas.
Laboratory, Session, 15 guineas.

Deposit, £3 3*s*., to be paid by all Students using the Chemical Engineering Laboratory.

Deposits will be returnable at the end of the session in which the Student completes his course of study, less the amount retainable for breakages. If the balance of the Deposit in any year is less than 50 per cent. of the total, an account for the amount of such breakages will be rendered at the beginning of the following session.

Figure 4 (continued)

It was 1945 or 1946 before most universities and colleges managed to re-start coherent undergraduate courses in laboratory subjects although UCL ran a one-year diploma course in chemical engineering for eight students in 1945.

It was around this time that Watson fell out with Ingold, the then professor of chemistry, over the teaching of this subject to chemical engineering students provided by Ingold's department. In a fit of anger Ingold told Watson to teach his own chemistry which forced the latter to hire a chemist when he next had a vacancy. This chance and eccentric event has had far reaching and beneficial consequences for, with subsequent expansion, chemistry teachers within the chemical engineering department have correspondingly increased. Thus, the department has maintained a strong research interest in chemistry (and later, biochemistry) which has been a healthy influence on the department's interests and future course. Ramsay no doubt would have been pleased at this unforeseen turn of events.

With the post-war reconstruction chemical engineering at UCL moved from the Science to the Engineering Faculty and in 1947 had a staff of four academics (H.E. Watson, M.B. Donald (now a Reader), J.P. Mullen and a new assistant lecturer, P.H. Calderbank), its old laboratory steward (R.S. Potter) and an intake of 24 undergraduates. H.E. Watson retired in 1951 to be succeeded by M.B. Donald, the fourth Ramsay Professor.

Donald's period as professor coincided with a massive post-war expansion of chemical engineering education in the UK, a trebling of university departments and an order of

Figure 5: The first purpose-built Ramsay Memorial Laboratory of Chemical Engineering. Opened in 1931 by HRH Prince George, later to become the Duke of Kent, it was destroyed in an air raid in 1941.

Figure 6: The new Engineering Building designed by Corfiato and opened in 1961 (11-storey building on right) and 1964 (smaller building on left). Chemical and Biochemical Engineering occupies much of the sub-basement, ground, first, second and third floors, while the Electrical and Mechanical Engineering Departments occupy the remainder.

magnitude increase in student numbers. Much of his effort was absorbed in dealing with unprecedented expansion including planning and preparation for a new engineering building on the crowded downtown UCL site. (Around 1970, some 7,000 students and 2,000 professional and supporting staff shared about 8 acres (3.25 Hectares), largely occupied by old three-storey buildings.) By 1965 Donald had eight

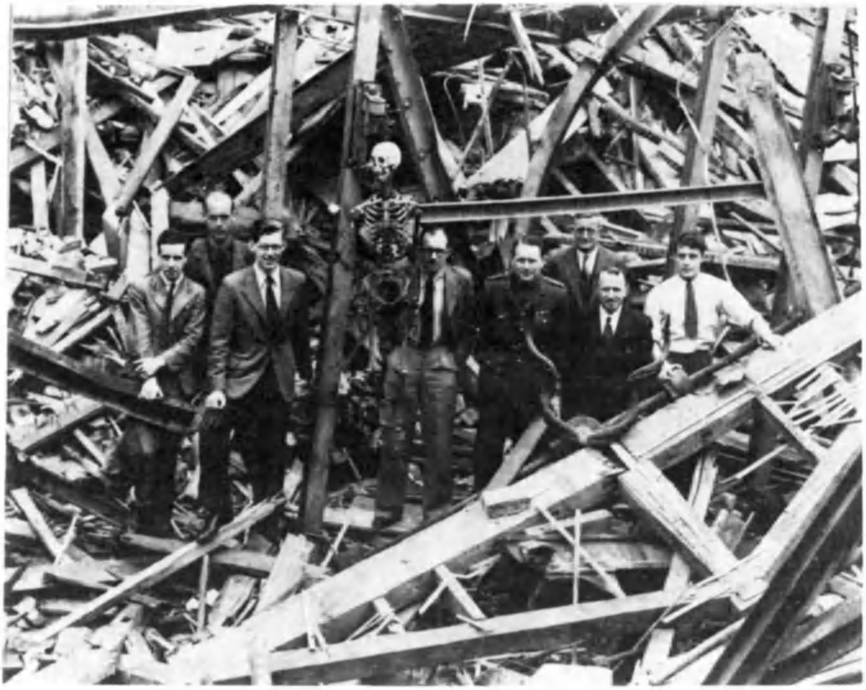

Figure 7: The ruins of the Ramsay Memorial Laboratory of Chemical Engineering after an air raid in May 1941. M.B. Donald (in military uniform) was to become the fourth Ramsay Professor in 1951. R.S. Potter (behind Donald's left shoulder) who had been the first person in the department on its establishment in 1923 continued to serve the department as Laboratory Superintendent until his retirement in 1966. H.W. Thorp (on Donald's left) had been associated with the department for many years in various capacities during the thirties and forties and was a part-time lecturer until 1968.

academic staff and the department had recently moved into $4000m^2$ of a new purpose-built building on the SW corner of the College rectangle. (Figures 6 and 8.)

In spite of his necessary pre-occupation with administrative and organisational matters, Donald pioneered research in the then novel area of biochemical engineering. During the 1950s exciting advances were being made in the understanding of biochemistry. Research progress was largely controlled by the availability of usable quantities of purified materials that were only obtainable by laborious separation from some naturally occurring source. E.M. Crook (1983) of UCL writes: "In 1950 if you wanted glutothione you bought 1/2 cwt. of bakers' yeast, spread it out to dry on filter paper in the teaching laboratories during the vacation and filtered the extract through 25 large Buchner funnels into every large vessel the department possessed. If you wanted ATP you had to kill a rabbit and purify it from an extract of skeletal muscles. There was no other way of obtaining it." During the 1930s Donald as a young lecturer had co-operated with Drummond, the then professor of biochemistry at UCL, in the isolation of vitamins A and E from fish liver oils and later from wheat germ. From this background he co-operated with Crook and others from the biochemistry department in a project funded by the Medical Research Council to isolate co-enzyme A from yeast. In 1953 this was being done in the chemical engineering department on a scale involving 100 gallon stainless steel vessels. Donald's work was reported regularly in the J. of Biochem. and Microbiol. Technology and Engineering from 1959, the year of the journal's foundation. Subsequent projects reported in the early 1960s include microbial oxidation of hydrocarbons to long chain fatty acids, lipid protein complexes extracted from human and animal lungs, nucleotide extraction from yeast, cell tissue culture from hydrocarbons and the attachment of enzymes to solid supports. By the time of his retirement in 1965 Donald and his co-workers had published around a dozen research papers in the area now known as biochemical engineering and fairly regular research funds were becoming available from the research councils.

By 1958 the reputation of this research group was such that the Guinness Co. funded the establishment of a lectureship in biochemical engineering within the chemical engineering department to which F.C. Webb was appointed in 1958. He came from long experience in the food and allied industries to set up the first one-year postgraduate course in biochemical engineering. He also wrote the first textbook so named. The course was in two streams to suit

Footnote: E.M. Crook, "Biotechnology" Symp. No. 48, The Biochemical Society, London, (1983) 1-7.

the needs of those who had graduated first in either biosciences or in engineering. Much the larger number came from the biosciences and the department became skilled in teaching the attitudes and basics of engineering to those who arrived with a quite different attitude to problem solving. A co-operative biochemistry department correspondingly introduced engineers to the mysteries of bioscience.

While biochemical engineering teaching and research were growing rapidly J.W. Mullin and colleagues were building up a strong research school in the field of crystallisation and J.A. Barnard and co-workers were establishing a research group in combustion chemistry and gas phase kinetics. These more conventional and perhaps less glamorous studies were overall responsible for most of the department's substantial research output.

Donald retired in 1965 and unhappily suffered ill-health which effectively terminated his further contributions to chemical engineering. The author of two books on early Elizabethan technology, he had intended to restore an old Cornish tin mine to its method of operation in the 16th century, but this scheme had to be abandoned.

P.N. Rowe succeeded as the fifth Ramsay Professor and brought a new research interest to the department. He came from AERE Harwell where he had established a research group in fluidisation and fluidised bed chemical reaction engineering in support of the then rapidly developing industry of uranium production. This new activity fitted well into the research interests of the department for all had an interest in particulate matter and it provided a much needed link between chemistry and engineering. The previously rather isolated groups became better coordinated and the departmental members functioned more as a team. The technical staff also became better integrated in overall activities.

The appointment of P.N. Rowe to the Ramsay Chair in 1965 has been described as an inspired appointment (see A.R. Burgess and J.G. Yates, J. Ramsay Society, 1986, 33, 7). He seemed to have an instinctive feel for what was needed. He made himself easily available to all members of the department and broke down intradepartmental barriers by his enthusiasm and encouragement. It is no coincidence that during his tenure three personal chairs were set up within the department and three other staff left for chairs elsewhere. The reputation of the department has grown during and since his tenure so that recently the University Grants Committee included it as one of the only four "outstanding" chemical engineering departments in country.

In 1965, in addition to the Ramsay Professor, there was one reader (J.W. Mullin), two senior lecturers (J.A. Barnard and F.C. Webb), five lecturers (A.R. Burgess, M.D. Lilly, C. Morris, A.W. Nienow and J.G. Yates) and one part-time lecturer (H.W. Thorp). Two research assistants and an honorary visitor made a splendid total of 13 names in the College calendar. Nine research papers were published by the department during the academic year 1965/66 when total College expenditure was £4.59M. But this was a period of rapid expansion and such figures changed dramatically soon after.

Donald was a modest and cautious man who had been reluctant in his last years as head of department to commit his successor by making appointments and otherwise expanding his department. Thus Rowe inherited considerable potential and was able to develop the department rapidly. By the time of his retirement in 1985 there were four professors, two readers, one senior lecturer, nine lecturers, two part-time lecturers, 16 research fellows and assistants, three honorary lecturers and five honorary research fellows, a grand total of 42. In 1984/85 the department published 31 research papers and College expenditure was £57.48M. Expansion in this period was not uniform for, by deliberate policy, biochemical engineering was specially encouraged so that now there is both an undergraduate and an MSc course in this subject and the department's present name reflects its major interest. Nonetheless, about two thirds of total effort is still in the area of conventional chemical engineering, and a new MSc course in "Chemical Process Engineering" has just been started.

J.W. Mullin succeeded as the sixth Ramsay Professor in 1985 after long association with the department, firstly as a diploma and research student in the early post-war days (1951-52, 1952-54) and subsequently as lecturer (1956-61), reader (1961-69) and professor (from 1969). His understanding of the way the College works, his outstanding dedication to both the department and College and his quiet determination are necessary qualities in the present difficult times which are being experienced in higher education. For the last 40 years or so, all UK universities have been largely supported from the public purse and the present Government is committed to reducing such expenditure. All academic institutions are facing severe financial restraints but the department founded in Ramsay's memory 65 years ago enjoys an enviable reputation both for teaching and research and the strong team spirit that exists amongst all its staff ensures its successful survival in the foreseeable future.

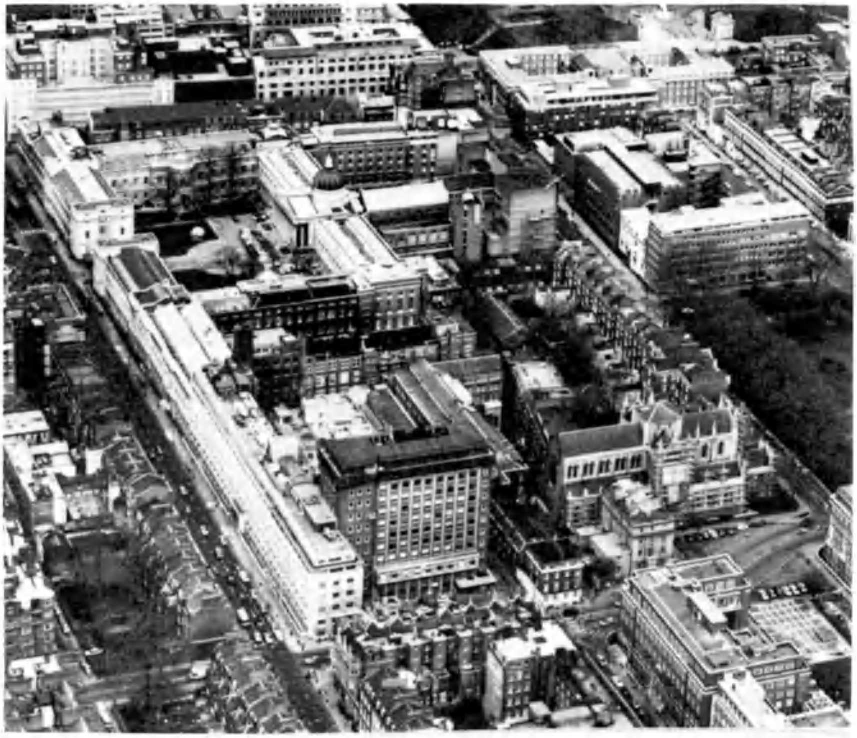

Figure 8: A recent aerial photograph showing the University College London site. The Chemical and Biochemical Engineering Department is housed in the block on the SW corner of the College rectangle (ie to the bottom right of the photograph).

Professor A. R. Burgess
Department of Chemical and Biochemical Engineering
University College London
Torrington Place
London WC1E 7JE
ENGLAND

A.J. Biddlestone and J. Bridgwater

FROM MINING TO CHEMICAL ENGINEERING AT THE UNIVERSITY OF BIRMINGHAM

ABSTRACT

The Department of Chemical Engineering at the University of Birmingham, England, has its origins in the founding of the University. The introduction of courses in petroleum mining by John Cadman, Professor of Mining, in 1910 began a sequence of developments leading to the present day. The transition from a small activity within a Department of Mining, through the intermediate stage of Oil Engineering and Refining to a large and successful Department of Chemical Engineering is described.

1. FOUNDING OF THE UNIVERSITY

Before tracing the history of the development of Chemical Engineering at the University of Birmingham, it is useful to set the development of the University in the context of higher education within the United Kingdom and the development of the City.

Whilst Britain has the reputation for a tradition of learning, the English have been rather unwilling to admit the value of higher education for other than a select few. This arises from a number of factors amongst which are historical predominance of the Universities of Oxford and Cambridge in the life of the country and the close relationship between the state and the Church of England. Until the nineteenth century, membership of the Universities of Oxford and Cambridge was confined to members of the Church of England. For a period the Scots had the right to say that the number of universities in their country exceeded the number in England!

If we set aside the development of the University of London and the University of Durham, the impetus for the modern British university system arose from the enthusiasm of Benjamin Jowett, the Master of Balliol College, Oxford who in 1860 was very influential in the founding of the University of Bristol. This institution was the fore-runner of a number of universities associated with successful

N. A. Peppas (ed.), One Hundred Years of Chemical Engineering, 237–244.

commercial areas of the country. Along with Birmingham, Institutions at Liverpool, Manchester, Sheffield and Leeds were founded in late Victorian times. These are the large civic universities and are the true so-called red-brick universities.

Birmingham developed as a city since it was indeed the heart of the Industrial Revolution. It became a centre for transport being the focal point of the canal system developed in England in the eighteenth and nineteenth centuries. Although the City is only now beginning to make use of its waterways again, it is worth noting that it has a greater length of waterway than Venice. Birmingham was a town that did not require those that worked belong to a trade guild and thus overtook its near neighbour Coventry. It also became a centre for non-Conformism. A final feature, and an important one for the present story, is that in areas immediately north of Birmingham called the Black Country, there were supplies of both coal and iron ore. These are now exhausted but the existence of raw materials was clearly a key factor in the development of Birmingham.

The first glimmerings of an interest in the University within the City of Birmingham arose in the 1830s but an institutional development only occurred in 1880 with the founding of Mason College which, in 1897, became Mason University College. This in due turn became the University of Birmingham which was founded in 1900 by Royal Charter and by the Birmingham University Act of Parliament, 1900, which transferred Mason College to the University.

The City was very proud of its achievements and the University came into being with the optimism and independence created by the hard work of the non-Conformists who had made the City so successful. The Campus of the University was donated from their estate by the Gough-Calthorpe family partly as a gesture of altruism and partly as a means of providing a barrier between their high quality residential areas and the industrial area developing in Selly Oak.

2. MINING AND MINERALS ENGINEERING

The local interest in raw materials naturally led to Mason College having an interest in mining and indeed for the period 1883-1889 a Professor of Mining and Colliery Management was resident in the College. When the University was founded, there was formed immediately a Department of Mining to which Professor R Redmayne was appointed in 1902. In 1908 he left the department to become His Majesty's Chief Inspector of Mines. He was succeeded as Professor of Mining by John Cadman, a Government Inspector of Mines, who had a background both in conventional mining and also in oil production, having spent some period working on this subject in Trinidad. In 1910, Cadman decided to introduce a course in petroleum production and refining in parallel with the course of mining in his Department.

After Cadman left in 1922, Professor K Neville Moss was in charge of Mining. In the period up to 1942, Professor Moss was Head of a successful department providing the mining industry, notably the coal industry, with a number of exceptionally able colliery managers. The present Chairman of British Coal is one of the graduates in the Department. In 1942 Dr Stacey G Ward, a member of staff in the Department of Mining was appointed Acting Head of Mining. In 1947, Professor T D Jones of University College, Cardiff was appointed to the vacant chair of Mining but was unfortunately killed two weeks later in a car accident. The University failed to respond and make an outside appointment to the Chair and appointed the Acting Head to the vacant Chair. The internal appointee, Professor Ward, had a strong background in coal chemistry but this gradually led to the growing gap between the Department and support from the coal industry which was dominated by mining interests. Sponsorship of students in the Department was withdrawn by the newly nationalised coal industry in the late 1940s and this set in train an inevitable series of events which led to its transformation to the Department of Mining and Minerals Engineering in 1960 and then the Department of Minerals Engineering in 1965.

3. OIL PRODUCTION AND REFINING

Sir John Cadman, as he had now become, left Birmingham University in 1922 and at that time there was formed out of part of the Department of Mining the Department of Oil Production and Refining. This was led through much of the period between the First and Second World Wars by Professor A W Nash who succeeded Professor Thompson in 1924. He was a productive research worker on the conversion of coal to oil. The Department had its own new building opened in 1926, and used to this day, paid for by industry subscription by Sir John Cadman. He ended his career as Chairman of what we now call British Petroleum, as Lord Cadman. However, the Department was never large, graduating with 5-10 students a year.

4. CHEMICAL ENGINEERING

In 1942 F H Garner came to the Department and he saw the need to transform the Department of Oil Engineering and Refining in order to embrace the more general discipline of Chemical Engineering and this occurred in 1946. Thus in 1946 the Department of Chemical Engineering was formed by the amalgamation of Oil Engineering and Refining and the Coal Utilisation section of Mining. Professor F H Garner was appointed Professor of Chemical Engineering and Director of the Department and Dr S G Ward was appointed to a second Chair of Chemical Engineering whilst retaining the responsibility of Acting Head of Mining. He relinquished the second Chair of Chemical Engineering upon appointment as Professor of Mining. A course in Petroleum Engineering continued for some years but student numbers were always low. It was finally abandoned about a year before North Sea oil was discovered! In the early years the Department of Chemical Engineering graduated 30-35 students per year but by 1960 it had reached 80, a figure substantially maintained to the present day. For example 92 students were admitted in 1987, this being some 10-15% of the UK's chemical engineering population. Academic staff are 27 in number. There are about 85 research students, research associates and research fellows. F H Garner was head until his retirement in 1960 when Professor J T Davies was appointed and he was head until 1983. The present Head of Department, from 1983, is Professor J Bridgwater.

The University recognised that the Department of Minerals Engineering had a great deal in common with the Department of Chemical Engineering and agonised at a number of periods as to whether or not these two Departments should be amalgamated. The severe cuts imposed on the University system in the early 1980s led to an opportunity to reduce the staff of the Minerals Engineering Department, a number of whom were tempted by early retirement offers. This was grasped by the University and this led to incorporation into Chemical Engineering in 1984. In fact it has turned out that the members of staff and their interests have fitted well into the new Department and perhaps provides unfortunate evidence for the Government that the roughness of their policies sometimes has beneficial results.

5. CURRICULUM DEVELOPMENT

The approach to teaching of the two early Departments carried a very strong practical element. A model coal mine of nearly an acre was built on the Campus to facilitate teaching in underground and surface surveying, ventilation measurement and to illustrate coal working methods. There was also a drilling rig near the Oil Engineering building and a drilling derrick once stood in the middle of what is now a car park.

Course development has been strongly influenced throughout the history of the Department by the needs of the industries concerned for a supply of appropriately trained graduates. It is important to note that changes in course content preceded formal changes in departmental structure described above.

In the decade before the establishment of the Oil Engineering Department, the Department of Mining was offering a BSc degree in Mining with courses designed to meet the requirements of those intending to become mining engineers, managers of metal mines, mine surveyors and those generally interested in mines and quarries. The core courses were in mining and surveying covering underground development and systems of work, mineralogy, mining laws and regulations, and dressing of minerals and fuels. The Mining Department also offered a course for the degree of BSc and a Diploma in Petroleum Mining for those who wished to practise as Petroleum Mining Engineers. The course comprised lectures and laboratory exercises in the principal and practice of mining, boring, surveying, petroleum mining law, and the transport, storage and refining of petroleum. This was a time of rapid development of the petroleum industry in various parts of the world, including the British Colonies, and Cadman was successfully meeting the needs for Petroleum Mining Engineers. Thus the seeds were sown for the establishment of the separate Department of Oil Engineering and Refining. The demand for mining engineers continued to be met by the Department of Mining.

The 1925 handbook giving details of courses in the Department of Oil Engineering and Refining stated that the courses were arranged to meet the requirements of those intending to become oilfield engineers and managers, refinery managers, chemists and engineers, petroleum geologists and technologists. A BSc and Diploma in Oil Engineering and Refining wasavailable requiring three years study after matriculation. A two year 'conversion' course was available for graduates of other science and engineering disciplines. The syllabus contained all the material previously given in the Department of Mining courses with much additional material on the general principles of refining, methods of distillation, design of retorts, stills, condensers, preheaters, agitators, coolers, refrigeration plants and chemical treatment of refined products. Some of the course content was beginning now to resemble a present day syllabus for chemical engineering. An interesting requirement of the 1925 courses was that students should spend at least six vacation months on an oilfield or refinery either at home or abroad before graduation. The present day Department of Chemical Engineering at Birmingham still retains a vacation course work requirement but of six weeks duration.

The course descriptions in 1941 immediately prior to the appointment of F H Garner were essentially the same as in the 1920s but the term Chemical Engineering was now in use. Chemical Engineer had been added to the list of careers for the graduates but more significantly a new laboratory course on chemical engineering as applied to refining was included. There were experiments to study heat transmission in exchangers and condensers and there was equipment for batch and continuous distillation with semi-commercial size equipment. The distillation equipment was the most modern available and the only unit of its kind in Europe. F H Garner was appointed Professor of Oil Engineering in 1942 and immediately the course content changed to include the fundamentals of heat and mass transfer, and fluid flow within a course described as Chemical Engineering I. Chemical Engineering II was an extension of I to cover unit operations.

The Department of Chemical Engineering came into existence in 1946 and the handbook for that year states the honours degree of BSc in Chemical Engineering as the primary degree. The Chemical Engineering I and II courses continued but were now supported by extensive tutorials in the solution of chemical engineering plant problems by stoichiometric calculations and the design of plant, equipment and processes. Laboratory work and vacation work in industry also expanded. The degree of BSc in Petroleum Engineering and Petroleum Exploration Geology was available in addition to the main Chemical Engineering degree. The combination of lecture courses, tutorials, design, industrial support and practical work continues to the present day as has variety in the degrees offered.

Petroleum engineering is no longer a feature of the department but degrees of Chemical Engineering with Biochemical Engineering and Chemical Engineering with Minerals Engineering are available in addition to the primary degree of Chemical Engineering.

The biochemical engineering version of the degree was introduced because of the growing biochemical engineering activity within the Department linked to industrial demand. The Minerals Engineering version was a consequence of the amalgamation of the Department of Minerals Engineering within Chemical Engineering in 1984 and a continuing requirement for graduates in the minerals processing industries. Immediately prior to 1984 half of the degree programme in Minerals Engineering comprised courses given in the Department of Chemical Engineering to its undergraduates and thus a Minerals Engineering version of the Chemical Engineering degree was a logical development.

A further aspect of note concerning course development is the relationship with the professional body, The Institution of Chemical Engineers. Effective dialogue between the Department and the Institution has existed from the founding of the Department. Approval of courses is now a formal procedure of re-accreditation every five years and the Department continues to have influence with the professional body in terms of the 'model' degree scheme for accreditation purposes.

6. RESEARCH THEMES

The research theme within the Oil Engineering Department of Professor Nash centred on what we would now call chemical reactor engineering (the work on coal/oil conversions) together with studies on unit operations (notably solvent extraction). In the period 1946-1980, work on mass transfer was pre-eminent. However, in 1958, Garner had founded a course in Biological (sic) Engineering and this gave a base from which to launch growing and successful activities in Biochemical Engineering with Garner's original building being extended substantially and refitted for the demands of modern practice in 1987/88. Since 1980 there has been development of substantial activities in novel continuous ore processing (this coming from Minerals Engineering), solids processing, and mixing in mechanically agitated vessels. The research base has certainly shifted to take account of a modern view of chemical engineering.

7. CONCLUSION

The current strong position of the Department is undoubtedly founded on the vision and hard work of Cadman and Garner. The Department is presently the largest undergraduate school in the United Kingdom and enjoys a substantial research activity and reputation. For example it was recently made one of the Science and Engineering Research Council's two national centres for Process Biochemical Engineering. Secondly, each of the three Professors, (J Bridgwater, A W Nienow and N A Warner) has been elected to the Fellowship of Engineering, thus confirming the significant influence of the Birmingham professoriate within the profession. The Department, University and discipline owe Cadman and Garner a huge debt.

School of Chemical Engineering
University of Birmingham
PO Box 363
Birmingham B15 2TT
England

D.C. Freshwater, B.W. Brooks and A. Foord

LOUGHBOROUGH - THE DEVELOPMENT OF A DEPARTMENT

SUMMARY

The Chemical Engineering Department at Loughborough has existed for some thirty one years although chemical engineering was taught there from 1947. The Department began with some thirty students and three staff and now has about 250 undergraduates, 50 post graduate students, 20 faculty and 20 or so ancillary workers. This paper traces the history of this development and records some of the innovative features which the department has pioneered.

1. INTRODUCTION

Chemical engineering in the U.K. has had a somewhat chequered history(1) despite the early start given to it by Geo.E.-Davis through his 1890's lectures and handbook. Only three institutions, University College (1923), Birmingham University (1930) and Imperial College (1933) can claim to have taught recognisable chemical engineering undergraduate courses prior to W.W.II. Although there are upwards of thirty such courses now in the U.K., all of them are essentially post war developments. At the end of the war the government of the day became aware of the vast superiority of the U.S. chemical industry and wishing to improve that in the U.K. sent a team of experts to America to see how people were trained for this work. This team led by H.W. Cremer, a distinguished consultant and past president of the Institution of Chemical Engineers published a report with the somewhat odd title of "Chemical Plant in the United States",(2) which recommended a very considerable increase in the number of training places available for chemical engineering. To implement this report the government chose, as the quickest and cheapest way, to set up a series of post-graduate courses in various colleges of technology in which people with degrees in chemistry or mechanical engineering could be "converted" into chemical engineers. Five such courses were approved at the colleges of Battersea (now the University of Surrey), Birmingham (now Aston University), Bradford, Loughborough and Salford.Thus

N. A. Peppas (ed.), One Hundred Years of Chemical Engineering, 245–261.

in 1947, chemical engineering teaching was begun at Loughborough under the government sponsored further education scheme and in one sense at least, its early history is also that of these other colleges.

2. THE BEGINNINGS

It was in January 1947 that the first students of chemical engineering arrived at Loughborough. They comprised some 21 students of whom 6 were ex-service men and all were significantly older that the usual 18 to 21 year olds. They were taught by H.K. Suttle who came from industry with a wide range of chemical engineering experience but more importantly, had a real gift for teaching and a boundless enthusiasm for imparting his knowledge to the students. Suttle was to spend the rest of his working life at Loughborough where he retired as a Reader in Chemical Engineering. His services to the then university were very properly recognised by the award to him of an honorary degree, one of the very few ever given to a member of the teaching staff.

The students in these early post-graduate courses were awarded diplomas which carried with them, exemption from all but part III of the professional examinations of the Institution of Chemical Engineers. This was accomplished not without some trials and tribulations but these properly belong to another story which will be told elsewhere. In passing it should be noticed that the college at this time was still under the direction of Dr. Schofield whose name will always be synonymous with the institution. He was the great entrepreneur of education and the purist historian might be forgiven for doubting the claim in this paper that 1947 saw the start of chemical engineering at Loughborough. There exists a college prospectus for 1936 which lists chemical engineering as one of the departments and purports to give details of a course in this subject(3). This was but a dream of the good Doctor and an example of his sometimes wishful thinking that was not to become reality for ten years.

3. EARLY STEPS

The first post graduate course was undoubtedly successful, many of its products going on to occupy senior positions in the chemical engineering world. It was followed by a similar course and at the same time, an undergraduate course of four years duration was introduced. This was largely on the initiative of Dr. R.F. Phillips who took over as head of the Department of Pure and Applied Science under whose aegis ch-chemical engineering developed.

This undergraduate course enabled qualified students to take the external degree of the University of London. Dr. Phillips was an enthusiast for the subject and saw clearly its potential as a growth point. It was because of his support that the section was enabled to grow by acquiring its own space and additional staff and equipment. Two new members of staff came to assist Mr. Suttle and chemical engineering was provided with space in an aircraft hangar previously used by the college's department of aeronautical engineering. This together with the two Quonset huts left over from wartime constituted the department's space until the end of 1961. The laboratory area was quickly filled with equipment, some generously donated by industry and much was made in the department's own small workshop using cast-off machine tools and second-hand pipe and fittings. Despite these limitations the department had an excellent range of experimental apparatus for all the common unit operations.

In the meantime, the undergraduate course continued to develop and although numbers were not large, it started to take over in size and importance from the post-graduate course. It was at this stage that the college authorities decided that chemical engineering was a significant enough activity to be raised to the status of a separate department.
The college advertised for a head for the new department and Dr. Freshwater, at that time a lecturer in the department at Birmingham University, was appointed. The department of chemical engineering thus officially came into being when he took up his duties in May 1957, just over 10 years since teaching of the subject began at Loughborough.

4. THE DEVELOPMENT YEARS

4.1. Background

Universities in the U.K. fall roughly into three groups: the ancient foundations including Oxford and Cambridge; the civic or "red brick" universities of 19th. century origin in large industrial cities like Birmingham and Manchester (London University is a special case); and the new universities dating from the 1950's when higher education was expanded rapidly. Some of the latter were completely new foundations e.g. Sussex and Warwick but others were developed from the existing colleges of technology including Strathclyde, Surrey and Loughborough.

Loughborough is a small manufacturing town in the East Midlands of England and an unlikely location for a university being neither a regional centre nor old and beautiful. The college began in 1909 as a small technical institute training young workers for the local industries; hosiery, foundries and electrical machinery. However the imagination, energy and persuasive powers of Herbert Schofield, college principal from 1915 to 1953, turned it into a reputable institution offering diplomas, teaching certificates and external London degrees whilst still continuing its role as a local technical college.

It became noted for engineering, craft and design and for training teachers in physical education. It drew students from all parts of Britain and from many overseas countries and built its own residential accommodation. To this day it has the highest proportion of student residential accommodation of any university in the U.K. Its very success led to its being split into four separate colleges in 1952, one of which was the College of Technology.

In 1957 under the conservative government, when H.W. Haselgrave was Principal, the latter college was designated a College of Advanced Technology (CAT) along with 9 others in one of the sporadic attempts by the British Government to arrest the decline of the manufacturing industry.

At the same time, so as to ensure high standards a new qualification, The Diploma in Technology (Dip.Tech.) was invented which was intended to be equivalent to a university first degree. To establish this equivalence a new body was created, The Council for National Academic Awards (C.N.A.A.) to act as both supervising and accrediting agency. This was later to change its names to the National Council for Technological Awards (N.C.T.A.) the title by which it is known to this day. This body was charged with approving courses in the newly designated CATs and eventually, awarding the Dip. Tech. to the students who successfully completed an approved course. However to be approved, a course had to have one important component not present in the conventional university course. This was a substantial element of supervised and relevant training in industry as an integral part of the course. It is necessary to give this background to explain what happened at Loughborough.

4.2. Industrial Training

The first and most important job for the new head of department was to revise the course in chemical engineering so as to meet the requirements of the CNAA and to gain approval for the award of the Dip. Tech. This task resolved into two parts. First to devise a satisfactory industrial training scheme for undergraduates and second to reshape the course to accommodate the periods spent away in industry as well as to prepare the students for this training. Naturally the two problems were not independent and the solution adopted was to send the students out for industrial training in the third year of their course. This had the advantage of (a) being able to send into industry a student who already had a good basic training in chemical engineering fundamentals and (b) allowing industry to have a student for a whole year which reduced the disturbance to the company and meant that the student could be expected to do useful work for a significant part of his time with the organisation. That this was a scheme that commended itself to industry was evident from the relative ease with which they were persuaded to try this new idea. The first year, some 23 students were sent into industry as the "guinea pigs" and from that time on, the industrial training has been an integral part of the Loughborough course. In its essentials, the scheme has changed but little in the thirty years since its inception although there have naturally been details which have developed in its implementation. Three things about it stand out. The first is the emphasis on its integration with the course in chemical engineering. The second is the degree of involvement of the faculty of the department with the company and the student trainee during the industrial period. The third and perhaps most important in the long term is the control of the scheme by the department itself which arranges the placing of students and helps to supervise their training.

The first may be illustrated by the insistence that the training should be real i.e. not a synthetic task invented to fill in the student's time and that it should involve chemical engineering work e.g. routine laboratory testing would not be acceptable. The second is demonstrated by the system of regular visits that the faculty make to each student during the training period and the reports that the student has to submit to the department each month. The third has ensured the evolution of a truly integrated training scheme with control of the training places by the department and not least, a constant refreshing of industrial contacts and experience for the faculty.

This scheme was a major variation on the "Sandwich Training" which usually meant alternating 6 month periods in industry and at college and was almost an article of faith with the C.N.A.A. board. However, they were persuaded to allow us to try this method and so well did it work that at least two other departments of chemical engineering adopted it later.

4.3. The Curricula

Once the framework of industrial training had been agreed it was a relatively easy matter to shape the course so as to fit in with this and at the same time be pedagogically acceptable. Since this paper is being read to a largely North American audience it is desirable to restate that the typical U.K. student enters university with a much greater knowledge of science and mathematic than his American counterpart. thus the first year of a U.K. chemical engineering course may be likened to the sophomore year of a U.S. course. In our case a conscious decision was taken back in 1958 to start the teaching of chemical engineering unit operations in the first year of the course, something that is taken for granted nowadays but which was quite new when we started it. This has two purposes. The first was to make the students aware that they were potential chemical engineers and not overwhelm them with the necessary mathematics and chemistry that they were taught in this year and the second, to lay the groundwork for the more intensive chemical engineering material which would be presented in the second year. Thus we regarded the students at the end of their second (or junior) year as having a good basic chemical engineering knowledge. This was then to be supplemented in their final(senior) year after their training in industry by additional lectures in more advanced chemical engineering topics and in economics and legal aspects.

The immediate result of these changes was what was most desired at the time which was recogntion of the course by the C.N.A.A. for the award of the Dip. Tech. The longer term result was the development of a very successful undergraduate course built upon this base. The next part of this paper will describe the evolution of this course in terms of both content and structure.

4.4. The Revised Undergraduate Course

This had begun in 1950 as a fairly conventional undergraduate course in chemical engineering. It had a "Loughborough" flavour in that it incorporated practical workshop experience in the Colleges own workshops that was such a strong feature of all the engineering courses. It also contained a significant amount of mechanical, structural and electrical engineering.

Both these features were to change in the immediate revisions made necessary by the C.N.A.A. requirements. For one thing, the four academic years had to be compressed into three and this inevitably meant the dropping of some subjects. In addition to this, one of the odder requirements of the C.N.A.A. was that all engineers must be taught "liberal studies". No one knew quite what these were (nor do they now) and many were the discussions that were held about them. The solution we adopted was to teach students something of the history of the chemical industry and of chemical engineering itself. Added to this was an option in a European language and this satisfied the C.N.A.A. The language study option continues to this day and has been useful in unexpected ways. In passing we would deplore these artificial injections of culture from which science and engineering courses in the U.S.A. are suffering today. Surely the real culture comes from a scholarly study of ones own subject since this scholarship rarely exists in isolation? Its practice tends to make the scholar interest himself in many other things of the mind. We have usually found engineers in general and chemical engineers in particular to be well read and knowledgable about the arts to a surprising degree whereas students of the arts boorishly boast about not being able to mend a blown fuse.

Be that as it may, Liberal Studies meant another slice out of the cirriculum and this was compounded by the (welcome) insistance of the C.N.A.A. on time for private study, thus getting away from the typical technical college philosophy that every waking hour must be timetabled. As a result of these constraints perhaps the first course revision was also the most dramatic in terms of time and subject although it was to turn out not to be the most significant in the long term. Having inserted a year of practical training in industry, the college workshop training was dropped. The mechanical and structural engineering also went soon to be followed by electrical engineering courses. Not all the gaps were filled but what space remained was largely taken up by more mathematics and also chemical engineering topics in earlier years. A typical distribution of subjects in the 60's is shown in Table I. where it is compared with that of a the average U.S. department at the same period (4).

4.5. New Developments in Teaching

Having slimmed down the syllabus cutting out all but the absolute essentials the next significant development was the introduction of new subject areas. The first of these was Particle Technology and it is thought that Loughborough was the first to teach this as a separate topic in an undergraduate course. This reflected both our growing awareness of its importance in the processing world and also our developing research interests in the area which was begun by the late Dr. N.J. Hassett.

At the same time we bagan to develop senior level courses in process control and optimisation which again reflected a research interest that was growing under two new faculty members, Dr. H.W. Kropholler and Dr. D.J. Spikins.

The second major innovation at this period was to change the shape of the senior year from the traditional three terms of teaching with final examinations at the end, to two terms of teaching followed by finals and then spending the whole of the Summer term on the design project. This had the advantages of enabling the students to work on their design having completed all their theoretical studies and at the same time, to have no other commitments to distract them from this major task. Moreover it meant working under pressure to a strict timetable in a simalcrum of the industrial situation. These were, and still seem to us, to be powerful arguments which have persuaded us to continue to practice this rather unconventional timing.

About this time, the Head of Department spent several months in the U.S.A. and returned with a whole new set of ideas not so much about the teaching of chemical engineering as about new paths that were developing in subject. It was as a direct result of this that one of our research groups was started and the report of that visit influenced the development of the department for a number of years (5).

So the course was gradually shaped to correspond with that which it has at the present time. Amongst the changes that have occurred are those in laboratory teaching including computing and the development of a wide ranging options system in the final or senior year, and the spreading of design teaching throughout all three years of the course.

4.6. Laboratory Work

For a long time, many of us were somewhat dissatisfied with the coventional approach to laboratory work involving set experiments which were supposed to illustrate theory taught earlier but often either lagged far behind or was significantly ahead of the classwork. A solution to this problem came by the introduction of project work to replace the conventional laboratories. By about 1966 an experimental project in the second year was being used to give experience of solving open-ended practical problems and this was followed in the late 60's by design projects which were largely experimental or mini-research studies.

At the same time, first year laboratory work in chemical engineering was introduced. This comprises a series of relatively simple experiments, mostly on physio-chemical principles. A number of these show that innovation and ingenuity continued to flourish in the department and they are described in a departmental publication (6). Not only did these serve to introduce the students to some elementary chemical engineering ideas but also provided a useful transition from the school laboratory to that of the university.

Over the years the absolute time devoted to laboratory work has changed significantly but the proportion of timetabled hours remains much the same.

5. STUDENTS

One quantifiable measure of relative performance amongst British universities is the grade average of undergraduates at entry. Almost all entrants are selected through a central system (UCCA) by offering places conditional upon gaining specified grades in advanced level examinations (A-levels) of the general certificate of education. These are nationally held public examinations normally taken at the age of 18. Pass grades run from A through E and by counting one point for E, two for D and so on, candidates can be ascribed scores which are reasonably comparable for a given set of subjects.

Almost all chemical engineering students take three A-levels, Chemistry, Physics and Mathematics giving a possible maximum score of 15 on this basis. The pre-1966 Colleges of Advanced Technology usually recruited students with low A-level scores, or with other qualifications gained after leaving school at age 16, e.g. National Certificate in Engineering. In 1962, the average score for Loughborough chemical engineers was about 4. As soon as the College became a university, the asking grade was raised to 8 points with the effect that the department moved at once into a higher echelon. Although progress has not been smooth, a keen eye to market forces by successive admissions tutors has helped put it amongst the leaders (on this criterion) with an average score of 13 points over the last eight years. In 1986, Loughborough was the most popular department, with about one third of all chemical engineering applicants making it their first choice. It had the third largest intake that year.

6. FACULTY

Students come and go unceasingly but faculty, like the poor, are with us always. They are usually the longest enduring and certainly the most important component in the department and without a strong and enthusiastic faculty no department can flourish or be successful. It is therefore worth examining the build up of this in the department. From the first it was intended to have as heterogeneous a body as possible. The dangers of inbreeding were not present since there were not enough older graduates to fill faculty positions. Thus the problem of recruitment resolved into getting good people from other schools. In the expansionist atmosphere of the late 60's and early 70's this proved to be not too difficult and the department was indeed fortunate to recruit some outstanding people. Three of these have subsequently obtained chairs elsewhere and two have been elected to chairs in the department. These were not the only measures of success and one must note the contribution of others to the build-up of research and the development of the undergraduate course. The expansionist atmosphere of the period also helped and most of the new faculty people were in their late twenties and early thirties direct from industry and with experience of process design and development. Up to about 1966, Ph.D's were the exception: some faculty were recruited primarily as researchers and completed their doctorates soon after becoming tenured. Others completed Ph.D's as a means to advancement in their later careers. As the department became better known it proved possible to recruit post-doctoral fellows.

There is little doubt that this young and adaptable faculty, free from the inertia of long teaching experience and willing to learn from their mistakes, ensured that new teaching ideas and initiatives were promptly taken up in the 1960's with sufficient vigour to secure the intellectual basis of the course.

The faculty grew in what was almost a geometric progression in the late 60's and in one year no less than 5 new members joined the department. In their original schools they represented eleven different universities and as well as chemical engineers, including three whose first degree was in chemistry, two physicists, two mechanical engineers and one mathematician. This spread of talents and origins did much to keep the department broad in its outlook as well as receptive to ideas from other institutions. Perhaps, most important of all, it brought in new ideas on research which were vital to an institution which had no research tradition and had to develop this from scratch.

7. RESEARCH

One of the tasks of the new department was to develop research as in those days it was regarded as axiomatic that good teaching had to be founded on good research - a gospel that is now seriously challenged largely because it is politically expedient to discourage university research. Our philosophy was that of a former chairman of the U.G.C. who wrote "he who learns from one who has finished learning, drinks from the green water of the stagnant pool". However developing a research school is easier said than done. Our solution to this was to propose a series of research groups so as to make the most of limied resources and to foster what were perceived to be fruitful ideas within a particular grouping. The original groupings were not plucked out of the air but were formulated around ideas and interests of members of the faculty sctively engaged in experimental research. Like all U.K. departments at the time, funds were available within the system to support research and could be allocated at the discretion of the department head. Other funds e.g. from research councils were available in theory but to get these one had to have a proven record of research and so to start with, new departments like Loughborough had to depend on their own resourses. The departmental policy then was to allocate its limited resources mainly to the research groups but always having some money to support ideas of individuals who didn't fit in or didn't wish to belong to a group. Independent lines of research were sometimes very successful as in the work of Teja and Rice in predicting fluid properties and Mason's work on porous media.

However the department is known for its particle technology group (with its information science service), its work on polymerisation reactions and residence time distribution theories, all originating with research groups.

Two strong research groups which developed almost immediately, were in Particle Technology and in Process Dynamics. In the course of time the first became bigger and better known whilst the second, after a fruitful period, declined and virtually disappeared due to the faculty in this group moving elsewhere. However, as one group declined another began and grew to take up the "space" that was left. Thus another group started in food engineering, now our largest research group and soon afterwards came the development of Loss Prevention which is currently perhaps the best known of the departments research efforts. The refereed Elsevier periodical, "The Chemical Engineering Journal" was founded by two members of the department and has been edited at Loughborough since its launch in 1970.

All this took place against a growing acceptance of the department as a research as well as a teaching establishment. This was reflected in the growth in outside funding for research which soon outstripped that received from the university. University administrators have different and sometimes odd ways of measuring the productivity of a department. The favourite at Loughborough recently has been the ratio between external funding and internal resourses the par figure being 1:1. Chemical engineering achieved this in 1977, at that time the second department to do so and has beaten the par by various margins ever since. Of this outside funding more than half has consistently been from industry with the remainder from S.E.R.C. (the U.K. equivalent of N.S.F.) and government departments.

In more objective terms, in a recent survey by the U.G.C., the departments research was rated above average, one of 7 such ratings out of the twenty or so departments in the U.K.(5). A similar recent rating of undergraduate teaching put Loughborough amongst the top five departments.

8. CONCLUSIONS

A paper such as this hardly has conclusions because it is in the nature of a report on a situation that is still developing. One cannot say "go out and do likewise" because conditions are so completely different. Neither can one turn back the clock and start again. Perhaps what it does show is the futility of the argument being put forward in many circles in the U.K. at present to the effect that big is beautiful. It is being argued that scarce resources would be better used by closing down some engineering schools which are small and transferring their work to larger schools. If this argument were correct then Loughborough itself, a successful modern university by outside tests, would not exist let alone its chemical engineering department. As Dr. Johnson remarked about Berkley's philosophy, "Sir, I refute it thus." Essentially then, this paper is an argument in favour of freedom to experiment and to be entrepreneurial in engineering education as well as in commerce. It is a lesson that sadly needs reinforcing in the world in which we live today.

Department of Chemical Engineering
Louisiana State University
Baton Rouge, Louisiana 40803-7300, USA

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Table 1

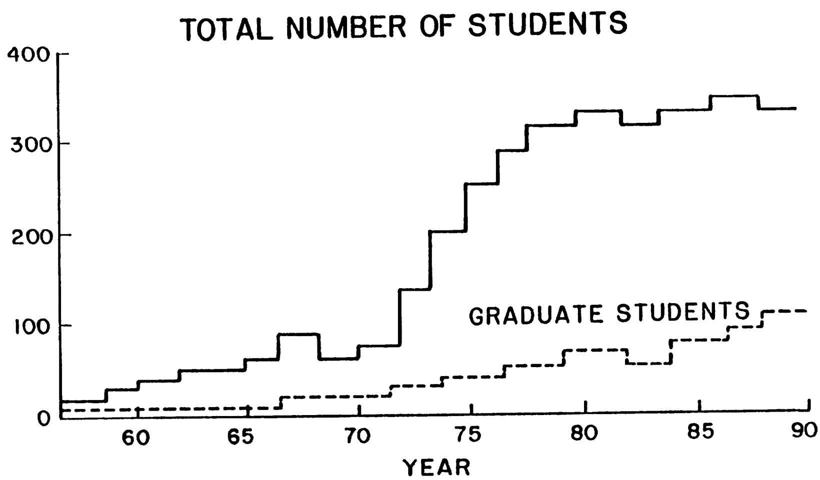
Percentage of Total Undergraduate hours spent on particular areas

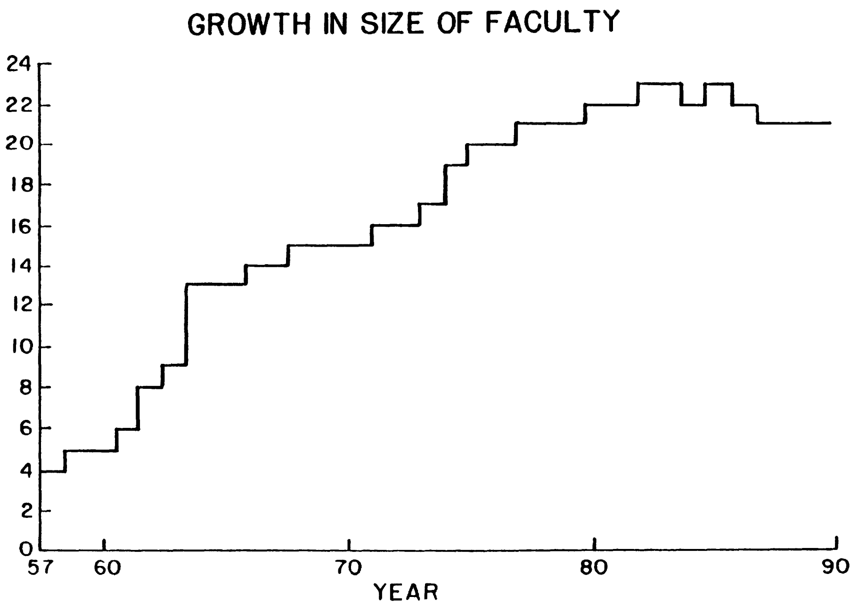
Comparison of U.S. and U.K. Course

Subject	% time in U.S.	% time U.K. (Loughborough)
Culture	12	10
Chemistry	21	13.4
Mathematics	12	23.6
Unit Operations	27	21
Chemical Reaction Engineering	7	8
Control	12	10.5
Design	6	7.5
Electives	3	6

Note:1) U.S. figures are averages for 90 institutions.
Note:2) The word "culture" is taken directly from the reference cited.

CHARTS SHOWING DEVELOPMENT OF CHEMICAL ENGINEERING AT LOUGHBOROUGH




GROWTH IN SIZE OF FACULTY
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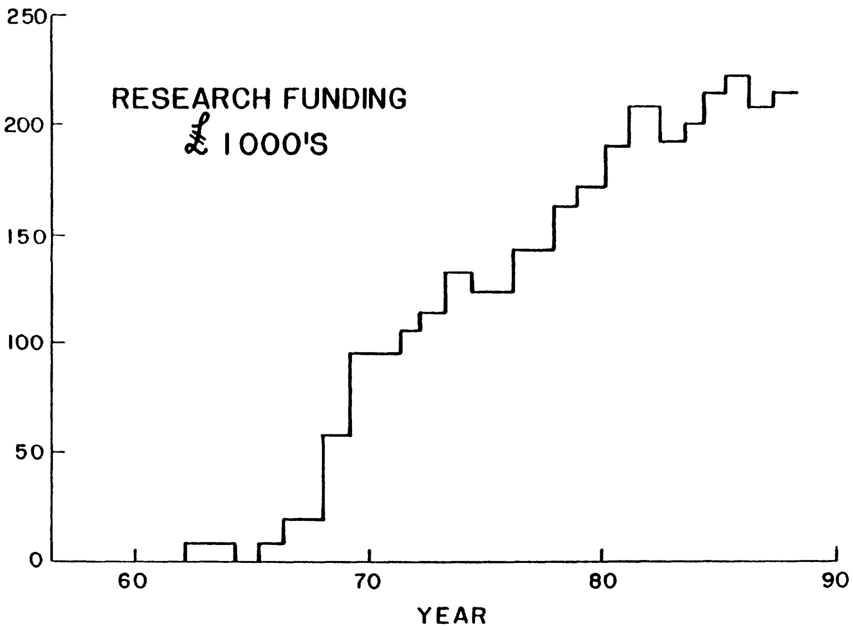
RESEARCH FUNDING
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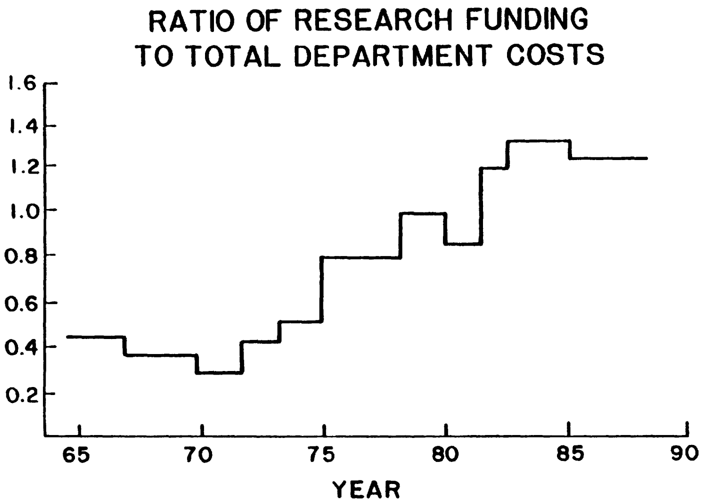
RATIO OF RESEARCH FUNDING
TO TOTAL DEPARTMENT COSTS
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
65
70
75
80
85
90
YEAR

Nikolaos A. Peppas and Ronald S. Harland

CHEMICAL ENGINEERING AT PURDUE UNIVERSITY

1. Chemical Engineering Before 1911

In the open fields of Indiana, roughly equidistant between Gary and Indianapolis and built on the then navigable Wabash river, lay in the middle 19th century a small town of 4,000 inhabitants, the town of Lafayette. A trade center for northwest Indiana, the town was inhabited mostly by German and Anglosaxon farmers and traders. As a result of the 1862 Morrill Act, the General Assembly of Indiana voted in 1865 to establish a land-grant university (1). The fierce competition between various towns continued for four years with Monroe, Marion and Tippecanoe counties becoming the three finalists. Finally, the balance tilted in favor of Lafayette, mainly because of the then generous contribution of $150,000 by John Purdue, $50,000 by the Tippecanoe County and 100 acres of land from local residents. Thus, in the fourth and final ballot in the Indiana House, Tippecanoe county received 52 votes, with 17 voting for Monroe and 8 for Marion county. In the Senate questions arose and the representatives of Bloomington (Monroe county) and Indianapolis (Marion county) "stigmatized as selfish vanity for Mr. Purdue to ask that the institution be named Purdue University (1)." On May 4, 1869 Purdue's offer was accepted with 32 to 10 votes in the Senate and 76 to 19 in the House.

The University was built in the village of Chauncey (now West Lafayette), on the right bank of the Wabash river opposite Lafayette at an equal distance between Fort Ouiatenon and the site of the battle of Tippecanoe. The first regular classes began on September 16, 1874 and the first degree was awarded in June 1875 to John B. Harper; it was a B.S. degree without designation. Engineering was one of the first subjects taught, and Mechanical (1882) and Civil Engineering (1887) were some of the very early Schools.

The Chemistry Department of Purdue was established in 1874. Under the expert leadership of several professors, especially Harvey Washington Wiley, who was probably the most influential figure of the University from 1871 to 1885, it soon developed a national reputation (2).

N. A. Peppas (ed.), One Hundred Years of Chemical Engineering, 263–299.

Thus, it was not surprising that its pioneering Head Percy N. Evans suggested in 1900 that some industrial applications be incorporated in the course Chem 15, *Technical Analysis*. Evans was fascinated by the news he was receiving from MIT about the development of a chemical engineering curriculum, and by a copy of Davis' *Handbook* that had just been purchased by the Purdue Library. Therefore, in September 1902 he offered for the first time the course Chem 7, *Industrial Organic Chemistry Lectures*, to a select group of undergraduate students in Chemistry. In the course he covered such diverse subjects as aniline chemistry, production of sulfuric acid and production of steel.

Chem 7, the first chemical engineering course given at Purdue University, became immediately a very popular course among Chemistry students. Thus, in 1904 Evans introduced three more courses: Chem 9 and 10 *Industrial Chemistry and Technical Analysis*, and Chem 24 *Metallurgy*, which he shared with Edward G. Mahin (later Professor Mahin of the Metallurgy and Chemical Engineering Departments (1925-1933) of the University of Notre Dame).

Evans was very much affected by the writings of Davis and then Thorpe of MIT. The term chemical engineering sounded to him like a good description of the plan of study he was developing around the courses Chem 7, 9, 10, 15 and 24. Thus, in 1906 he approached Dean William F.M. Goss (Dean of the Schools of Engineering, 1900-1907) and asked for his support in establishing a chemical engineering curriculum in the Chemistry Department. Goss was very positive (3).

December 20, 1906 is one of the two most important dates in the history of Chemical Engineering at Purdue. On that date the faculty approved the new curriculum. This approval was followed by approval by the Board of Trustees upon recommendation by President Winthrop E. Stone (1900-1921) on April 26, 1907. Here is a portion of the recommendation (4) of President Stone:

> A distinct course has been arranged by combining certain subjects in chemistry and engineering now taught in the Schools of Science and Engineering. Such a combination has not before been available to a student of any of these Schools. The purpose is to train students for service in those industries which involve the application of the principles of both chemistry and engineering. It includes the subjects of chemical science and the elements of engineering such as shop practice, drawing, mechanics and electricity, together with the general cultural subjects required of all candidates for the bachelor's degree.

This was the beginning of chemical engineering at Purdue. But as Bray (5) points out "there was no Head, no staff, no laboratory, only a plan of study."

In May 1909 51 students were registered in the new curriculum, 29 freshmen, 19 sophomores, 2 juniors and one senior. The senior, who graduated in June 1909, Benjamin M. Ferguson (1886-1965), has the honor of being the first Purdue graduate to receive a B.S. in Chemical Engineering.

The class of 1911 had 79 registered students! For a young curriculum that had started only five years earlier this was an impressive number. A large number of the students were residents of Indiana; and the industrial revolution of Gary, South Chicago and more generally the Midwest had its impact on the career plans of the high school seniors of that period. Purdue had already developed a reputation for its excellent engineering program, and President Stone was sure that Purdue would be a prime University to establish an independent School of Chemical Engineering.

2. Early Development of the School (1911-1934)

In the minutes of the meeting of the Board of Trustees (6) of June 14, 1911, the following entry can be found as item 18:

> Four years ago a new course of study in Chemical Engineering was established. It has steadily made progress and the first class of ten students has now been graduated. The enrollment in this department during the present year was 32 freshmen, 22 sophomores, 15 juniors and 10 seniors, or 79 in all.
>
> Thus far the department has had no distinctive head. Having now become established along what seems to be the right lines, it is recommended that the department be designated as the School of Chemical Engineering, of coordinate rank with the other Schools of the University, and that there be appointed a Head for the School of similar rank and responsibility with the Heads of other Schools of the University.
>
> For this position I recommend Mr. H.C. Peffer, a graduate of Pennsylvania State College, and a man of rather unusual experience in the field of Chemical Engineering and who has agreed to accept the appointment at an annual salary of $2250.

Figure 1. Professor Harry C. Peffer, the first Head of the School, in 1911, the year he arrived in West Lafayette.

Figure 2. The Purdue Hall, where the School was housed from 1923 to 1930.

President Stone's recommendation was approved by the Board of Trustees and on June 14, 1911 the School of Chemical Engineering was a reality.

Harry C. Peffer, the first faculty member and Head of Chemical Engineering, arrived at Purdue in October 1911 and had many problems to attend to and obstacles to overcome. He revised the plan of study adding chemical engineering courses, but also adding more courses in chemistry, engineering, economics and German language. Later he added physical chemistry to the plan of study. Stone was correct in his prediction. By 1915, just four years after Peffer's arrival, the School had 138 enrolled students, 57 of them freshmen.

Indeed, very early in the School's history the ChE curriculum became quite demanding. This reputation started spreading all over the campus, to the delight and pride of "the Chemicals," as chemical engineers were called then. The *Debris* (the University yearbook) of 1927 (7) states that "it is a popular belief, and without a doubt a truthful one, that the Chemical *(sic)* course is the toughest in the curriculum. At least the 'chemicals' manage to put in more hours per week in school than any of their classmates in the other engineering courses." And in the *Debris* of 1929 we find (8): "As members of the most difficult and consequently the smallest school in the university, the chemical engineers have long considered themselves somewhat exclusive."

In 1913 the first graduate student enrolled in Chemical Engineering. The first advanced degree awarded by the School was a professional degree of Ch.E. given to Merle R. Meacham in 1916. One more professional Ch.E. degree was offered in 1921 and two in 1922. However, it would take another five years before the School graduated its first M.S. student, Ernest H. Hartwig.

A *Chemical Engineering Society* was formed (9) in 1911 with Professor Peffer as its advisor. It was progressively changed to an AIChE Student Chapter. The Catalyst Club was formed much later, in 1922.

Peffer was trying to do whatever he could with the minimal facilities he had and the non-existent support he was getting from the University. For example, the reader must note that in the Spring of 1923 Peffer was in charge of 176 students! However, one cannot avoid comparing this with some of the Departments that were competing for recognition (10) in chemical engineering. In 1923 MIT had seven professors (11) (W.K. Lewis, W.H. McAdams, C. Robinson, R.T. Haslam, W. Whitman, H.C. Weber and W.P. Ryan), the University of Michigan (12) six (A.E. White, W.L. Badger, C. Upthegrove, J.C. Brier, E.H. Leslie and G.G. Brown), the University of Wisconsin (13) four (C.F. Burgess, O.L. Kowalke, O.P. Watts and O.A. Hougen) and Purdue only one! If this was any consolation to Peffer, Purdue had the largest number of graduates with B.S. degrees. But it would take many years before it had also a respectable graduate program.

As mentioned earlier, students had been enrolled in the graduate program of Chemical Engineering since 1913. These however were difficult times because of the War. It was not until 1921 that Ernest H. Hartwig (a 1919 B.S. graduate) received the first M.S. degree given by Chemical Engineering.

A highpoint in the history of the School and the life of Harry Peffer occurred in the summer of 1923. Fifty seven B.S. graduates (the largest number in this country) and one M.S. student had just finished their studies and the new enrollments were showing that the School was growing beyond any expectations. A total of 176 students had registered in chemical engineering. Peffer made his point to Dean Andrey Abraham Potter (1882-1979, dean from 1920 to 1953) and he finally succeeded in obtaining a series of concessions that would bring the status of the School to a more prominent position.

In the Fall of 1923, the School was moved to the south half of the building Purdue Hall. Equipment was finally purchased and a laboratory was started with the help of Dean Potter. And finally, a second faculty member was hired, a young MIT graduate, John L. Bray, who became an Assistant Professor.

Major changes in the curriculum were also occurring so that in September 1923 a revised plan of study was proposed with courses in elements of chemical engineering, thermochemistry, metallurgy, mineralogy and general engineering. After 1922 faculty members from other Departments had started helping Peffer in teaching.

Amidst all the difficulties of the early years and the large number of students that he had to advise or teach, Peffer found the time to do research. His first "publication" from his years at Purdue, indeed the first original research done in chemical engineering at Purdue University, appeared in 1923 in the form of a U.S. Patent (No. 1,465,173 issued August 14, 1923) with H.C. Pierce on *Electrodeposition of Co and Cr.*

Even after 1923, the funds available for research equipment were insufficient (3). Thus, Peffer decided to concentrate on one specific area of research, one that was quite prominent in the structure of the early ChE program, metallurgy. For the next 30 years Purdue's School of Chemical

Engineering remained a leading research institution in metallurgical engineering because of the contributions of Peffer and Bray.

In 1924 a new student society was started at Purdue, the AIChE Student Chapter. Originally a Chemical Engineering Society loosely associated with AIChE, it was the fifth Chapter of the Institute. It became a full chapter in 1929. Harry Peffer served as its advisor until 1934.

The academic year 1924-25 saw a major reorganization of the graduate program of the School. Until then, graduate studies consisted only of the preparation of a thesis much as in the German educational system. The first graduate course given was, logically enough, ChE 108, *Advanced Metallurgy*. The first real ChE graduate course - *Advanced Chemical Engineering* - was instituted in 1925 and it was taught by Peffer. This course was a rather primitive approach to unit operations, although by 1927 the famous book by Walker, Lewis and McAdams of MIT was adopted as a text.

A survey of the employment of the 1911-1924 graduates taken in 1926 shows that out of 331 responding alumni 17.5% were employed as "chemists," 37.2% as "engineers," 7% as "metallurgists," 19.6% as "executives" (an impressive number indeed), 3.3% as "teachers," 3.3% as graduate students and the rest were in other functions. In fact, employment of ChE graduates was not a problem even during the depression years, as the *Debris* of 1932 notes (14): "Due to his broad and inclusive foundation in fundamental sciences, the chemical engineer has demonstrated himself to be the most versatile and adaptable member of the engineering profession. The increasing demand in this field is illustrated by the fact that during normal times the openings available for Purdue graduates in chemical engineering are several times the number of those graduating; during the depression period, over three-fourths of the graduates of this school had positions on graduation."

The School was now mature enough to proceed with the hiring of its third faculty member, Professor Harold L. Maxwell, who joined the faculty in September 1926 as an Associate Professor. This was a much needed addition, not only because the enrollment had increased to 218 students and the teaching load was becoming difficult for Bray and Peffer, but also because Professor Maxwell brought to the School the prestige of a Ph.D. degree (Ph.D. '24 Iowa State), much needed for a School that was organizing a graduate program. Indeed, Peffer never received a Ph.D. degree, a normal event in those days for a professor, and Bray received it from MIT several years later, in 1930, while a full Professor.

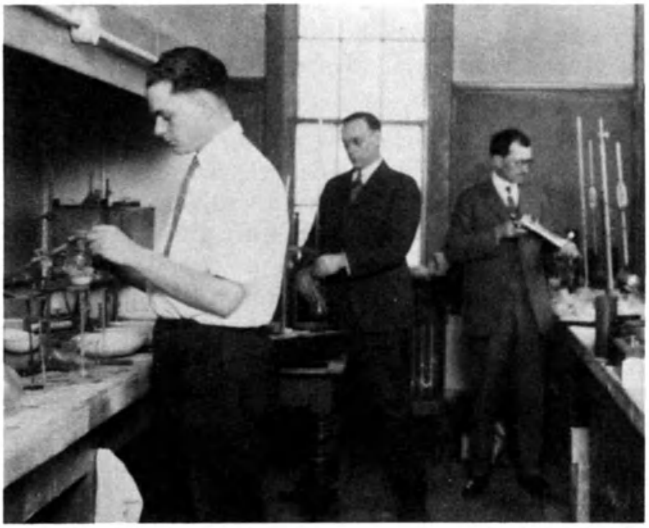

Figure 3. A rare photograph of Professor Harry Peffer (right) and his students doing research in the first ChE laboratories in 1925.

Bray and Maxwell had research interests in metallurgy. Thus, they sought to establish an independent graduate program in Metallurgical Engineering. It is not clear how students and professors decided how to classify the theses written during that period and it took significant search in old files and the registrar's office to discover that the first M.S. thesis in Metallurgical Engineering was written by Charles Gregory Dryer (M.S. '30) under the supervision of H.L. Maxwell. The subject was *A Metallographic Study of Failures in Boiler Plates.*

In 1930 the School had rather strong programs ("options" as they were called) in Metallurgy, Gas Engineering and Geology. But a major component of the curriculum of those days, Organic Chemical Technology, was not available. One could not think of a good Chemical Engineering Department without a thorough analysis of the processes needed for production and treatment of organic chemicals. Harry Peffer and Richard B. Moore, then Head of the Department of Chemistry and Dean of the School of Science, spent a major portion of 1929 and the Spring of 1930 trying to attract to the School an already successful industrial chemist who had his own private consulting practice, a 1907 A.B. graduate *summa cum laude* of Harvard University, who would become the most influential chemical engineer at Purdue, and one of the most important academic researchers and educators of the pre-and early post-World War II era, R. Norris "Benny" Shreve. Shreve was finally convinced to join Purdue in the summer of 1930, at age 45, first as an Associate Professor and after 1931 as Full Professor. On March 11, 1931 he was writing (15): "I do not know whether you by chance saw notices about my joining the faculty of Purdue University or not. The fact is that last summer I was *persuaded* (the italics are the authors') by this institution to start new work here in Organic Technology... The work turns out to be very interesting and particularly so to a man of my training, since this institution is preeminently an engineering one, laying stress upon industrial training, industrial research and industrial contacts."

With Maxwell's departure, Shreve's arrival and Bray's return from MIT, the faculty had six professors, several instructors or part-time faculty (usually from other Schools) teaching peripheral courses and an impressive number of 441 enrolled students with 58 B.S. graduates and 7 M.S. graduates in May 1933. After 1932 the curriculum had been modernized with new courses in organic chemical technology, plant design, etc. and six options: General, Metallurgical, Gas, Military and Chemical Engineering, and Organic Technology.

At this point, some changes in education must be mentioned. An internal survey of the "requirements" of the chemical engineering curriculum in 1926 had shown that although Purdue was doing well in terms of courses in mathematics, physics, mechanics and "other engineering" with respect to the AIChE-recommended curriculum ("arbitrary" as the anonymous writer of the report was calling it), only 5.7% of the courses were truly ChE, with AIChE recommending 10.3%.

Harry C. Peffer came to Purdue in 1911 at the age of 38, to start an obscure program alone, without laboratories or offices, without assistants or substantial funds, only with great enthusiasm and conviction that what he was doing would pay off. He molded a chemical engineering curriculum that was perfect for students who went to industry. He had 768 B.S. students graduate under his supervision, and started a graduate program that by 1934 had produced 24 M.S. and 26 professional Ch.E. and Met.E. degrees - an impressive number for the standards of that time. When he died in 1934, he had molded a Department that was recognized nationwide.

3. The Origins of the Purdue Educational Philosophy (1934-1951)

To the casual reader of the chronological evolution of chemical engineering, major changes and achievements in this field occurred slowly, progressively and with a certain methodology, often by adaptations of universities to the needs of a particular era. For the deeper researcher of historical facts, however, it is evident that major directions in chemical engineering education and research, important changes in philosophy and practice, and exhibition of far-reaching insight into the future needs of the chemical engineering profession are usually traced, programmed, and controlled by a strong person, a gifted leader with characteristic attributes and (often) with an unusual background. Warren K. Lewis at MIT, George G. Brown at Michigan, Olaf A. Hougen at Wisconsin, Neal R. Amundson at Minnesota and Allan P. Colburn at Delaware were some of these gifted leaders who changed the course of chemical engineering. For Purdue, this important leader, who shaped the directions of research and education from 1930 until approximately 1960, was R. Norris Shreve, the mature consultant and industrial chemist that Professors Moore and Peffer had tried to attract to Purdue so eagerly in 1929.

Shreve was Head at Purdue for a relatively short period of time (1947-51). He was, however, the most active researcher, externally the most recognized faculty member of the School and the most successful promoter of the graduate program. His directions were "accepted" and his ideas soon became the *credo* of almost the entire ChE faculty at Purdue University. His zenith was achieved during the years of headship of John L. Bray (1935-47). Especially after 1943 when Bray was weakened by continuous illness, Shreve was effectively the captain of the ship, the leader of the School.

On July 1, 1935 John Leighton Bray, the faculty member with the longest tenure, was appointed to succeed Peffer as the second Head of the School. Bray had joined the School in 1923 with only a B.S. from MIT (1912) but with significant industrial experience which included several years as a mining engineer in Chile, Honduras, Canada (British Columbia) and USA (New York).

Bray's early research was on metallurgical processes, the subject that would occupy him throughout his career at Purdue. He took a leave of absence in 1929 and returned to MIT where he completed his Ph.D. that he had started writing at Purdue, working under the direction of Professor R. Williams in the Metallurgical Engineering Department (now the Department of Materials Science).

He returned to Lafayette in August 1930 in time to welcome a new faculty member who was about to join Purdue a month later, R. Norris Shreve. The first four years of Shreve's presence at Purdue were years of great activity. Bray and Shreve concentrated on the development of the graduate program and by 1934 several Ph.D. students had enrolled. Laboratory equipment was brought in with various funds, most of which were coming from the industrial contacts of Shreve. The lack of a Ph.D. program until then was not totally unacceptable in a "good" Chemical Engineering Department. R.C. Reid states (17) that the first Ph.D. degrees in chemical engineering were awarded to C.H. Herty and J.L. Keats of MIT in 1924. Soon thereafter the Universities of Michigan and Wisconsin, Columbia and the University of Pennsylvania gave their first Ph.D. degrees in the same area. Thus, Purdue was not far behind other leading Schools.

In the fall of 1934 Clifton Lee Lovell (1901-1948, Ph.D. '31 University of Iowa) was appointed Assistant Professor. He inherited the *Chemical Engineering* course originally taught by Peffer which he soon changed and developed into a course in *Unit Operations*. He was instrumental in promoting the "acceptance" and teaching of the "MIT system" at Purdue. He used modern textbooks and was liked by the students. In 1935 he became professor in charge of the Summer Session of Chemical Engineering. He became ill in 1946 and was obliged to take a leave of absence in 1947. He passed away in 1948. His research was in the forefront of chemical engineering of those days as he worked on distillation, evaporation and heat transfer. He supervised 5 Ph.D. and 32 M.S. students, more than any other faculty member of those times, except for Shreve.

Clifton Lovell was a great pioneer of the School, a man with far-reaching insight into the future of the School and chemical engineering in general. The reader interested in academic genealogy may find it a bit more than coincidental that Lovell was a student of George H. Coleman (a distinguished industrial chemist at the University of Iowa) and almost a contemporary of H. Frazer Johnstone who moved to the University of Illinois, where he created a great Ch.E. Department. Lovell was a pioneer in research. He supervised the first ever ChE theses in fluid mechanics, distillation and biochemical engineering. His contributions to education are also numerous. Olaf A. Hougen (18) of the University of Wisconsin, remarks also that the introduction of unit operations by Walker, Lewis and McAdams of MIT during the 1920's "marked the beginning of the distinctive American system of chemical engineering education." This was the approach strongly supported by Professor Lovell at Purdue University.

Meanwhile, the research program of Shreve was maturing and in May 1935 he offered for the approval of the faculty the first two Ph.D. candidates of the School. The two men who had this honor were William N. Pritchard, Jr., who graduated on May 21, 1935, and Miller W. Swaney, who graduated on May 24, 1935. The graduation of the first two Ph.D. students in May 1935 was an event worthy of every celebration. Perhaps an even more important event was the graduation of the first woman chemical engineer, Elizabeth Henius, in June 1935.

When John L. Bray became Head of the School he changed the name of the School to "School of Chemical and Metallurgical Engineering." Then, a required summer session was instituted for juniors to work in a unit operations laboratory with Clifton Lovell in charge.

Bray had to face three major problems early in his Headship. First, the enrollment in Chemical Engineering was reaching explosive proportions. In March 1936 there were 450 undergraduates (156 freshmen, 99 sophomores, 95 juniors and 74 seniors) and 27 graduate students, seven of them Ph.D. candidates, with only four professors (Bray, Serviss, Shreve and Lovell) although several instructors and professors from other Schools were helping. An announcement made by Potter in April 1936 that a new program, General Engineering, was to be formed starting the next fall (where all the freshmen engineers could be educated) would not change the situation much, since in the fall of 1936 the School had 356 sophomores, juniors and seniors.

By June 1937 a monumental decision had been made. The sophomore admission standards from General (Freshman) to Chemical Engineering would be raised to achieve a certain screening of students and hopefully a decreased enrollment. This measure gave some initial results (reduction of the 1941 senior class by 32%) until the World War II years and the G.I. bill led to the biggest enrollment the School has ever seen.

Bray's second problem, a lack of sufficient faculty, was solved by funds made available to him, but often with strings attached, which did not allow him to do a serious national search for new faculty members.

The third problem was the construction of a new building. Already in 1935 it was evident to Bray, Shreve and Lovell that with its growing graduate program, the School would be unable to satisfy the demand for graduate research space in Heavilon Hall by 1936. President Elliott, to his credit, recognized the need for a new building, which became a reality in 1940. New equipment was being purchased continuously, because after 1937 the research programs of Bray, Lovell and especially of Shreve were increasing almost exponentially. To be sure, the younger faculty members were also active in research. In 1939 the School had more than 60 enrolled full-time graduate students (30 of them for the Ph.D. program), 52 of them supported as "fellows" or "research assistants" and 8 as "teaching assistants."

In 1939 the graduate plan of study included 18 courses and *two* foreign languages. However, there were neither qualifying examinations for admission to the Ph.D. program, nor preliminary examinations, only a Ph.D. thesis defense for which a faculty committee of six or more was required. It was only in 1949 that the number of faculty members of a thesis committee was reduced to three, and only in 1953 that C.O. Bennett, J.M. Smith and H.C. Van Ness demanded the institution of *qualifying examinations* as a method of screening the students who wished to perform a Ph.D. thesis.

Another interesting attitude of the 1930's was the conviction of the faculty that technical German should be a required course for chemical engineers. These were the pre-World War II years, when *Ullman, Beilstein, Gmelin* and the *Zentralblatt* were the main sources of chemical engineering education and research, or, if you wish, chemistry research.

The fifth faculty member to join Chemical Engineering in 1937 would stay here 23 years until his retirement in 1960, when he became the

Figure 4. Professor Clifton L. Lovell (1901-1948), shown here in a 1941 photograph, was instrumental in modernizing the School with the introduction of fluid mechanics, separations, heat and mass transfer and other related courses.

first Professor of Chemical Engineering to receive the title Professor Emeritus. George William Sherman, Jr. (1890-1970, M.S. '14 Purdue University, Electrical Engineering) was an electrical engineer who joined Purdue in 1912, thus having the distinction of the faculty member with the longest continuous service to Purdue University, an impressive 48 years. From 1912 to 1937 he was in the Department of Physics, where at the instigation of Professor Peffer he developed a course in pyrometry, namely the study of the techniques of measurement of high and low temperatures. He transferred his course to ChE. Sherman initially had a half-time appointment in ChE and after 1942 a full-time appointment. He became Full Professor in 1948. His course was modernized in 1942 and changed to *Instrumentation* (ChE 155) with the addition of other techniques of measurement such as pH, "height of liquids," velocity and pressure.

Since the mid 1930's, Bray had bombarded Dean Potter with memoranda stating the need for a new building to house the School of Chemical and Metallurgical Engineering. Potter was very supportive of these ideas which he had relayed to President Elliot on several occasions. It soon became obvious that the lack of laboratory facilities and space would severely curtail the research activities of the School, which in the late 1930's were at a high level. Especially concerned about this problem were Shreve, Bray and Lovell, the three most active researchers of the School. For example, in September 1938 the enrollment was 274 sophomores and juniors, 108 seniors, 16 MS and 20 Ph.D. students and it was necessary to limit the graduate enrollment to 35 students.

Finally in 1938, as both Bray (5) and Knoll (16) describe it, "Santa Claus came to Ch.E.," in the form of significant state appropriations. At that time, only the Electrical and Mechanical Engineering Buildings and the Executive Building (now Hovde Hall) existed. During 1938 and 1939 Bray taught very little, concentrating on the design of the building and the allocation of space. Finally, construction was completed in 1940 and the staff moved to the new building, CMET building, in August 1940. At that time Purdue Ch.E. had the most modern building in the country with ample space for all types of operation.

During the Second World War, several faculty members, notably Bray, Shreve, and Lovell, engaged in various projects for the Federal Government. In 1942-45 Shreve and George T. Austin, a 1943 Ph.D. of the School and now Professor Emeritus of the Washington State University, established in the School an accelerated training program (including laboratory) in the manufacture of munitions which was attended by 200 men who eventually worked in the munition factories of the USA.

The post-World War II period of the School began in August 1945 when the educational program went back to the four-year system and Bray was again able to start recruiting faculty members. However, Bray had developed serious health problems and in the last two years of his Headship he would not be able to cope with the tremendous work load of his position. Lovell, stricken in 1946, was pretty much incapacitated (he died in 1948). Thus, in the next few years there was a serious need for teaching and research staff in Unit Operations and Metallurgy and, with the upcoming retirement of Shreve, in unit processes or related subjects. Between 1945 and 1949 nine new Instructors and Professors were appointed to the faculty (R.E. Swift, T.J. Hughel, J.T. McCormack, S.C. Hite, J.C. Lottes, G.M. Enos, T.C. Doody, C.O. Bennett, D. Evers).

In the last two years of Bray's Headship, two professors with similar research interests were hired to start and develop a new (for Purdue University) research field, that of thermodynamics. In the 1930's theoretical and applied thermodynamics became an important research and educational area in ChE, probably triggered by the 1935 publication of the revolutionary textbook on *Thermodynamics for Chemical Engineers* by Harold C. Weber of MIT, later revised by Herman P. Meissner. At the same time the University of Wisconsin was contributing three textbooks that included thermodynamics, chemical kinetics and some reaction engineering, those of Olaf A. Hougen, Kenneth Watson and Ronald A. Ragatz under the general title *Chemical Process Principles*, with subtitles *Material and Energy Balances, Thermodynamics, and Kinetics and Catalysis*.

These textbooks were quickly accepted by all the major Departments of Chemical Engineering. Soon thereafter, industrial recruiters started asking for graduates who had a good knowledge of these "new subjects." At Purdue University, the strong areas of research and education were unit operations, unit processes (or industrial chemistry) and metallurgy. It is to the credit of Bray that he recognized the need for a change.

One of the two men, who were hired to develop these new areas, was Dysart Edgar Holcomb (1917 - , Ph.D. '41 University of Michigan) who had worked with G.G. Brown and was interested in thermodynamics and, in a more general sense, in unit operations. He had worked with Universal Oil Products in Chicago before coming to Purdue. Holcomb's contributions to the School are immense despite the fact that he stayed at

Purdue only two and one-half years. A dedicated researcher, he graduated two Ph.D. students during that period. All things considered, the reader of the history of the School should recognize the immense contributions of two "mavericks," Clifton L. Lovell and Dysart E. Holcomb, two researchers who had great ambitions and hopes for the research program, hopes that did not always materialize.

The selection of the second man who was hired for his interest in thermodynamics, turned out to be one of the happiest and best decisions of John Bray and the faculty in those days. In his name the School would find the first internationally recognized, "modern" chemical engineer, whose contributions to research, education and philosophical direction of the School would be many and significant. Joe Mauk Smith (1916 - , Sc.D. '43 MIT) was educated during the best days of MIT under the direction of the legendary Warren K. "Doc" Lewis. He became an Assistant Professor at the University of Maryland in 1943 and joined Purdue in 1945. He became Assistant Dean of the Graduate School in 1949 and Assistant Director of the Experimental Station in 1954 until his departure from Purdue in February 1957.

At the end of the 1946-47 academic year, John Bray stepped down because of his deteriorating health. Of course, there was no question as to who would be the new Head of the School. Indeed on September 1, 1947, the man who had produced the largest number of graduate students in the history of the School, the researcher who had established an epoch for the School and for chemical engineering in general, R. Norris Shreve, finally became the Head. He stayed in this position only until 1951, since at that time there was a mandatory retirement of Purdue administrators at the age of 65. Shreve continued as a "regular" (if this word can be used for him) faculty member until 1955 when he retired.

Shreve's ascent to the Headship of the School almost coincided with another major event in the history of Purdue University, the undertaking of the Presidency by a chemical engineer, Frederick L. Hovde. Hovde became the youngest President in the history of Purdue University (at age 37) and the third consecutive chemistry-educated President of the University; from 1900 until 1971 the Presidency of Purdue was in the hands of chemists or chemical engineers. He attended the University of Minnesota and graduated with a B.S. in Chemical Engineering in 1929. He was a Rhodes Scholar at Oxford University where he received a B.A. and M.A. in Chemistry.

Hovde's presidency (1946-71) was very beneficial to the School. He soon developed a deep friendship with Shreve which lasted for 30

Figure 5. Professor Joe M. Smith (1916-), shown here in a 1944 photograph, brought to Purdue new ideas about the teaching and research in the fields of thermodynamics and reaction engineering.

years. Their correspondence (20) is long and very revealing of the respect that the President had for Shreve and the School; their letters are kept in a special volume in the office of the Dean of Engineering. From them comes a very clear picture that, at least between 1947 and 1966, Shreve had become the advisor and "senior spokesman" of the School, although his Headship lasted only four years.

Shreve's short period of administration is highlighted by his successful recruitment of three important faculty members and an unprecedented number of graduate students. These graduates of the School (1947-55) are today the leading executives of major companies around the world. During Shreve's administration the School had a large number of students, both undergraduate and graduate. Indeed, in the post-war period enrollment climbed rapidly, due to the so-called "G.I. Bill" which allowed returning veterans to enroll and obtain a university education. Thus, enrollment reached its maximum in September 1948 with 635 undergraduate students in Chemical Engineering, 212 in Metallurgical Engineering and 103 graduate students in both divisions.

Administratively, Shreve divided the School into three divisions: Chemical Engineering, Metallurgical Engineering and Engineering Geology. These were not officially recognized entities until 1953. In a 1950 leaflet prepared probably by Shreve one finds that in Chemical Engineering, Shreve was in charge, with himself, Lottes and Brink working in unit processes; Doody and Myers in unit operations; Smith and Bennett in Thermodynamics; Sherman in instrumentation, and Hite in gas research. In the Division of Metallurgical Engineering, George M. Enos was in charge, with himself, Evers, Hughel and Hoefs (at Fort Wayne) working in physical metallurgy and Bray and McCormack in process metallurgy. In the Division of Engineering Geology, Serviss was in charge, with Johnstone in physical geology and Guttorsmen in paleontology.

Shreve's executive memoranda and publications during the 1947-55 period reveal a major change in his research and his views about chemical engineering. When Shreve arrived at Purdue, and roughly between 1930 and 1937, he worked on what could broadly be described as applied organic chemistry, what the pre-World War II Germans had called *Organische Chemische Technologie.* His many interactions with colleagues from other universities, especially through ACS meetings and the Chemists' Club of New York, led to his realization that unit operations were an important part of chemical engineering. Thus, around 1937 he started promoting the idea that industrial chemistry could be taught and researched in a similar way, by dividing each industrial process into distinct *unit processes* such as oxidation, nitration, sulfonation and alkylation. This idea was further catalyzed by the publication in 1935 of the very successful book *Unit Processes in Organic Synthesis*, edited by P.H. Groggins, to which Shreve contributed the chapter on alkylation. Consequently, in the 1940's Shreve promoted the idea of unit processes and started writing the monumental textbook *Chemical Process Industries* which was finally published in 1945 by McGraw-Hill.

However, after about 1949 and, as he was approaching retirement, Shreve tried to merge his ideas with modern chemical engineering ideas. Thus, many of his Ph.D. theses of 1952-54 were on more fundamental research subjects such as gas adsorption towers, the engineering aspects of polymerization reactors, and fluidization processes. Around 1950 the Division of Metallurgical Engineering became quite independent, awarding degrees in this area independently of Chemical Engineering. Consequently, and for the purposes of this *History*, after 1950 we will follow only what was going on in Chemical Engineering. For the record, the Schools were officially separated in 1959.

In his last days Bray was occupied with some research (Samuel C. Hite, his last Ph.D. student, graduated in 1951) and the writing of his second major book on *Ferrous Production Metallurgy*, which became a classic in the area.

4. Reevaluation of Educational and Research Directions (1951-1967)

In August 1951 R. Norris Shreve was asked to step down as Head of the School, since he had passed the retirement age for Purdue administrators (65 years old). The position of the Head was filled by a nationally known researcher from the University of Illinois, Edward W. Comings.

Edward Walter Comings was the first Head of the School since Peffer that was not previously a Purdue University faculty member. He arrived in August 1951 with outstanding recommendations and many research laurels from his years at the University of Illinois, where he had worked on high pressure technology.

Carroll O. Bennett and John E. Myers arrived at Purdue in 1949 and 1950, respectively. They were both influential in education and research. Their contributions were predominantly in the areas of thermodynamics, transport phenomena and applied mathematics. They combined their interests and talents to write *Momentum, Heat and Mass Transfer*, which became one of the most successful undergraduate textbooks in chemical engineering. Four faculty members were hired in 1952 and 1953: J.M. Woods; H.C. Van Ness; W.H. Tucker and J.A. Brink, Jr.

John Melville Woods (1922- , Ph.D. '53 University of Wisconsin) was educated at the University of Wisconsin under C.C. Watson. He joined the School in 1952, and embarked upon important research in kinetics and reaction engineering. Later he became involved in process design and computer-aided design. As an educator, Woods introduced new courses in kinetics and reaction engineering both at the undergraduate and graduate levels. Hendrick Charles Van Ness (1924- , D. Eng. '53 Yale University) joined the School in the fall of 1952. At Yale University he worked with B.F. Dodge, thus becoming the second Purdue faculty member (after Bennett) to work under this pioneer of ChE thermodynamics. During his short stay here, Van Ness supervised six students and made significant research contributions in the area of thermodynamics. He left Purdue in 1956 for Rensselaer Polytechnic Institute where he is now Institute Professor of Chemical Engineering (21). While at Purdue, Van Ness started his association with J.M. Smith, which led to the second edition of Smith's thermodynamics textbook. *Smith and Van Ness* is synonymous with thermodynamics and has taught three generations of chemical engineers.

A major change in the Engineering administration occurred in 1953. After more than 30 years, Dean Potter retired. Potter was a contributor to the status of Purdue Engineering. The new Dean was George A. Hawkins (1907 - 1978, Ph.D. '35 Purdue University, Mechanical Engineering), an outstanding mechanical engineer, well-known for his work in high-temperature, high-pressure steam. In the spring of 1953, the undergraduate enrollment of the School had decreased to the manageable number of 297 sophomores, juniors and seniors. The graduate student enrollment had stabilized at about 60 and the faculty could embark upon important changes in the curriculum. In the fall of 1953 several new courses were added in fluid dynamics, kinetics, process design, etc. Chemical processes were still a significant research area at Purdue.

Comings was interested in promoting research in the School. He started offering incentives to the faculty including reduced teaching loads and time to write proposals. By 1956 the research funds of the School had tripled with respect to 1953.

Four faculty members joined the School in 1954: J.W. Tierney; R.A. Morgen; A. Sesonske and A.H. Emery, Jr. Alexander Sesonske (1921- , Ph.D. '50 University of Delaware) was the chemical engineer who brought nuclear engineering to the School. He concentrated his teaching efforts on transport phenomena and the development of new courses in nuclear engineering. He did imaginative research in the areas of liquid metal heat transfer and nuclear reactor engineering. Sesonske has written more than 80 publications and two books, the classic *Nuclear Reactor Engineering* (1963) and a book on *Nuclear Power Plant Design Analysis* (1973).

Alden Hayes Emery, Jr. (1925- , Ph.D. '54 University of Illinois) has the distinction of being the faculty with the longest tenure in the history of the School, 35 years in 1989. Emery made significant contributions in the field of thermal diffusion and after 1960 in non-Newtonian fluid mechanics. After a 1971 sabbatical leave to Israel, he changed research directions. He started working on biochemical engineering, a research area that still occupies a major portion of his time. In the 1970's and 1980's he formed the powerful biochemical engineering research team with H.C. Lim and G.T. Tsao.

Meanwhile in May 1955 an era was coming to an end. On May 12, 1955 in a most emotional gathering, the faculty, administrators, staff and students paid tribute to R. Norris Shreve, on the occasion of his retirement. It was hard to believe that "Benny" was 70 years old and even harder to accept that he had been at Purdue for only 25 years. Shreve, however, would continue to work beyond his retirement. He simply transferred his office to the Executive building and continued to contribute to Purdue either via the Purdue-Taiwan project or in many other ways.

The year 1955 marked an important change in Engineering education throughout the United States. In May 1952 S.C. Hollister, the President of the American Society for Engineering Education (ASEE) and an one-time professor of structural engineering at Purdue, appointed a *Committee on Evaluation of Engineering Education* with the goal to evaluate engineering education and suggest new approaches to teaching engineering. Two of the members of this ASEE committee were Dean George A. Hawkins and Professor J. Henry Rushton who would join Purdue in 1955. When the report of this committee was published on June 15, 1955, a long chapter in the history of engineering education had ended. The report was only thirty-six pages long. It was polite to the older tradition but firm in its recommendations to the new generation (22).

Gradually the committee built the framework of a scientifically oriented curriculum. According to their recommendation the curriculum should consist of humanistic and social studies (one fifth), mathematics and the basic sciences (one fourth), engineering sciences (one fourth), engineering analysis and design (one fourth), and elective courses (one tenth).

The recommendations of the Hollister report created much discussion throughout the country. The older generation of instructors opposed them vehemently. The younger generation accepted them. For the first time the word *engineering science* was appearing in an official document on engineering education. At Purdue University, Dean Hawkins was quite new when the movement toward scientifically oriented curricula started. He did not oppose it. He formed several committees and sought to adjust the engineering programs to the new ideas. Finally, in 1957 a report prepared by a committee headed by Hawkins was sent to President Hovde. The implementation of the committee's suggestions started that same year.

The Hollister report had addressed the weaknesses of the present ChE program and sought to make changes similar to those occurring in all the major ChE Departments in the United States. The group of professors within the ChE department at Purdue, included, among others, Professors Bennett, Myers, Emery and Coughanowr, who made a serious effort to change the curriculum both at the undergraduate and graduate level. It must be noted that all these faculty members were very active researchers. The efforts of the ChE faculty to implement the Hollister recommendations started in 1957. It took seven years, and a number of new faculty members, to change the curriculum. In September 1964 the new undergraduate program and a new program for graduate studies were finally activated. The new plan of study was kept until 1981, when the present one was adopted.

The year the Hollister report appeared, two new Professors were added to the faculty, J. Henry Rushton and Lyle F. Albright. Both became extremely active in research and education and offered much to the progress of the School. Rushton came from the Illinois Institute of Technology, where he was Chairman of the Department. He stayed here for 16 years until his retirement in 1971. After his retirement he continued to do research and write publications until he fell sick around 1980. Rushton was a recognized expert in the area of mixing for more than 30 years. He is also the faculty member with the largest number of awards and recognitions in the history of the School.

In the last three years of his tenure at Purdue, Comings hired five professors: S.W. Briggs; L.C. Case; D.R. Coughanowr; D.B. Smith and P.T. Shannon.

In the spring of 1959, Edward W. Comings, after eight years as the Head of the School, left to become Dean of Engineering at the University of Delaware. That same year Bennett and Morgen resigned as well. J.M. Smith and Van Ness had left earlier. A serious situation was developing in the School and Dean Hawkins oversaw the selection of the new Head that would direct the School in the critical period of the 1960's. From April 1 to July 1, 1959, Dean Hawkins served as an interim Head.

The fifth Head of the School was the first and only Purdue ChE graduate to direct the School. Brage Golding had studied under Shreve and had received his Ph.D. in 1948 working on *Oil Soluble Phenolic Resins and their Varnishes*. Between 1948 and 1959, he was associated with Lilly Varnish Co. of Indianapolis where he eventually became Director of Research. This company sponsored a major portion of the School's research in the early 1950's. Golding had the position of Visiting Professor during those same years.

When Golding took over the Headship of the School on July 1, 1959, he encountered major problems. The year Golding became Head, the School of Chemical and Metallurgical Engineering was finally split into two Schools. The School of Metallurgical Engineering became independent and evolved into the present School of Materials Engineering. That same year the Cooperative Education Program in Chemical Engineering was started with Henry Tucker as its first Coordinator. This program has become very popular among undergraduate students.

In 1961 the School celebrated its 50th Anniversary. The festivities were rather limited. Professor Shreve had collected material for the *History of the School*, but his participation in the Purdue-Taiwan Project did not allow him to write his book. Meanwhile, Golding continued his efforts to replace some of the departing faculty members. In 1961 he hired Lowell B. Koppel from the California Institute of Technology.

The next faculty member, Robert G. Squires, came in 1962 to start a new research area for the School. Already in the 1950's a major change in the study of catalytic reactions had occurred both in academia and industry. More emphasis was placed on a thorough analysis of the catalytic surface properties, and the use of sophisticated spectroscopic equipment was becoming important. Shortly after his arrival, Squires established an ambitious program in catalysis, working initially with IR spectroscopy and then with other spectroscopic techniques. In the 1970's along with W.N. Delgass and R.P. Andres, he established the catalysis research program of the School. To further strengthen the areas of transport phenomena and control, Golding hired D.P. Kessler and R.E. Eckert in 1964, R.A. Greenkorn, C.E. Wales and T.J. Williams in 1965, and R.G. Barile and H.C. Lim in 1966. These were the last actions of his administration. On November 30, 1966, Brage Golding left Purdue University to become Vice-President of Ohio State University in Dayton, Ohio. Three university presidencies followed until his retirement in 1983. He is the only graduate in the history of the School to have become President of three universities.

5. The Modern Era (1967-present)

The past twenty years have been years of major educational and research achievements. Indeed, four Heads have guided the progress of the School during this period: Robert A. Greenkorn (1967-73), Lowell B. Koppel (1973-81), Ronald P. Andres (1981-87), and Gintaras V. "Rex" Reklaitis (1987-present). The reader will find many details about the names, education and achievements of individuals in the past twenty years in our more extensive *History of the School of Chemical Engineering of Purdue University* (28).

6. Research in Chemical Engineering

During the early years of the School of Chemical Engineering, research work *per se* was non-existent. Whatever research was done by Professor H.C. Peffer was carried out by undergraduate students, who were required to write a B.S. thesis. This thesis was on a short research project performed in the last semester of the senior year. Experimental subjects were always selected and the work could be completed in two to three weeks.

With the addition of Bray in 1923 and Maxwell in 1926 some research work was started in the areas of metallurgy and metallography, although the first true publication in a serious research journal did not appear until 1928 in the form of the article entitled *A Continuous Extraction Apparatus* and authored by H.L. Maxwell (29).

The graduate program in chemical engineering was established in 1924. Within the next six years 20 M.S. and Ch.E. theses were issued under the advisorship of Peffer, Bray, Maxwell and Leckie. Most of these theses were in the area of metallurgy.

The year 1928 marks the beginning of serious research efforts in the School. Two events were responsible for this change: the establishment of the Indiana Gas Association grant and the collaboration of Peffer with R.L. Harrison of Rostone, Inc. At its annual meeting in May 1927, the Indiana Gas Association voted a five-year grant to Purdue University to enlarge its program of instruction, research and extensions in gas engineering effective 1928. As a result of this program, Professor Robert B. Leckie was hired in 1928 to be in charge of the Gas Engineering program.

The second project is related to the development and characterization of a synthetic stone by Peffer. In 1923 Peffer started working on the use of a local shale as a raw material for construction. A few years later David E. Ross, at that time President of the Board of Trustees, started supporting Peffer's research on this raw material which outcropped in Attica, Indiana. The initial experiments were carried out in the Purdue Hall by Harrison, who became known as the "mud-pie maker." Gradually, Ross advanced more funds and four patents were filed by Peffer and his collaborators. Eventually, Ross built a plant for the crushing, grinding, and processing of this shale. This project finally developed into Rostone, Inc., a local company where Peffer became Vice-President until his death in 1934.

In 1930 the Organic Technology option was started under R.N. Shreve who became the most influential Purdue researcher of the 1930's and 1940's. His second M.S. student, John W. Olson (1932), was the first ChE student to prepare a thesis on a subject related to organic chemicals instead of metals, gases or inorganic chemicals. Some of the early research projects of Shreve were on the synthesis and properties of certain drugs and dyes. The drug β–phenyl–azo–α–α′– diamino-pyridine hydrochloride was the subject of the Ph.D. thesis of Miller W. Swaney (1935) and the M.S. thesis of Westcott C. Kenyon (1935). It was commercialized by Mallinckrodt as a genito-urinary antiseptic drug under the trade name Mallophene. Work on barium, strontium and calcium salts was also done in the 1930's under the sponsorship of Mallinckrodt.

During his days as an independent consultant before he joined Purdue, Shreve had developed a strong interest in nitrogen-containing heterocyclic compounds because of their potential applications as dyes and explosives. We know now that he had a more than casual interest in the scientific studies of the Russian chemist Chichibabin, who had sent him many of his articles from 1916 to 1928. In 1928 they met in Russia and the next year Chichibabin defected to France. The studies of Shreve and Chichibabin were translated into short-lived commercial products in the 1920's. After Shreve's arrival at Purdue, the studies of the chemistry of these compounds became the basis of more than forty theses on dyes, under the sponsorship of Mallinckrodt and other companies.

Other research areas pursued by Shreve in the 1930's and early 1940's were fur bleaching, preparation of plastics and coatings, hydrogenation of vegetable oils and esterification reactions.

After the arrival of Clifton L. Lovell, the first true chemical engineering theses were issued. Indeed, the first thesis on unit operations was the M.S. thesis of Forrest D. Stoops (1933) on *Entrainment Velocity Limits in Fractionation.* The first Ph.D. thesis of true chemical engineering content was that of William J. Burich (1942) on the *Influence of Free Convection Currents near Critical Values of Reynolds Number.*

Lovell's research addressed important aspects of chemical engineering within the framework of unit operations, and later fluid mechanics and mixing. In the 1930's he did research on distillation, heat transfer and mixing. In the early 1940's he expanded his research to the areas of fluid mechanics - where he became nationally known for his outstanding work - absorption and extraction. A true pioneer he examined many chemical engineering phenomena related to fluid flow. Unfortunately, his failing health did not allow him to publish most of his papers, and many of his significant results from his more than 35 theses remained unknown to the wider ChE community. It is interesting that Lovell had no research laboratories of his own; instead he used the equipment in the undergraduate unit operations laboratory, of which he was in charge.

By 1937 Shreve, Lovell and Bray had brought to the School old industrial equipment including a distillation column, crystallizers, evaporators and filters. Shreve had the most modern research facilities.

By 1936 the number of publications had increased to a respectable 1.2 publications per faculty per year.

Here is a list of the contracts, grants and gifts of the School in June 1936, which shows that fifty years ago there was already significant research activity in chemical engineering at Purdue.

Funding Agency	**Project**	**Funds ($)**
Indiana Gas Association	Gas manufacture	4,500
Engineering Foundation	Dye technology	1,850
American Cyanamid Co.	Cyanamid studies	1,000
Various Gifts	Equipment	8,000
American Gas Association	Fellowship	1,350

The move to the new building in 1940 led to a significant increase in funding. For example, in the fall of 1940 graduate research was supported by grants from J.G. Seagram & Sons, the Mixer Corporation, the Hill-Rom Company, Mallinckrodt, the American Welding Society, IGA, duPont, New Jersey Zinc Company, International Nickel Company, U.S. Steel Corporation, and the Calcium Chloride Association; these grants totalled more than $40,000. It was in 1940 that David E. Ross offered to Purdue 300 shares of Ross Gear and Tool Company which created a special fund from the income of which the first *David Ross Fellowships* were given.

In the mid and late 1930's one half of the projects were on unit processes (Shreve), the rest divided between metallurgy and unit operations. A single project on thermodynamics was supervised by Bray in 1938-39 but it did not yield a thesis. The first thesis on a heat transfer subject appeared in 1939. It was the M.S. thesis of Herbert F. Wiegandt, now professor emeritus at Cornell University, entitled *A Comparison of Thermocouple Installations Used in Heat Transfer* (C.L. Lovell, advisor). In the early 1940's research on distillation, mixing, adsorption, fluid mechanics, heat and mass transfer, unit processes, organic chemical technology and (somewhat primitive) kinetics was performed. In 1942-43 Lovell achieved another first, by supervising the M.S. thesis of Ramon I. Lindberg on *Liquid-liquid Extraction of 2,3-Butanediol from Fermented Grain Mesh.* This was the first thesis in biochemical engineering, a subject area that forty years later would be the strongest research area of the School.

The School made significant contributions to technical problems of a chemical nature during World War II. A training school to develop technically competent superintendents for the operation of munitions plants was established. Cresol, which was no longer available from the European chemical industries, was produced in the laboratories on a semicommercial scale. It was needed to produce a flexible plastic for war material.

A chemically pure mustard gas was produced in quantity for needed studies of comparison against the commercial product. Quantitative studies of high energy chemical reactions which gave promise for improved rocket propellants were made for the government. Finally, in collaboration with the Chemistry Department, an extensive study was carried out of methods for analysis and control of production processes separating U^{235} and U^{238}. The methods developed were used in production of materials for the atomic bomb.

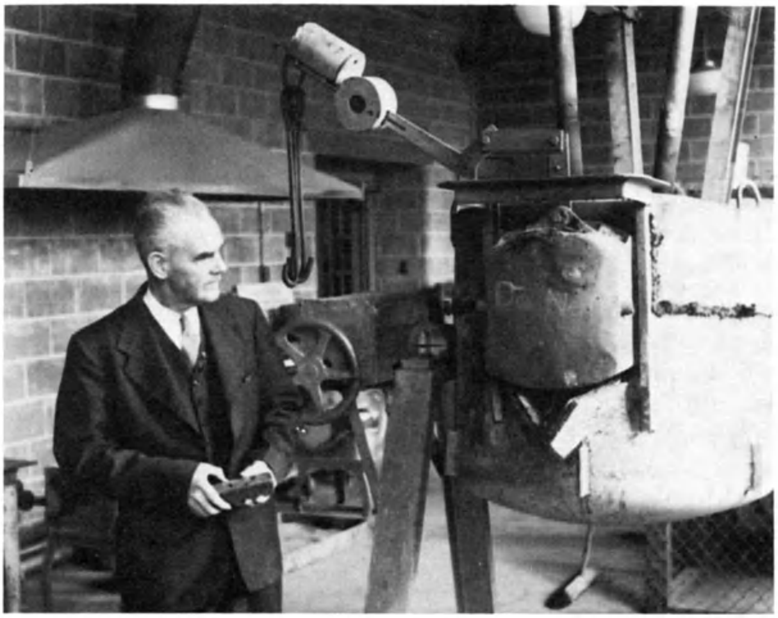

Figure 6. Professor John L. Bray (1890-1952) inspecting a furnace in the fall of 1951.

In 1945 the School started hiring new faculty members, prominent among which would be J.M. Smith and D. Holcomb. Clifton Lovell, this pioneer of chemical engineering, would stay active only until 1946 when he took a leave of absence for health reasons. He had time to produce one more biochemical engineering M.S. thesis on the *Clarification of Malt Converted Degerminated Corn Mash Prior to Fermentation* (Francis A. Hilinski, M.S. '45).

Shreve was extremely active in research from 1945 until his retirement in 1955. His research was gradually turning towards subjects such as kinetics, reactor design, fixed beds, adsorption and even polymerization reactor design.

J.M. Smith established in 1945 an ambitious research program with students working on kinetics, catalysis, thermodynamics and heat transfer. The first thesis on the subject of kinetics and reactor design was the M.S. thesis of Robert R. Cartnell on *Vapor Phase Hydration of Ethylene Oxide* (1947) supervised by Smith. The first thesis in thermodynamics was authored by Albert J. Barnes, Jr. (1947) and it was supervised by Dysart E. Holcomb; its subject was *Phase Relations for the Two-Component System: Stearic Acid and Water.*

By 1950 the School had a very active research program - 15 M.S. and 11 Ph.D. degrees were awarded in 1950 - and significant funding for research. For example, the Indiana Gas Association supported the research of J.L. Bray and S.C. Hite on subjects such as hydrogenation of coal, control of mixed industrial gases, temperature and pressure-relief valves, electric ignition for gas appliances and venting of direct heaters. The same investigators supervised research on home humidity control sponsored by the American Gas Association (research started in 1945).

J.M. Smith was in charge of a variety of research projects. Studies of temperature gradients in continuous gas-solid catalytic reactors were supported by Petroleum Research Foundation (PRF), whereas from 1946 until 1950 the Research Cotrell Corporation supported his work on heat and mass transfer in fluidized gas-solid systems, and after 1950 his work on flow in fluidized systems. The Engineering Experimental Station was the sponsor of Smith's work on vapor-phase hydration of ethylene oxide, and in 1947 the Texas Company gave him a grant for the study of the radial temperature gradients of gas-solid catalytic converters. Finally, his studies on the reaction of sulfur vapor and methane were sponsored by the Eastman Kodak Company and the Pure Oil Company.

In his short time at Purdue, Holcomb studied the liquid-liquid extraction of fatty materials (work sponsored by Procter and Gamble

Company and Shell) and the thermodynamic properties of ternary hydrocarbon mixtures. Doody had already started in 1947 his work on vapor-liquid equilibria, which was supported by Shell, and on boiling phenomena, supported by PRF. Finally, Bennett started working on liquid-liquid equilibria, soon after his arrival in 1949.

Shreve had the largest research program during that period. His work on alkylation was supported by the American Cyanamid Co. from 1946 to 1952. Lilly Varnish Company started supporting his work on surface coatings in 1946 and continued doing so for nine years. At one time eight graduate students were working on this project. In fact the first thesis in the field of polymers at Purdue was the Ph.D. thesis of Brage Golding (1948) on *Oil Soluble Phenolic Resins and their Varnishes* supervised by Shreve. In 1950 Edwal Laboratories supported Shreve's work on dyes made from amino derivatives of toluene. Other minor companies supported his work on derivatives of methylnaphthalene and dyes from nitrogen-containing heterocyclic compounds.

In the early 1950's Bennett and J.M. Smith embarked upon important research in thermodynamics, and Myers started his pioneering work on fluidized drying and heat transfer. A major Department of the Army contract supported the work of Comings and Myers on gas dynamics. Comings was also involved in high pressure research, and Van Ness was hired to contribute in the area of thermodynamics. In the early 1950's Lilly Varnish was supporting around eight different projects on polymers and coatings under the direction of Shreve and Visiting Professor Brage Golding.

Major changes in the direction of Ch.E. research at Purdue were observed in the period of 1955 to 1960. The number of projects in unit processes had gradually decreased and in the spring of 1956 the last two students working in this research field graduated. After 26 glorious years at Purdue University, unit processes had been absorbed in the more modern areas of kinetics and chemical processes.

For more than 20 years the financial support for the research projects of the graduate students came from industry. Over the next fifteen years (1956-1971) a major effort would be made to balance this financial support with funds from federal agencies. These grants were usually given for more fundamental research. The first two Purdue Ch.E. grants from the National Science Foundation (NSF) were awarded in the fall of 1955 to Edward W. Comings for a proposal on the *Thermal Conductivity of Gases at High Pressure* and to John M. Woods and Joe M. Smith for their proposal on the *Kinetics of Vinyl Chloride Production*.

In 1959, of 58 research projects, 12 were funded by federal agencies (Woods, Emery, L.C. Case and Myers by NSF, Bennett by DOD, Sesonske by the Atomic Energy Commission, and Rushton by ACS/PRF), 5 by the Indiana Gas Association, 22 by companies, 9 by the Engineering Experimental Station and 10 by the School. Major research emphasis was placed on heat transfer (Myers, Sesonske, B.D. Smith) and mass transfer (Bennett, Emery, B.D. Smith, Tucker). Work on fluid mechanics was performed by Bennett, Rushton and Shannon, and the thermodynamic properties of fluids were investigated by Bennett, Comings, Albright, Doody, Emery and B.D. Smith. Research in chemical processes was performed by Albright and in chemical reaction kinetics by Coughanowr and Woods. Finally, an ambitious polymer program was established by L.C. Case and Emery. The total research expenditures were $97,000 or 9% of the total engineering budget.

After approximately 1961 Koppel and Coughanowr established an ambitious research program of national reputation in the area of process control. Support by NSF and various companies continued for over a decade. The addition of Lim and Weigand in the late 1960's further contributed to the recognition of this program. The first Purdue ChE thesis in the area of control was published in 1962 by Wayne E. Luetzelschwab. He was a student of Coughanowr and his M.S. thesis was entitled *An Analog Computer Simulation of a Steam-jacketed Kettle and Control System.* One year later, the first purely theoretical thesis was accepted by the faculty. Supervised by Paul T. Shannon, this was the M.S. thesis of Martin R. Feinberg, now professor at the University of Rochester, on the *Thermodynamics of the Steady-state from an Information Theory Viewpoint.*

In the early days of Greenkorn's administration, the main research areas of emphasis were kinetics and reaction engineering, optimization and control, simulation and design, thermodynamics and transport phenomena. A comparison of the emphasis on research in January 1970 with that of December 1985 shows the major research changes in the School.

Research Field	Percentage of Research Projects	
	1970	1985
Applied Mathem.	-	3.4
Biochemical Engr.	-	18.0
Biomedical Engr.	-	3.4
Catalysis	-	11.2
Chemical Processes	-	1.1
Colloid & Surf. Sci.	-	3.4
Environm. Engr.	-	1.1
Kinet. & React. Engr.	16.4	6.7
Optim. & Control	17.9	5.6
Polymers	-	18.0
Separation	-	4.5
Simul. & Design	10.5	11.2
Thermodynamics	10.5	9.0
Transport Phenom.	44.7	3.4

Over the past fifteen years there has been a shift towards research projects in new technological areas such as biochemical engineering, catalysis, polymers, and computer-aided design. There is a broader distribution and representation of research areas in 1985 than in 1970. Research in thermodynamics has stayed at a constant level. Emphasis in kinetics and reaction engineering seems to have decreased in the last 15 years, but this is a false conclusion since (i) a large number of projects in biochemical engineering address kinetic problems, and (ii) the projects in catalysis may include kinetics as well. Research in optimization and control has decreased somewhat at Purdue, but again some of the control work is applied to biochemical problems. Then the major change in the research direction of the School is in transport phenomena which in 1970 covered about 45% of all the research, whereas in 1985 only 3% of the projects are in this field. The last conclusion also needs some qualifying statements. Research in fluid mechanics is now performed within the framework of non-Newtonian fluids (polymers). Classical mass transfer (unit operations-type) research has disappeared, but significant research in this area is carried out in the polymers and separations areas. Finally, heat transfer research is not an active research area in the School.

The research developments at Purdue University over the past fifteen years have led to strong programs in a wide range of research fields. Presently, research in applied mathematics is carried out by Ramkrishna. Biochemical engineering is a major research field and faculty involved include Tsao, Lim, Emery, Ramkrishna and Wankat. Some biomedical engineering work is carried out by Wang, Hannemann and Peppas. Catalysis is another major research area for the School under the leadership of Delgass, Squires, Takoudis and Andres. Chemical processes are studied by Albright and Eckert, colloid science by Franses, and environmental engineering by Greenkorn. Reaction engineering problems are addressed by Ramkrishna, Takoudis and Andres. The areas of optimization, control, simulation and process design are the focus of research attention by Reklaitis, Lim and Andres. Polymer science and engineering is the research area of Caruthers and Peppas, and separation science that of Wankat and Wang. A strong thermodynamics group has been established by Chao and Greenkorn. Finally, classical transport phenomena are the subject of research by Greenkorn, Kessler and Houze.

The classification of research projects cannot show the wide range of interests of the faculty, and the unusual research subjects available to graduate students. For example, genetic engineering work is carried out by Tsao's group, chemical vapor deposition and polymer research as related to microlithography are carried out by Takoudis and Peppas, aerosol science is studied by Andres and coal research is a subject of interest of several faculty members.

For 63 of its 75 years of history, the School has been an active research institution. Since the publication of Peffer's first original research contribution in 1923, the Ch.E. faculty members have not stopped contributing to research. Some statistical facts will be presented which show the prominent position of the School in the American and world-wide Ch.E. research.

Since 1923 more than $21,000,000 has been received for support of research from external sources. Since 1975, Purdue Ch.E. has been one of the first five Ch.E. Departments in the country in research funds.

In 1986 the School celebrated its 75th birthday. During its 75 year history the School awarded 338 Ph.D. degrees, 32 professional Ch.E. degrees and 838 M.S. degrees. In number of Ph.D. degrees awarded, Purdue Ch.E. is fifth in the country after MIT, the University of Michigan, the University of Wisconsin and the University of Minnesota. This is a remarkable achievement considering that at Purdue University the first Ph.D. degree was given in 1935, much later than in these other Schools (excluding the University of Minnesota).

A significant percentage of these 338 Ph.D. students have become faculty members elsewhere. With 77 Ph.D. students having become professors (23%) Purdue is only second to the University of Michigan and ahead of its perennial competitors MIT, University of Minnesota and

University of Wisconsin in the percentage of Ph.D. students continuing in academia. This fact is of course a surprise for those who believed for years that Purdue was only a good School for industrial preparation. With a total number of 170 professors having received at least one degree from the School, Purdue is second only to MIT in this category.

Related to research achievements is the scientific output of the faculty and students. Since 1923, when the first Purdue Ch.E. publication appeared, 47 books and approximately 1500 publications have been written.

Finally, if the number of publications is an indication of faculty and student research productivity, then the School of Chemical Engineering of Purdue University is now at its peak of performance with 5.5 publications per faculty per year in 1984. But what is even more impressive is the quality of the research done at Purdue. The 1983 report (30) *An Assessment of Research-Doctorate Programs in the United States* published by the National Research Council ranks our School second after the University of California at Berkeley in the "overall influence of scholarly work on chemical engineering." And this is a recognition to cherish.

7. Affiliation of Authors

School of Chemical Engineering
Purdue University
West Lafayette, Indiana, USA

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John C. Friedly

HISTORY OF CHEMICAL ENGINEERING AT THE UNIVERSITY OF ROCHESTER

Introduction

Just over a hundred years ago in 1881 George E. Davis in England first tried to found a Society of Chemical Engineers [1], a term that he was believed to have newly coined. Just a few years later in 1888 MIT started Course X, the first program designated as chemical engineering in the United States. Several other American schools quickly followed their lead [2]. The pace of expansion continued to quicken so that by the end of 1920 the AIChE identified as many as 78 programs in chemical engineering [3]. The University of Rochester first authorized a chemical engineering curriculum in 1915.

At the turn of the century the University of Rochester was poised to make the transition from a primarily local college for arts and science to a University of some national standing. Rush Rhees had become president in 1900, only the third since the University's founding in 1850. Ralph Waldo Emerson had used the founding of the University as an illustration of Yankee enterprise, saying [4]

> a landlord in Rochester had an old hotel which he thought would rent for more as a university; so he put in a few books, sent for a coach-load of professors, bought some philosophical apparatus, and by the time the green peas were ripe had graduated a large class of students.

Rhees' presidency would be a long one that would see more notable accomplishments than any other: from the reluctant admission of women on the strength of Susan B. Anthony's pledge of her entire insurance fund, through the founding of the Eastman School of Music and the School of Medicine and Dentistry, full circle to the establishment of the new River Campus exclusively for the Men's College. Rhees' vision included studies in applied sciences to complement the established sciences.

N. A. Peppas (ed.), One Hundred Years of Chemical Engineering, 301–319.

Beginnings of Engineering

Rhees' attitude toward engineering was quite different from that of Martin B. Anderson, Rochester's first president. Anderson had turned a deaf ear on the offer of Hiram Sibley, the founder of Western Union, to finance the formation of an engineering program. In 1904-5 Rhees convinced Andrew Carnegie to pledge $100,000 in a challenge grant for a new laboratory building for the applied sciences. By the end of 1907-8 he had raised the $100,000 necessary to match Carnegie's gift and could pursue his goal in earnest. Although a biblical scholar, Rhees spent his sabbatical year in 1908-09 largely observing the developments in engineering taking place in Europe. He reported being duly impressed by being invited to take tea with Prandtl in his Applied Mechanics Lab at Goettingen [5].

On returning to Rochester the plans for the new Carnegie Laboratory on what is now called the Prince Street Campus were put together with the help of Millard Ernsberger, a mechanical engineer who was hired from Cornell to head the Applied Science Department at Rochester. A handwritten notation in the President's Annual Report of 1908-9 indicated that Ernsberger was paid a salary of $500 for the year (although possibly not for full-time work the entire year). This figure is contrasted with that for Victor Chambers, chairman of chemistry, whose $2500 salary was the highest for a full professor at the University. Chambers had been hired away from Columbia that year after having earned his PhD at Johns Hopkins under Ira Remson, later to be a distinguished president at Hopkins. Both Ernsberger and Chambers had received their undergraduate degrees at Rochester before the turn of the century.

The early applied science program was strictly mechanical engineering, but did include courses in applied electrical sciences. The philosophy of the program was summarized by President Rhees in 1908 [6]:

> ... this new work will <u>not</u> [emphasis added] undertake to give the full training necessary to develop engineers ... Graduates from this group would thus be prepared to enter on commercial careers with all the advantage offered for such careers by technical training, coupled with the distinct advantage arising from a more general liberal culture.

The implication was that this program would be different from others in that no attempt would be made to train graduates for specific industrial positions. Those students wishing that kind of training would have to go on for further study at other schools, like Cornell. There is no evidence that students felt compelled to complete a more traditional engineering education, but the latter part of the statement would remain a hallmark of the Rochester education to the present time.

The applied science major in mechanical engineering proved popular and with the renovation of the chemistry laboratories in Reynolds Laboratory in 1915, it was time to initiate a program in applied chemistry. Professors Ernsberger and Chambers, who respectively taught courses in power engineering and industrial chemistry, proposed a joint curriculum in chemical engineering. The new major was first listed in the 1915-16 catalog.

The applied chemistry program was immediately as popular as chemistry or mechanical engineering, with 10 freshman students enrolled in 1916. Chemical engineering students, however, unlike green peas, took considerable time to ripen, especially in wartime. In spite of the war, or perhaps because of it, Otto Wiele Cook received the first chemical engineering degree in 1920, graduating Phi Beta Kappa. Cook had joined the Chemical Warfare Service during the war, but an unfortunate powder flareup forced him to leave, permitting his return to school and the completion of his degree. Cook later managed cine processing at Kodak.

Perhaps not coincidentally, an honorary Master of Science degree was awarded to Albert Huntington Hooker at the commencement exercises of 1920. Hooker was the technical director for the Hooker Electrochemical Company of Niagara Falls and brother of its founder Elon Huntington Hooker. Elon was a Rochester graduate who was a member of the Board of Trustees of the University at that time, like his grandfather Elon Huntington who had been on the original Board of Trustees in 1850.

A year after Cook graduated, Professor Ernsberger resigned to return to Cornell, but was replaced by Joseph W. Gavett, also from Cornell. He, along with Professor Chambers in chemistry, was to continue teaching all of the specific chemical engineering courses for a number of years. The latter part of the decade saw sporadic growth of the chemical engineering program as the University planned the new River Campus for the Men's College. The new campus opened in 1930 and included an Engineering Building suitably removed from the main quadrangle and adjacent to a maintenance building, just as the Carnegie Laboratory had been deliberately situated close to the power plant. The Engineering Building, later renamed for Joseph Gavett, has remained the home of chemical engineering.

Coming of Age

The chemical engineering program of the early ´30s was not far different from that at the beginning. Professors Gavett and Chambers continued to carry the brunt of the teaching activities. There was apparently no thought of hiring faculty specifically for chemical engineering. The enrollments continued to grow however, roughly paralleling those in chemical engineering across the country.

On the growing strength of engineering, the University scheduled an accreditation visit by the Engineering Council for Professional Development in the academic year 1935-36, not long after ECPD began accrediting engineering programs. The mechanical engineering program was accredited, but chemical engineering was not. As is typical even today, failure to receive accreditation precipitated a crisis within the University. President Alan Valentine visited the ECPD team head, Dean Joseph W. Barker of Columbia, to discuss the conclusions in person.

From today´s perspective the reasons for nonaccrediting were clear: there were no chemical engineering faculty, there was no unit processes laboratory, and in spite of plenty of chemistry and mechanical engineering in the program the curriculum should have been organized more toward chemical engineering. However, Barker´s off-the-cuff estimate of $80,000 to set chemical engineering straight had President Valentine ready to abandon the program. Frank Lovejoy, Chairman of Kodak, in a letter to Valentine in December 1966, was not much more encouraging

> So far as our company is concerned, I can assure you it would make not [sic] difference to us if the University dropped its course in chemical engineering; or, in other words, we can get better qualified men from the institutions named above [MIT, Michigan] than we could hope to get from the University here.

It reminds one of the studied response of one anticipating a proposal for a substantial grant.

Fortunately, Valentine sought additional advice. Professor Gavett was determined to improve the chemical engineering program. He obtained more detailed cost estimates of about $5,000/year for three years to establish a unit processes laboratory and a continuing cost of $4,000 to 5,000 for a faculty member. Then in May 1937 President Valentine, Dean Leonard Carmichael and Professors Gavett and Chambers met with a group of trustees to decide the fate of chemical engineering. The decision was positive. Dean Carmichael's annual report that year resolved rather weakly that the

> ... University will continue to offer work in chemical engineering only if its work in this field can be demonstrated objectively to be at least as adequate as any work in chemical engineering in this country.

Faculty recruitment occupied much of 1937-38. Donald Bentley Mason, Jr., BS'22, of Freeport Sulphur was mentioned as a possible candidate. Negotiations progressed with Charles Winding, then Instructor at Cornell, but Winding spent his entire career at Cornell. Finally, Howard S. Gardner accepted the position of first chemical engineering professor, effective September 1938, at a salary of $4,500. Gardner had received his BS ('30) and MS ('31) from MIT. (His D.Sc. was not awarded until after the war.) Most recently Gardner had directed the MIT practice school program in Bangor, Maine, but he had previous industrial experience with Eastman Kodak. While at Kodak he had taught chemistry part-time in thee University extension program.

Gardner brought instant credibility to the chemical engineering program which had existed for 23 years without ever having a faculty member. Although chemical engineering was only a program within the Engineering Department chaired by Prof. Gavett, Gardner was its acknowledged head. In 1939 Gardner supervised the first MS thesis in chemical engineering by Ralph E. Pike, who served DuPont for many years afterwards. In 1940, Dean Lee DuBridge, the physicist who later became president of CalTech, announced that equipment had been installed in the high bay area of the engineering building for the first unit processes lab. The program was accreditated by ECPD in 1941 and has maintained continuous accreditation since then.

Growth to a Department

For the next twenty years or so the chemical engineering program operated with a faculty of about three. Faculty listings are included in Table I. Orrington E. Dwyer was the second faculty member of professorial rank, joining the program in 1939 after finishing his D.Eng. research under Barnett Dodge at Yale. In this period an impressive list of instructors served the program on their way to distinguished

Table I. Faculty Lists During Calendar Years Shown

Year	Chair	Professor	Assoc.	Asst.	Instr.
1940	Gardner			Dwyer	Hovde Martin
1945	Gardner			Dwyer	Martin
1950	Dwyer		Su	Kraybill	Clump
1955	S.Miller		Su	Kraybill	A.Miller
1960	S.Miller	Su	Kraybill	Middleman Smith	A.Miller
1965	S.Miller	Perry Su	Douglas Eisenberg Kraybill Ramalho	Bartlett Middleman Smith	
1970	Ferron	Horn Saltsburg Su	Eisenberg Smith	Anderson Byers Feinberg Friedly Osmers Wiehe	
1975	Ferron	Horn Saltsburg	Eisenberg Feinberg Friedly Smith	Donaldson Heist Osmers Palmer	
1980	Brenner	Ferron Saltsburg	Eisenberg Feinberg Friedly Palmer Smith	Donaldson Heist	
1985	Friedly	Feinberg Ferron Jorne Saltsburg	Heist Palmer	Chen Chimowitz Sotirchos	Olsen

careers elsewhere. Frederick L. Hovde, who had received his BChE at Minnesota (while starring in football) and his BA in chemistry while a Rhodes Scholar at Oxford, aided Gardner in addition to serving as Assistant to President Valentine. Dwyer's arrival permitted Hovde to spend more time in the President's Office, preparing himself for a distinguished 25 year career as President of Purdue. The late Joseph J. Martin served as instructor from 1940 while he earned his MS before going on to Carnegie Tech for his PhD. Martin of course taught at Michigan for many years and served a term as President of the AIChE. Hendrik Van Ness followed Martin in 1946 after receiving his BS ('45) and his MS ('47) under Martin's direction. Van Ness went on to Yale for his doctorate under Dodge and taught at Purdue before assuming his current position at RPI. Curtis W. Clump earned his PhD at Carnegie Tech before joining the Lehigh faculty.

In 1937-38 Dean Carmichael had turned down Professor Gavett's request that engineering should be a separate school instead of a department in the College of Arts and Sciences. However, the climate had changed near the end of World War II. Following Gavett's death in 1942 an offer was made to Colonel Harrison Belknap to become chairman of the Division of Engineering, still within the College of Arts and Sciences. Service commitments kept Belknap away until 1946, but he immediately proposed separate departments for three engineering programs. The Chemical Engineering Department was officially approved in June 1947 with Gardner as chairman. However, Gardner resigned the next month to become Director of Research and Development of Fibreboard Products in California and Orrin Dwyer was named chairman.

Dwyer's resignation in 1951 to take a position at Brookhaven National Laboratory precipitated a significant change in direction for the Department. Gene Su, an MIT graduate, served as Acting Chairman while a successor to Dwyer was found. Su had joined the staff in 1947 after having worked for Seagrams in the war effort and having taught at National Tsing Hua University in China. In September 1952 Geoffrey Broughton become chairman. Broughton was educated at the University of London and received his DSc at MIT in 1938. He had worked at Kodak in paper services and had most recently been chairman of Paper Engineering at Lowell Textile Institute.

Broughton died tragically at age 42 in 1954 but he left his mark on the department. It was announced in June of 1953 that three candidates for the PhD had been admitted.

Even then US graduate students were hard to find and all three were from abroad. Before his death Broughton laid the groundwork for a strong research program and expansion of staff and program. Broughton also put together an industrial advisory board to help lobby for the changes he had in mind. Donald B. Mason (BS´22), Technical Director of Freeport Sulphur, was one of the charter members and Joseph Noble (BS´34), Technical Assistant to the President of Xerox, joined the board shortly after.

Modern Department

The foundations of a modern chemical engineering program were laid by Broughton in his brief tenure but were implemented under the direction of Shelby A. Miller. While the search for a new chairman was conducted, Gene Su again filled in. Miller was a professor at Kansas, but had industrial experience at DuPont after receiving his PhD at Minnesota in 1940. He came to Rochester for the academic year 1955-56.

Miller´s first few years were occupied with two noteworthy events. First, the separate men´s and women´s colleges were abolished and the women finally were permitted to move to the River Campus. As Miller called it, this "unnatural bifurcation" that President Rhees had insisted on almost from the time Susan B. Anthony forced the admission of women was finally broken. Not that it wasn´t possible for women to major in chemical engineering before, but the barrier of separate campuses was hard to overcome. Although a woman had received a mechanical engineering degree in the late ´30s, only a single chemical engineering woman received her degree (in 1955) before the colleges were merged.

Collapsing the men´s and women´s colleges provided President Cornelis de Kiewiet an incentive for more natural academic divisions. The University debated forming a professional college for engineering, business and education, but a separate College of Engineering was established in September 1958. de Kiewiet had resolved to expand the engineering program substantially, newly organizing an electrical engineering program and searching for a dean capable of building a first rate teaching and research faculty. John W. Graham, later President of Clarkson College, arrived in July 1959 and was largely responsible for the tremendous growth in the college.

A new engineering building was necessary to house the new faculty and research laboratories. First though, additional floor space was generated within Gavett Hall. The high bay laboratory area in Gavett Hall was divided up into a number of smaller laboratories and a mezzanine was constructed over all but a small part of the chemical engineering laboratory. The mezzanine provided a large amount of needed research laboratory space. A third floor was added to the wing of Gavett that had been added in the late ´40s during Belknap´s short term as chairman of the Division of Engineering. The final addition to Gavett Hall was completed in 1961 and chemical engineering inherited additional space when electrical and mechanical engineering moved their offices into the new Hopeman Engineering Building in 1963.

With Dean Graham´s support, Shelby Miller set out to develop the chemical enginering research capabilities that Geoffrey Broughton had projected. The first PhD had been awarded in 1957, not to one of the candidates who entered first but to Robert W. Heeks, who had switched to work with Broughton after his undergraduate degree in chemistry. Professor Su supervised Heek´s PhD dissertation, the first of many he would direct. Heeks spent his entire career at Xerox. The research capability doubled in 1960-61 with the addition of Rubens Ramalho, Stanley Middleman and W. David Smith. The following year Richard Eisenberg transferred from Mechanical Engineering and John Bartlett (BS´57) was newly hired. By the end of Miller´s tenure at Rochester the faculty size had grown to a dozen, with additions of Robert Perry, James Douglas, Charles Byers, Irwin Wiehe, Martin Feinberg, Herman Osmers and John Friedly. Miller was on leave during 1967-68, with Bob Perry acting as chairman, and became Associate Director of Education Programs at Argonne National Laboratory in March 1969.

Such a dramatic change in emphasis within the college was not without growing pains. Research programs tended to become much more applied science oriented. As early as 1953 Broughton´s advisory committee suggested a course of action that is not inconsistent with the philosophy today

> ... committee felt that all undergraduate studies should be pointed to broad and fundamental courses and they should be of such a caliber assuming that all students would be preparing for graduate work.

However, chemical engineering grasped the new engineering science concepts gingerly, if not reluctantly. Miller's report to the advisory board in 1963 described the purpose of the department as

> deliberate dedication to curricula that are expressions of scientific engineering rather than strongholds of engineering empiricism (no matter how effective) or outposts of undiluted engineering science (no matter how powerful)

A self-assessment study of the department bears the unmistakable Miller prose [7]

> ... in all this the key concept is engineering - not science, essential ingredient that it is - nor engineering science, inseparable organ of engineering that it is - nor economics, code of law to the engineering industry that it is - but engineering, the composite of all these and other components

Perhaps an effect of the rapid expansion and the successes of the '60s, the department underwent a retrenchment when Miller resigned. Five faculty left in short succession, including several of some prominence. Perry, who had taken over the editorship of the Chemical Engineer's Handbook from his father, left for private practice. Both Douglas and Middleman left for the University of Massachusetts. Realizing a crisis was possible, Dean Robert Loewy, later to become Provost at RPI, acted as chairman in 1968-69 until John Ferron was hired from Delaware. Ferron had earned his PhD in 1958 at Wisconsin after having worked for several years at DuPont.

Ferron quickly stabilized the department by adding senior faculty Fritz Horn and Howard Saltsburg and junior faculty James Anderson and Harvey Palmer, who had received his BS at Rochester in 1965. Later Richard Heist and Terry Donaldson were added to the faculty. With these additions, the Department made significant moves in new research directions, strengthening the emphasis on engineering science that was begun when the College was established in 1958. Horn's experience in reactor theory complemented Feinberg's developing interest. Saltsburg and Anderson provided surface science/catalysis experience for the first time. Palmer, Donaldson and Heist brought differing interests in interfacial phenomena. Although others had dabbled in biomedical research previously, Donaldson became the first to focus a research program in biochemical engineering.

Ferron's nine year term as chairman was challenging educationally as well. The student unrest of the '60s had generated a cynical view of science and technology. Social relevance was the watchword. The undergraduate enrollment was going through a period of stagnation, if not retrenchment. Ferron initiated major thrusts to attempt to interest students in engineering. The faculty taught elective courses, such as Anderson's "Science, Technology and Human Values," intended to attract socially conscious students into engineering programs. The College experimented with courses for freshmen showing new and exciting applications of technology. Ferron recognized that chemical engineering was overlooking a significant source of students by not attracting sufficient numbers of women. When he arrived there were no women in any of the four years of the program. With the aid of a grant from DuPont he developed programs specifically to appeal to women. The payoff came gradually but by the late '70s Rochester consistently graduated a significantly larger fraction of women than the average program. From 1977 on there were on the average nearly thirty percent women in the graduating classes. This is to be contrasted with the national figures of about 1% in 1970, 16% by 1980 and 26% only by 1986.

The lower undergraduate enrollments in the early '70s permitted the department to focus on the quality of research and the graduate program. The department chose to push that emphasis further by hiring Howard Brenner from Carnegie-Mellon to become chairman in 1977. He had received his ScD in 1957 at NYU and had been on the faculty there before moving to Carnegie. Brenner pushed hard to improve the research productivity as well as the quality of the graduate program. In spite of Brenner's administrative responsibilities he maintained his personal research productivity. He became Rochester's first faculty member named to the National Academy of Engineering.

Brenner chose not to continue as chairman after his term expired in 1980. Before he left for a chaired professorship at MIT in 1981, the department was reduced to seven continuing faculty. At this same time, the undergraduate enrollment was approaching its all-time high. The entering freshman class was estimated to include about 120 prospective chemical engineers, over 10% of the entire freshman class of the University. John C. Friedly took over as chairman in 1981. He had been on the faculty since 1968 and had previously taught briefly at Johns Hopkins and worked for General Electric after having received his PhD at Berkeley in 1965.

When the boom in chemical engineering, fueled by the energy crisis, went bust in early 1983, the Department had to cope not only with a poor job market and large numbers of students still in the pipeline but also with a relatively depleted faculty as well. However, Shaw-Horng Chen had been added in 1981, and Jacob Jorne, Eldred Chimowitz and Stratis Sotirchos came the next. Then after several quiet years with more faculty and falling numbers of undergraduates, David Wu was added in 1987 and Sam Jenekhe in 1988.

Undergraduate Curriculum

In the early days chemical engineering programs were initiated as a result of a combination of local circumstances and one might expect that the curricula would reflect them. The early curriculum outlined by Ernsberger and Chambers was a rigorous program of traditional mechanical engineering with all of the advanced machine design courses replaced by chemistry. In addition, Ernsberger's special courses in power engineering and laboratory and Chamber's course in industrial chemistry were required of the chemical engineers. By 1922 the electrical engineering requirement had been dropped from the chemical engineer's curriculum as well as more of the machine design emphasized by the mechanical engineers. Chemical engineers were required to take every chemistry course the chemists had to take, plus three others.

Although a specific materials course was introduced in the mid-'30s, the curriculum remained pretty much the same until Howard Gardner arrived. The 1938 catalog showed the first influence of the shift toward true chemical engineering. The industrial chemistry courses specific for chemical engineers were replaced with unit operations and with chemical engineering laboratories. By 1940 the requirements had progressed to the point that the chemical engineering curriculum was significantly different from both mechanical engineering and chemistry. Plant design and projects were an integral part of the curriculum, the latter serving as a means of developing the laboratory.

In the following years substantial changes in the curriculum were few. A summer laboratory course was taught from about 1950 through the ´60s. By 1963 the principles of fluid flow and heat and mass transfer had taken the name of transport phenomena. A separate course in unit operations appeared in the mid-60s, changing its title officially to separation processes by the ´70s. In 1978 a microcomputer laboratory was added to the curriculum, the start of a very successful endeavor to introduce all students to interfacing computers with experiments [8]. The engineering materials requirement remained in the curriculum until 1983.

Chemical engineering curricula across the country tend to be rather uniform as a result of tight enforcement of accreditation guidelines. Figure 1 shows how the Rochester curriculum has changed over the years relative to those at Carnegie-Mellon [9], Michigan [10], and Purdue [11]. The curricula have been divided into the general categories of chemical engineering, chemistry, other engineering, electives (presumably technical), mathematics, other sciences, and humanities and social sciences to show the general trends. Judgment had to be used to categorize some of the specific courses in each curricula but it has been used consistently throughout. The stacked bar graphs show the percentage of courses in each of the categories at the specific years shown for each school.

As would be expected, the Rochester curriculum started out heavy in chemistry and mechanical engineering relative to the others. Michigan, perhaps as a result of its earlier beginnings in 1898, had more chemical engineering than the other programs. It was unusual as well in that technical electives were available at that time. The other programs were totally specified. The chemical engineering curriculum at Rochester grew very slowly until Professor Gardner arrived. Rochester tended to require less chemical engineering and more chemistry than the other schools, as might be expected since there were no chemical engineering faculty at Rochester. On the other hand, the fraction of the curriculum devoted to engineering, largely mechanical, was not far different from the other schools. The Purdue curriculum in 1936-37 appears anomalous with less chemical engineering and more electives. Then Purdue experimented with a number of well-defined options for their students, perhaps showing more freedom than was actually there.

The chemical engineering component of the Rochester curriculum grew rapidly in the late ´30s, at the expense of both chemistry and mechanical engineering. By the early

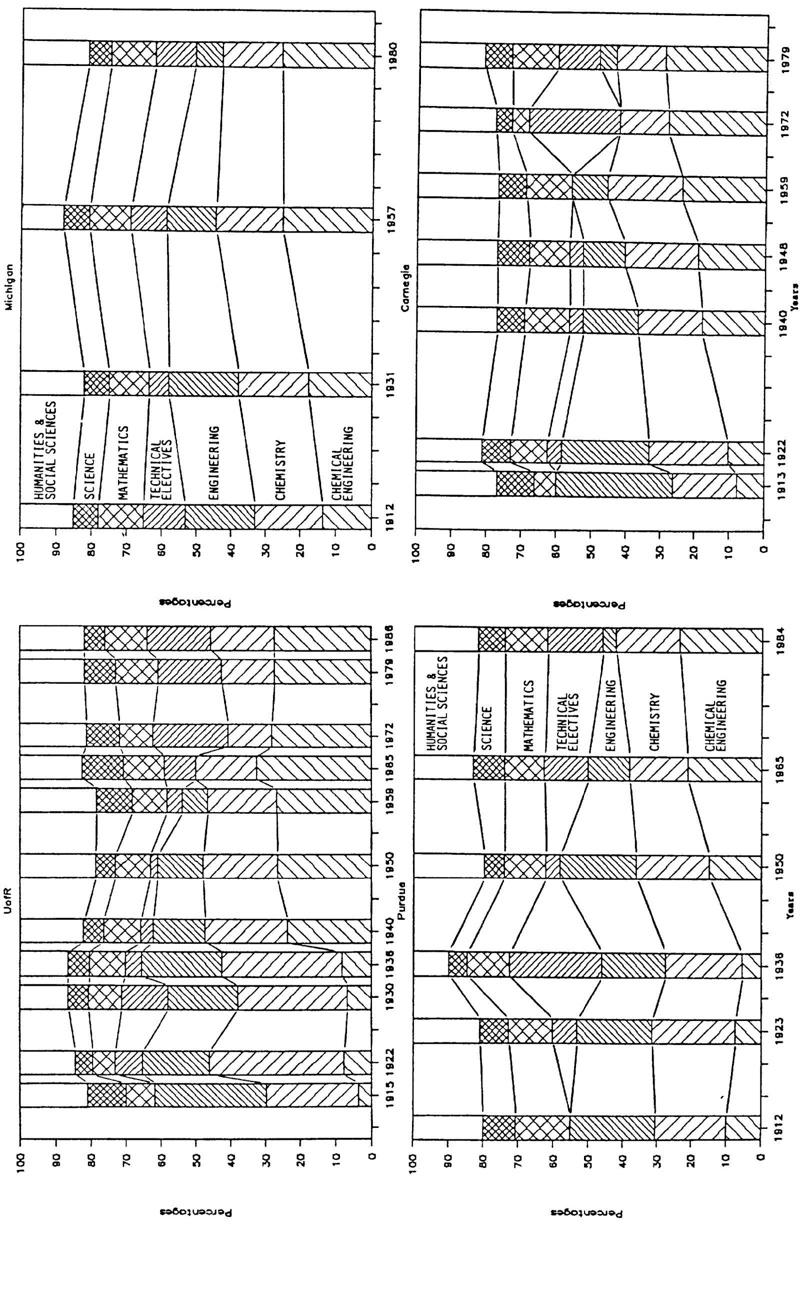

Figure 1: Comparison of Curricula. Bars show fraction of courses in each category.

´40s the curricula did not look significantly different among the four schools. Overall, it is clear that there has been a downward trend in both chemistry and other engineering courses, being replaced by chemical engineering. Mathematics, other sciences and even the humanities/social sciences component of the curriculum have not changed a great deal over the years. Elective courses have fluctuated, but there tends to be more flexibility in later years. Student unrest in the late ´60s and the consequent disillusionment with science and engineering was responsible in part for the increased fraction of electives in the early ´70s. With the exception of the electives, the curricula are all remarkably similar today.

Research Activities

A condition on hiring Howard Gardner must have been the opportunity to perform research. The first MS thesis was submitted within the year of Gardner´s arrival. The faculty with professorial rank supervised the research, with most of the instructors either working for the MS or just having finished the MS degree. The one exception was Joe Martin who was still an instructor when he supervised Hendrik Van Ness´ MS research.

When Gene Su arrived in 1947 he shouldered the bulk of the research load until the ´60s. Table II gives a list of all faculty and the number of MS and PhD theses submitted under their direction. Joint advising within the department results in the few fractional theses in the table. Su´s long career and active research program still holds the record for total MS and PhD theses supervised, more than twice as many as anyone else.

Through May 1988 a total of 84 PhD and 208 MS theses have been accepted in the department. Gene Su supervised about one out of every six of both the MS theses and the PhD theses.

Figure 2 contains an attempt to categorize the research research activities as a function of time. Each MS and each Phd has been assigned to one of eight broad categories based primarily on the thesis title. Each data point on Fig. 2 represents the cumulative total number of theses in that category accepted during the five year period (normally) since the preceding point.

Table II. Numbers of Theses Supervised by Rochester Faculty (through 1988)

Faculty	Dates	MS Theses	PhD Theses
Su	1947-74	33 1/3	15
Friedly	1968-	10 1/2	7 1/2
Smith	1960-80	10	7 1/2
Middleman	1960-69	8	7
Palmer	1971-	8 1/2	5 1/2
Saltsburg	1970-	3 1/2	5 1/2
Bartlett	1962-69	4	4
Osmers	1968-78	7 1/2	3 1/2
Ferron	1969-	12	3
Kraybill	1950-67	11 1/3	3
Douglas	1965-68	4	3
Chen	1981-	2	3
Feinberg	1967-	3	2 1/2
Donaldson	1974-80	7 1/2	2
Wiehe	1966-72	7	2
Cokelet*	1978-	3	2
Notter*	1980-	1	2
Miller	1955-69	14	1
Brenner	1977-81	2	1
Sotirchos	1982-	1	1
Jorne	1982-	1	1
Perry	1964-68	0	1
Byers	1966-70	3	1/2
Horn	1970-77	2	1/2
Dwyer	1939-51	14 1/3	
Gardner	1938-47	14	
Heist	1974-	6	
Eisenberg	('45)'61-83	3	
Ramalho	1961-65	3	
Broughton	1952-54	3	
Chimowitz	1982-	2 1/2	
Anderson	1970-73	2	
Martin	1940-46	1	

*primary appointment in Medicine & Dentistry

Through the '40s distillation was the most popular research area, although mixing studies and thermodynamics was of some importance later in the decade. Thermodynamics

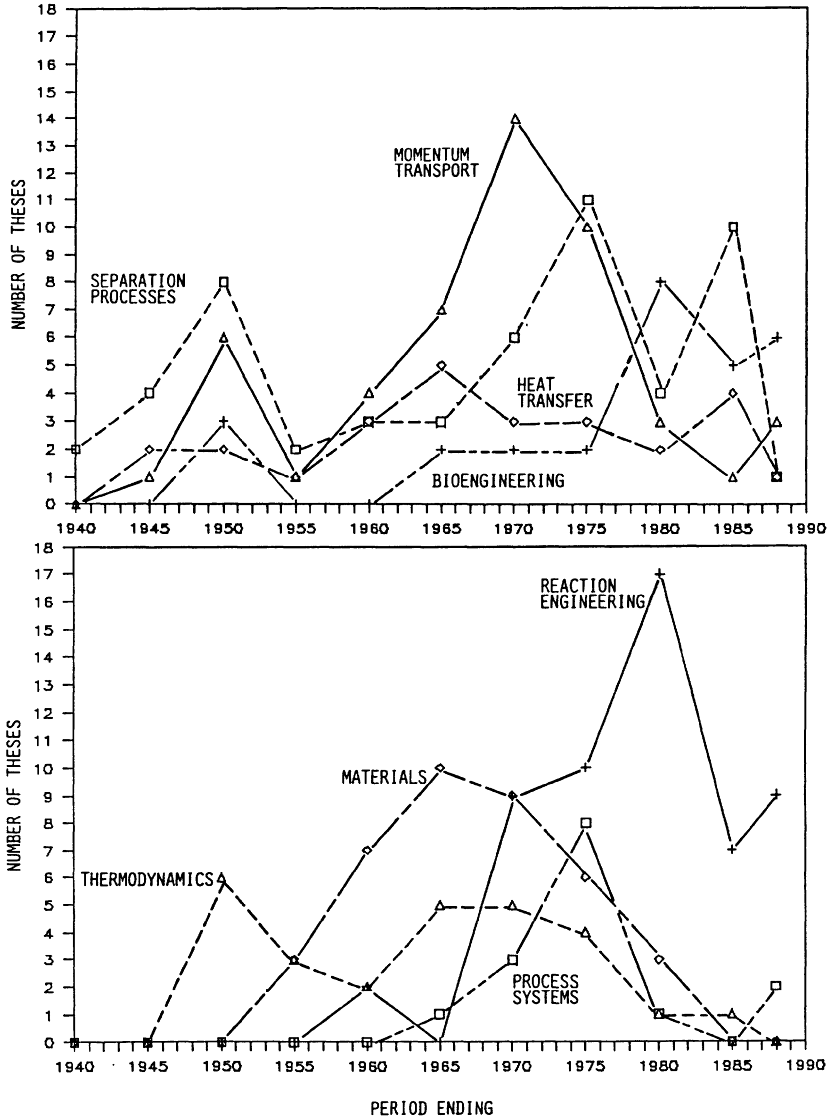

Figure 2. Number of theses (MS and Phd) written in each of eight broad subject areas. Each point represents the cumulative number of theses written since the previous point.

and the growing interest in materials, especially optical materials, was most important in the first half of the ´50s. Optical materials remained dominant in the research through the first half of the ´60s, when interests in transport phenomena and fluid mechanics developed strength. In the later half of the ´60s fluid mechanics research, especially that dealing with non-Newtonian fluids, was clearly dominant. However, optical materials research was still strong and interests grew in reaction engineering and diffusional processes, the latter showing up as a resurgence in separations related research. In the early ´70s fluid mechanics was overtaken by both separations and reaction engineering studies. Reaction engineering, especially catalysis, was clearly dominant in the late ´70s. Diffusion and reaction engineering seem to have alternated in importance since that time.

Early in Gene Su´s career at Rochester he developed an interest in the characterization and properties of amorphous materials. A large number of Su´s students studied the physical chemistry of glass. Although such research was a natural for the Rochester area because of its concentration of glass and optically oriented manufacturing and research, Su´s work was before its time. When his last student finished in 1974 there was no one to continue that research area. Recently, optical and electroactive polymers again became an active research area in the department in the research programs of Chen and Jenekhe.

Alumni

Through 1988 a total of 991 BS degrees, along with 306 MS and 84 PhD degrees, have been granted. A study of alumni records and memories of a number of long-standing members of the department revealed some surprising statistics about the aggregate of graduates. At least one out of every eight graduates of the department is known to have earned a doctoral degree, including MD´s as well as PhDs. More surprising, at least one out of every twenty graduates is or has been a president or vice president level officer of a company. Although many of these work(ed) for major companies, most are officers of their own businesses. In addition, there are many more not counted in this list who are privately employed but choose not to list such a title in the alumni records. One out of every thirty graduates has been a full-time faculty member at a university.

The faculty list includes, for example, Robert Rothfus ('41) at Carnegie-Mellon, Hendrik Van Ness ('45,MS'47) at RPI, John Prausnitz (MS'51) at Berkeley, John Seinfeld ('64) at CalTech, Henrik Pedersen ('74) at Rutgers and Jenny Linderman ('82) at Michigan. Rochester alumni have included an AIChE president (Joe Martin (MS'45) of Michigan), two members of the National Academy of Engineering (Prausnitz and Seinfeld) and two Rochester Trustees (William F. May ('37), former president of American Can, and Edmund A. Hajim ('58), president of Furman Selz et al.)

Department of Chemical Engineering
University of Rochester
Rochester, New York 14627

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James O. Maloney

CHEMICAL ENGINEERING EDUCATION AT THE UNIVERSITY OF KANSAS 1895-1988

Abstract

A degree program in chemical engineering was established at the University of Kansas in 1895. The curriculum included a mixture of courses in chemistry and engineering. From its inception until 1935 the program had no budget, no staff members with degrees in chemical engineering and contained no chemical engineering courses. In 1935 the University created a department with a budget, hired an assistant professor of chemical engineering and applied in 1936 for accreditation of the program. Accreditation was denied and the denial was repeated on further inspections up through 1940. By 1948 four men with Ph.D.s in chemical engineering were on the faculty and accreditation was achieved in 1949. Without the accrediting process which provided critical and helpful comments, it is doubtful that the University administration would have been aware of any deficiencies in the program or been moved to correct them. Through 1988 1536 B.S., 243 M.S. and 81 Ph.D. degrees have been awarded.

Introduction

Chemical engineering at Kansas has been associated with two other engineering programs during its existence, namely metallurgy and petroleum engineering. As a consequence, some preliminary explanation about these associations is necessary.

N. A. Peppas (ed.), One Hundred Years of Chemical Engineering, 321–351.

The first in order of occurrence was metallurgy. In 1918 when the chemical engineering program had been in existence twenty-three years a metallurgical option was established in the chemical engineering program. A student who took the metallurgical option was awarded a degree in chemical engineering, with nothing in the commencement program to indicate that the graduate had completed this option. In 1937 this option was terminated and the equipment and staff associated with it were transferred to the Department of Mining Engineering and that departmental title augmented to the Department of Mining and Metallurgical Engineering. In 1943 a B.S. degree program in metallurgical engineering was authorized and this program was continued until 1968.

Petroleum engineering programs developed first as options in mechanical engineering and mining engineering in 1924. A department of petroleum engineering was created in 1937 with a degree program. In 1961 the Departments of Chemical Engineering and Petroleum Engineering were combined and have remained combined to the present.

The treatment of chemical engineering education at the University of Kansas is divided as follows:

The first forty years (1895 - 1935)
The drive for accreditation (1935 - 1949)
The development of the undergraduate chemical engineering curriculum 1935 - 1986
The graduate programs
Some end results
 a. Degrees awarded
 b. Student performance
 c. Academic activities and awards to the staff

Miscellaneous
- a. List of chairmen
- b. List of professorial staff

The First Forty Years 1895-1935

The program in chemical engineering was established by an action of the Board of Regents on June 3, 1895 which is recorded as follows:

> "Motion carried that the following course (program, ed.) in chemical engineering be adopted:"

A list of courses by semester then follows. Unfortunately no information has been found in the minutes or elsewhere which states the reasons for this action. One may, however, infer the purpose of the program from the description given in the 1895/96 catalogue. The description is:

> "In the course in chemical engineering, in addition to the work taken in common with the other students of this school, in the junior year the students begin quantitative analysis, which is to a large extent the foundation of the chemical course, and involves the accurate determination of the composition of various substances, both organic and inorganic. This is followed by the course in the manufacture and purification of chemicals, especially those of an inorganic character, and at the same time work is begun in organic chemistry, which includes both lectures and recitations, and a complete elementary course in the laboratory. It is an essential preparation for the work of the senior year. In the last year the student devotes more special attention to chemistry. Here he has an opportunity to specialize to a greater extent than in previous years, as several optionals are offered. The practical side of the work is not overlooked, and on this

> account such subjects as metallurgy, assaying, chemical technology and sanitary and applied chemistry are included."

The chemical engineering program was the third engineering program to be established at the University of Kansas but its organization was entirely different from the two earlier ones, civil and electrical engineering. These two programs had men associated with them who were titled professors in the particular field. Both programs had departmental status after 1891 and after 1893 were overseen by a dean of engineering and each had a budget which was in the School of Engineering. Chemical engineering from its beginning in 1895 until 1935 had no faculty member associated with it carrying any professorial rank in chemical engineering and the program had no identifiable budget. Any administrative duties which were associated with the operation of chemical engineering were performed by the head of the Chemistry Department.

Irregular arrangements such as existed at Kansas at that time were not uncommon in the early days of chemical engineering education; but by the end of World War I sounder organizations began to be developed. The professional society which developed around chemical engineering (The American Institute of Chemical Engineers, A.I.Ch.E.) was stating by 1920 that chemical engineering education should be associated with the engineering portion of the institution and that chemical engineering education centered around a number of topics known as the unit operations. These unit operations, for the most part, were unique to chemical engineering and were not portions of chemistry or other engineering subjects.

By 1924 the A.I.Ch.E. had studied the chemical engineering curricula of a number of schools and had certified sixteen programs in the nation as offering adequate undergraduate instruction for a B.S. in chemical engineering. This certification process became known as accreditation. The A.I.Ch.E. was the first professional society to embark on the accreditation process. The other societies did not initiate accreditation until around 1934; and when they did, they relied heavily on the experience of A.I.Ch.E.

Twenty-one programs had been accredited by the A.I.Ch.E. by the end of 1932; but the program at Kansas was not one of the twenty-one. These programs all included extensive education in the quantitative aspects of material and energy balances, and a thorough treatment of many of the unit operations coupled with extensive laboratory work.

A study of the curriculum in chemical engineering at Kansas from 1895 - 1935 shows no chemical engineering courses being taught that the A.I.Ch.E. thought important. Also there was no staff member in the university who had formal education in these important courses. From time to time one finds in the records of the university and in reports by deans and departmental chairman descriptions of their activities. None of the descriptions from these times mentions the chemical engineering program. Perhaps it was not considered important enough to mention. Even so the dean of engineering, George Shaad, and others in 1932 seemed to believe that they were operating a sound chemical engineering program. They were disabused of such a belief when they attempted to have the chemical engineering program accredited by A.I.Ch.E. only to have accreditation denied.

The Drive For Accreditation 1935-1949

This section on accreditation is rather extensive in that it shows in some detail the deficiencies in the chemical engineering program that had been allowed to exist for decades. It also illustrates the observation that an organization has difficulty in reforming itself, and that reform usually requires a strong external agent. The account also shows that funds can be found to rectify deficiencies even when, one would suppose, few, if any, funds, were thought to exist.

Dean Shaad in a letter to the Chancellor of the University, Ernest Lindley, in 1932 states that he discovered that the program in chemical engineering had not been accredited by the A.I.Ch.E. He sent a very complete report to the A.I.Ch.E. on the program and requested that it be inspected with the end to having it accredited. On May 15, 1933 the Accrediting Committee on Chemical Engineering responded to the request by denying it. There were several central criticisms. The response, in part, is as follows:

> "1. There is no one on the faculty who is by training or experience qualified to teach specialized chemical engineering subjects, or to set up and direct a chemical engineering laboratory.
> "2. The curriculum is not a satisfactory one. It lacks the major chemical engineering subjects, and there is, in fact, but little chemical engineering included in it.
> "3. Your laboratory facilities for chemical engineering are very inadequate.
>
> "It is to be understood that none of the criticisms of our Committee refers in any way to the excellent Chemistry Department at Kansas, except, of course, the implied criticism that the Chemistry Department is operating an unsatisfactory chemical engineering course."

Dean Shaad did not believe that the action of A.I.Ch.E. was justified and decided in 1934 to try another method for having the program recognized. At this time only the chemical engineering profession had an accrediting body; but the State of New York through its Education Department, upon request, would register graduates from various engineering schools who were deemed to have followed a satisfactory program. The individuals could then begin the practice of engineering in New York. So Dean Shaad requested that all of the graduates from the various engineering programs at Kansas be registered in the State of New York. The Education Department of that state then deferred action on two programs and refused to register the chemical engineering program. The Education Department, in taking this latter action, merely repeated the findings of A.I.Ch.E.

Taking into account these criticisms Dean Shaad in 1934 proposed to Chancellor Lindley the following actions which he believed would put the program in chemical engineering in a satisfactory condition for being accredited.

1. Organize a Department of Chemical Engineering in the School of Engineering and have the staff of the Department revise the curriculum along the lines suggested by the A.I.Ch.E.
2. Hire a highly qualified professor of chemical engineering.
3. Transfer the professor of metallurgy from the Department of Chemistry to the newly created Department of Chemical Engineering and make him acting head of the Department.
4. Allocate substantial funds ($10,000) for the purpose of building up the chemical engineering laboratories.

Shaad, in 1934, made these recommendations, which were accepted, at a time of great financial stress on the University. Salaries of the faculty had been reduced in 1933 by about 25% and maintenance and equipment funds had also been sharply cut! Additional funds for equipment and faculty continued to be provided in subsequent years to chemical engineering until 1940. The accrediting body had obviously gotten the attention of the dean and the chancellor at Kansas and the deficiencies were going to be remedied.

All of these recommendations had been carried out by the fall term of 1935. T. H. Marshall was hired as an assistant professor. He had a B.S. and M.S. in chemical engineering from accredited schools and had been an instructor at Case Institute, an accredited school. He was obviously a person well qualified in chemical engineering subjects. About 2000 sq. ft. of space were set aside in the basement of the chemistry building for chemical engineering offices and laboratories.

But there was another problem that had not been mentioned by A.I.Ch.E. or anticipated locally. It had to do with awarding a B.S. degree in chemical engineering to students who followed a metallurgical option. This option had been created in 1918 and continued to exist after these 1935 changes. The University discovered in 1936 that the A.I.Ch.E. would not accredit a curriculum in which chemical engineering degrees were awarded to students following other engineering options.

By 1935 a procedure for accrediting all engineering programs had been worked out and an organization known as the Engineering Council for Professional Development (E.C.P.D.) was ready to send a team to KU to conduct an on-site study of the various programs for which accreditation was requested. A.I.Ch.E. furnished a visitor to the team for any chemical engineering program being inspected. Furthermore A.I.Ch.E. had an agreement with E.C.P.D. that E.C.P.D. would not accredit any chemical engineering program that was not first approved by A.I.Ch.E. This agreement placed all chemical engineering departments in the unique position of having to satisfy two organizations rather than one. This situation persists today.

Chancellor Lindley in early 1936 had requested that E.C.P.D. inspect all of the engineering programs including chemical engineering. Dean Shaad died unexpectedly before the fall term and for a year the School was administered by an executive committee of which Professor F.A. Russell was chairman. Nevertheless, the decision was made to proceed with the accrediting operation.

The visiting team, led by A. A. Potter Dean of Engineering at Purdue, arrived in November 1936. Potter had served as Dean of Engineering at Kansas State from 1913 - 1918 and probably knew more than anyone on the team about engineering education in Kansas. Another member of the team was Dean Ivan C. Crawford from Idaho who within a year would accept the post of Dean of Engineering at Kansas. Dean Potter wrote to Chancellor Lindley an informal report of the findings of his team. He did not comment on chemical engineering but left that matter to A.I.Ch.E. E.C.P.D. on October 6, 1937 informed Lindley that it would not accredit the chemical engineering program. The chairman of the Accrediting Committee of A.I.Ch.E., A.B. Newman, provided the following comments about the program.

> "While there has been a marked improvement during the past three years, chemical engineering is still not given the dignified position it should have. The work is being given by two Associate Professors, and the average salary for this rank is stated to be $2410. One of these men is Acting Head of the Department. It is difficult to believe that qualified men

> can be induced to accept that salary. The faculty is too small for a curriculum with two options (chemical and metallurgical). The men are overloaded and have no time for research activities either individual or with graduate students."

In the light of these comments, the new dean, Ivan C. Crawford, took the following actions with respect to chemical engineering.

1. Discontinued the metallurgical option in chemical engineering. He believed that chemical engineering would never be accredited as long as a degree in chemical engineering was awarded to students in the metallurgical option.

2. Transferred the professor of metallurgy to a newly titled Department of Mining and Metallurgical Engineering and had his position renamed as associate professor of metallurgical engineering.

3. Made associate professor T. H. Marshall acting chairman of the Department of Chemical Engineering.

Marshall was made chairman of the Department of Chemical Engineering as well as a full professor in 1939. So after almost a half century the department had its first chairman, its first full professor, and its own budget. In 1938 Walter Deschner was hired as an assistant professor of chemical engineering. He had a Ph.D. in chemical engineering from Michigan and had been an instructor at Pratt Institute from 1935 - 1938. He, like Marshall, had the qualifications to develop the chemical engineering program. At the same time plans were being developed for a new building which would house, among others, the departments of chemical, mining and metallurgy, and petroleum engineering.

In 1940 another unsuccessful attempt was made to have the chemical engineering program accredited. The chairman of the accrediting A.I.Ch.E. group wrote a letter on November 20, 1940 to the new chancellor, Deane W. Malott, in which he detailed in two and a half pages the reasons for the denial of accreditation. The main criticisms were as follows:

> "I cannot escape the conviction that this department is not quite ready for accreditation. The reasons for my belief may be summarized as follows:
>
> 1. A perusal of the sample problems and examination questions indicate to me that the quality of the instruction is below good standards.
> 2. The curriculum has to me, at least, several questionable features.
> 3. The present curriculum is, being followed only by sophomores.
> 4. The salary scale is low.
>
> No one of these factors alone would be sufficient to influence me to vote unfavorably, but the combination weighs heavily against favorable action."

At this point essentially all activities directed toward accreditation probably ceased. Professor T. H. Marshall, who was a reserve officer, entered the army in 1941. Professor Deschner resigned in early 1942 to work for J. F. Pritchard. This left only T. T. Castonguay, who was hired in 1941, to carry on until late 1945. He served as an instructor (1941 - 42), an assistant professor (1942 - 45) and an associate professor (1945 - 46). He was also acting chairman from 1942 to 1945. Castonguay resigned in 1946 to accept a position as chairman of the Department of Chemical Engineering at the University of New Mexico. Deschner continued to be associated with Pritchard for many years. Marshall rose to the rank of Brigadier General during WWII and then worked for many years in a subsidiary of American Cyanamid.

The reader might conclude, at this point, that the graduates from 1900 to 1940 were poorly educated. Such was not the case. These men had taken rigorous courses in engineering, science and mathematics and they were able to make their way in the world. They were just uneducated in chemical engineering.

As World War II drew to a close many engineers began to think of their post-war work. In the DuPont Company there were six engineers in the Technical Division who were to enter the educational field. In the early summer of 1945 J. O. Maloney of the Technical Division approached Dr. Roy Cross of Kansas City, Mo. regarding the possibility of developing a strong chemical engineering program at the University of Kansas. Maloney had been an employee of Cross's in 1936 and felt that Cross, an eminent authority on petroleum processing, a man with wide technical and scientific connections, and a K.U. graduate, could give him a good estimate of the K.U. situation. Cross discussed the matter with Chancellor Malott and Maloney visited Lawrence in July. He was subsequently informed that the University was prepared to offer him a professorship and the chairmanship of the Department. Further he would be allowed to fill three associate professorships with mutually acceptable men. Also he would be provided sufficient funds for equipment. The terms of the offer were accepted and the University met the terms completely. It was clear to everyone concerned that getting the department accredited was the primary objective. Maloney was also to serve half-time as Executive Director of the recently-formed Research Foundation.

Maloney arrived in December of 1945. S. A. Miller came from the Technical Division in 1946. The other four DuPont engineers dispersed themselves as follows: W.R. Marshall went to the

University of Wisconsin and R.L. Pigford to the University of Delaware. Charles Lapple and Mars Fontana both went to Ohio State. Fred Kurata came to Kansas from Atlas Powder Company in 1947 and S. M. Walas from Stone and Webster in 1948. These four men (Maloney, Miller, Kurata and Walas) who constituted the Kansas staff all had Ph.D. degrees in chemical engineering and all of them had at least four years of industrial experience. They formed a stable department for almost a decade. Miller left in 1955 to become chairman of the department at the University of Rochester. The other three remained at Kansas until they retired.

The post-war situation for the chemical engineering program was promising. The University was at last willing to provide the funds for staff, space and equipment. Four professors with impressive credentials had been hired, new quarters in a new building were available and funds for equipment were allocated. The Department applied for accreditation in 1949 and it was accredited with only one comment; namely, that the chemical engineering students should take the same first two chemistry courses that the chemistry majors took rather than the first two chemistry courses all engineers were taking. Table I shows the growth in the number of accredited departments from sixteen in 1924 to one hundred thirty five in 1984.

Thus the University of Kansas after more than a half century could state, without fear of contradiction, that it had a satisfactory undergraduate chemical engineering program. Had it not been for the accrediting procedure of the A.I.Ch.E. it might well have been many years more before the attention of the University would focus on this program.

After 1949 and until the present the department has remained accredited and most of the adverse criticisms leveled at it after each subsequent inspection have been the same as those leveled at all the curricula in the School - too much credit for R.O.T.C., too few humanities courses, not enough core courses in the engineering sciences and not enough emphasis on design.

The Development of the Undergraduate Chemical Engineering Curriculum 1935-1986

The engineering profession has a formal definition of its purpose, and each branch of the profession in turn has a definition of its purpose which is a sub-section of the overall definition. These definitions in a general way set the educational objectives of the undergraduate engineering programs. Two of the definitions are of interest and are as follows:

> "Engineering is the profession in which a knowledge of mathematics and natural sciences gained by study, experience and practice is applied with judgement to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind"
>
> from 42nd Annual Report, Engineers' Council for Professional Development, New York, 1974.

> "Chemical engineering is the profession in which a knowledge of mathematics, chemistry and other natural sciences gained by study, experience and practice is applied with judgement to develop economic ways of using materials and energy for the benefit of mankind"
>
> from Article III, Constitution and By Laws, American Institute of Chemical Engineers as of March 28, 1983.

These two definitions might give the impression that engineering is a judicious combination of the natural sciences and that it contains no subject matter particular to the profession or its sub-branches. Such, of course, is not the case and every accredited undergraduate program has as a major component of its program a series of courses which cover engineering principles and practices particular to the field of specialization. In Table II the entire chemical engineering program has been broken down into its components for a number of years extending from 1934 to 1986. The 1934 program, with at most two courses having a chemical engineering slant, might be judged to be a program in applied chemistry. At that time about four percent of the total course work was in chemical engineering. Over the years this percentage has grown until today (1986) it is about thirty-eight percent of the program. Probably few scientists would consider these present-day courses in chemical engineering as merely applied science.

A significant change in the undergraduate program had occurred by 1969 in that the number of semester hours for graduation was seventeen less than a decade earlier. The reduction to 132 total hours was a school-wide action and was based on the following assumptions:

1. If the hours required for graduation were close to those required in the College of Liberal Arts and Sciences (128 hr.), more students would be attracted to engineering, and
2. If the hours were reduced, many more students would obtain their degrees in eight semesters.

So the reduction occurred, but no studies have ever been made to check the validity of these two assumptions.

In reducing the hours to 132 the departments in engineering were under a number of constraints from an accrediting standpoint. They could not reduce credits in the humanities and social sciences, English, mathematics, physics or chemistry (in the case of chemical engineering). In mathematics the School decided that the courses in college algebra and trigonometry would not carry credit toward graduation and that these two courses should be taken in high school. The only possible action was to reduce the hours in engineering subjects outside the department and this was done. In addition, another complication arose in that more new subject matter needed to be included.

The net result has been that the students now have more chemical engineering work and less other engineering work than ever before. These students are better informed about chemical engineering matters but are uninformed of the elements of other engineering subjects. Probably the students in the other programs are equally ignorant outside their specific discipline. Whether or not this change has been a sound development for the profession of engineering goes remains to be seen.

In Tables III and IV the developments in the courses in chemical engineering in the program are shown. Using Table III a comparison of the national developments with those at Kansas is possible. In 1935 Kansas was several decades behind the accredited schools; but by 1955 the Kansas curriculum was in a reasonable accord with those of most other schools and has remained so until the present. Table IV shows how the number of courses and the number of semester credit hours in chemical engineering subjects have changed over the last half- century.

The enrollment of women in chemical engineering has increased markedly from two in 1972, to as high as eighty eight in 1982. Over the fifteen year period 1972 - 1987 about 23% of the undergraduates in chemical engineering have been women, and women have constituted about 17% of those receiving B.S. degrees in chemical engineering. These percentages are the highest of any program in the School. The first woman to be awarded a B.S. degree in chemical engineering from K.U. is believed to have graduated in 1946.

Graduate Programs

There is a difference between the undergraduate and advanced degree programs. The contents of the undergraduate program is largely established by the accrediting bodies (A.I.Ch.E., E.C.P.D. and ABET). There is no accrediting body for advanced programs, but there is a general uniformity across the nation with respect to courses and examinations. The principal difference between undergraduate and graduate work is the great emphasis placed on research and the preparation and defense of a thesis.

Various kinds of advanced degrees available to students have been developed and changed through the years. The first degree was the professional degree. It was available to persons who had an undergraduate degree from any program in the School, who had had several years of important experience in industry doing engineering work and who could prepare and successfully defended a thesis on some aspect of their work. It did not require any advanced course work. The designation in the graduation program was chemical engineer, civil engineer, etc. This kind of degree was awarded from 1900 to 1960.

The two most prevalent degrees have always been the M.S. and Ph.D., and the Department offers both. Two special categories of M.S. degrees which were offered for a time were the M.S. in Nuclear Engineering and Nuclear Science. Another special category is an M.S. in Petroleum Management. This latter program was initiated in 1957 and it continues to the present time.This is basically a joint program with the School of Business which combines certain aspects of management and petroleum engineering. The majority of the students in the program have been military officers who are following a service career in the operation and management of fuel depots for the military.

Two other programs developed in the late sixties in the School of Engineering - the Master and Doctor of Engineering (M.E. and D.E.). These two programs center around the management of engineering efforts.

All of the previously awarded degrees in the Department except for the M.S. in Petroleum Management require a combination of course work, research work and the preparation and defense of a thesis.

The advanced degree programs in chemical engineering did not develop rapidly until after WWII. Previously, only a few M.S. degrees had been awarded and all of them were under the supervision of Professor Marshall the first chairman of the department. Until 1935 there was no advisor available who had an advanced degree in chemical engineering; the staff was heavily overloaded with teaching; there were no significant funds to support graduate students or to purchase equipment; and finally there was no space for doing research.

In the decade from 1945 to 1955 the situation changed markedly. There were four professors with Ph.D.'s and industrial experience. They were familiar with research work and its supervision and had well-founded opinions about research subjects; the teaching staff was sufficient and assistants were provided to help; and significant funds became available from the Atomic Energy Commission and the National Science Foundation to support students and to purchase needed equipment. In addition some of the students were receiving support funds from the G.I. Bill. Also extensive new space was available. In that decade the Department had the staff, the ideas, the money and the students.

Research is conducted by professors for a variety of reasons but one of them is that research is a controlling factor inside the University when it comes to promotion and salary increases. The research pursued in general, follows the interest of the faculty member. These interests are in turn controlled somewhat by his research as a graduate student, his industrial experience, the academic fashions of the moment and, of course, the availability of financial support. Maloney directed research in the area of his graduate work, (absorption and distillation), his DuPont experience (centrifugation) and his wartime atomic bomb work, (heavy water production and the application of radioactive tracers). Miller's research was based on his graduate studies and his DuPont experience (agitation, mixing and filtration). Kurata's main research followed along the lines of his graduate work (the behavior of hydrocarbon mixtures). Walas did not follow up on his graduate research but developed an interest in chemical reaction kinetics (producing a text on the subject) and in process design.

In 1957 two more professors were added to the staff - Mesler and Rosson. Both of these men had prior experience in heat transfer work and nuclear energy. In addition to doing research work in heat transfer at KU, they developed and taught courses in nuclear engineering and supervised the construction and operation of the nuclear reactor. The nuclear operations continued for almost a quarter of a century before being terminated. The additions of Preston (1962), Swift (1962), Green (1964) and Willhite (1970) strengthened the department in several areas of petroleum research. Bishop (1967) arrived with a background in process control and computer utilization. He has been heavily involved in computer development in the School for many years. Howat (1981), along with

Swift, has a background in process design and in the behavior of hydrocarbon systems. Thiele (1983) is actively involved in polymer studies, and Subramaniam (1985) is carrying forward studies in reaction kinetics and catalysis.

The major support for research within the Department for the three decades from 1945 to 1975 was the federal government. During the last decade the State of Kansas has also provided significant support for the development of methods to increase the recovery of oil from petroleum reservoirs. The State also provides general research funds to the University and a number of faculty in the Department has obtained research support from these funds. Three major research efforts which have endured for many years are the work in thermodynamics and the behavior of hydrocarbon-containing systems initiated by Professor Kurata and carried forward by Swift and Howat, the work in nucleate boiling being done by Professor Mesler and the program in enhanced oil recovery methods under Professors Green and Willhite. Now, in 1988, the staff is well qualified to teach and direct research in many of the important areas of chemical engineering. Efforts, however, are underway to bring in new faculty with expertise in the so-called emerging areas of technology, such as materials science and bioengineering.

An interesting side light on the faculty in the Department of Chemical and Petroleum Engineering is the influence of the University of Michigan, direct and indirect, on the department. Professors Deschner, Kurata, Walas, Weinaug and Mesler all received Ph.D. degrees from Michigan, and Preston an M.S. Professors Swift, Green and Bishop are second generation Ph.Ds, so to speak, in that they received graduate instruction under Michigan Ph.D. graduates. Professor Howat is a third generation staff member having done his Ph.D. work under Swift.

Several faculty members have been active in foreign educational matters. Kurata was in Peru, Mexico and Algeria. Maloney held Fulbright Lectureships in Italy, Egypt and Greece and Preston has spent time in Venezuela and Trinidad.

An advisory board, composed of alumni with wide backgrounds in chemical and petroleum matters, was established in 1986. This board has been of great assistance in helping the department to focus on its future direction.

In 1975, after thirty years in Lindley, the department moved into new quarters in Learned Hall. These quarters have been a great improvement.

Some End Results

Table V provides a summary of all the degrees awarded in chemical engineering decade by decade through 1988. From 1918 to 1937 undergraduates students could follow either the chemical engineering program or an option in metallurgical engineering. The degree awarded, however, was a B.S. in chemical engineering and is so counted in Table V. The first B.S. degree was awarded in 1900. The first M.S. degree was awarded in 1937. The first Ph.D. degree in chemical engineering, and in the School of Engineering, was awarded to in 1951.

As early as 1934 the American Institute of Chemical Engineers had prepared and issued a "student contest problem". This problem can be attempted by any student who had not completed a B.S. degree in chemical engineering. The contest rules are that the solution was to be done independently and within thirty consecutive calendar days. Each department of chemical engineering can submit up to two solutions for national judging. A first, second and third prize plus honorable mentions may be awarded with the awards being made at the annual national meeting of the A.I.Ch.E. In recent years these problems have emphasized the design aspects of chemical engineering.

The department at K.U. since 1948, when Stanley Walas joined the staff, has been fortunate to always have a person teaching design who has up-to- date-industrial design experience. Walas has been followed by Swift and in turn by Howat as design instructors. Not many chemical engineering departments have had such qualified persons. The competencies of these men have resulted in the development of some outstanding performers in solving the student contest problem.

Year	Student	National Award
1940	O. R. McIntire	Honorable Mention
1958	Thomas Rogers	Second
1981	Brian Thompson	First
1982	Robert Boland	Second
1984	Russel Berland	Second
1985	Richard Kuckelman	First
1985	Richard MacDonald	Third
1986	Diana Jobson	First
1986	Nancy J. Roberts	Honorable Mention

The basic purpose of the undergraduate chemical engineering curriculum has always been to prepare a student to work successfully in industry in the capacity of a chemical engineer. Nevertheless a substantial number of our students have gone on to other schools to do graduate work principally in chemical engineering. In no case has a student failed to perform satisfactorily in doctoral work at the major universities of the nation. Possibly their successes merely proves the old adage that it's hard to ruin a good student. On the other hand, their success at other schools may be due, in part, to the instruction they received at K.U.

The members of the department have been recognized for excellence in several areas. Four of the staff are holding named professorships. Mesler is the Warren S. Bellows Professor; Swift is a Deane E. Ackers Professor; Willhite is the Forney Professor; and Green is the Conger-Gabel Professor. The Conger-Gabel Professorship was the first endowed professorship in the university awarded for excellence in undergraduate education. Professor Kurata during his career held a Spencer and a University Professorship. Professors Swift, Green, Terry and Howat have received School and University awards for excellence in teaching. Four of the present staff, Green, Maloney, Mesler, and Swift are fellows of the American Institute of Engineers; and three are Distinguished members of the Society of Petroleum Engineers - Green, Swift and Willhite.

Three laboratory areas have been named for staff members. The Kinetics Laboratory area has been named for Morris Teplitz in light of his interest in chemical reactors, and the Unit Operations Laboratory area has been named for James Maloney because of his interest in this type of laboratory work. The Kurata Thermodynamics Laboratory Building recognizes Professor Kurata for a lifetime of productive work in thermodynamics.

The staff have been active in producing books for the profession. Professor Walas has written three texts "Reaction Kinetics for Chemical Engineers" (1959), "Phase Equilibrium in Chemical Engineering" (1985) and "Chemical Process Equipment" (1988). Professor Green, with Maloney as his assistant, acted as editor of the sixth edition of "Perry's Chemical Engineers' Handbook", (1984). Professor Willhite has prepared a commissioned text for the Society of Petroleum Engineers entitled "Waterflooding" (1986).

The vast majority of the chemical engineering graduates have entered industry upon receiving their B.S. degree and some of them such as Bill

Douce, Joe Davidson, Wren Gable and Paul Pankratz have risen to high management levels. Others with advanced degrees, such as John Dempsey, Tom Edgar, Dale Laurance and Ted Szabo have developed international reputations. One graduate, Paul Haney, is a member of the National Academy of Engineering. Twenty six of the graduates have followed the example of their professors into university teaching. These educators all have doctoral degrees and are listed in Table VI.

At the present time the majority of the naval officers responsible for the management of fuel supplies for the Navy throughout the world received their degrees in petroleum management from the department. The success of this program is due in large measure to the vision of the late Professor Weinaug.

Not only have the departmental graduates been successful in the fields of chemical and petroleum engineering but a number of them have gone on to other careers such as banking, law, medicine and the military service.

Miscellaneous

Tables VII and VIII contain a list of the chairmen of the Department and a list of the faculty respectively. The faculty members have been able over the years to maintain a friendly, tolerant and mutually respectful attitude toward one another. This attitude has allowed the department to achieve resolution of issues in a harmonious fashion and has helped make the duties of being chairman a relatively pleasant activity.

James O. Maloney is an emeritus professor of Chemical Engineering at the University of Kansas, Lawrence, Kansas 66045.

Table I

Chemical Engineering Programs Accredited
1925 - 1984

Year	Total Number Accredited	Remarks
1924	16	First Accrediting Action. A.I.Ch.E.
1935	25	Joint A.I.Ch.E. - E.C.P.D. Accr.
1949	63	K.U. Program Accr.
1960	100	
1970	119	
1980	127	

Table II

Distribution of Credit Hours by Subject Areas and Years
Undergraduate Chemical Engineering Program
University of Kansas

Year Subject Areas	1934	1939	1949	1959	1969	1979	1986
				Credit Hours			
Chemical Engineering	6	29	34	38	39	42	50
Chemistry	40	30	32	24	27	27	26
Math. & Physics	30	28	28	28	26	26	23
Other Engineering	42	33	30	25	11	9	8
Communication Subjects English and Speech	8	9	10	12	9	9	9
Humanities and Social Sciences	0	9	11	13	15	15	13
Others	13	3	3	9	5	4	3
Total Semesters Hours	139	141	148	149	132	132	132

Table III

Chemical Engineering Curriculum Development
Nationally and at the University of Kansas

Period	Nationally	Univ. of Kansas
1898 - 1915	Industrial chemistry and descriptions largely nonquantitative, of processes used in industry.	1910 First course in industrial Chemistry 1912 Two courses - Inorganic industrial chemistry Organic industrial chemistry
1915 - 1925	The unit-operations concept, chiefly the application of physics, took hold and was the central educational theme.	No change from 1912
1925 - 1935	Unit operations were still the dominant theme, but more emphasis was being put on material and energy balances.	No change from 1912
1935 - 1945	Applied thermodynamics and process control assumed importance, but the development does not imply necessarily less emphasis on unit operations.	Unit operations, material and energy balances, and applied thermodynamics courses appeared. Descriptive industrial chemical courses were retained.
1945 - 1955	Applied chemical kinetics and process design came to the fore. Unit operations losing its uniqueness as it was-consolidated into other concepts.	Basically no change in the subject matter except for the inclusion of some reaction kinetics in one of the chemical process courses.
1955 - 1986	More and more emphasis placed on engineering science. Rather than emphasizing unit operations, the present trend is to concentrate on the basic engineering sciences; ***** one uses momentum and mass transfer and energy transfer.	Inclusion of courses in reaction kinetics, process control, economics of the chemical industry, project evaluation and increased emphasis on process design. A decade of courses in transport phenomena end with a partial shift back to the unit operations.

The first and second columns are from F.T. Van Antwerpen, "The Origins of Chemical Engineering" pp 1-13 History of Chemical Engineering, Wm. F. Further, Ed. Amer. Chem. Society, Washington, 1980.

Table IV

Number of Courses and Credit Hours
In Undergraduate Chemical Engineering Subjects
University of Kansas 1934-1986

Year	Courses	Semester Hours
1934	2	6
1935	9	20
1939	15	29
1949	14	34
1959	16	38
1969	14	39
1979	17	42
1986	17	50

Table V

Degrees in Chemical Engineering
University of Kansas
1900 - 1988

DECADE	B.S.	CH.E.	Masters	Doctors
1900 - 1909	16	1	--	--
1910 - 1919	57	1	--	--
1920 - 1929	63	4	--	--
1930 - 1939	159	2	2	--
1940 - 1949	223	3	20	--
1950 - 1959	216	--	31	7
1960 - 1969	173	--	56	24
1970 - 1979	270	--	60	32
1980 - 1988	359	--	74	19
TOTALS	1536	11	243	82

Table VI

Graduates Active in Education
Department of Chemical and Petroleum Engineering
University of Kansas

Name	K.U. Degree	Activity
Boylan, David	B.S. Chem. Engr. 1943	Dean, Iowa State Univ.
Dealy, John	B.S. Chem. Engr. 1958	Professor, McGill Univ.
Dougherty, Elmer	B.S. Chem. Engr. 1951	Distinguished Prof., Pet. Engr., USC
Economides, Chris. E.	M.S. Chem. Engr. 1977	Co-Founder of Dept. of Pet. Engr. Univ. of Alaska (Formerly)
Economides, Michael	M.S. Chem. Engr. 1976	Co-Founder of Dept. of Pet. Engr. Univ. of Alaska (Formerly)
Edgar, Tom	B.S. Chem. Engr. 1967	Chm. Chem. Engr. Univ. of Texas, Austin
Evers, Jack	Ph.D. Pet. Engr. 1970	Formerly Chm. Pet. Engr., Professor Univ. of Wyoming
Gioia, Franco	M.S. Chem. Engr.	Chm. Chem. Engr. Univ. of Naples, Italy
Harmony, Marlin	B.S. Chem. Engr. 1958	Chm. Dept. of Chemistry Univ. of Kansas
Howat, Colin	Ph.D. Chem. Engr. 1984	Associate Professor, Chem. Engr. Univ. of Kansas
Knapp, Roy	Dr. of Engr. 1973	Chm. Pet. Engr. Univ. of Oklahoma
Kohn, James	Ph.D. Chem. Engr. 1956	Professor, Chem. Engr. Notre Dame
Kritikos, Bill	Dr. of Engr. 1981	Assistant Professor, Pet. Engr. Louisiana Tech Univ.
Lyons, William C.*	Ph.D. Engr. Mech. 1965	Formely Chm., Pet. Engr., Professor New Mexico Institute of Mining & Technology
Manley, David	Ph.D. Chem. Engr. 1970	Professor, Chem. Engr. Univ. of Missouri, (Rolla)

*Not a graduate of the Department

Mesler, Russell	B.S. Chem. Engr. 1949	Distinguished Professor Chem. Engr. Univ. of Univ. of Kansas
Miner, J.R.	B.S. Chem. Engr. 1959	Chm. Agriculture Engr. Oregon State Univ.
Myers, John	Ph.D., Chem. Engr. 1964	Professor, Chem. Engr. Villanova
Ostermann, Russell	Ph.D., Chem. Engr. 1980	Chm. Pet. Engr. Univ. of Alaska (Co-Founder, Dept. Pet. Engr. Univ. of Alaska)
Rannie, R.P.	M.S. Chem. Engr. 1960	Professor, Computer Science, Northern Illinois Univ.
Reynolds, Paul D.	B.S. Pet. Engr. 1960	Professor of Sociology Univ. of Minnesota
Rosenwald, Gary	Ph.D. Chem. Engr. 1972	Formerly Associate Prof., Pet. Engr. Univ. of Wyoming
Swift, George	Ph.D. Chem. Engr. 1959	Chm. Chem. & Pet. Engr. Distinguished Professor Univ. of Kansas
Wagner, Jan	Ph.D. Chem. Engr. 1976	Professor, Chem. Engr. Oklahoma State Univ.
Win, Maung M.	Ph.D. Chem. Engr. 1969	Chm. Chem. Engr. Univ. of Rangoon, Burma
Witherspoon, Paul	B.S. Pet. Engr. 1951	Professor Pet. Engr. Univ. of Cal. Bkly.

Table VII

Head/Chairman, Chemical Engineering Department
University of Kansas

1895 - 1935	No chairman, Chemistry Department chairman acted as a quasi-chairman
1935 - 1936	E.D. Kinney (acting)
1937 - 1939	T.H. Marshall (acting)
1939 - 1941	T.H. Marshall, chairman
1941 - 1942	W.W. Deschner (acting)
1942 - 1945	T.T. Castonguay (acting)
1945 - 1964	J.O. Maloney, chairman
1956 - 1957	F. Kurata (acting)
1964 - 1970	H.F. Rosson, chairman
1967 - 1968	D.W. Green (acting)
1970 - 1974	D.W. Green, chairman
1974 - 1979	F.W. Preston, chairman
1979 - 1985	H.F. Rosson, chairman
1985 - 1988	G.W. Swift, chairman

Table VIII

Professorial-Level Faculty Through 1987/88
Department of Chemical and Petroleum Engineering
University of Kansas

Allen, H.C.	1935 - 1945
Kinney, E.D.	1935 - 1938
Marshall, T.H.	1935 - 1941
Deschner, W.W.	1939 - 1942
Castonguay, T.T.	1941 - 1946
Teplitz, M.	1943 - 1972
Maloney, J.O.	1945 - 1985
Beaton, R.H.	1946 - 1946
Berg, L.	1946 - 1946
Miller, S.A.	1946 - 1956
Kurata, F.	1947 - 1977
Korpi, K.	1947 - 1948
Walas, S.M.	1948 - 1984
Cram, K.H.	1955 - 1957
Mesler, R.B.	1957 - Present
Rosson, H.F.	1957 - Present
Weinaug, C.F.*	1962 - 1969
Preston, F.W.*	1962 - Present
Jones, K.*	1962 - 1967
Swift, G.W.	1962 - Present
Green, D.W.	1964 - Present
Bishop, K.A.	1967 - Present
Willhite, G.P.	1969 - Present
Himmelstein, K.	1977 - 1982
Terry, R.	1978 - 1981
Davis, J.C.	1980 - Present
Howat, C.S.	1981 - Present
Vossoughi, S.	1982 - Present
Thiele, J.L.	1982 - Present
Subramaniam, B.	1985 - Present

*Weinaug, Preston and Jones entered from Petroleum Engineering when the two departments combined.

Ralph Wells Moulton

HISTORY OF ChE AT THE UNIVERSITY OF WASHINGTON

The University of Washington as an educational entity is not old compared to many other institutions of higher learning in the United States. It was founded in 1861 at a time when the northwestern section of the United States was still being developed politically and geographically into the present states of Washington and Oregon. Approximately ten acres of land in what is now downtown Seattle was set aside for the territorial university. As the State grew and increased in population, so did the city of Seattle. The need for a university was present but the number of students with the right preparation to enter a university was minimal. The financing of the institution was shaky and during the first decades of its existence the University opened and closed at different times depending upon the availability of money to meet operating expenses. In spite of this rather erratic beginning, the university continued to grow and became stronger and more of a definite entity toward the end of the 19th century.

It became apparent some time in the 1880's that the amount of land available for the University was inadequate for the long term and also that the land had much more value in terms of other uses such as business development than it would have as a site for the University. Through negotiations with the Federal Government, one section of land (640 acres) was obtained for the permanent home of the University. This land was located about four miles north of what was then the city center of Seattle. Preparations were made in the early 1890's to move the university to this new site. The move actually occurred about 1893. The first building to be built on the new site was Denny Hall, which is named after one of the pioneers who had settled in Seattle, Washington.

Denny Hall housed a number of departments. The University began its existence at the new site with programs in many areas. These were mostly liberal arts, history, and what was later known as upper campus type courses. However, chemistry was one of the sciences that was recognized as important by the University administration and chemistry was always an important part of the overall academic structure at the University.

When organized the Chemistry Department was placed in the hands of Professor Henry Myers whose period of service was from 1897 to 1899. In the fall of 1899, Dr. H. G. Byers was placed in charge of the work in chemistry with Thomas W. Lough, a member of the first graduating class, as an assistant. Following that date other persons were brought into the faculty: Professor Henry G. Knight 1903-1904, Dr. E. S. Hall 1903-1905, Dr. I. W. Brandel 1907-1911, followed by Mrs. A. F. Morgan and Irene Hunt Davis, Acting Associate in Chemistry. The rapid development of both chemistry and pharmacy called for an increased staff, and Dr. Charles Johnson was brought from the University of

N. A. Peppas (ed.), One Hundred Years of Chemical Engineering, 353–362.

Michigan with the understanding that he should become the Dean of the College of Pharmacy after a time. This was brought about in 1903 and since that time Chemistry and Pharmacy have functioned as separate administrative units within the University.

Denny Hall

It was at this time, too, that graduate students appeared, and it was necessary to extend the range of subject matter and of instruction. Due to the departure of Henry G. Knight, to become the Professor of Chemistry at the University of Wyoming, Dr. Henry K. Benson was brought from John Hopkins University in 1905 and entrusted with the work of developing the courses in industrial and physical chemistry. The courses in industrial chemistry eventually became Dr. Benson's major work in the University. The classes in physical chemistry grew rapidly in numbers and were subsequently taken over by Professor Harlan Trumball, who later became affiliated with the research division of the B. F. Goodrich Rubber Co.

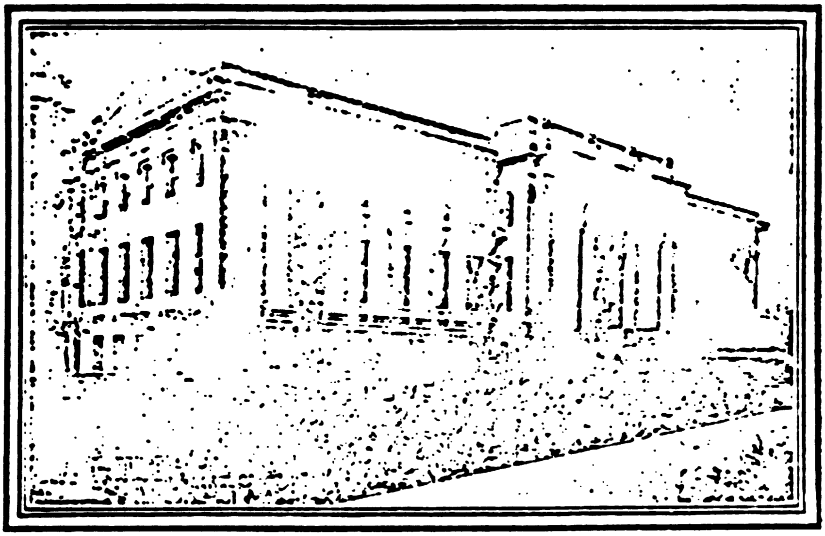
By 1908 there were four temporary structures adjacent to Denny Hall that were used by the Chemistry Department. As enrollment continued to grow, it was apparent that in the very near future a building to house the Department would be essential. This opportunity came when the State made appropriations for three buildings to be erected for the Alaska -Yukon Exposition in 1909. These buildings were to revert to the University after the Exposition. Bagley Hall was erected in 1908 and was used as a fine arts building during the exposition. Bagley Hall was named for one of the pioneers that settled Seattle, Mr. Daniel Bagley.

Bagley Hall

The first course offered in chemical engineering was in 1904. The first graduate of the chemical engineering program at the University of Washington was Mr. Horace G. Deming in 1907. He went on to do graduate study at the University of Illinois and received his Ph.D. from that institution. In 1911 the first meeting of a group called "The Society of Undergraduate Engineers at the University of Washington" was held. Dr. H. K. Benson was an important leader in the formation of this organization and its accomplishments. At that time there was in existence an approved curriculum leading to the degree of Bachelor of Science in Chemical Engineering at the University of Washington. This was a four year program comprising basic courses in mathematics, physics and chemistry consistent with other University programs. Following these first courses were included surveying, mechanical engineering, machine design, mechanics and hydraulics, and electrical engineering. In addition, particular courses in industrial chemistry and chemical technology were introduced. There was, at that time, an emphasis in the chemical engineering area toward water analysis, gas and fuel analysis, electro chemistry and some other options.

Following the initial meeting of the Society of Undergraduate Chemical Engineers at the University of Washington, a second meeting was held one year later in 1912. Chemical Engineering was now firmly established at the University of Washington and developments following these formative years were rapid.

First Bulletin
of the
Society of Undergraduate Chemical Engineers of the University of Washington Seattle, Washington



BAGLEY HALL

Containing Addresses on Chemical Engineering, Courses in Chemical Engineering in the University of Washington, and the Object, Constitution and By-Laws of the Society

1911

First Chemical Engineering Curriculum

When war was declared on April 6, 1917 many changes occurred on the University of Washington campus. The students were excited and wanted to volunteer for service in the army and other branches of the government. Several of the professors took leaves of absence to assist in any way that they could with the war effort. Many changes occurred on the campus as all of these things happened.

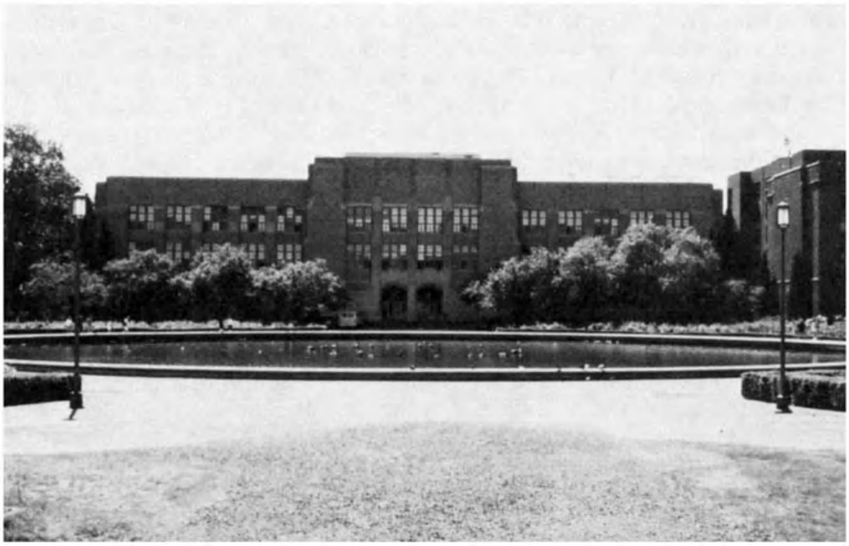
At the end of the war period, after twenty years of unselfish and commendable service to the University of Washington, Dr. Byers resigned to become eventually head of the Department of Chemistry at Cooper Union Institute in New York City. Professor Benson then took over Dr. Byers work, and Dr. George McPhail Smith was secured from the University of Illinois to become Professor of Inorganic Chemistry and was placed in charge of the freshman classes.

About this same time, chemical engineering courses which had been firmly established under Dr. Benson's leadership, were further developed. Mr. George E. Whitwell, a graduate of the Massachusetts Institute of Technology, was secured in 1919 to assist in the Chemical Engineering instruction. During his residence at the University of Washington, Mr. Whitwell assisted in the development of the "Back Run Process" which was later used widely for the manufacture of watergas. In 1920 Professor W. L. Beuschlein joined the faculty of the Department and his particular interest was the chemical engineering field.

The Department as it was organized in the early 1920's was one including both chemistry and chemical engineering. The name of the Department was the Department of Chemistry and Chemical Engineering. The school of Pharmacy was completely separate from the Department of Chemistry and Chemical Engineering even though it was housed in the same building. Dr. Myers was the original head of the Department, followed by Dr. Byers, and in 1919 the office was filled by Dr. Benson who was given the title of Executive Officer. The Executive Officer reported to two deans: the Dean of Arts and Science for the Chemistry Division of the Department and the Dean of Engineering for the Chemical Engineering Division of the Department. This administrative structure worked well during the 20's, 30's and 40's. Some very significant benefits were achieved by the close cooperation between the chemistry group and the chemical engineering group. There was a close kinship and feeling of cooperation between the two faculties and the undergraduate and graduate students. At a much later date, 1953, and for more or less extraneous reasons, it was decided to actually divide the Department into two separate Departments. Thus, one department became two separate entities within the University system.

During the period from 1920 to 1930, Chemical Engineering at the University of Washington developed rather dramatically. The permanent full time faculty doubled from two faculty members to four. The addition of faculty members increased the breadth of knowledge in the Department. During these years, Professor Beuschlein exerted a very powerful influence on the Department. Dr. Benson was at that time executive officer of the Department of Chemistry and Chemical Engineering but he spent most of his time and energy with administrative matters relating to the Chemistry division which outnumbered the Chemical Engineering division by perhaps about three or four to one. It was during this decade that the first Ph.D.'s were granted in Chemical Engineering. The authority to grant the Ph.D. was derived from the association with the Department of Chemistry which had this authority from the Board of Regents of the University of Washington. Mr. Waldo L. Semon received his Ph.D. degree in 1924, and Mr. James R. Lorah received his Ph.D. degree in 1928. These two individuals were listed as chemical engineers even though their thesis topics were in a field that today could be construed as either chemistry or chemical engineering. It was during these years also that Mr. Calvert C. Wright and Mr. Bert E. Christensen began their Ph.D. research under Professor Beuschlein and these two individuals later in the 30's received their Ph.D. degrees from the Department. Their research was on topics that were strictly chemical engineering. Mr. R. W. Moulton began his Ph.D. research in 1934 and completed his degree requirement in 1937.

The Department was accredited by the American Institute of Chemical Engineers in 1926. In the year 1925, accreditation of undergraduate programs in chemical engineering was initiated in the United States by the American Institute of Chemical Engineers. In 1925 about a half a dozen schools in the east were accredited. In 1926 the University of Washington became the first school on the Pacific Coast, perhaps the first school west of the Mississippi to achieve accreditation status. Enrollment increased during this decade and the number of degrees granted at the bachelor's level in Chemical Engineering increased from about six per year to about fifteen per year.



New Bagley Hall

During the decade from 1930 to 1940 the number of full-time permanent faculty in the Department increased from about four individuals to six. This increase in the number of faculty brought additional fields of specialization to the instructional area and it was during this ten year period that considerable graduate research activity was initiated. Graduate course offerings increased dramatically together with graduate student research both at the master's level and at the Ph.D. level. The building housing the Department of Chemistry and Chemical Engineering which was built in 1909 for the Alaska - Yukon Exposition, was becoming very crowded and several adjacent annexes provided additional space. These annexes were in the main wood frame buildings of a temporary type. Funds were obtained to construct a new building for the Department of Chemistry and Chemical Engineering and for the College of Pharmacy.

The building construction was initiated in 1935 and completed in 1937. The building was named Bagley Hall and the former building housing the Department which had been named Bagley Hall, was turned over to another department and renamed. The new building provided excellent and adequate space for all three areas: Chemistry, Pharmacy and Chemical Engineering.

The early 30's were times of trial for the University with respect to funds, as was true generally throughout the United States. Toward the latter 30's business conditions improved and enrollment increased. At the end of the 30's and just before World War II started, the number of undergraduate degrees granted per year was between 20 to 25.

In the decade between 1940 and 1950, many changes occurred. Probably the most important change as far as the Department was concerned had to do with the effect of World War II. Over the ten year period represented by this decade, the faculty increased from about six permanent full-time faculty members to eight; but during the decade there was a big turnover of faculty with individuals leaving for jobs both in industry and in the service, and other people were being hired with some purely on a temporary basis.

A student chapter of the American Institute of Chemical Engineers was established at the University of Washington in 1940. This, too, represented a first for the Pacific Coast and this Chapter has been in existence since that date and has been quite active. During World War II, the size of the student body dropped dramatically as students were drafted into the service and the number of faculty dropped correspondingly. After the war the veterans returned to the campus and the student body was swelled to rather large numbers on a temporary basis. The number of students graduating approximated 70 during the immediate postwar period.

The breadth of course offerings and the graduate research being offered by the department continued to grow during this time period. An interest in nuclear engineering developed as secrecy restrictions were lifted on Atomic Energy Commission activities after World War II.

During the decade from 1950 to 1960 the faculty number increased from about eight to about ten individuals. Nuclear Engineering became well established as a separate department but at the graduate level. New areas of research were initiated.

Pressure for more space became acute. In 1953 R. W. Moulton became chairman and remained in that position until 1977 at which time he returned to full-time teaching and research.

During the decade from 1960 to 1970, the permanent full-time faculty increased from about ten individuals to fourteen. Again the Department of Chemical Engineering outgrew its assigned space in Bagley Hall and a request was made to the University administration together with a proposal being sent to the National Science Foundation for funds to construct a new building that would house Chemical Engineering and Nuclear Engineering. This request was supported by the Department of Chemistry inasmuch as they would benefit from Chemical Engineering vacating their building, Bagley Hall. The National Science Foundation approved the request with one of the conditions of the proposal being that the University supply matching funds. This initiated a building plan. The building construction was started in 1965 and completed in 1967. During this decade student enrollment increased both at the undergraduate and graduate level. There was a marked increase in graduate work in the Department both in terms of course offerings and in graduate research. The number of graduate students increased to about 60 at any one time with the number of seniors graduating increased to about 40 to 45 per year.

Benson Hall

The Department of Chemical Engineering has had a long history of interest and a working relationship with the pulp and paper industry in the State of Washington. Because of this and for other reasons, a program was developed through the College of Forestry on the campus of the University of Washington to offer a curriculum leading toward a Bachelor of Science Degree in Pulp and Paper Technology. This curriculum was designed so that a student graduating with a Bachelor of Science Degree in Chemical Engineering could, by going one additional year in the College of Forestry, receive a degree in Pulp and Paper Technology. The reverse was also true: a graduate of their program could by going one additional year in the Department of Chemical Engineering receive a Bachelor of Science Degree in Chemical Engineering. Because of this relationship there were several joint appointments of faculty between the College of Forestry and the Department of Chemical Engineering. This was good for both groups and this trend has continued.

During the decade from 1970 to 1980, the faculty again increased in numbers from about fourteen to about sixteen. The newer, younger faculty members brought into the Department additional specialities. With the large number of faculty at this time the Department offers a broad spectrum of fields for specialization at the graduate level. Examples of areas of specialization are Polymer Composites, Surface Science, and Bioengineering areas related to the Medical School.

The Department continues to grow and prosper with a very substantial amount of funded research through government agencies and from other sources. Again the Department is suffering from space limitations and it is probable that during the next five to ten years the University will be asked to provide more space for the ongoing activities of the Department.

Professor Emeritus, R. W. Moulton
Department of Chemical Engineering
University of Washington
Seattle, Washington 98105

Chemical Engineering Faculty at University of Washington *

Date	1905	1910	1915	1920	1925	1930	1935	1940	1945	1950	1955	1960	1965	1970	1975	1980	1985
Heads	**Byers**	**Byers**	**Byers**	**Benson**	**Benson**	**Benson**	**Benson**	**Benson**	**Benson**	**Benson**	**Moulton**	**Moulton**	**Moulton**	**Moulton**	**Moulton**	**Sleicher**	**Sleicher**
Professor Emeritus																*Moulton* *Gardner* *David*	*David* *Johanson* *Moulton* *McCarthy* *Gardner*
Professor			Benson					Beuschlein		Moulton	McCarthy	McCarthy	McCarthy Johanson Babb David Sarkanen	Babb David Gardner Johanson McCarthy Sarkanen Sleicher	Babb Berg David Finlayson Gardner Garlid Heideger Johanson McCarthy Sarkanen	Berg Allan Babb Finlayson Garlid Heideger Hoffman Johanson McCarthy Sarkanen	Berg Allan Babb Finlayson Garlid Davis Heideger Bowen Hoffman Sarkanen
Associate Professor		Benson		Whitwell			Beuschlein	Kobe	Moulton	McCarthy		Johanson Babb David	Heideger Sleicher	Berg Garlid Heideger Sather Finlayson Larson	Hoffman Larson		Krieger Seferis Ricker
Assistant Professor	Benson				Beuschlein	Beuschlein	Kobe		McCarthy	Gerald West	Johanson Babb David	Heideger	Berg Garlid Sather				
Instructor								West			Olin Bengtson	Anderson Kabel Ratkowsky			Sather	Seferis Ricker Krieger	Hager Kaler Stuve Holt

The Department Heads are at the top. Shading indicates Professors Emeriti and Associate Professors. Full Professors and Assistant Professors are in unshaded areas.

* Including in the early years only those whose stay was of significant duration.

Satish J. Parulekar and Darsh T. Wasan

THE HISTORY OF CHEMICAL ENGINEERING AT ILLINOIS INSTITUTE OF TECHNOLOGY (IIT)

ABSTRACT. The Department of Chemical Engineering at IIT is one of the oldest chemical engineering departments in the U.S.A. The Unit Operations Laboratory at IIT, started in the 1910s, is said to be the first in the U.S.A. [1]. Significant development of the educational programs occurred prior to 1960. Substantial growth of the research programs occurred beginning in the late 1950s. The development of undergraduate and graduate educational programs and research programs during the period 1904-1988 is reviewed.

1. Introduction

The origin of IIT's Department of Chemical Engineering (ChE) can be traced back to 1901 when a chemical engineering curriculum was first offered under the directorship of Professor W.T. McClement at the then Armour Institute of Technology, established in 1895. The real beginning of the department dates from the arrival at the institute of Professor Harry McCormack in 1904. For the next forty-two years, he developed the department, with respect to both undergraduate and graduate education, and maintained its top ranking among all fully accredited chemical engineering departments [1]. We review here the development of undergraduate and graduate educational programs and research programs during the period 1904-1988.

The department currently offers a Bachelor of Science (BS) degree and three graduate degrees: Master of Science (MS), Master of Chemical Engineering (MChE), and Doctor of Philosophy (PhD). The department annually awards nearly 40 BS, 10 MS, 10 MChE, and 8 PhD degrees.

The department has been served by six chairmen to date: (1) W.T. McClement (1901-1904), (2) H. McCormack (1904-1946), (3) J.H. Rushton (1946-1953), (4) R.E. Peck (1953-

N. A. Peppas (ed.), One Hundred Years of Chemical Engineering, 363–377.

1967), (5) B.S. Swanson (1967-1971) and (6) D.T. Wasan (1971-1987). Significant development of the educational programs occurred under the leadership of Professor McCormack. The growth of the educational programs continued under the leadership of Professor Rushton. The expansion of the research programs began under the leadership of Professor Peck and continued under the leadership of Professors Swanson and Wasan.

2. Development of Undergraduate Program

The Unit Operations Laboratory at IIT was started in the early 1910s. The Unit Operations outlook was developed by Professor McCormack in the form of senior projects. The laboratory instruction book contributed many of the experiments in the book "Applications of Chemical Engineering," edited by Professor McCormack. Students worked in teams of two or three on projects proposed by instructors or proposed their own experiments. Usually the project involved the building of an equipment item. These equipment items and the experiments were updated from year to year. The laboratory portion of the curriculum required the completion of twenty-four of these home-grown and continuously modified experiments over a span of three semesters. The result was a chemical engineering graduate who could devise a practical way to evaluate the results of industrial processes and to determine the best way to develop these processes.

The chemical engineering curriculum until the 1930s was heavily chemistry oriented with students being exposed to a variety of chemistry courses such as general chemistry, qualitative analysis, quantitative analysis, methods of commercial analysis, organic chemistry, physical chemistry and engineering chemistry. This last course dealt with the origin, analysis and variation of solid, liquid and gaseous fuels, combustion, refractory materials, design of furnaces, heat transfer, pyrometry, ferrous and non-ferrous metals and alloys, composition and making of cement, and chemistry of the materials of paint and varnish and other protective coatings.

The ChE courses in these years included three metallurgy courses, four chemical engineering lecture courses and four chemical engineering laboratory courses distributed evenly in the four semesters of the junior and senior years. The chemical engineering courses dealt with unit operations such as evaporation, crystallization, metallurgical operations, centrifugal separation, filtration, flow of heat and measurement of temperature. A specialization in metallurgy was available at this time to interested students who would take the courses in metallography and heat treatment and general metallurgy.

In 1936, the cooperative education program was instituted at IIT. Under this plan, students divided their time between academic study and work in industry. The first class began in February 1936 with an enrollment of 82 students working with 29 cooperating companies.

The development of both undergraduate and graduate educational programs received significant impetus from the sabbatical visit of Professor Olaf A. Hougen in 1937, participation by several distinguished visiting faculty in the summer graduate school in 1940, and arrival in 1938 on the IIT campus of Max Jakob, an internationally recognized authority on heat transfer. Merging with the Lewis Institute of Arts and Sciences in 1940, the Armour Institute of Technology became the Illinois Institute of Technology.

In these years, in addition to the core undergraduate and graduate courses, the faculty developed several electives. The content of these electives gradually became part of the core undergraduate chemical engineering courses, evolving in the process the modern day undergraduate chemical engineering. Many of the modern day undergraduate courses were, in fact, developed in these years as graduate courses which slowly trickled down into the undergraduate curriculum. A list of the undergraduate courses that were developed over the years is provided in Table 1. The names in the parentheses indicate the name of the faculty member who first taught the course(s). Many of these courses are still offered at IIT on a regular basis [2].

The engineering chemistry laboratory focused on the study of fuels and related industrial materials and products. The course on size reduction dealt with operations such as crushing and grinding. The catalysis course, which was chemistry oriented, was taught by Vasili Komarewsky who joined the ChE department as a research professor. A course on reaction kinetics and reactor design was not offered until the late 1950s.

The course on chemical process technology introduced the concepts of flowsheeting, material and heat balances, phase equilibria, and pressure and temperature effects. The

Table 1. Undergraduate Chemical Engineering Courses Developed Since 1944

Year introduced	Course title (First instructor)
1944	Bacteriology [1 hr. lecture, 3 hrs. lab.]
	Engineering chemistry laboratory
	Plastics (McCormack)
1946	Catalysis (Komarewsky)
	Chemical engineering plant design (McCormack)
	Size reduction (Kintner)
1947	Chemical process technology
	Stoichiometry
	Unit operations of chemical engineering - lectures
1948	Chemical engineering thermodynamics (Peck)
1949	Colloidal and amorphous materials
	Process control and instrumentation (Swanson)
1951	Protective coatings
1952	Preparation and study of catalysts
1957	Dimensional analysis and scale-up
	Flow of incompressible fluids
	Introduction to nuclear engineering (Fagan)
	Thermodynamics laboratory
1958	Chemical reaction engineering (Levenspiel)
1963	Chemical engineering operations
1970	Introduction to air pollution
1972	Applied particulate technology
	Food packaging technology
	Polymer processing (Vrentas)
1974	Instrumentation analysis in food and nutrition science
1986	Discrete time systems and computer control (Cinar)
	Introduction to biotechnology (Keller, Parulekar)
	Microelectronics fabrication (Selman)

course in stoichiometry dealt with material and energy balances related to fuel processes and was a precursor to the modern-day material and energy balances course.

Undergraduate students were able to take advantage of the elective courses during their junior and senior years to specialize in various branches of engineering sciences, or in economics, management and allied fields. The ChE specializations in the 1940s included chemistry, food technology, gas technology, instrumentation and control, management and metallurgy. The significance of the options in chemistry and metallurgy decreased progressively as undergraduate programs in chemical engineering, chemistry and metallurgical engineering developed distinct identities. Student participation (equivalent to one earned credit) in the AIChE student chapter contests started around 1950. The new electives offered in the 1950s included protective coatings, preparation and study of catalysts, dimensional analysis and scale-up, and flow of incompressible fluids. The thermodynamics lecture course was appended with a laboratory course from 1960 to 1963. Until 1958, the department did not offer any course at the undergraduate level in chemical reaction engineering. Students had to learn reaction kinetics in some of the physical chemistry courses. The arrival at IIT in 1958 of Octave Levenspiel led to introduction of this important topic in the chemical engineering curriculum. In 1963, a course in ChE operations was offered and it dealt with scale-up techniques, generalization theories, and integration of several unit operations. Together with the plant design course offered in the '40s, this course paved the way for the modern day version of the process design courses starting in 1964.

The electives offered throughout the years reflected the changing needs of the chemical engineering profession. A course related to air pollution was introduced in 1970 and after few years was absorbed into the Environmental Engineering curriculum upon formation of that department. Professor James Vrentas joined IIT in 1972 and since then an elective course in polymer processing has been offered frequently.

To comply with the changing needs of the chemical engineering profession, the specializations in bioengineering, energy technology and process development were made available for undergraduate ChE students. The close relations that IIT has with the two neighboring institutes at the IIT Center, Institute of Gas Technology and IIT Research Institute, both of which have substantial involvement in energy-related research activities, have made the energy technology option very popular and successful.

The four-year undergraduate teaching program in engineering has always been the primary effort at IIT. For nearly forty years since its inception, the department enjoyed a monopoly on chemical engineering education in Chicago [1]. During these years, if a Chicago student wished to follow such a career, he/she had to either come to Armour Institute or leave the city for a college a hundred or more miles away. To acquire and keep a progressive instructional staff in these years, it became necessary to initiate a graduate program, the development of which is discussed next. Graduate courses are also in demand as continuation education efforts in every large industrial city. IIT remains Chicago's key agency for continued education.

3. Development of Graduate Program

The graduate program in chemical engineering at IIT started in the early '30s with the first MS and PhD degrees being awarded in 1933 and 1939, respectively. Interaction with the ChE faculty of other universities through their visits to IIT campus, interaction with distinguished colleagues such as Professor Max Jakob in other IIT departments, and initiation of research activities at the Armour Research Institute were all conducive to the development of the graduate program in the late '30s. These were also the days of the development of processes for making petrochemicals from fossil and non-fossil fuels. The graduate ChE curriculum indeed reflected this as can be seen from courses such as applied chemical thermodynamics (which dealt with phase equilibria in multicomponent hydrocarbon/organic mixtures), catalysis, fuels and combustion, organic chemical technology, petroleum refining, chemistry of petroleum hydrocarbons and industrial applications of catalysts. Table 2 provides a list of the graduate courses developed since 1938. Many of these courses continue to be offered on a regular basis [2].

Metallurgy was another field where chemical engineers were very strongly involved. The undergraduate and graduate courses offered in this area prepared the students to choose careers in metallurgy. Interestingly, many of the modern day undergraduate ChE courses were offered for several years as graduate courses. Course material developed in such

Table 2. Graduate Chemical Engineering Courses Developed Since 1938

Year(s) introduced	Course title (First instructor)
1933-38	Applied chemical thermodynamics (Freud)
	Catalysis (Komarewsky)
	Chemical engineering calculations (Kintner, McCormack)
	Chemical engineering plant design (McCormack)
	Chemistry of petroleum hydrocarbons
	Cracking of petroleum
	Diffusional operations (Kintner)
	Distillation
	Filtration
	Fuels and combustion
	Metallurgical materials of construction
	Organic chemical technology
	Physical metallurgy
1939	Industrial applications of catalysts (Morrell)
1940	Advanced physical metallurgy
	Instrumentation and process control (McCormack)
	Mechanical operations (Kintner)
	Vaporization operations (Kintner)
1940	Summer graduate school - visiting faculty
	ChE thermodynamics - B.F. Dodge [Yale]
	ChE plant design - F.C. Vilbrandt [VPI]
	Industrial catalysis - J.C. Morrell [UOP]
	Interpretation of ChE data - C.C. Furnas [Yale]
1944	Applications of mathematics to ChE (Peck)
	Metallurgy of aluminum and magnesium alloys
	Plastics (McCormack)
1947	Cryogenic engineering
1949	Chemical engineering process kinetics
	Mixing (Rushton)
	Radiant heat transfer
1950	Combustion and furnaces
1951	Mass transfer operations (Peck)
1952	Applications of fluid motions in ChE
	Chemical engineering process economics
1958	Chemical reaction engineering (Levenspiel)

Table 2. Graduate Chemical Engineering Courses Developed Since 1938 (Contd.)

Year(s) introduced	Course title (First instructor)
1960	Applications of digital computers in ChE
	Non-Newtonian fluid behavior (Skelland)
	Process and control dynamics (Swanson)
	Process control through instrumentation (Swanson)
1964	Fluidization (Levenspiel)
1966	Air Pollution Control → Env. Eng.
	Dispersed two-phase systems
	Fluid dynamics
	Industrial wastes → Env. Eng.
1968	Biochemical engineering
	Transport phenomena
1970	Advanced reaction engineering
	Fundamentals of electrochemical engineering
	Process optimization
1972	Computer-aided design
	Polymer processing (Vrentas)
	Topics in biomedical engineering (Weinstein)
1974	Enzyme reactor engineering (Tavlarides)
1976	Petrochemical systems design (Lindahl)
1986	Fundamentals of reservoir engineering (Arastoopour)
	Separation processes (Hong)
1988	Polymerization reaction engineering (Blanks)

graduate courses was valuable in updating/modifying the undergraduate curriculum. This is the case with distillation, filtration, heat transfer, and diffusional, mechanical and vaporization operations. The similarity among chemical engineering calculations and plant design and modern day material and energy balances and ChE process design is worth mentioning.

The institute invited in 1940 sixteen distinguished teachers from other educational institutions and equally distinguished engineers and scientists from industry to teach summer courses for graduate students. The changing attitude toward graduate curricula had its beginning with this summer school in which ChE Thermodynamics was taught by Professor B.F. Dodge of Yale, interpretation of ChE data by Professor C.C. Furnas of Yale, and ChE Plant Design by Professor F.C. Vilbrandt of VPI. A course on the application of mathematics to chemical engineering was offered for the first time by Professor Peck in 1944. A graduate course on plastics was also introduced in 1944. This course was in some ways a precursor to the polymer processing course introduced in 1972. Other process-specific courses offered in the late '40s and early '50s were metallurgy of aluminum and magnesium alloys, cryogenic engineering, combustion and furnaces and radiant heat transfer. By the early 1950s, when conventional chemical engineering unit operations were much better understood, the focus of the graduate courses changed from design of specific processes to engineering fundamentals, partly following the national trend and partly due to addition of faculty with a different perspective of chemical engineering. Towards the late '50s, courses such as applications of fluid motions in chemical engineering, chemical engineering process kinetics, non-Newtonian fluid behavior, chemical reaction engineering, process and control dynamics, fluidization, dispersed two-phase systems and fluid dynamics were increasingly oriented toward teaching engineering fundamentals. Chemical engineering process kinetics dealt with heat transfer, mass transfer, and chemical reaction processes.

Around the late 1960s, chemical engineers had extended their interests to pollution abatement. The department offered two graduate courses in this area until their eventual incorporation into the new Environmental Engineering program. Prior to 1958, the ChE department did not offer a course dealing exclusively with reaction kinetics. Students were partially trained in this area via an advanced physical chemistry course. Increasing usage of digital computers and computational techniques necessitated a course offering in this area and such a course has been offered since the early '60s. In 1968, fluid dynamics, mass transfer and a portion of heat transfer were combined to offer a single course in transport phenomena. The elective in heat transfer continues to be offered.

Industrial short courses in specific areas of chemical engineering have been offered since the 1960s when Professor

Peck first taught such courses in drying theory and technology [3]. In the 1970s and 1980s, many advanced courses in conventional and emerging areas of chemical engineering were developed. These include advanced reaction engineering, process optimization, computer-aided design, topics in biomedical engineering, enzyme reactor engineering, reservoir engineering, petrochemical systems design, separation processes and polymerization reaction engineering.

The interactive instructional television network (IIT/V) was established in 1975. Many of the graduate courses, particularly the core courses, are televised through the IIT/V network. Remote centers for reception of these telecasts are located near several of the industrial centers (within a fifty-mile radius from the IIT campus) for the benefit of part-time students.

The enrollment figures for undergraduate and graduate programs are shown in Table 3. The enrollment figures for

Table 3. Enrollment Statistics
Co-op - participants in cooperative education program, FT - full-time, PT - part-time.

Years	Undergraduate Average	Graduate Average
47-50	338	22
51-60	187	18
61-70	96	33
71-75	76	35
76-81	300	112 (FT + PT)
82-87	212	114 (FT + PT)
Present	129, 22 (Co-op)	50 (FT), 47 (PT)

undergraduates dropped substantially in the '50s compared to the '40s. As mentioned earlier, until the mid-'40s IIT enjoyed a monopoly in the Chicago area as far as the chemical engineering program was concerned. In recent years, we have had to share the pool of potential undergraduates with two other programs in the Chicago area, those at Northwestern University and University of Illinois, Chicago. Undergraduate enrollment, however, reached its maximum in the period 1977-81. The decline in the enrollment in the past few years is consistent with the national trend in undergraduate ChE enrollment. The graduate enrollment, on the other hand, has increased steadily since 1960. As will become evident later, substantial expansion in research activities occurred in the post-1950 period. Currently, we have 50 full-time and 47 part-time graduate students. Many of the part-time students opt for the MChE degree.

IIT has been fortunate to have had several excellent educators. The Chemical Engineering Department owes the development and growth of both undergraduate and graduate programs to Professors H. McCormack, R.C. Kintner, J.H. Rushton, B.S. Swanson and R.E. Peck. We are proud that three of our former and current faculty members, Peck, Swanson and Wasan, have been the recipients of the American Society for Engineering Education's (ASEE) Western Electric Fund Award for excellence in teaching. Professor Swanson also received an educational award from the Instrument Society of America. Professor Levenspiel's well-received texts, <u>Chemical Reaction Engineering</u> and <u>Fluidization</u>, have been of great service to chemical engineering education, both in the U.S. and abroad. In the '60s and '70s, the department was fortunate to have the services of another outstanding teacher, Professor William Langdon. In appreciation for his dedication to teaching, the award for best teacher in the department is named after him. We continue our tradition in excellence in teaching. The ChE department was the recipient of the 1987 Illinois Energy Award for Outstanding Achievements in Energy Education. Every addition to the staff has left his mark upon the educational structure that exists today. It is expected that the process will continue in future with the infusion of new ideas by new and very bright young persons.

4. Development of Research Programs

Finally, we review the development of research programs in chemical engineering at IIT. In 1930, UOP set up a research professorship in chemical engineering. Vasili Komerewsky was appointed as the first UOP research professor in 1936. His field of research was catalysis in organic chemistry, especially its application to the chemistry of petroleum.

The Armour Research Institute (ARI, now known as the IIT Research Institute) was the first not-for-profit research institute formed in the United States. The research areas pursued in the department in the late '30s were compatible with the activities of the ARI. These were catalysis, chemical filtration, chemistry of oils, oil combustion and heat transfer. In the areas of combustion and heat transfer, significant interaction occurred among researchers in IIT's chemical engineering and mechanical engineering departments and the Institute of Gas Technology (IGT). IGT was established in 1941 as a not-for-profit energy research and education organization and has its headquarters at the IIT Center. Professors Peck and Jakob had research interaction on projects related to combustion and heat transfer. The research interests of the chemical engineering faculty in 1940s were catalytic reactors, distillation, drying, liquid-liquid extraction, mixing, process control, and hydrogenolysis of coal, oil shale and petroleum fractions. With the movement of the ChE department into the first building built on the new IIT campus in 1947, considerably more room became available for research.

The research interests of the ChE faculty were substantially broadened in the 1950s with the faculty pursuing research in fluid mechanics, fluidized bed systems, heterogeneous catalysis, mass transfer, partial combustion and thermodynamics. In those days, graduate student research took precedence over fund-raising for research activities. The research activities in the 1960s emphasized dispersed phase systems, interfacial phenomena, turbulent mixing of jets, reactor engineering and biomedical engineering.

In the 1970s, the research activities of newly recruited faculty were concentrated in the areas of transport phenomena (diffusion in polymers, liquid-liquid dispersions, gas-solid transport) and electrochemical engineering. Henry R. Linden, a member of the National Academy of Engineering, was appointed as a Research Professor in chemical engineering in 1978.

The bulk of the current ChE faculty were added in the 1980s [2]. The research areas/topics pursued currently include analysis of energy conversion processes, biochemical engineering, colloidal and interfacial phenomena, combustion, energy technology, enhanced gas and oil recovery, expert systems, flow in porous media, fossil fuel conversion, high temperature reaction engineering, multi-phase flow, multi-variable control, process dynamics, and transport in biological systems. Undergraduate participation in research projects is encouraged in the form of senior research or special projects. Currently, our undergraduate students are participating in ten research projects. The research funding in the past two academic years (1986-87 and 1987-88) has been $1.13 million and $1.17 million, respectively.

The research efforts of the ChE faculty have been recognized through professional society awards. Professor Octave Levenspiel was a recipient of the R.H. Wilhelm Award of the American Institute of Chemical Engineers (AIChE) and the ASEE ChE Division Lecturer. Professor James Vrentas was a recipient of the William Walker Award of AIChE. These awards were made after the two had left IIT. Some of the work cited, however, was conducted by them during their tenure at IIT. Professor Dimitri Gidaspow was a recipient of the Donald Kern Award of the AIChE and the Special Creativity Award of the National Science Foundation (NSF). Professor Darsh Wasan was a recipient of the Hausner Award of the Fine Particle Society and a medal of honor from the University of Sofia, Bulgaria. He has twice been named recipient of the Special Creativity Award of the NSF.

Interdisciplinary research has been a strong tradition at IIT and several joint initiatives with other departments have evolved to address problems in critical emerging areas. Some of the faculty have cooperative research activities with the Institute of Gas Technology, IIT Research Institute, Argonne National Laboratory, Universal Oil Products, Michael Reese Hospital and Loyola University Medical Center [2]. All such interactions provide an intellectually stimulating environment for graduate students. An industrial advisory committee for Chemical Engineering was established in 1969. Through the activities of this committee there has been constant improvement in communication with industry.

5. Alumni

Over the years, the department has graduated many competent engineers, a number of whom have obtained significant national prominence in their professional careers. Many of them hold top level executive positions in industry. Two of our alumni--Drs. James Oldshue and John Sachs, both received their PhDs at IIT--are past presidents of AIChE. Although a majority of our alumni have pursued professional careers in industry, we are proud that, over the years, a significant number have joined chemical engineering faculties at major institutions. Two of the alumni who are currently on ChE faculties in the United States, Professors Henry Linden (PhD, IIT, currently at IIT) and Kenneth Bischoff (PhD, IIT, currently at the University of Delaware) are members of the National Academy of Engineering (NAE). Another alumnus, the late Professor W. Robert Marshall (BS, IIT), Director of the University-Industry Research program at the University of Wisconsin at the time of his death, was also a member of the NAE and a past president of the AIChE. Our other alumni who are faculty in universities in the United States include Professors L.T. Biegler (BS, IIT, currently at Carnegie-Mellon University), M.P. Dudukovic (PhD, IIT, currently at Washington University), D. Kirwan (BS, IIT, currently at University of Virginia), B.J. McCoy (MS, IIT, currently at the University of California at Davis), R. Narayanan (PhD, IIT, currently at the University of Florida), G.V. Reklaitis (BS, IIT, currently at Purdue University), V.E. Sater (PhD, IIT, currently at the Arizona State University), S. Szepe (PhD, IIT, currently at the University of Illinois at Chicago), and W.A. Weigand (PhD, IIT, currently at the University of Maryland).

6. Closure

As the chemical engineering profession changes and adapts to the technology needs of the next decade and the next century, so must the chemical engineering education. In the coming years, the curriculum content will be modified to accommodate new technology areas in chemical engineering. At IIT, we are developing courses to integrate these emerging areas into our curricula while, at the same time, leaving the emphasis on science and engineering fundamentals unchanged. In the last three years, courses in the emerging areas such as biotechnology, microelectronics and artificial intelligence have either been offered or were developed. Consistent with the national trend, there is increasing interest among undergraduate and graduate students to participate in research activities in these areas.

IIT is currently developing a very strong research and educational center in food technology and food safety at the Moffett Technical Center (located in the Chicago area). Some of the chemical engineering faculty will be closely associated with this center.

Professor Satish J. Parulekar
Department of Chemical Engineering
Illinois Institute of Technology
Chicago, Illinois 60616, USA

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Deran Hanesian, Angelo Perna and Joseph Joffe

HISTORY OF CHEMICAL ENGINEERING AT THE NEW JERSEY INSTITUTE OF TECHNOLOGY 1881-1988

New Jersey Institute of Technology is an outgrowth of the Newark Technical School which was founded in 1881, by an Act of the New Jersey General Assembly, to meet the demands of the industrialization of northern New Jersey. During this period following the Civil War, northern New Jersey, had undergone industrialization in all areas of mechanical, chemical and electrical engineering. Although civil engineering, the oldest of the engineering professions had played a significant role in construction of bridges in the New York area like the Brooklyn Bridge, the Newark Technical School initially focussed on chemical, electrical and mechanical programs. In fact, its yearbook was named, "KEM-LEC-MEK". Northern New Jersey was also the center of invention. Thomas Alva Edison did his work not far from Newark and Alexander Graham Bell invented the telephone in this area. There were many other inventors and industrialists operating near Newark, and the financial capitol at Wall Street was only 10 miles away. The time had come to begin an educational program to support this industrial expansion. In the beginning, the enabling legislation founding the school, stated

- "The Newark Technical School has for its object in all departments the advancement of the manufacturing interests of the city, and its course is arranged with special reference to the intellectual wants and improvement of the working classes.

  As far as is consistent with this, all interference with the plan or object of other educational institutions in the city will be avoided. It is not a professional school, and does not aim to make experts."

The initial courses of study, outlined in 1893-94 are shown in Table 1. A high school diploma was not necessary for admission. The first enrollment was about 100 students compared to about 8000 now. The school was originally housed in a single building on High Street overlooking down town Newark. This building was originally built in 1856 as an estate. It remained until about 1958. A second academic laboratory building, Colton Hall, named after the first President, was built in about 1896, and the third building, Campbell Hall was built in 1926. Both Colton Hall and Campbell Hall are used today. Today NJIT covers over 20 acres; consists of a

N. A. Peppas (ed.), One Hundred Years of Chemical Engineering, 379–397.

physical plant of about 20 buildings worth approximately 125 million dollars.

The Newark Technical School became Newark College of Engineering in 1919 when college-level degree programs were first offered in chemical, mechanical and electrical engineering, leading to bachelor of Science degrees in these disciplines at the end of four years of study. For the first time, a high school diploma was needed for admission. Over the years the name of the school has evolved as shown in Table 2. The day and evening divisions operated under different names until 1945.

All programs were operated on a cooperative basis starting with the sophomore year. Students spent six weeks in industry alternating with six weeks of college classwork. The academic program was somewhat accelerated to compensate for the time lost from classes during periods of work in industry. The academic year was thirty-six weeks in length. While attending classes, students were in class or laboratory thirty-three hours a week, including three hours on Saturday mornings. During the depression of the thirties it became increasingly difficult to place students in industry for their six-week periods of work experience. Additionally, the four-year cooperative program came under heavy criticism from engineering educators who felt that the normal time-span for such a program should be five years. As a result, the cooperative program was abandoned in 1936 and a regular four-year academic program was instituted in its place.

The Department of Chemical Engineering at its inception in 1919 was a combined department of chemical engineering and chemistry and conducted classes in both chemical engineering and chemistry. Only one bachelor's degree was awarded by the Department, that of B.S. in Chemical Engineering. Department faculty consisted of both chemists and chemical engineers. Vernon T. Stewart, holder of a bachelor's degree in chemical engineering from MIT came to Newark College of Engineering in 1921 and served as Head of the Chemical Engineering Department from 1922 to 1946. Other prominent members of the Department during the early years were Paul M. Griesy and James A. Bradley. Frederick D. Crane was Instructor in Industrial Chemistry, with a PhD from John Hopkins University. Dr. Griesy held a B.S. in Chemical Engineering from Ohio State University and a Ph.D. in Chemistry from Columbia University. Professor Bradley was an organic chemist with a bachelor's and a master's degree in Chemistry from Harvard University.

In founding the Department, it was stated that

- "There has arisen an opportunity for the technical worker who is able to fill the gap between the industrial and analytical chemists on one hand, and the mechanical, electrical and hydraulic engineers on the other. This viewpoint, distinctly different from that of any one of the foregoing professions, blended with theirs, produces a product unique in industry. His field of action is largely or exclusively in the plant as opposed to the laboratory. He is a man of action and decision as distinguished from the student or investigator.

  The earlier part of the course in Chemical Engineering provides the essential foundation of mathematics, physics and chemistry, with more than the usual emphasis upon physics."

The name of the Department changed over the years as shown in Table 3. The degrees given by the Department are shown in Table 4. Graduate degrees were given early after the founding of the Newark College of Engineering and are shown in Table 5. The recipients of these first degrees are shown in Table 6.

The first President of the Newark College of Engineering, Allan R. Cullimore, a graduate civil engineer, had a strong orientation toward chemistry and was himself a member of the American Chemical Society. As a result, there was strong emphasis on chemistry in all engineering curricula during the early years. All engineering students had a full year of general chemistry in the freshman year followed by a second year which consisted of qualitative analysis, water and coal analysis, and some chemistry of engineering materials. Chemical engineering students took in addition, a year of quantitative analysis and a year of organic chemistry in the junior year, followed by a year of physical chemistry in the senior year. The chemical engineering course sequence consisted of "Industrial Chemical Calculations" in the sophomore year, and chemical engineering thermodynamics and unit operations (taught from the Walker, Lewis and McAdams text) in the senior year. The chemical engineering curriculum also included, as did other engineering curricula at the college, two years of engineering drawing, electrical engineering lecture and laboratory, and a year of mechanical engineering laboratory. In the early nineteen thirties it became obvious that the chemical engineering curriculum needed greater emphasis in the unit operations area. Dr. Donald Othmer of the Brooklyn Polytechnic institute was engaged as a consultant, and a unit operations laboratory was set up with his help and advice in the basement of Campbell Hall in 1935. Two young instructors, Arthur Kohler and George Keeffe were given the responsibility of developing this laboratory. The application of the Department for accreditation by AIChE in 1936 was denied. The denial of accreditation had a very discouraging effect on the Department. President Cullimore decided forthwith to change the name of the curriculum from chemical engineering to industrial chemistry. The only substantial change in the curriculum was to make unit operations in the senior year elective instead of a required course. The student AIChE chapter, organized in 1935, was disbanded in 1940. The American Chemical Society Chapter had first been established in 1925. One class of students was graduated in June 1941 with degrees of B.S. in Industrial Chemistry.

With the outbreak of World War II in the Fall of 1941, it became obvious that the degree in chemical engineering would be much more valuable to our graduates than the degree in industrial chemistry. Accordingly, very soon thereafter the chemical engineering curriculum and degree were reinstated and the degree in industrial chemistry was dropped.

In 1945, at the conclusion of World War II, an extensive reorganization of all departments and curricula took place. Department heads in each department were replaced by a dual team of Department Chairman and Executive Associate Chairman. In chemical engineering Vernon T. Stewart was replaced with Acting Chairman Joseph Joffe and Executive Associate George C. Keeffe. Table 7 shows the various department heads since 1881. The fact that only seven men have chaired the department in 107 years clearly shows the stability.

The department itself was split, with a separate Department of Chemistry being set up under Lelyn Branin as Chairman. The new chemistry department had a somewhat limited mission, that of administering chemistry courses common to all engineering disciplines, which in effect limited its course offerings to freshman and sophomore chemistry. Physical and organic chemistry, courses offered to chemical engineering students only, were left under the administration of the Department of Chemical Engineering.

Starting in 1939 Newark College of Engineering began to offer graduate courses in various disciplines, among them in chemical engineering and chemistry. Under an agreement with Stevens Institute of Technology up to fourteen credits in such courses could be offered toward a Master's degree at Stevens. In 1941 Newark College of Engineering launched its own Master's degree programs. The programs were tailored to part-time students, who held positions in industry and would attend classes in the evening. The Department of Chemical Engineering offered two programs: 1) The M.S. in Chemical Engineering with strict concentration requirements in chemical engineering, including Advanced

Unit Operations and Advanced Unit Operations Laboratory. 2) The M.S. with a major in Chemical Engineering with less stringent prerequisites and requirements which tended to attract industrial chemists desirous of developing some chemical engineering knowledge but unable or unwilling to meet the more stringent requirements of the M.S. in Chemical Engineering program. Both master's programs had as a requirement the completion of an individual six-credit master's thesis. These master's programs became very popular, attracting a large number of students among the technical and professional personnel in North Jersey chemical companies.

Soon after the reorganization of the chemical engineering department in 1945-46, the undergraduate chemical engineering curriculum was revised and modernized. A two-year sequence in unit operations was introduced, with unit operations laboratory in the senior year. A two-semester plant design course was added to the Senior year curriculum. In 1948, Dr. Charles L. Mantell was brought in to head the Department as Chairman and to teach the newly organized plant-design course. In 1950 the Department applied for and received accreditation from the AIChE and ECPD. The student AIChE chapter was reorganized in the same year. Omega Chi Epsilon, Eta Chapter, the Chemical Engineering Honorary Society was founded in 1957. The decade of the fifties was devoted mainly to further modernization of the undergraduate curriculum and to expansion of the Master's programs. Gradual reduction in teaching loads during the forties and fifties made it possible for the faculty to devote time to supervision of graduate thesis work and to do a modest amount of personal research and publication. In 1961 the College was granted by the State, the right to offer doctoral degrees in chemical and in electrical engineering. A day graduate program was instituted, support for full-time graduate students being largely provided by government fellowships and by teaching and research assistantships. The first Doctor of Engineering Science degree in Chemical Engineering was awarded to Edwin O. Eisen in June 1964. Thereafter there were two or three graduates from the doctoral program in Chemical Engineering each year.

The first graduates of the department for various degrees are shown in Table 6. It should be noted that in 1930, the first COED, Edythe Raabe received her degree in chemical engineering. It has been stated that Edythe Raabe was the first woman to receive a B.S. in Chemical Engineering in the United States. Today, over about one fifth of the classes are women.

The Department of Chemical Engineering outgrew its facilities in Campbell and Colton Halls by the early fifties. In 1956 the College acquired, through the generosity of Mr. Tiernan of Wallace and Tiernan Inc., a former pharmaceutical plant building no longer in use as a plant. As a result, at a very modest conversion cost about 50,000 square feet were made available to chemical engineering and chemistry as instructional and research laboratory space and for offices and classrooms. The building, located at 240 High Street, was named Tiernan Hall. This facility had the research space needed for the development of a doctoral program in chemical engineering.

During the period 1956-66 the chemical engineering curriculum was further modernized and strengthened with the introduction of courses in chemical reaction engineering and process control, and elective courses in transport phenomena, mathematical methods, process analysis, and research and independent study.

Dr. Charles Mantell retired as Chairman of Chemical Engineering in 1963 but he continued to teach the Plant Design course until 1967. Dr. Joseph Joffe succeeded him in this position. In 1966 upon the retirement of the Chairman of Chemistry, Dr. Lelyn Branin, chemistry was combined with chemical engineering in one department and two divisions: chemical engineering and chemistry. Dr. Joffe became Chairman of the combined Department with two Associate Chairmen under him. George C. Keeffe for chemical engineering and Avner Shilman for chemistry. Chemistry courses previously taught in the Department of Chemical Engineering were consolidated with all other chemistry courses in the Division of Chemistry.

In 1975, Dr. Joffe retired after 44 years of service, and Dr. Deran Hanesian was appointed chairman after a search. Another leader in our department, Dr. Saul Kreps, had left for Israel in 1973. Dr. Kimmel who was appointed Associate Chairman of Chemistry in 1972 served until 1988. Professor Keeffe retired in 1976 after 41 years of service and was replaced as Associate Chairman of Chemical Engineering by Dr. Jerome Salamone. Dr. Salamone served until 1979 when he retired after 32 years of service. Dr. Salamone was replaced by Dr. John McCormick who served until 1988 when he retired after 26 years of service. Both Dr. Hanesian and Dr. McCormick were recipients of the Robert Van Houten Award for Teaching Excellence.

Newark College of Engineering became New Jersey Institute of Technology following the formation of the New Jersey School of Architecture. Newark College of Engineering remained to cover the engineering programs. In addition, the College of Science and Liberal Arts was added. Another school, the School of Management will soon be added to the Institute.

The period 1975 to 1988 was marked by an increased emphasis on research. Research in the department which was one of the leaders in the Institute, increased from almost no funding to about $2,000,000 per year.

The department was active in procuring industrial funds and played a leading role in developing the environmental area.

By 1967 it had become apparent that a new building was needed for Chemical Engineering and Chemistry. Grounds was broken in 1969. In general, the campus was the scene of much new construction between 1965 and 1988. In addition to the new chemical engineering/chemistry building and the construction during the 1950's of Cullimore Hall and Weston Hall, Faculty Memorial Hall was built to house Electrical Engineering, a new library, a new physical plant building and a new student center were built, a newly acquired building was renovated for Mechanical Engineering, two dormitories were built and a physical education building with adjacent field facilities was constructed. The buildings together with the original Colton Hall, Campbell Hall, and a former estate and orphanage building called Eberhardt Hall, formed the campus which occupied more than 20 acres in downtown Newark. Currently, a new building is being constructed to house the Institute of Hazardous and Toxic Waste Management. Another building is being constructed for Computer Integrated Manufacturing and the "Factory of the Future." Today, the campus consists of about 20 buildings with a physical plant worth 125 million dollars.

The new chemical engineering building was one of the first in this new construction era. It was made possible by a State of New Jersey bond issue. It was completed for occupancy in January 1972.

The new chemical engineering laboratory for the new building was constructed beginning with the summer of 1973. Dr. Hanesian had received two National Science Foundation Undergraduate Instructional Scientific Equipment Grants. The first, in 1967 was for building a Process Dynamics and Control Laboratory. The second, in 1972, was for building a Chemical Reactor Engineering Laboratory. In 1972 Dr. Hanesian, Dr. Angelo Perna and Professor George G. Keeffe obtained a large grant from the State of New Jersey to build the Unit Operations Laboratory. Construction was under the supervision of Dr. Hanesian who was assisted by Mr. William Forster, the departmental Administrative Assistant. The laboratories were built by various Model Makers, Charlie Kenyon and Edward Karan directing the work of students who worked summers and the during the year under the Work-Study program. A good deal of the business and paper work was handled by Genevieve "Chip" Lardier, our secretary. A total of 33 experiments were built by 1975 covering five floors of laboratories in the new building. Since 1975 Dr. Hanesian has directed the activities in the new laboratories aimed at upgrading the new equipment with "state of the art" instrumentation.

In the last part of the 1970's, enrollments in chemical engineering reached a new high. For about three years our enrollment was among the highest in the nation. The journal, Chemical and Engineering News annually presented data which showed we were the largest department in the nation in undergraduate enrollment and in total undergraduate and graduate enrollment. The oil shortage in the late 1970's caused enrollments to grow rapidly nationwide. The number of Bachelor of Science degrees granted nationwide rose from about 3500 to about 7500-8000. The recession in the chemical industry in the early 1980's and the renewed abundance of oil, worldwide, caused a marked decline in demand for chemical engineers. The class of 1983 had very few job offers and enrollments at our school and nationwide plunged. Despite the decline in undergraduate enrollment, the graduate program grew. By about 1987-88, undergraduate enrollments had begun to show an upturn. There were discussions of the new emerging areas of chemical engineering in biotechnology, electronic materials, genetic engineering and new composite materials. The curriculum was re-examined to add flexibility for these new areas but the general opinion in the chemical engineering professional community was to move cautiously with changes and to maintain training in the basics of chemical engineering education. Our curriculum changes followed this advice.

Other historic events in the department are shown in Table 8 and the highlights of our curriculum changes, far too numerous to detail, are shown in Table 9. It should be noted here with great pride that our student chapter of the AIChE was awarded, in 1987, its seventeenth consecutive Outstanding Chapter Award among schools in the U.S. This accomplishment has established a national record with the closest school having nine consecutive awards.

During the early 1980's it became apparent that the Chemistry Division should offer its own degrees in addition to the Master of Science in Engineering Science with a specialty in chemistry. In 1984 a Bachelor of Applied Chemistry degree was approved. The division is currently seeking approval for granting Master's and Doctor's degrees in Applied Chemistry. A Doctorate degree is also being approved in Environmental Science which became a separate division in the department in 1986.

Chemical Engineering was always a popular program at our Institute. Over the years we have enjoyed full accreditation by ABET (ECPD) in both day and evening programs. Our graduates have enjoyed a good reputation in industry and are sought by recruiters. They, in turn, have performed well in industry, and have further enhanced the reputation of the department. The department has long encouraged student involvement in professional and honor related activities. The first undergraduate student professional chapter chartered was the undergraduate American Chemical Society Chapter in 1925 which was followed by the American Institute of Chemical Engineers Chapter founded in 1937. The AIChE student chapter has achieved national recognition for its 17 consecutive years of being designated the recipient of the Outstanding Chapter Award. In 1957 Eta Chapter of Omega Chi Epsilon, the Chemical Engineering Honor Society, was chartered. Today these three organizations have been joined by the Biomedical Club. These organizations have played an important role in fostering professional and technical development in the chemical engineering student body. They have also added greatly to the faculty-student-staff relations in the department.

The future will bring many changes to chemical engineering at New Jersey Institute of Technology. These changes will be much more rapid than those of the past 107 years. These changes will be in all areas of undergraduate and graduate education and will prepare our young people very well to confront the new problems and challenges facing our nation in the years ahead as we all prepare for the twenty-first century.

Professor Julian C. Smith, a mentor of Dr. Hanesian's at Cornell stated very clearly in his department's history, "The only certainty is that things will change, sometimes for the better, sometimes not. The story of the school will go on". He quoted Dusty Rhodes whose words of thirty years ago are still appropriate,

- "The school now belongs to the younger faculty; it is now their responsibility to insure that it is used with the utmost effectiveness to train young men and women for the greatest possible proficiency in their chosen profession and the greatest possible service to society".

Professor Deran Hanesian
New Jersey Institute of Technology
Newark College of Engineering
Department of Chemical Engineering,
Chemistry and Environmental Science
Division of Chemical Engineering
Newark, New Jersey 07102, USA

TABLE 1

CURRICULUM

1893-1894

FULL COURSE OF STUDY

The full course of study exclusive of the preparatory class, requires four years.

PREPARATORY.- Arithmetic, Writing and Composition.

FIRST YEAR, - Algebra, to equations of the second degree. Physics; properties of matter. Descriptive Chemistry to the Alkalies. Free-hand Drawing.

SECOND YEAR - Geometry, Free-hand Drawing, Descriptive Geometry, Physics: dynamics, heat, dynamic and static electricity and magnetism.

THIRD YEAR - Algebra and Geometry completed, theory of Cutting Tools, Mechanical or Achitectural Drawing, Descriptive Geometry, Physics: dynamics, heat, dynamic and static electricity and magnetism.

FOURTH YEAR - Trigonometry, Mechanics, Technical Chemistry, Physics: sound and light; Descriptive Geometry, Mechanical or Architectural Drawing, Steam Engineering: a course of ten lectures on the physical properties of steam, steam generators, steam motors and the indicator.

TECHNICAL CHEMISTRY

The lectures on Technical Chemistry relate to the applications of chemistry in manufacturing industries, and include among others the following subjects: Soap, Illuminating Gas, Coal Tar and its derivatives, Sugars, Photography, Bleaching, Dyes, Dyeing and Tissue printing, Fermentation and Brewing. The chemical nature of the materials used and the changes which they undergo in the course of manufacturing processes are considered, and collections of specimens illustrating the processes are shown as far as possible.

TABLE 2

NAME OF THE SCHOOL

DAY	EVENING
Newark Technical School 1881-1919	Newark Technical School 1881-1945
Newark College of Technology 1919-1920	
College of Engineering of Newark Technical School 1920-1927	
College of Engineering of Newark 1927-1930	
Newark College of Engineering 1930-1975	Newark College of Engineering 1945-1975
New Jersey Institute of Technology 1975-Present	New Jersey Institute of Technology 1975-Present

TABLE 3

NAME OF THE DEPARTMENT

TECHNICAL CHEMISTRY	1881-1919
CHEMICAL ENGINEERING (CHEMISTRY COMBINED)	1919-1937
INDUSTRIAL CHEMISTRY	1937-1943
INDUSTRIAL CHEMISTRY ENGINEERING	1943-1945
INDUSTRIAL CHEMICAL ENGINEERING (CHEMISTRY SEPARATED)	1946-1948
CHEMICAL ENGINEERING	1948-1966
CHEMICAL ENGINEERING AND CHEMISTRY	1966-1985
CHEMICAL ENGINEERING, CHEMISTRY AND ENVIRONMENTAL SCIENCE	1985-PRESENT

TABLE 4

NAME OF THE DEGREE (UNDERGRADUATE)

DIPLOMA OR CERTIFICATE	1881-1919
B.S. CHEMICAL ENGINEERING (High School Diploma Required)	1919-1936 (Four years)
	1930-1937 (4 or 5 years)
B.S. (CH) INDUSTRIAL CHEMISTRY	1937-1942
B.S. (CHE) CHEMICAL ENGINEERING	1937-1939
B.S. (CHE) CHEMICAL ENGINEERING	1942-PRESENT
EVENING DEGREES	
TECHNICAL CHEMISTRY (DIPLOMA)	1881-1925
CHEMICAL COURSE (DIPLOMA)	1925-1934
CHEMICAL COURSE (DIPLOMA) (DEPT. OF CHEMICAL ENGINEERING)	1934-1951
B.S. CHEMICAL ENGINEERING	1951-PRESENT

TABLE 5

NAME OF THE DEGREE (GRADUATE)

CHEMICAL ENGINEER	1923-1936
CHEMICAL ENGINEER	1937-1939
CHEMICAL ENGINEER	1943- 1948
JOINT WITH STEVENS INSTITUTE OF TECHNOLOGY	
M.S. CHEMICAL ENGINEERING	1948-PRESENT
DOCTOR SCIENCE ENGINEERING	1961-PRESENT

TABLE 6

RECIPIENTS OF THE FIRST DEGREES

1923 First Graduates of the College of Engineering with a B.S. in Chemical Engineering

Frederick C. Fraser
Milton Holmes
Joseph P. Wlodyka

1927 Degree of Professional Engineer

Ira E. Bergman (BSChE 1924)
"Theories of Photographic Processes"

Lawrence J. Pattersen (BS ChE 1924)
"Accelerated Weathering in the Paint and Varnish Industry"

1930 Edythe Rose Raabe BSChE
Academic Honors in Course
Professional Honors out of Course
First Woman Chemical Engineer

1950 Master of Science in Chemical Engineering

Ernest A. Adler
Charles R. Whitehead

1964 Doctor of Engineering Science

Edwin O. Eisen

TABLE 7

DEPARTMENT LEADERSHIP

CHARLES A. COLTON	1881-1917
JOHN Q. FREY	1917-1918
DAVID K. HOWARD	1918-1922
VERNON T. STEWART	1922-1946
JOSEPH JOFFE (ACTING)	1946-1948
CHARLES MANTELL	1948-1963
JOSEPH JOFFE	1963-1975
DERAN HANESIAN	1975-1988

TABLE 8

OTHER HISTORIC EVENTS

<u>CO-OP</u>	
CO-OP (FULL FOUR YEARS)	1925-1936
CO-OP (SENIOR HONORS)	1936-1944
CO-OP (THIRD YEAR)	1977-PRESENT
BS/MS CO-OP	1987-PRESENT
<u>ACCREDITATION</u>	
MIDDLE STATES ASSOCIATION OF COLLEGES AND SECONDARY SCHOOLS AND AMERICAN COUNCIL ON EDUCATION	1936
ABET (ECPD)	1950-PRESENT
<u>STUDENT SOCIETIES</u>	
AMERICAN CHEMICAL SOCIETY	1925
AMERICAN INSTITUTE OF CHEMICAL ENGINEERS	1935
OMEGA CHI EPSILON ETA CHAPTER	1957-PRESENT

TABLE 9

HIGHLIGHTS OF CURRICULUM CHANGES

1920-21	• Hours not Credits • Ethics • One ChE Course
1925-26	• Chemical Engineering Thermodynamics Introduced
1926-27	• Senior Year Chemical Engineering Course added based on Walker, Lewis & McAdams
1934	• Senior Year ChE Course Strengthened in Hours • Added Course Based Upon Badger and Baker in Organic Chemical Technology
1936	• Dropped ChE Thermo as Separate Course • Chemical Engineering Course given throughout Junior Year, Containing Thermo, Hydraulics,UO • Senior Year Course Strengthened with UO Lab Plant Design
1940-41	• First Two Years of Engineering Common to All Engineering (Upper and Lower Division)
1947-48	• Unit Operations Added as Separate Course
1950-51	• Increased Upper Division Content • Process and Plant Design Course
1962-63	• Only First Year Common • Listed Credits Not Class Hours
1964-65	• Chemical Engineering Stoichiometry Sophomore Course • Chemical Reaction Engineering
1966-67	• Process Dynamics and Control

1960's	•	Reductions in Credits Needed for Graduation Dropped Electrical Engineering Strength of Materials, Laboratory Courses, etc.
1972	•	Strengthen Design
	•	Humanities Dropped From 33 to 27 Credits, Still Above ABET Minimum of 18.
1987-88	•	Added Chemistry Analytical Techniques
	•	Added More Credits for More Electives to Meet Demands of Flexibility of New Engineering Areas

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