Chemical Engineering: A rich and di

BY IRENE KIM

Chemical engineers are a unique breed. They're a small, elite group of engineers with a rigorous education, a thorough knowledge of chemistry, and highly developed analytical, project-management and problem-solving skills. They're team players who are accustomed to typically getting little or no credit for the work they do — which usually involves a near-impossible goal with next to no budget.

But that's about as far as you can go in generalizing chemical engineers. Given, many of them work in the chemical process industries (CPI), including chemicals and fuels. They're also involved in newer, less-traditional industries, such as biotechnology, semiconductors, advanced materials and nanotechnology. But you'll also find them in other places: intellectual-property management, environmental law, public administration, venture capital firms, education, even magazine writing (See profiles following this article). One of the founders of modern chemical engineering, Arthur D. Little, wasn't a process engineer — he was a consultant. Jack Welch, Roberto C. Goizueta and Andy Grove, who became heads of their respective organizations (General Electric, Coca-Cola and Intel), all graduated as chemical engineers. So did film personality Dolph Lundgren — in fact, he was on his way to an MIT doctorate on a Fulbright scholarship when Hollywood intercepted him.

The history of chemical engineering is as diverse as the individuals themselves. Chemical engineers have been responsible for delivering just about every product we use — from the silicon chips in our computers, to the paper we write on, to the water we drink. "Engineering facilitates things that we take for granted in our daily life," points out Ralph Larson, staff vice president of engineering at 3M (St. Paul, MN), who has been with the firm for 35 years. "Engineers are involved in everything from product conceptual development on the bench, through developing a process for that particular innovation, to managing our factories, to managing the supply chain."

Although the youngest of the big engineering disciplines, chemical engineering is perhaps the toughest to chronicle. A ten-volume set couldn't sum up all the important achieve-

1670 Robert Boyle reacts metals with acid,forming hydrogen

1738 Daniel Bernoulli publishes Hydrodynamica,which includes the basis for the kinetic theory of gases

1749 Lead-chamber method used to produce sulfuric acid

1752 Joseph Black discovers "fixed air" – carbon dioxide

1789 Antoine Lavoisier publishes Traité elémentaire de chimie

1791 Samuel Hopkins receives first U.S.patent for improvement "in the making of Pot ash and Pearl ash by a new apparatus and process"

1802 Eleuthere Irenee du Pont builds a gunpowder factory along the Brandywine River (Delaware)

1807 Humphry Davy obtains elemental potassium and sodium by electrolysis (and calcium, strontium,barium,and magnesium the following year)

1811 Amadeo Avogadro demonstrates that equal volumes of all gases under the same conditions of temperature and pressure contain the same number of molecules

1824 Sadi Carnot publishes "Réflexions sur la puissance du feu et sur les machines propres à développer cette puissance" on the thermodynamics of the steam engine

1846 Ascanio Sobrero invents nitroglycerine

1852 American Society of Civil Engineers and Architects founded (now ASCE,with 123,000 members)

2S left: Alfred H.White (left), one of the founders of chemical engineering at Michigan, and George G.Brown, a ChE faculty member, in the 1920s [credit: J. Wilkes, U. Michigan]. **2S right:** John H.Sinfelt, developer of bimetallic catalysts for Standard Oil (later Exxon) that enabled lead-free, high-octane gasoline production at low cost, in 1994 [credit:Chemical Heritage Foundation Image Archives, Othmer Library of Chemical History, Philadelphia PA]. **3S left:** Wallace H.Carothers, developer of nylon and neoprene at DuPont, in the early 1930s. **3S right:** Arthur D. Little (center) worked on MIT's college newspaper The Tech as an undergraduate – an experience that served him well in later years as industry spokesperson, president of AIChE (1919), and head of one the U.S.'s most successful consulting firms [credit:Arthur D. Little Inc.]

verse history

ments of chemical engineers throughout the years, much less a short article.

So, while we've made the conscious decision to focus on the U.S. CPI and process engineers, we recognize that there are too many chemical engineers, and chemical-engineering achievements, that just won't fit. Given that, we've decided to make this discussion a celebration of the field — a look at its origins, and a somewhat arbitrary selection of highlights to illustrate its development over a century or so. Suffice it to say that we salute all the chemical engineers who have contributed to the prosperity, comfort and well being we enjoy today, and hope that they see the spirit — if not the specifics — of their achievements in the pages to follow.

PRACTICAL MATTERS

The CPI and chemical engineering have been inseparably entwined throughout much of their history. While the spotlight usually falls on the scientist who makes the initial discovery, the hurdles of pilot testing, scale up, and commercialization are overcome by the chemical engineer. It was this focus on the practical that attracted Paulette Clancy, associate professor of chemical engineering at Cornell Univ. (Ithaca, NY). Clancy, who formally trained in Europe as a chemist, was visiting chemical engineering professor Keith Gubbins (now at NCSU) when she was impressed by his students' strong math skills and focus on practical applications. "I found that the focus on solving specific technological problems intrigued me more than simply looking at modeling in the abstract," explains Clancy.

It's difficult to pinpoint the exact date when chemical engineering came into being — one could argue that industrial processes calling for chemical engineering-like skills go back as far as the alchemists of the Middle Ages, or even farther (early technologists were melting copper with tin to produce bronze in 3500 B.C.). However, most agree that the Industrial Revolution marks the beginning of the events that led up to the establishment of chemical engineering as a recognizable discipline.

In the late 1800s, Europe's Industrial Revolution was in full swing. The advent of the steam engine fueled the burgeoning textile industry, in turn launching unprecedented demand for dyestuffs and other industrial chemicals, such as sulfuric acid and soda ash. The processes for these materials presented perfect opportunities for chemical engineering skills.

In England, the hotbed of the Industrial Revolution, the processes for making sulfuric acid and soda ash had remained the same for several decades. John Glover and Ernest Solvay, respectively, are credited with developing innovative processes that recycled valuable nitrates, on the one hand, and did away with toxic byproducts, on the other.

In the early 1800s, sulfuric acid was made by the lead-chamber method. Sulfur and saltpeter (about 70% KNO_3) were combined in a ladle, ignited and placed on a tray in-

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1856 Bessemer process invented to cast steel

1863 Alkali Works Act passed by British government – measure to control environmental emissions

1866 Celluloid invented by Alexander Parkes

1870 Standard Oil Co.formed by John D.Rockefeller

1872 Solvay process introduced for soda ash

1876 American Chemistry Society founded (now with 163,000 members)

1880 George E. Davis unsuccessfully suggests forming a Society of Chemical Engineers; American Society of Mechanical Engineers founded

1881 Society of Chemical Industry founded

1882 Course in Chemical Technology offered at University College, London

1884 American Institute of Electrical Engineers founded (later combined with Institute of Radio Engineers to form IEEE); Solvay Process Co.opens in Syracuse,NY

1887 George E.Davis offers lectures on "chemical operations"(unit operations) at Manchester Technical School

1888 Lewis M.Norton initiates Course X,Chemical Engineering, at MIT

Left: In the 1880s, Solvay Process Co. established the first soda-ash plant in the U.S. **Center:** In 1870, John D. Rockefeller consolidated his five oil companies into one:Standard Oil Co. **Right:** Michigan's East Engineering Building, which housed Chemical Engineering in the 1920s [credit: J. Wilkes, U. Michigan]

side a chamber made of riveted lead sheets, the floor of which was covered with water. The combustion gases condensed on the walls and were absorbed in the water. To achieve sufficient concentration of the acid, the process was repeated several times. Incremental refinements included blowing steam into the chamber, and moving the charge outside the chamber.

The process resulted in the loss of nitric oxide to the atmosphere, so a make-up stream of costly nitrates — imported from guano deposits in Africa, and then Chile — was needed.The Glover process, introduced in 1859, used a mass-transfer tower to recover some of the nitrates — sulfuric acid trickled down, while burner gases flowed up. Some of the nitric oxide was absorbed in the gas, which was flowed back to the lead chamber.

In the Leblanc method for producing soda ash, predominant until the 1870s, salt was first reacted with sulfuric acid. Then the intermediate was reacted with limestone and coal, to form soda ash — with hydrochloric acid, calcium sulfide and carbon monoxide as byproducts. A method invented by A. J. Fresnel used a concentrated brine solution, which was saturated first with ammonia, then carbon dioxide. No hazardous byproducts were created by the process, but scaleup attempts failed to produce viable commercial results until Ernest Solvay added a carbonating tower. By the 1870s, a Solvay unit was producing about 10 tons per day. Themes that were to shape the discipline — recycling, environmental protection and cost efficiency — had begun to emerge.

And in the U.S., where the chemical industry had been relatively insignificant through the first half of the century — with a few plants producing chemicals on a small scale — the 1870s marked the beginning of dramatic growth for the fledgling industry. Between 1880 and 1900, for example, the average number of employees per plant went from 9,700 to 19,000; and overall production rose from $38.6 million to $62.6 million (Statistical Abstract of the United States, 1909).

SOCIETY FOLKS

In 1881, the Society of Chemical Industry was inaugurated in London, with 360 members and with chemist Henry E. Roscoe as its first president (the American Section, originally called the "New York Section," was born in 1894). Among the founders of the new society was George E. Davis, an alkali inspector from the Midland region of England (a highly industrial area immortalized a few decades later by D.H. Lawrence). Davis, who had witnessed first-hand the effect of engineering principles on chemical manufacture, lobbied vigorously to call the new organization the "Society of Chemical Engineers." Although his bid was defeated, Davis took an active hand in ensuring that the group, from its inception, supported chemical engineering.

In 1905, a familiar question arose: "Why not the American Society of Chemical Engineers?" This time, it came in the form of an editorial by Richard K. Meade, founder of the periodical The Chemical Engineer. He argued that the body of U.S. chemical engineers — who, in his estimation, numbered about 500 at the time — needed a professional society to help them gain legitimacy. Process design, such as it was, had up until then, been the domain of the industrial chemist, the applied chemist or the mechanical engineer. The American Chemical Society, established in 1876, was already a considerable force in the industry and many of its members opposed the formation of a new society, arguing that pure chemists could simply learn the business of industry.

Meade reprinted the editorial in 1907, and called a preliminary meeting in June of that year. A committee of six

Engineering is the conscious application of science to the problems of economic production. — H.P. Gillette, 1910

1891 MIT awards seven B.S.degrees in chemical engineering (first goes to William Page Bryant)

1892 University of Pennsylvania establishes program in chemical engineering

1894 Tulane University establishes chemical engineering department

1898 University of Michigan, University of Wisconsin, Tufts University establish chemical engineering programs

1899 Bayer aspirin available to public

1900 John Herreshoff develops the first contact method for sulfuric acid in U.S.

1902 American Electrochemical Society founded; Monsanto begins manufacturing saccharin; 3M founded

1904 The Chemical Engineer begins publication

1905 University of Wisconsin awards first Ph.D.in chemical engineering to Oliver Patterson Watts

1907 Linde Air Products founded (later Praxair)

1908 American Institute of Chemical Engineers founded

1910 General Bakelite Corp. established by Leo Hendrik Baekeland

1911 U.S. Supreme Court breaks up Standard Oil trust into 34 companies,including Jersey Standard and Socony (predecessors of Exxon and Mobil)

was formed, which conducted exhaustive series of queries to chemists about the advisability of establishing the new society, and finally decided to put the question to the vote of 50 prominent chemists and chemical engineers. Of the respondents, 22 favored the idea of starting a society, 7 opposed, and 7 were neutral. And the first AIChE meeting finally took place at the Philadelphia Engineers' Club on June 22, 1908. Nineteen were present.

Rather than threatening to "splinter off" from the ACS, AIChE decided early on to be a complementary organization, and one that emphasized practice over academics. With this in mind, its founders adopted restrictive membership requirements: An active member had to be at least 30 years old, proficient in chemistry as well as some engineering discipline, and have 10 years of practical manufacturing experience (or 5 years of experience plus an academic degree).

Over the next couple of decades, AIChE was to take an active part in the training, educating, and aiding in career development of its members. It created an accreditation system for chemical engineering curricula, publishing its first list of accredited schools in 1925. To facilitate information exchange among its members, AIChE published its Transactions.

When its permanent headquarters opened in Philadelphia in 1930, AIChE boasted a strong, eminently qualified membership of 872. While the organization relaxed its rigorous restrictions in later years (largely due to the urging of president Arthur D. Little to include more academics and talented engineers without the requisite qualifications), its charter remained the same as its membership expanded — to provide an inclusive, comprehensive educational and career infrastructure for chemical engineers throughout the country.

EARLY REACTIONS

The first CPI innovators, although not chemical engineers by training (since none existed yet), focused on optimizing processes — and laid the foundations for some of the most powerful firms over the next century. Although a chemist by degree, Herbert H. Dow had a healthy interest in both engineering and business. Since college, he had been intrigued by the brines of the U.S. Midwest. In the early 1890s, Dow focused on a bromine-rich brine found in Midland, MI. The prevailing practice in the area was to boil the brine down to separate out the salt, leaving a solution that was treated with oxidizing agents, then distilled to yield bromine liquid.

Realizing that much energy was being wasted in the two separate steps of evaporation and distillation, Dow decided to try a combination of electrolysis and an air blowing-out process. By 1890, he offered bromide products of pharmaceutical quality. He then used electrochemistry on sodium chloride to yield sodium hydroxide and chlorine, diversifying into chlorine chemicals, then organic chemicals, and then magnesium. In 1930, his son and heir Willard, a prominent chemical engineer, took over the family business.

Union Carbide, formed in 1898, owed much of its early success to a process originally intended to produce aluminum. Thomas Willson in 1892 had wanted to produce metallic calcium by heating lime and tar in an electric arc furnace (he hoped to combine the calcium with aluminum oxide, to reduce the compound to the metal). Instead, he got calcium carbide, which combined with water to produce acetylene — a useful gas for torches, and a successful product for Union Carbide.

Charles M. Hall, who also set out to produce aluminum, ended up successfully doing just that. The Oberlin College-trained chemist, who found early on that aluminum oxide was difficult to reduce, focused his efforts on finding a solvent that didn't react with aluminum ions. He decided on cryolite, which was heated in a carbon-lined crucible. When he passed an electric current through it, aluminum was formed. Although Hall discovered the process in 1886, it took many years of work, and substantial funds, to scale up. The company, initially called the Pittsburgh Reduction Company, was renamed the Aluminum Co. of America (Alcoa) in 1907.

In part, the chemical engineers' ability to roll with the punches, so to speak, has kept these and other long-lived CPI giants successful for so many decades. For example, 3M's original founders had wanted to make grinding wheels out of the minerals they found on the north shore of Lake Superior, says Larson. But when they found the material didn't have the integrity to stand up to the application, they decided to make sandpaper with it — which required, in addition to the abrasive, paper and an adhesive.

FLOURISHING UNDER PRESSURE

Necessity, as the saying goes, is the mother of invention. In the early days of chemical engineering, shortages drove much innovation. For example, European chemists had reigned supreme in organic chemistry in the late 19th century, mostly using coal-tar derivatives as the raw material for a variety of products. While some U.S. firms emulated the Europeans, other U.S. chemists and chemical engineers turned to plentiful agricultural feedstocks, such as corn and animal fats, to produce sugars, oils, glycerin and fatty acids.

1912 AIChE institutes code of ethics; William M. Burton patents batch process for thermal cracking of hydrocarbons

1913 BASF introduces Haber-Bosch process for ammonia

1915 Arthur D.Little coins term "unit operations"

1916 Société de Chimie Industrielle founded

1918 Chemical Engineering Group of the Society of Chemical Industry is formed

1920 George Eastman buys wood-distillation plant; forms Tennessee Eastman Corp.

1921 Union Carbide begins commercial cracking of natural gas

1922 Institution of Chemical Engineers founded; Thomas Midgely adds tetraethyl lead to gasoline to reduce engine "knock"

1923 Principles of Chemical Engineering published by William H. Walker, Warren K. Lewis,and William H. McAdams

1925 Warren L. McCabe and Ernest W. Thiele combine graphical methods with experimental data to determine number of theoretical plates needed to establish given concentration difference in a distillation column; Fischer-Tropsch synthesis for indirect coal liquefaction developed; 3M introduces Scotch Masking Tape

When war broke out in 1914, the U.S. found itself cut off from Europe — the main supplier of many industrial chemicals. "That was the turning point… We imported raw materials from Switzerland, Germany or England," said Swiss scientist and future Monsanto president, Gaston DuBois, in a 1951 interview. "Then came the war, and we had to start making our own raw materials."

U.S. industries met the challenge with characteristic innovation, swiftly ramping up production of industrial chemicals to meet demand. Before the war, for example, virtually all dyestuffs were imported from Germany. When the war ended in 1918, U.S. companies — led by DuPont and National Aniline — were meeting the nation's dyestuffs needs. In addition, DuPont, which had diversified its line of nitrocellulose-based products to include paints and celluloid, had supplied 1.5 billion pounds of military explosives to Allied forces, and 840 million pounds of dynamite and blasting powder to U.S. industry by war end.

Besides developing their own new processes, U.S. companies also showed considerable initiative in emulating others. The Haber-Bosch process, a high-pressure catalytic method for producing ammonia from hydrogen and nitrogen developed by Fritz Haber in 1909 and scaled up by Karl Bosch a few years later, was one such example. The approach — perhaps the first commercially successful high-temperature process — offered a promising new pathway to many other chemicals. DuPont was among the firms that built large ammonia plants based on this technology in the 1920s.

Providing nitrogen for these plants were the industrial-gas companies that had sprung up in recent decades, such as Linde Air Products (later Praxair). These companies, in turn, used a continuous process developed by German professor Carl von Linde in 1895 to liquefy air through a series of compression and expansion cycles. The liquid air was then distilled into oxygen and nitrogen.

The story of civilization is, in a sense, the story of engineering — that long and arduous struggle to make the forces of nature work for man's good—L. Sprague DeCamp, 1963

FUELING INNOVATION

In 1920, Standard Oil opened the first U.S. petrochemical plant. Although the U.S. had been in the oil business for many decades — with as many as 15 refineries in the mid-1800s — the only salable petroleum-based product, for a long time, was kerosene, which could be burned in lamps. A simple distillation process separated the oil into naphtha, kerosene and heavy oils. Before that, petroleum had been chiefly used as a medicine. In 1850, for example, Samuel Kier of Allegheny County sold eight-ounce bottles of the material, or "rock-oil," as "chiefly a liniment…recommended for cholera morbus, liver complaint, bronchitis, and consumption," reported The History of the Standard Oil Company.

Shortly, however, oil tycoon John D. Rockefeller found that gasoline was a useful fuel for the new automobiles that were starting to crowd the streets. In 1909, William M. Burton, a chemist at Rockefeller's Standard Oil, began to investigate ways to increase gasoline yield. Three years later, his team had developed a pressure-distillation method of cracking long hydrocarbon molecules into the smaller ones that made up gasoline. The process doubled the amount of gasoline yielded from each barrel of crude oil and boosted its octane rating.

When the stock market crash of 1929 ushered in the Great Depression, the chemical process industries were less negatively affected than most businesses. The petrochemical industry, for instance, continued to witness considerable advances in innovation, including Eugene Houdry's work with silica-alumina catalysts.

Houdry, a French mechanical engineer, first developed the catalysts for producing gasoline from coal, later refining the process to use low-grade crude oil as a feedstock. When Houdry moved to the U.S. in 1930, he teamed up with two U.S. companies — first, Socony Vacuum and then Sun Oil — that provided funding for further development of his process for gasoline from heavier petroleum fractions. In later years, he worked on adapting his catalytic cracking method for producing high-octane fuel for aircraft. By 1942, 90% of Allied aviation fuel was produced by the process.

The Houdry process, however, resulted in coke deposits on the catalyst — necessitating shutdown and burning off the coke. Chemical engineer and MIT professor Warren K. Lewis and his former student, chemist Eger V. Murphree were among the researchers who conceived of a moving-bed method, in which catalyst would circulate between a reactor

1928 Donald F. Othmer constructs "the first simple,precise system for determining vapor-liquid equilibria"

1931 Walter L.Badger and Warren L. McCabe publish Elements of Chemical Engineering

1934 John H. Perry publishes first edition of Chemical Engineering Handbook

1937 Houdry catalytic cracker is installed at a Sun Oil plant

1939 DuPont begins production of polyamide nylon; Imperial Chemical Industries begins production of low-density polyethylene

1940 Nylon stockings go on sale – with almost 800,000 pairs sold on the first day

1941 Archer J.P. Martin and Richard L.M.Synge develop liquid-liquid partition chromatography; Dow extracts magnesium from seawater on commercial scale

1942 Manhattan Project is formed; Society of Plastics Sales Engineers founded (later Society of Plastics Engineers)

1943 DuPont produces poly(tetrafluoroethylene) (Teflon)

1944 Dow Corning begins industrial-scale manufacture of silicone used for sealant

Left: E.I.du Pont's first facility, established on the banks of the Brandywine River near Wilmington DE in 1802. **Center:** In St.Louis, Monsanto Chemical Works opened in 1901 **Right:** Donald Othmer, co-editor of the Kirk-Othmer Encyclopedia of Chemical Technology, holder of more than 150 patents, and philanthropist (with his wife Mildred), in 1960 [credit:Chemical Heritage Foundation Image Archives, Othmer Library of Chemical History, Philadelphia PA]

and a regenerator. It was Lewis and chemical engineer, Edwin R. Gilliland, who thought of using a "fluidized" catalyst, which could flow to a regenerator. With the help of other industry chemical engineers, the team designed a plant, bringing a full-scale facility onstream in 1942.

Another crucial development in the petroleum industry was platforming, developed by chemical engineer Vladimir Haensel, who also wanted to eliminate coke deposits on catalysts. He found that at high temperatures, a platinum catalyst not only prevented coke deposits, but also resulted in higher-octane gasoline. The process also converted naphthenes in the feedstock to aromatics, which had previously been produced from coal.

In the meantime, groundbreaking work was going on in the world of polymers. In 1930, DuPont researcher Wallace Carothers isolated chloroprene, a compound that polymerized to form a rubberlike solid — neoprene. Another researcher, Julian W. Hill, discovered strong synthetic fibers that, several years later, would lead to the development of nylon. With the creative efforts of two pioneering engineers — Crawford H. Greenewalt and Roger Williams — DuPont commercialized the new material in 1940. Other materials developed by the company later in the decade included Teflon and Lucite acrylic.

BACTERIA, BEWARE

While penicillin had been discovered back in 1928, when Alexander Fleming found an uninvited mold growing in one of his Petri dishes and killing his bacterial culture, attempts at scaling up production of the antibiotic had failed for more than a decade. Because researchers were unable to produce the material in even pilot-scale quantities, no effective testing and development could be done with the medicine.

In 1939, British doctors Howard Florey and Ernest Chain succeeded in extracting enough penicillin to allow clinical testing; and two years later, Florey traveled to the U.S. to solicit support to pursue a large-scale manufacturing process. A major cooperative program, involving 35 academic, government and industrial organizations, was established under the American Committee on Medical Research and the British Medical Research Council.

The U.S., embroiled in World War II after the December 1941 attack on Pearl Harbor, had an urgent need for penicillin for the Allied wounded.Pharmaceutical firms rose to the challenge, rushing to find effective ways to scale up production. Pfizer, for one, adopted a deep-tank fermentation method it had been using to produce citric acid from molasses;Merck, for another, developed its own submerged fermentation process. By June 1945, U.S. firms including these and Abbott, Lederle, and Squibb, were producing 646 billion units per month.

This was yet another case where chemical engineering made the difference between lab oddity and viable product. For instance, the amount of penicillin that Florey and three of his colleagues were able to produce in a lab environment was insufficient to save the life of the first patient — even when they recycled penicillin from his urine. In order to make usable product from penicillin, a notoriously unstable substance, chemical engineers had to develop not only tank-fermentation methods, but the complementary processes based on the unit operations of sterilization, solvent extraction, vacuum crystallization and freeze drying.

MORE SUCCESSES…AND CHALLENGES

Synthetic plastics, strictly speaking, had been around for a while. In 1870, John Wesley Hyatt had developed celluloid, while looking for a replacement for ivory in billiard balls. And, in 1907, Leo Hendrik Baekeland invented Bakelite, a plastic made from phenol and formaldehyde, while looking for a shellac replacement. In the 1920s, Herman Mark had already confirmed Hermann Staudinger's hypothesis that polymers consisted of high-molecular-weight molecules. But it was the 1950s, one could argue, that was the age of plastics.

As polymer science advanced in the 1950s, innovations allowed finer control over polymerization reactions. The

1947 Fischer-Tropsch process used to generate hydrocarbons; Chemical Engineering Progress begins publication,as well as Vol.1 of Encyclopedia of Chemical Technology; ship loaded with ammonium nitrate explodes,destroying Monsanto plant in Texas City and killing more than 500 people

1948 Transistor invented

1950 Society of Women Engineers founded

1951 DuPont manufactures poly(ethylene terephthalate) – first polyester

1955 American Academy of Environmental Engineers formed

1957 General Electric introduces polycarbonate plastics

1959 Monsanto opens plant to produce ultra-pure silicon

1960 R. Byron Bird, Warren E. Stewart, and Edwin N. Lightfoot publish Transport Phenomena; silicon microchip invented

1962 Silent Spring published by Rachel Carson, highlighting the dangers of unsafe environmental practices; Eugene Houdry patents catalytic converter

1965 DuPont introduces Kevlar

1966 Monsanto introduces AstroTurf, based on carpet-fiber technology

1970 Clean Air Act enacted; AIChE forms Environmental Div.; first Earth Day

1971 Society of Black Engineers formed (later National Society of Black Engineers)

1972 Clean Water Act passed

1973 Arab oil embargo

organometallic catalysts discovered by Karl Ziegler and Giulio Natta, for instance, allowed for the creation of linear, stereoregular molecular chains at relatively lower pressures and temperatures than had ever been possible. In addition, changing the catalyst changed the placement of the side groups on the molecule — resulting in a rubberlike or plastic material — allowing synthesis of materials that mimicked naturally occurring polymers. The introduction of Ziegler-Natta catalysts dramatically affected processes for polypropylene and polyethylene.

The late 1950s and early 1960s, by and large, were years of expansion in the CPI. in 1959, U.S. annual shipments of chemicals and allied products passed the $25 billion mark. And the expansion included a global component: DuPont formed its International Department in 1958, while Eastman established a European sales headquarters in Switzerland in 1960, and 3M opened its first non-U.S. research lab in England in 1963.

But in 1962, a book appeared that was to forever change the way most consumers saw the CPI. Silent Spring, by biologist Rachel Carson, alerted readers to the effect of the powerful insecticide DDT on the environment. Developed in 1939, DDT had been used to kill malaria-carrying mosquitoes in the South Pacific during World War II, and had been provided for civilian use in 1945. The compound, Carson wrote, was metabolized slowly in animals, and so traveled up the food chain — killing not only the target insects, but birds and mammals as well, and produced extensive harm to the environment.

Public reaction to the book was devastating to the industry. Pesticides, while only a small fraction of the overall CPI, were big business — accounting for about half a billion dollars in sales in 1962. But environmental protection had always been a theme held dear by chemical engineers, who continued their work of developing products and processes that would cause less harm to the environment. Making detergents biodegradable, for example, was the innovation of Monsanto researcher James Roth. He used platinum catalysts to produce detergent molecules that were linear, and thus more digestible by natural microbes in lakes and streams.

But environmental advances notwithstanding, there were more public-relations nightmares in store for the CPI. In 1965, Dow made the ill-fated decision to manufacture napalm for the U.S. Dept. of Defense. A couple of years later, its college recruiters routinely met with picketing on campuses, and sometimes rioting. Before napalm, consumer polls showed that only 38% of Americans had heard of Dow;after, 91% said they "knew something about" the company. Dow, which by then was producing some 800 different products by the late 1960s, had become famous for only one.

The 1970s and 1980s held more difficult times for the CPI. The 1970s were marked by toxic leaks from Love Canal and huge jumps in oil prices (1973 and 1979); the 1980s, a methyl isocyanate leak that killed almost 4,000 in Bhopal, and the meltdown of a reactor core in Chernobyl. During this time, many firms were forced to make layoffs and shutdowns to address excess capacity. Some responded to the tough business environment by diversifying their lines. DuPont, for instance, began divesting much of its basic chemicals and polymers capabilities, and concentrating on more value-added products, including pharmaceuticals. Monsanto, in turn, focused on agricultural chemicals and forged into the realm of biotechnology. In the next wave of restructuring, the opposite trend prevailed — many firms spun off ancillary businesses to focus on their core competencies.

THE SHAPE OF THINGS TO COME

In 1987, "Chemical Engineering Frontiers" — better known as the Amundson Report — took the first systematic, industry-wide look at the chemical engineering profession, and identified areas of future growth, as well as of continuing strength. As we look back now from our vantage point in the 21st century, how has the discipline changed?

BIBLIOGRAPHY

1. "50 Years of Progress," pp. 31-82, *Chem. Eng.Prog.*, pp. 31-82 (Jan.1997).

2. "75 Years of Progress: A History of the American Institute of Chemical Engineers 1908-1983," Reynolds, T.S.; Forman, J.C., Resen, L., eds. New York: American Institute of Chemical Engineers (1983).

3.Bowden,M.E., and J.K.Smith, "American Chemical Enterprise: A Perspective on 100 Years of Innovation to Commemorate the Centennial of the Soc. Of Chemical Industry (American Section)," Philadelphia, Chemical Heritage Foundation (1994).

4. "The Amundson Report on the Future of Chemical Engineering," *Chem.Eng.Prog.*, pp. 62-64 (Dec.1987).

5.Bowden,M.E., "Chemical Achievers: The Human Face of the Chemical Sciences," Philadelphia, Chemical Heritage Foundation (1997).

6.Klemas,L., "A Chemical Engineering Timeline," http://www.geocities.com/combusem/CHEHIST.HTM

7.Haber, L.F., The Chemical Industry During the Nineteenth Century:A Study of the Economic Aspect of Applied Chemistry in Europe and North America, London, Oxford University Press (1958).

8. Chemicals and Long-Term Economic Growth:Insights from the Chemical Industry. Arora, A., Landau, R., Rosenberg, N., eds. New York:John Wiley & Sons Inc.in conjunction with Chemical Heritage Foundation (1998).

9.Brandt,E.N., Growth Company:Dow Chemical's First Century, E.Lansing, MI, Michigan State University Press (1997).

10.Pafko, W., "History of Chemical Engineering & Chemical Technology," http://www.pafko.com/history.

11.White, A.H.,and C.Upthegrove, "The Department of Chemical and Metallurgical Engineering"from The University of Michigan — an Encyclopedic Survey, Vol.VII, University of Michigan Press, Ann Arbor, pp. 1190–1200 (1953)

12.Peppas,N.A.,with R.S.Harland, "History of the School of Chemical Engineering of Purdue University," West Lafayette, IN, School of Chemical Engineering, Purdue University (1986).

13.Tarbell,I.M., "The History of the Standard Oil Company," New York:McClure, Phillips and Co. (1904).

14.Caruana,C.M., "Neal Amundson Assesses a Changing Profession," *Chem. Eng.Prog.*, pp. 76-79 (Dec.1987).

15.Scriven,L.E., "The Role of Past, Current, and Future Technologies in Chemical Engineering," *Chem.Eng.Prog.*, pp. 65-69 (Dec. 1987).

16.Smith, J.C., "The School of Chemical Engineering at Cornell:A History of the First Fifty Years," Ithaca, NY, College of Engineering, Cornell University (1988).

17."Six Commentaries on the Amundson Report," *Chem.Eng.Prog.*, pp. 70-75 (Dec. 1987).

18. Uncaging Animal Spirits:Essays on Engineering, Entrepreneuship, and Economics. Landau, R.;Gottron, M.V., ed. Cambridge, MA:The MIT Press (1994).

19. The U.S. Petroleum Industry: Past as Prologue 1970-1992. Washington, D.C.: Energy Information Admin., Office of Oil and Gas, U.S. Dept.of Energy (1993).

1974 Unleaded gasoline introduced; Society of Mexican American Engineers and Scientists and Society of Hispanic Professional Engineers formed

1975 Optical fibers developed

1976 Resources Conservation & Recovery Act passed; Design Institute for Emergency Relief Systems formed at AIChE; National Academy of Sciences reports on deleterious effect of chlorofluorocarbons on ozone layer

1978 Design Institute for Physical Property Data (DIPPR) formed at AIChE; chlorofluorocarbons banned

1979 Human insulin synthesized

1980 Comprehensive Environmental Response,Compensation & Liability Act (CERCLA) passed; 3M introduces Post-It Notes

1981 DuPont buys Conoco Inc., nearly doubling its assets and revenues

1982 Monsanto scientists genetically modify plant cell for the first time

1984 A gas leak from a tank of methyl isocyanate at a Union Carbide plant in Bhopal,India results in 3,800 deaths

1985 Center for Chemical Process Safety formed at AIChE

Well, computer technology has made a huge impact. “We have gone from manual calculations and drawings, to CAD systems with sophisticated modeling capabilities, so we can basically create a virtual laboratory,” points out 3M’s Larson. Sophisticated process-control systems are found in plants everywhere. New fields continue to open up in research, as developments like the completion of the Human Genome Project push the envelope of genomics and genetic engineering.

The more things change, however, the more they stay the same. Chemical engineers’ skills and knowledge have always enabled them to fill a wide spectrum of roles — inside and outside the CPI. “The field still has room for the highly focused researcher, the applied engineer, the manager, the inventor, and so forth,” points out Elisabeth Drake, a chemical engineer at MIT’s Lab for Energy and the Environment. “A strength of the profession is its diversity of opportunities.”

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An evolution in education

In 1887 at the Manchester Technical School (now UMIST), George E. Davis delivered a series of lectures, which he published in 1901 under the title, “A Handbook of Chemical Engineering.” His introduction to the book foreshadows many of the themes predominant in chemical engineering today — process optimization, process safety, rigorous technical knowledge and practical hands-on experience:

> …Chemists, it is true, have a much greater knowledge [than previously] of the methods of substitution, of isolation, and of recombining different and various organic radicles, and to their researches we owe much of our present prosperity in the chemical trade; but the greatest progress has been made in the mechanism of plant, and in the way in which chemical operations have been carried out on the large scale. Though chemical operations are now much more intricate than they were a quarter of a century ago, they are carried out less expensively, more completely, and with greater safety to the work people, and at least the moiety of this improvement must be credited to the Chemical Engineer. Of course ‘practical experience’ is a very good master when the pupil is an apt scholar, but practical experience uncombined with scientific knowledge, is a poor staff to rest upon, and is very soon played out.

Another of Davis’s themes was the idea that diverse industrial processes held a common thread: a relatively small number of distinct operations, such as evaporation, separation, and mixing. The “unit operations” theme was implicit from the earliest days of chemical engineering, although the nomenclature didn’t appear until 1915, when Arthur D. Little reiterated the idea in a letter to the president of his alma mater, MIT:

> …any chemical process, on whatever scale conducted, may be resolved into a coordinate series of what may be termed Unit Operations, as pulverizing, dyeing, roasting, crystallizing, filtering, evaporation,electrolyzing, and so on. The number of these basic unit operations is not large and relatively few of them are involved in any particular process. The complexity of chemical engineering results from the variety of conditions as to temperature, pressure, etc., under which the unit operations must be carried out in different processes, and from the limitations as to material of construction and design of apparatus imposed by the physical and chemical character of the reacting substances.

MIT had been the first to introduce a chemical engineering curriculum in 1888, when it first offered Course X — a four-year bachelor’s degree in chemical engineering — taught by Lewis M. Norton, a professor of organic and industrial chemistry. Bachelor’s programs in chemical engineering were introduced at the Univ. of Pennsylvania in 1892, Tulane Univ. in 1894, and Univ. of Michigan and Tufts Univ. in 1898. Nicholas Peppas, chemical engineering professor and chronicler at Purdue Univ., points out that an independent school of chemical engineering — the Industrial and Commercial Academy — existed in Athens, Greece, as early as 1894.

Most schools would take a while to establish a standalone department for the discipline — not until 1920 at MIT, for example. In 1923, a landmark textbook that quantified unit operations — Principles of Chemical Engineering — was published by MIT’s Lewis and colleagues William H. Walker and William H. McAdams. Combined with Little’s identification of the importance of unit operations, the book helped chemical engineering shift from the realm of the descriptive to the domain of the scientific.

Around this time, many young men experiencing a tight labor market following World War I flocked to engineering schools, particularly attracted by chemical engineering (Michigan reports that in 1920 more than 100 sophomores chose it as their specialization). The spike receded, but it had helped raise awareness of the fascinating new subject.

As time went on, professors gradually continued to enrich their teaching with new research findings in petroleum, metals, organics, and other areas. Recognizing the importance of synergies with industry, schools introduced co-op programs (at Purdue, for example, in 1959). By the mid-1960s, such new fields as biochemistry and microelectronics were beginning to appear; and it was in the 1970s that chemical engineering began to be recognized as the “universal” engineering discipline.

“Over the past 70 years, the study of chemical engineering has been put on a firmer scientific basis, and there is now an even greater emphasis on mathematics,” says professor emeritus James Wilkes, who has taught at Michigan since 1960. The computer, of course, has made a huge impact. In research, says Cornell Univ. associate professor Paulette Clancy, “there is an increased focus on teams, and the emphasis has changed — nano-everything, materials (hard and especially soft), and the rise of interest in bioengineering in its broadest sense, and in biomimetics.”

Graduates’ destinations, not surprisingly, have shifted away from oil and gas companies, says Clancy. Popular areas of prospective employment now include microelectronics and consumer products. To that list, Wilkes adds pharmaceuticals, bioengineering, food processing, agriculture, and the environment. What about unrelated CPI sectors? “A few of our students take jobs with the financial houses and banks, who like what they assume is a rigorous engineering training,” says Wilkes.

1986 Reactor core melts down in Chernobyl,Ukraine nuclear power plant

1988 American Chemistry Council launches Responsible Care initiative; National Academy of Engineering publishes Frontiers of Chemical Engineering (Amundson Report)

1989 Exxon Valdez runs aground in Alaska, releasing more than 11 million gallons of crude oil; Procter & Gamble introduces bottle made completely of recycled PET

1990 Clean Air Act Amendments; Pollution Prevention Act passed

1994 Advocates for Women in Science,Engineering and Mathematics founded

1995 Dow Corning files for bankruptcy; Dow takes over three companies in former East Germany

1997 Monsanto spins off chemicals business as Solutia to concentrate on life sciences

1998 Exxon and Mobil merge; DuPont introduces first once-daily treatment for HIV and AIDS

1999 Dow and Union Carbide merge

2001 Human Genome Project completed; DuPont announces intent to sell pharmaceuticals business to Bristol-Myers Squibb