01
Chemical Engineering
- An Overview

Objectives

When you have completed study of this chapter you should be able to:

- Understand the background of the chemical engineering field;
- Grasp the impact of chemical engineering in industrial development;
- Explain the concept of unit operations;
- Be familiar with the role of chemical engineers;
- Appreciate the ten major achievements in chemical engineering .

1.1 Chemical Engineering Defined

In the early stages, chemical engineering was related to trades involving chemicals. In the latter half of the 18th century, chemical engineering began to earn the status of an independent division of knowledge. Therefore, it was accepted as a science, to be explored further. In 1772, J. Beckman, Professor of the Gottingen University, coined the term 'Chemical Engineering'. He was also instrumental in compiling the first ever book on chemical engineering.

1.1.1. A Brief Historical Outline

In the 19th century, quite a number of books, manuals and studies in chemical engineering were published. The appearances of these books were due to the rapid expansion of chemical processing. The latter half of the 19th century saw an ever-growing scientific interest in catalysis, with the result that many new chemical manufacturing processes could be commercialized. One example is the discovery of the contact process for the manufacture of sulphuric acid. . Sulfuric acid was first among these "industrial chemicals". It was said that a nation's industrial might could be gauged solely by the vigor of its sulfuric acid industry . Theoretical and experimental work in chemical thermodynamics solved many problems faced by the chemical process industries (CPI's). Special mention should be made of the work done by Le Chatelier, Nernst and Haber in the synthesis of ammonia from nitrogen and hydrogen. A large-scale follow-up of Justus von Liebig's studies in the field of agricultural chemistry gave rise to a new branch of CPI's – fertilizer manufacture. Without fertilizers, it would be hardly possible to feed the ever-growing population of our planet Earth today.

The branch of chemical engineering from its early days was tailored to fulfill the needs of the chemical industry. At the fag end of the 19th Century these demands were acute across the globe. Competition between manufacturers was stiff and all aimed to become the "cost effective producer". Hence, chemical plants had to be optimized. This necessitated the advent of continuously operating reactors (as opposed to batch operation), recycling and recovery of unreacted reactants and cost effective purification of products. These advances warranted piping systems (for which traditional chemists where unprepared) and detailed physical chemistry knowledge . The new chemical engineers were capable of designing and operating the increasingly complex chemical operations which were rapidly emerging. Current studies in Chemical engineering have contributed greatly to the development in a number of fields such as intensive farming, environmental control, nuclear science and many other tasks.

1.1.2 Early Industrial Chemistry

Sulfuric Acid Production

Lead -Chamber method was extensively used to manufacture sulfuric acid . This technology required air, water, sulfur dioxide, a nitrate, and a large lead container. Of these ingredients the nitrate was the most expensive. This was because during the final stage of the process, nitrate (in the form of nitric oxide) was lost to the atmosphere thereby necessitating a make-up stream of fresh nitrate. This additional nitrate, in the form of sodium nitrate had to be imported making it very costly proposition.

In 1859, John Glover helped solve this problem by proposing a mass transfer tower to recover some of this lost nitrate. In this tower, sulfuric acid (still containing nitrates) was trickled downward against upward flowing burner gases. The flowing gas absorbed some of the previously lost nitric oxide. Subsequently, when the gases were recycled back into the lead chamber the nitric oxide could be re-used.

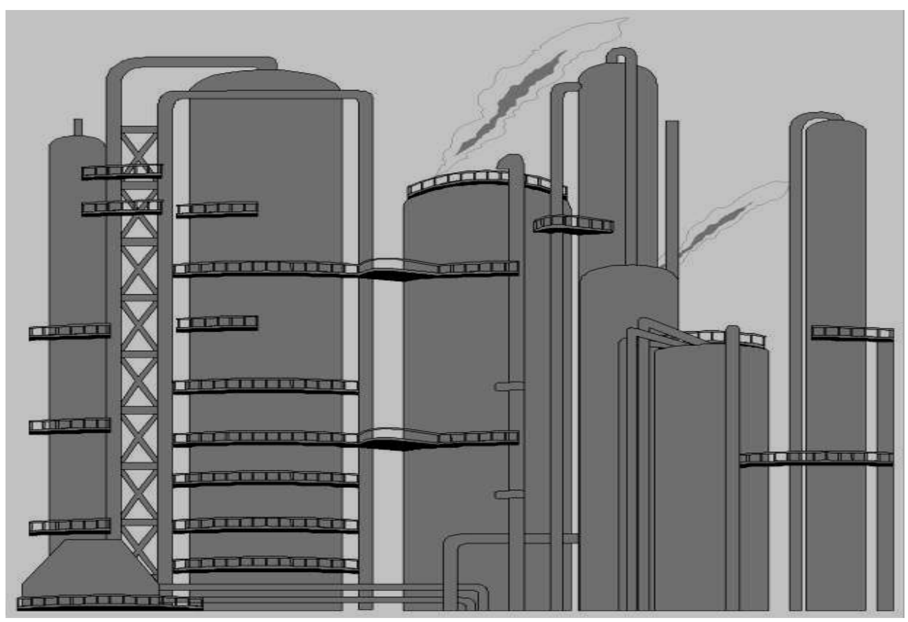

Figure 1.1
Chemical Process Plant - A Bird's Eye View

The Glover Tower represented the trend in many chemical industries during the close of the 19th Century. Competition was propelling rapid development and modernization of chemical plants. A well designed plant with innovative chemical operations, such as the Glover Tower, often meant the difference between success and failure in the highly competitive chemical industries.

Alkali & The Le Blanc Process

The manufacture of soda ash (Na $_2CO_3$) and potash (K_2CO_3) - another very competitive (and ancient) chemical industry was a significant development . These Alkali compounds found great use in a wide range of products including glass, soap, and textiles and were in tremendous demand

A Frenchman named Nicholas Le Blanc discovered a process for converting common salt into soda ash. The Le Blanc Process in 1810 and was continually improved over the next 80 years through elaborate engineering efforts. Most of this efforts was directed at recovering or reducing the byproducts of the process. Hydrochloric acid, nitrogen oxides , sulfur, manganese, and chlorine gas were all produced by the Le Blanc process and because of these chemicals many manufacturing sites were identified as sources for environmental pollution.

Soda Ash & the Solvay Process

In 1873 a new and much required process replaced Le Blanc's method for producing Alkali. While the chemistry of the new Solvay Process was much more direct than Le Blanc's, the necessary engineering was many times more complex. The straight-forward chemistry involved in the Solvay Process had been discovered by A. J. Fresnel way back in 1811, however scale up efforts had proven fruitless until Solvay came along 60 years later. No doubt this is why the method became known as the Solvay Process and not the Fresnel Process.

The heart of the Solvay's Process was an 80 foot tall high-efficiency carbonating tower. Here the ammoniated brine was fed down from the top while carbon dioxide gas bubbled up from the bottom. These chemicals reacted in the tower forming the desired sodium bicarbonate. Solvay's engineering resulted in a continuously operating process free of hazardous by-products and with an easily purified final product. By 1880 it was evident that the Solvay Process would rapidly replace the traditional Le Blanc Process.

1.1.3 The Struggle for Survival

For the purpose of discussion the chemical engineering profession began in 1888. While, the term "chemical engineer" had been floating around industrial circles throughout the 1880's, there was no formal education for such a person. The "chemical engineer" of these years was either a mechanical engineer who had gained some fundamental knowledge of chemical process equipment, a chemical plant foreman with a lifetime of experience but little education, or an applied chemist with knowledge of large scale industrial chemical reactions.

An pioneering effort in 1880, by George Davis to unite these varied professionals through a "Society of Chemical Engineers" proved unsuccessful. However, this confused state of affairs changed in 1888, when Professor Lewis Norton of the Massachusetts Institute of Technology introduced "Course X" (ten), thereby uniting chemical engineers through a formal degree. Other schools, such as the University of Pennsylvania and Tulane University, quickly followed suit adding their own four year chemical engineering programs in 1892 and 1894 respectively

While chemical engineers ultimately gained a formal education in 1888, this was certainly no guarantee for their success. Many prominent people saw no need for this new profession. Also, it was unclear what role chemical engineers would play in industry.

To survive, chemical engineers had to claim industrial territory by defining themselves and demonstrating their uniqueness and worth. With this objective in mind, the American Institute of Chemical Engineers (AIChE) was formed in June of 1908. However, AIChE also confronted difficult challenges in defining its own scope. The old (since 1876) and powerful (5000 members) American Chemical Society (ACS) had already laid claim to all realms of American Chemistry, both pure and applied.

Barely weeks after the formation of AIChE, the ACS would launch its own "Division of Industrial Chemistry & Chemical Engineering" placing itself in direct competition with AIChE for the hearts and minds of the new engineers.

Chemical Engineering Today & Tomorrow

The "Big Four" engineering fields comprises of civil, mechanical, electrical, and chemical engineers. Of these, chemical engineers are numerically the smallest group. However, this relatively small group holds a very cardinal position in many industries and chemical engineers are, on average, the highest paid of the "Big Four". Also, numerous chemical engineers have found their way into upper management. A chemical engineer is either currently, or has previously, occupied the CEO position for: 3M, Du Pont, General Electric, Union Carbide, Dow Chemical, Exxon, BASF, Gulf Oil, Texaco, and B.F. Goodrich. Even a former director of the CIA, John M. Deutch, was a chemical engineer by training.

More typically, chemical engineers concern themselves with the chemical processes that turn raw materials into valuable products. The required skills encompass all aspects of design, testing, scale-up, operation, control, optimization and require a detailed understanding of the various "unit operations", such as distillation, mixing, and biological processes, which make these conversions possible. Chemical engineering science utilizes mass, momentum, and energy transfer along with thermodynamics and chemical kinetics to analyze and improve on these "unit operations."

Today there are thousands of practicing chemical engineers around the world. Chemical engineering is not a profession that has to dwell on the achievements of the past for comfort, for its greatest accomplishments are yet to come.

1.2 Chemical Engineer – Scope & Responsibilities

It is apparent that chemical engineers are comfortable with chemistry, but they do much more with this knowledge than just produce chemicals. In fact, the term "chemical engineer" is not even intended to describe the type of work a chemical engineer performs. Instead it is meant to reveal what makes the field different from the other branches of engineering.

All engineers utilize mathematics, physics and the engineering art to overcome technical problems in a safe and economical manner. Yet, it is the chemical engineer alone that draws upon the vast and powerful science of chemistry to solve a wide range of problems. The strong technical and social ties that bind chemistry and chemical engineering are unique in the fields of science and technology. This link between chemists and chemical engineers has been beneficial to both sides and has rightfully brought the envy of the other engineering fields.

The breadth of scientific and technical knowledge inherent in the profession has resulted some to describe the chemical engineer as the "universal engineer. Chemical engineers are extremely versatile and able to handle a wide range of technical problems.

As a very rough explanation, chemical engineers are technocrats who deal with plant-scale production of chemicals, which are produced by means of chemical processes. They are also involved in both economical and technical calculations in chemical industry.

However, it is not strange to see people who cannot distinguish the functions of a chemical engineer from that of a chemist. Let us clarify this point with a simple example: A chemist may find out that when chemicals X and Y are reacted in a test tube in the presence of catalyst Z at a given temperature and pressure, a product P which has a higher market value than both X and Y could be obtained. From this stage on, the chemical engineers get into the act. Primarily, a laboratory scale experiment is by no means a proof for a commercially applicable process. The chemist may react 10 mg of X and 20 mg of Y to get 30 mg of P, but it does not guarantee that you can build a plant which produces 750000 tons of chemical P per year. Moreover, the catalyst Z can increase the rate of reaction under experimental conditions, but is it also true for the conditions of a commercial chemical plant? Even relatively simple parameters such as temperature and pressure may cause problems. It is relatively easy to construct a small vessel which can withstand pressure differences of hundreds of atmospheres, but when it comes to design a compressor which will increase the pressure of a gas stream, every single unit of pressure added will mean additional wall thickness, extra money and more unexpected problems.

So, the first task seems to be designing and constructing a pilot plant, which is neither a laboratory scale operation nor a commercial scale plant. . The chemical that are intended to produce might have been commercially produced before, or it may be decided to save some money by excluding a pilot plant and taking the risk of a commercial failure. These concepts are both economically and technically detailed points to consider and usually require an extensive study on the specific case.

Subsequently, the feasibility research commences. The market conditions for the chemical are investigated. Is it being produced at the moment, at any place in the world? If yes, which companies have the "know-how" information for this substance? If no, has any other similar chemical been manufactured? What is the market value for the product? What are the possible raw materials, how can they be obtained? Are there any legislations or laws that put a restriction on the production, transportation or storage of the chemical? Is it environmentally safe to produce it in bulk amounts? Questions such as these must all be answered before starting a "base case design" procedure.

The base case design is the preliminary design for the grass root plant under consideration. Initially, a "base case design capacity" is calculated and the capacities of all the equipment are determined accordingly. Then follows the technical design of process equipment, which is generally called "unit design". Integration of these instruments is achieved by means of "process design" which must have been already done before starting unit design. Moreover, it should be kept in mind that the base case design is just a preliminary study and it is followed by various other steps which get into more detail and which require more accuracy.

If a plant already exists, or if the construction stage is completed, then the chemical engineer plays his/her role in plant operation. The optimization procedures may be applicable to get a better profit or to solve some technical issues. Process control instrument must be installed to keep track of variations and avoid any irregularities in the product quality. Debottlenecking may be required after some years of operation, in which the chemical engineer is again responsible for both economical and end technical calculations. The available technology may become obsolete because of a newly exploited process or technology, hence the plant must be either revised or shut-down, etc.

The instruments that chemical engineers frequently use include fluid mechanics, heat transfer, thermodynamics, mass transfer, mathematical modeling, reaction kinetics and reactor design, unit design, process design, process economics, optimization and process control. A strong academic background in mathematics is required, numerical methods and differential equations being two of the most frequently encountered topics. Only a broad exposure of chemistry is sufficient, indeed no "process engineer" feels any need to know the details of chemistry. However, if a chemical engineer chooses "polymers" or "biochemical engineering" as his specialization topic, he/she would be more involved with chemistry.

1.3 “Ten Greatest Achievements” of Chemical Engineering

The Atom

Biology, medicine, metallurgy, and power generation have all been transformed by the capability to split the atom and isolate isotopes. Chemical engineers played a significant role in achieving both of these results. Early on chemical facilities were used in warfare which ultimately resulted in the production of the atomic bomb. Today, these technologies have found uses in more peaceful applications. Medical doctors now use isotopes to monitor bodily functions; quickly identifying clogged arteries and veins. Similarly biologists gain invaluable insight into the basic mechanisms of life and archaeologists can accurately date their historical findings.

The Plastic Age

The start of 19th Century witnessed tremendous achievements in polymer chemistry. However, it required the vision of chemical engineers during the 20th century to make bulk produced polymers a viable economic reality. When a plastic called Bakelite was introduced in 1908 it heralded the dawn of the "Plastic Age" and quickly found uses in electric insulation, plugs & sockets, clock bases, iron cooking handles and fashionable jewelry. Now, plastic has become so ubiquitous that we hardly notice it exists. Yet, nearly all aspects of modern life are positively and deeply impacted by plastic.

The Human Reactor

Chemical engineers have been engaged in detailed study of complex chemical processes by breaking them up into smaller called-"unit operations." Such operations might comprise of heat exchangers, filters, chemical reactors and the like. Subsequently , this concept has also been applied to the human body. The implications of such analysis have aided to improve clinical care, suggest improvements in diagnostic and therapeutic devices and led to mechanical wonders such as artificial organs. Medical doctors and chemical engineers continue to work in tandem to help us live longer fuller lives.

Wonder Drugs for the Masses

Chemical engineers have been adept to take small quantities of antibiotics developed by distinguished researchers such as Sir Arthur Fleming (who discovered penicillin in 1929) and increase their yields several thousand times through mutation and special brewing techniques. Today's low price, high volume, drugs owe their existence to the work of chemical engineers. This ability to bring once scarce materials to all members of society through industrial creativity is a defining characteristic of chemical engineering.

Synthetic Fibers

Right from blankets and clothes to beds and pillows, synthetic fibers keep us warm, cozy and provide a good night's rest. Synthetic fibers also help reduce the strain on natural sources of cotton and wool, and can be tailored to specific applications.

Liquefied Air

When ambient air is cooled to very low temperatures (about 320 deg F below zero) it condenses into a liquid. Chemical engineers are then capable to separate out the different components of air. The purified nitrogen can be used to recover petroleum, freeze food, produce semiconductors, or prevent unwanted reactions while oxygen is used to make steel, smelt copper, weld metals together and support the lives of patients in hospitals.

The Environment

Chemical engineers furnish economical solutions to clean up yesterday's waste and prevent tomorrow's pollution. Catalytic converters, reformulated gasoline and smoke stack scrubbers all help keep the world clean. Additionally, chemical engineers help reduce the strain on natural materials through synthetic replacements, more efficient processing and new recycling technologies.

Food

Plants require large quantities of nitrogen, potassium and phosphorus to grow in abundance. Chemical fertilizers can help provide these nutrients to crops, which in turn provide us with a bountiful and balanced diet. Fertilizers are especially important in certain regions of our earth where food can sometimes be scarce. Advances in biotechnology also offer the potential to further increase worldwide food production. Finally, chemical engineers are at the forefront of food processing where they help create better tasting and most nutritious foods.

Petrochemicals

Chemical engineers have assisted to develop processes like catalytic cracking to break down the complex organic molecules found in crude oil into much simpler components . These building blocks are then separated and recombined to form many useful products including: gasoline, lubricating oils, plastics, synthetic rubber and synthetic fibers. Petroleum processing is therefore recognized as an enabling technology, without which, much of modern life would cease to function.

Running on Synthetic Rubber

A prominent role is played by chemical engineers in developing today's synthetic rubber industry. During World War II, synthetic rubber capacity suddenly became of great importance. This was because modern society runs on rubber. Tires, gaskets, hoses, and conveyor belts (not to mention running shoes) are all made of rubber. Whether you drive, bike, roller-blade, or run; odds are all are running on rubber.

1.4 Unit Operations - The "Big Stick" of Chemical Engineering

A chemical process is an assemblage of individual steps or operations which, when completed, produces a derived end product from a few basic raw materials. Some of the component operations are needed in order to prepare the reactants for a chemical reaction, that is, to make them most reactive. Suitably prepared, the reactants are reacted with one another; this interaction often includes several steps. Between these steps, it may prove to be necessary to again utilize the mechanism of heat and mass transfer as well as some other physical processes. A chemical reaction yields a mixture of the end product(s), by-products and unreacted reagents. Quite logically, the final step(s) has the objective to separate the mixture, again using heat and mass transfer, filtration, centrifugation, distillation, absorption, extraction and so on. The products are either stored or processed further; the unreacted materials are re-used as recyclables. The final steps may also include the recovery of waste, heat and the treatment of process wastes (both liquid and gaseous) for removal of whatever values they may carry and as a way of averting any likely damage to the surroundings. Thus, on the whole, a chemical process is a multifaceted system consisting of interrelated elements and interacting with the environment.

Although there are a number of individual processes, each one can be broken down into a series of steps, called operations; each of which, in turn, appears in process after process. The individual operations have common techniques and are based on the same scientific principles.

The unit operations are largely used to conduct the primary steps of preparing the reactants, separating and purifying the products, recycling unconverted reactants and controlling the energy transfer into or out of the system. Because unit operations out of engineering, they are based on both science and experience. Theory and practice must combine to yield designs for equipment that can be fabricated, assembled, operated and maintained.

In transforming matter from inexpensive raw materials to highly desired products, chemical engineers became very familiar with the physical and chemical operations necessary in this metamorphosis. Examples of this include: filtration, drying, distillation, crystallization, grinding, sedimentation, combustion, catalysis, heat exchange, extrusion, coating, and so on. These "unit operations" repeatedly find their way into industrial chemical practice and became a convenient manner of organizing chemical engineering knowledge. Additionally, the knowledge gained concerning a "unit operation" governing one set of materials can easily be applied to others.

A typical process flow diagram indicating the unit operations involved for Lime-Sulphuric Acid recovery process is shown below:

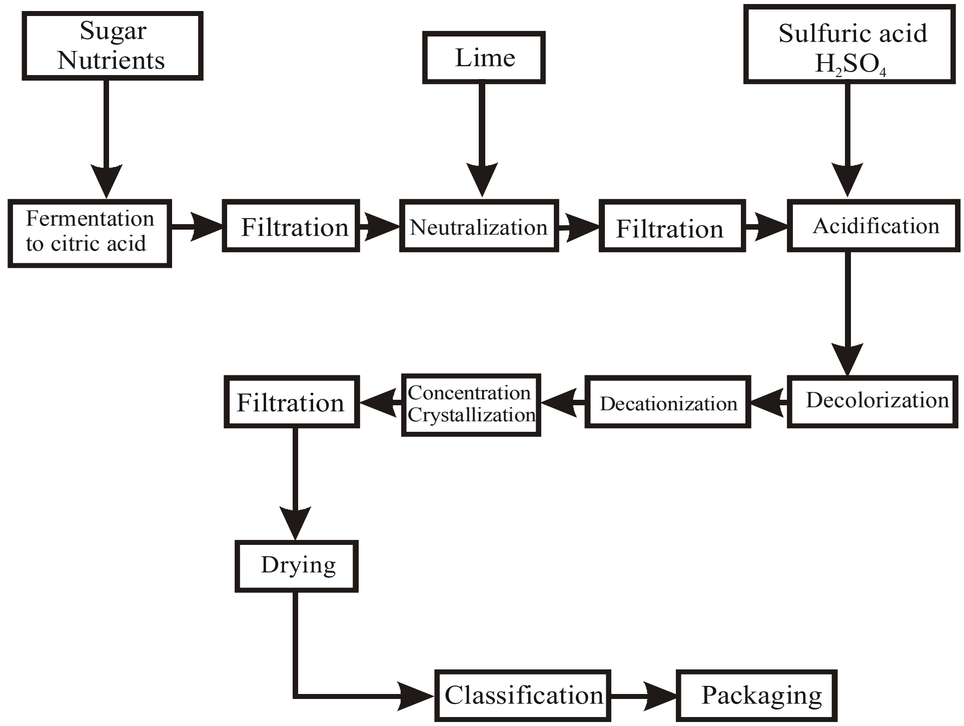

Figure 1.2
Typical Industrial Unit Operation

The "unit operations" concept had been latent in the chemical engineering profession ever since George Davis had organized his original 12 lectures around the topic. However, it was Arthur Little who first recognized the potential of using "unit operations" to separate chemical engineering from other professions. While mechanical engineers focused on machinery, and industrial chemists concerned themselves with products, and applied chemists studied individual reactions, no one, before chemical engineers, had concentrated upon the underlying processes common to all chemical products, reactions, and machinery. The chemical engineer, utilizing the conceptual tool that was unit operations, could now claim to industrial territory by showing his or her uniqueness and worth to the chemical manufacturer.

1.5 A Century of Contributions

The chemical engineering profession emerged from under its industrial chemistry heritage with the help of the unit operations concept.

However, the metamorphosis of chemical engineering did not end here. The addition of material and energy balances, thermodynamics, and chemical kinetics brought the profession closer to something a modern chemical engineer would recognize. With stress on mathematical competence, as necessitated by chemical reactor modeling and a more detailed examination of transport phenomena, chemical engineering continues to broaden in scope. A further requirement in computer literacy, as necessary for process control, allows today's chemical engineer to be much more efficient with their time.

Along the way, this changing educational emphasis has helped the chemical engineer keep up with the changing industrial needs and continue to make significant contributes to society. Today their broad background has opened doors to many interdisciplinary areas such as catalysis, colloid science, combustion, electrochemical engineering, polymer technology, food processing, and biotechnology. The future of chemical engineering seems to lie with these continuing trends towards greater diversity.

1.5.1 Developments in Chemical Engineering

Recent approaches in chemical engineering are directly related to the global problems facing mankind. These developments have become necessary to address the expansion of earth's food supplies, the search for new sources of raw materials for industry, the acquisition of alternative energy sources and the control of the pollution of the biosphere. All these problems are interrelated and call for a unified approach to find a long-lasting solution.

In order to meet the demands for CPI's raw materials, work is underway to expand the availability of hydrocarbon feedstock and petrochemicals by deriving more fractions from crude oil and with greater reliance on non-petroleum raw materials.

A prevailing trend in chemical engineering is the tonnage production of new chemicals and source materials, each of which could serve a wide variety of end uses. Among them are molecular hydrogen, ammonia, hydrazine and methanol; these can double as chemical reactants and alternative fuels.

Another important trend is an increased emphasis on nuclear power and heat generation, which will, in the long run, make huge amounts of fossils materials now burned as fuel, available for use as chemical reactants.

The integration of chemical engineering and nuclear power generation will enhance further progress in science and technology.

In terms of its effects on the environment, man's economic activity has become comparable with natural phenomena and has led in many instances to irreversible and detrimental changes in the biosphere. This is the reason why greater importance is attached to a more enlightened and intelligent use of the biosphere and its protection against harmful processes. Here chemical engineering can do much by evolving better ways and means of industrial waste disposal and control. The ultimate goal is to devise manufacturing processes that would leave no waste at all so that nothing would have to be discharged into the atmosphere or into the water bodies.