الجامعة التكنولوجية

قسم الهندسة الكيمياوية

المرحلة الاولى

اللغة الانكليزية

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UNIT ONE
WHAT CHEMICAL ENGINEERS DO

Special Terms

Chemical Process Industries (CPI): A large group of industries that use chemical and engineering principles to separate or change materials into salable products.

Raw Material: The material that comes into a plant, where it is processed to produce a salable product. Petroleum is the raw material for the manufacture of gasoline. Sulfur is the raw material for the manufacture of sulfuric acid (H_2SO_4).

Unit Operation: One of the processing steps that materials undergo in a chemical process plant. Mixing and drying are examples of unit operations.

Feasibility Study: An analysis of a project to see if it can be carried out successfully. This is a common preliminary step in the planning of a new plant.

Research and Development (R&D): The gathering of the basic information needed for the design of a plant. Some of the information may be found in the library or learned from experts; the rest must be discovered in the laboratory.

Process Design: Making the decision on equipment to be used and developing all the other information needed for building a chemical process plant.

Flowsheet: A diagram that shows the equipment used and the steps by which a raw material is changed into a finished product. All process design is based on the flowsheet.

Instrumentation: The devices used for measuring or controlling a property such as temperature or pressure. The individual devices are called instruments. In an automobile, for example,

the instrumentation includes the speedometer, the gasoline-level indicator, and the water-temperature indicator.

Plant Operation Engineer: The engineer in charge of a process plant after it is built. He or she may be the plant manager or may report directly to the plant manager.

Preventive Maintenance: The job of maintaining equipment in working order before it breaks down. In a chemical process plant the breakdown of an important piece of equipment may force the entire plant to be shut down, which can be very expensive in terms of lost production.

Consultant: An expert in some field who sells specialized knowledge to persons who need it.

Vocabulary Practice

1. What are the *chemical process industries*? How is the term usually abbreviated?

2. What is a *raw material*? Give two examples.

3. What is a *unit operation*? Is mixing a unit operation?

4. What is a *feasibility study*? When is one likely to be made?

5. What is *research and development*? How is the term abbreviated?

6. What is *process design*? Which comes first, R&D or process design?

7. What is a *flowsheet*? Who would use one?

8. What is *instrumentation* used for?

9. What is a *plant operation engineer*?

10. Name some instruments you are familiar with.

11. What is *preventive maintenance*? Why is it particularly important in chemical process plants?

12. What does a *consultant* do?

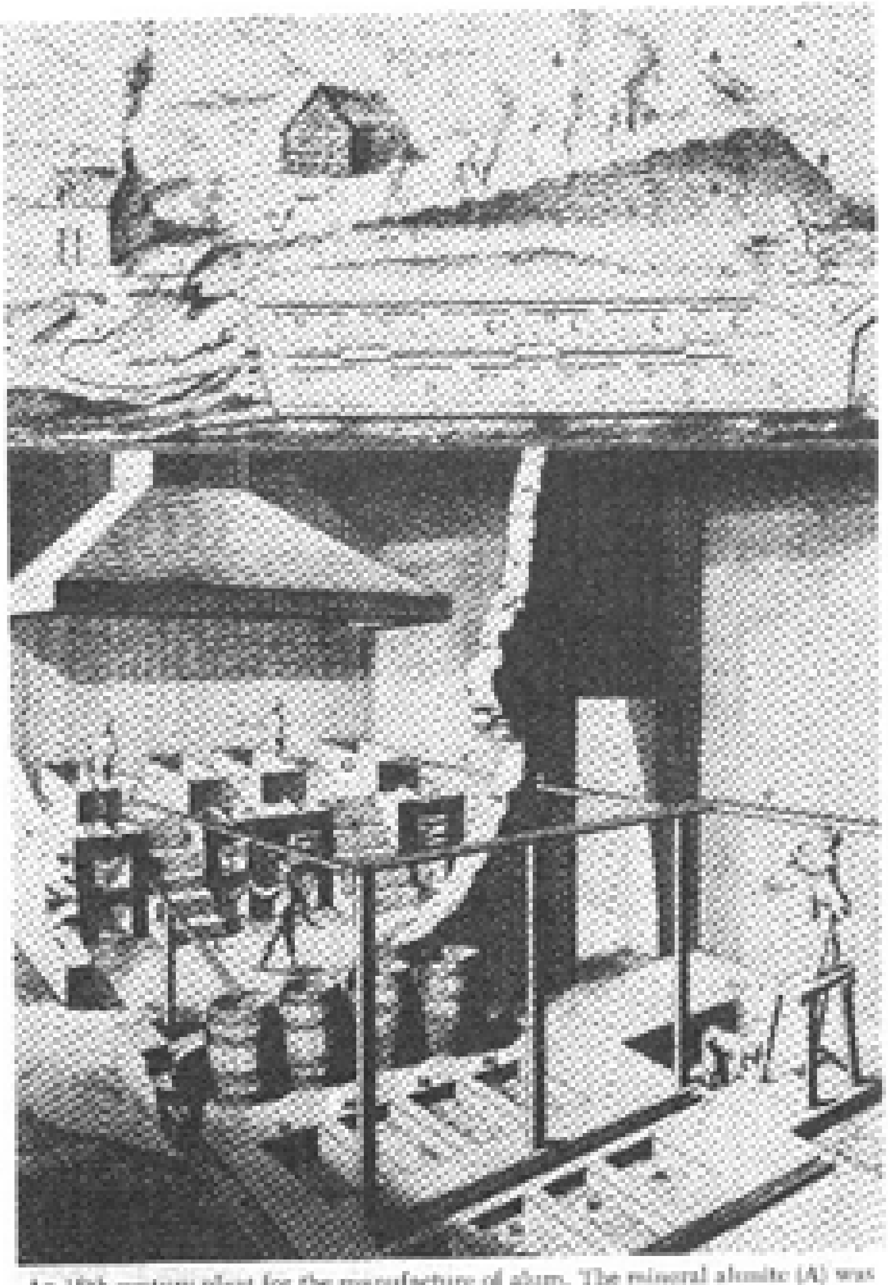
Most chemical engineers work in the *chemical process industries*. These include the plants that manufacture such things as food products, plastics, paper, fertilizers, petroleum products (gasoline, kerosene, fuel oil), synthetic (manmade) fibers such as nylon, and the basic chemicals used by many industries, such as acids, alkalis, and dyes. These are all industries in which *raw materials* are separated or changed into useful products.

Almost all chemical engineers are college-trained in mathematics and physics, with particular emphasis on chemistry. However, the basis of chemical engineering is the study of *unit operations*.

Before the first World War (1914 to 1918), all chemical process plants were designed and operated by chemists. (Even today, in some countries such as Germany, this work is done by specially trained chemists.) However, shortly after the war, three American college professors—Walker, Lewis, and McAdams—published a book based on principles common to all chemical process plants. They noted that in all plants materials were mixed together, heated, cooled, moved from place to place, and wanted materials were separated from wastes. Each of these steps was termed a unit operation, and the student was taught both the engineering principles that underlie each one, and the procedures used to design or select equipment for each operation.

Every chemical process consists of a number of sequential unit operations. Much of this book consists of descriptions of unit operations, so they will not be further discussed at this time.

How does a chemical process plant come into being? It starts with an idea—an idea for a completely new product, for improvement of an existing product, or for a way of producing an existing product at a lower cost. Ideas for completely new products usually come from a company's research laboratories but improvements on existing products may occur to almost anyone.



An 18th century plant for the manufacture of alum. The mineral alunite (A) was heated (*BB*) and extracted by water in ponds (*CC*). The liquid containing the alum was evaporated (*G*) and sent to settling basins (*MM*) where the alum crystallized and was removed.

Once the executives of a company have become interested in the idea of building a new plant, their first step is usually to call for a *feasibility study*. Such a study involves estimating production costs for the product as well as its potential market. Since essential engineering information is usually lacking, these estimates may contain major uncertainties.

If it appears that the plant will make a reasonable profit, the next step is to develop the engineering data that will be needed in designing it. This is the job of the *research and development* engineer. The R&D engineers who work for a CPI company are generally chemical engineers, although in large companies some mechanical, electrical, and civil engineers may also be employed.

R&D engineers do part of their work in the library with books and articles. They often work with other specialists, most often chemists, who are expert in some aspect of the problem. And they may do or direct some laboratory work themselves. But there is a great deal of difference between making a product in a laboratory and making it in a chemical plant. For example, penicillin was developed by growing a mold on a nutrient solution in a flask. The first commercial production was the result of doing the same thing in thousands of flasks.

When chemical engineers were called in to work on the problem, they devised a method of growing the mold in thousand-gallon tanks. Large quantities of sterile air were bubbled through the tanks to provide the oxygen the mold needed for growth. (The air had to be sterile so that no bacteria would grow in the solution.) In the flasks, the mold grew only on the surface where it could get oxygen from the air. But in the tanks, there was sufficient air so that the mold could grow beneath the surface as well. Within a short time production was so high—and the price so low—that the drug was widely available.

Because commercial production can be different from the laboratory process, the R&D engineer will often build and operate a model of the proposed plant in order to find out what kinds of problems may develop and how to solve them. When the research and development work is completed, enough information is available so that the original cost estimate can be refined to a fairly exact figure. Again, the company management has to decide whether to go ahead with the plant or to cancel the project.

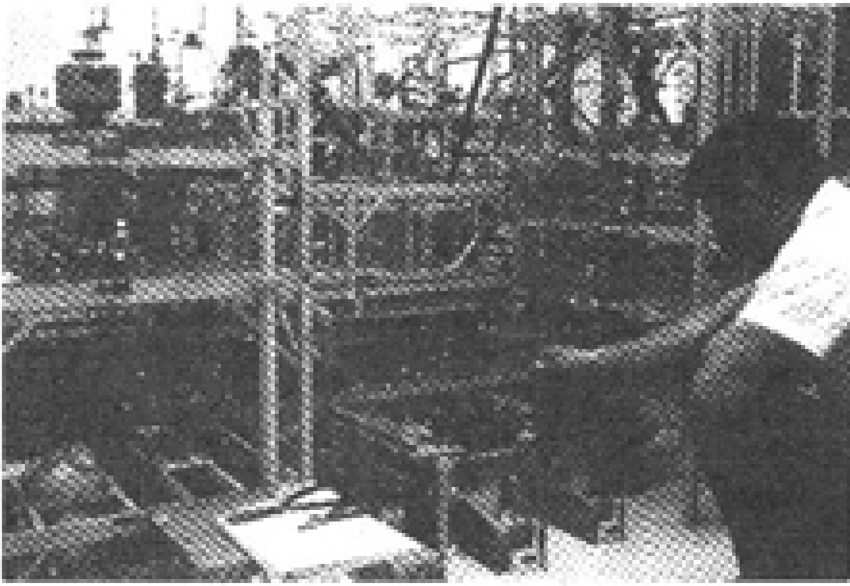
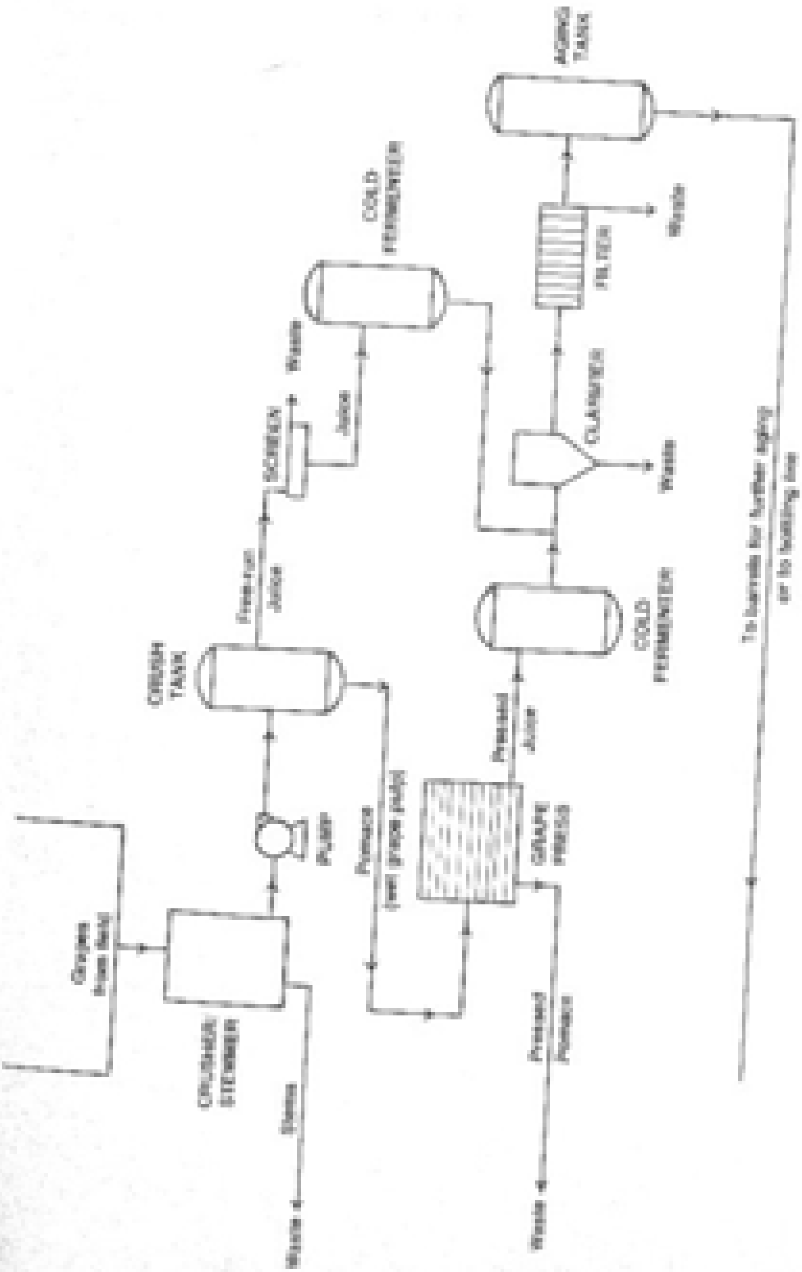


Photo Courtesy Du Pont

Research and development engineers often build a scale model of a proposed plant to help predict and solve future problems.

If the company decides to go ahead, the next step is *process design*. In this stage, the chemical engineer decides what kinds of equipment will be needed for each unit operation and calculates the size of each item. He or she must also select the material that each equipment item is to be made of—usually metal, plastic, or glass—and contact various equipment manufacturers about prices.

One of the tools with which the process design engineer organizes all this information is the *flowsheet*. This is a diagram that shows what happens from the time a raw material comes into the plant to the time it emerges as the desired product. The R&D engineer will probably have made a simple flowsheet to help him or her understand the process, but the one made by the process design engineer will be much more complete. It will show all the pieces of equipment in the plant and how they are connected. The flowsheet will indicate the temperatures, pressures, and flows at each step of the process, and other things as well. One of these other things is the *instrumentation* that will be needed for operating the plant. Most processes in a CPI plant take place inside the equipment and it is only by using instruments that the operators can tell what is happening. If something might lead to a dangerous condition, the in-



A flowsheet for a winemaking plant.

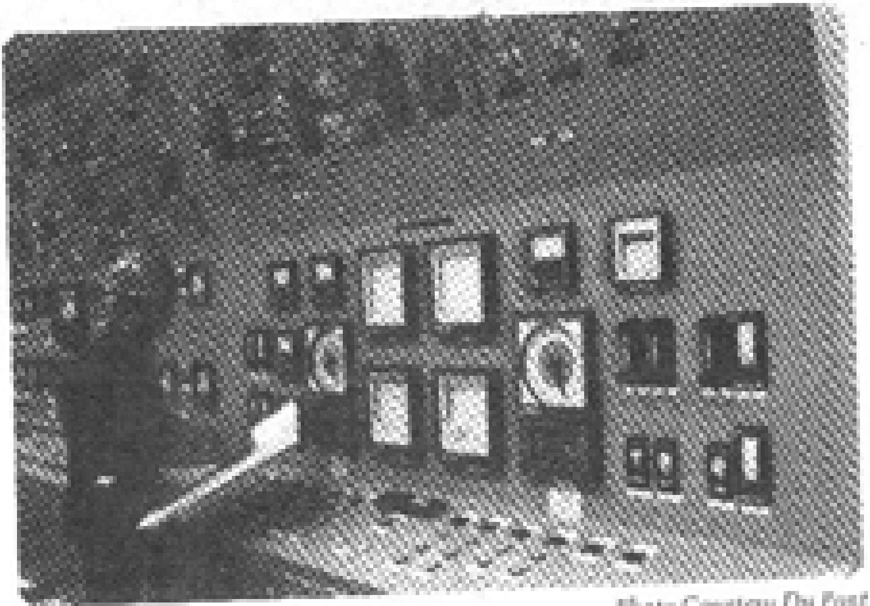


Photo Courtesy Du Pont

Instrumentation does so much of the work that it is possible to run a large chemical plant with only a few operators.

strumentation designer will generally provide flashing lights or ringing bells to call the operators' attention to the developing problem. If it cannot be solved immediately, the entire plant may have to be shut down.

In many plants, instruments not only indicate what is happening but also run the process automatically. A person walking through a modern chemical process plant for the first time is often surprised at how few people are working there. It is possible to run a very large plant with only a few operators and maintenance people because the instrumentation does so much of the work.

After the process design has been completed, the design engineer often supervises the building of the plant. Chemical process plants are usually built by specialized construction companies accustomed to working closely with process design engineers. When the plant is finished, chemical engineers are placed in charge of it to ensure its proper operation. They are known as *plant operation engineers* and are usually executives who spend most of their time at desks. Many people work under them: operators who run the plant on a day-to-day basis; maintenance personnel who keep the equip-

ment operating; material handling personnel who move materials from place to place in the plant; cleaners, clerks, and others. Supervising equipment maintenance is an important part of the plant engineers' work. They must be sure that both spare parts and trained maintenance personnel are always available to prevent shutdown of the plant. The main priority is to anticipate and prevent machinery problems. Repairing equipment before it breaks down is called *preventive maintenance*. Sometimes instruments are installed to indicate if equipment is running hot or vibrating excessively. But more often, elaborate records are kept on critically important machines—records that show how long each part is expected to last so that new parts can be installed before the previous ones fail. Another responsibility of the plant operation engineer is to keep a supply of raw materials on hand, although some raw materials, like natural gas, are brought into the plant by pipeline and are always available. Another term for raw material is feedstock.

It is not uncommon for a CPI plant to run continuously for a year without a break. But some pieces of equipment, such as high-speed pumps, cannot be expected to run that long without being stopped for maintenance. In such cases, a spare piece of equipment will be installed permanently, with piping arranged so that either one can be used. Then, if the item must be repaired, the spare can be put into service to handle the load.

Although most chemical engineers work either in R&D, process design, or plant operation, some follow other careers. They may become college teachers to train new engineers or they may become salesmen of chemical-process equipment. An engineer who has become well known as an expert in some phase of chemical engineering may work as a *consultant*, charging high fees for solving problems too difficult for the average engineer. (College professors often earn extra money by working as consultants.) And recently, more and more engineers are taking jobs with government. These usually involve enforcing laws that relate to health or safety.

Discussion

1. Why is a plant that makes dynamite one of the chemical process industries?

2. Petroleum is the raw material for a large industry. List some products made from petroleum.

3. What stages might the chemical engineers of a chemical process company go through if they wanted to build a plant to make a new kind of fertilizer?

4. Most homes contain various kinds of equipment, particularly in the kitchen. How might an engineer use preventive maintenance to keep such equipment in working order?

5. What are some of the things done by the engineer in charge of plant operation?

6. Why is a consultant likely to be highly paid?

7. Most chemical engineers work in R&D, process design, and plant operation. What are some of the other jobs chemical engineers may do?

8. In your country, is the government passing laws for improved health and safety? Why might chemical engineers be hired to help enforce such laws?

Review

A. Look around the room and make a list of some things that are products of the CPI. (Hint: Don't forget your clothing and the objects in your pockets.)

B. If you go into a plant that makes automobiles you will find it full of workers. Why does a chemical process plant seem so empty of people when compared to an automobile plant?

C. Match the terms in the left column with the proper phrase in the right column. Only one definition is appropriate for each term.

1. CPI	___ A step in a chemical process
2. Feasibility study	___ Devices for measuring and controlling
3. Unit operation	___ Chemical process industries
4. R&D	___ Keeping equipment from breaking down
5. Flowsheet	___ Collecting basic information for a new process
6. Instrumentation	___ Diagram of a chemical process
7. Preventive maintenance	___ Material that is made into a different product
8. Consultant	___ Determining if a project can be successful
9. Raw material	___ An expert in a special field

UNIT TWO
RESEARCH AND DEVELOPMENT

Special Terms

Laboratory: A place especially equipped for experimentation, testing, and/or analysis in a particular field of science or technology.

Flowmeter: An instrument used for measuring the flow of fluids (liquids or gases). Many different types are available.

Hopper: A container, usually funnel-shaped, for storing and delivering powdered or granular material. It is filled from the top, and the bottom is often equipped with a device for delivering measured quantities of the material.

Steam Jacket: A shell fashioned around a tank or other vessel. Steam is introduced into the space between the vessel and the shell, thereby heating the vessel and its contents.

Batch Process: A way of manufacturing chemical products. Measured quantities of materials are carried through a series of operations, step-by-step, to produce the final product.

Continuous Process: A way of manufacturing chemical products in large quantities. Raw materials are fed continuously into one end of the processing plant, flow through various operations, and emerge as the desired product. Continuous processes may run for months or years without stopping.

Proportioning Pump: A device usually consisting of several interconnected pumps. They are designed so that their outputs are adjustable, thereby permitting the ratios of materials discharged to be changed.

Heat Exchanger: A device for heating or cooling fluids. Steam is usually used for heating and cold water for cooling.

Pilot Plant: A miniature plant used for experimentation.

Shift Work: A way of staffing a plant or laboratory continuously for long periods of time. The workers are divided into groups; each group works at a different time.

Group Leader: The person in charge of a group of people. In experimental work, the leader is usually an engineer or scientist.

Progress Report: A description of the work of a group of researchers. Generally, a progress report is written each month.

Vocabulary Practice

1. What is done in a *laboratory*?
2. For what purpose is a *flowmeter* used?
3. What is a *hopper*? What kinds of devices are often used at the bottoms of hoppers?
4. Describe a *steam jacket*.
5. What is a *batch process*?
6. What is a *continuous process*?
7. Describe a *proportioning pump*.
8. What does a *heat exchanger* do? What is usually used in it for heating? For cooling?
9. What is a *pilot plant*?
10. Describe *shift work*.
11. What is a *group leader*?
12. What is a *progress report*? How is it usually presented?

Research and Development

The chemical process industries spend more money on research and development than do most other industries. As a result, we now use many kinds of products unheard of a few years ago. Countless items in our daily lives are different from those our parents used, because of this innovation. Much of our clothing is now made of synthetic fibers instead of natural materials such as wool or cotton. The toys our children play with are often made of plastics that replace wood or metal. And many of us drink instant coffee rather than brewing the beverage from ground coffee beans.

These kinds of products have come about through research and development in research *laboratories*. These laboratories are usually staffed by chemists who do their experimentation in the usual laboratory glassware. For example, when two materials must be mixed together, the chemist may do it with a glass rod or by merely shaking the container. The mixture can be heated by placing the container over a small gas burner or cooled by setting it in cold water. But many of the things that seem so easy in the laboratory are much harder to do in the plant. Even making the same product in the same way, but on a larger scale, presents many problems.

Let us look at a very simple process as the chemist does it and as it might be done in a chemical process plant. He or she (many chemists are women) takes a bottle of Chemical A from a shelf and pours the required quantity into a glass measure. The chemical is dumped into a flask and a second liquid, Chemical B, is measured and added in the same way. Chemical C, a powder, is weighed on a small laboratory scale and added to the two liquids. The chemist mixes the chemicals together by shaking the flask and heats the mixture over a small gas flame, with constant shaking. Finally, the mixture is rapidly cooled by placing the flask into a container of crushed ice. The chemist may have made a total quantity of a half-liter or less of product.

Now consider the same process carried out in a plant in batches of a thousand gallons. (Most chemical plants in English-speaking countries still use the old units such as pounds, feet, and gallons.) Instead of a glass flask, the container will be a thousand-gallon metal tank. Chemical A will not be in a bottle on a shelf—it will be in a storage tank. The proper amount of Chemical A will be added by pumping it from the storage tank through a *flowmeter* in-

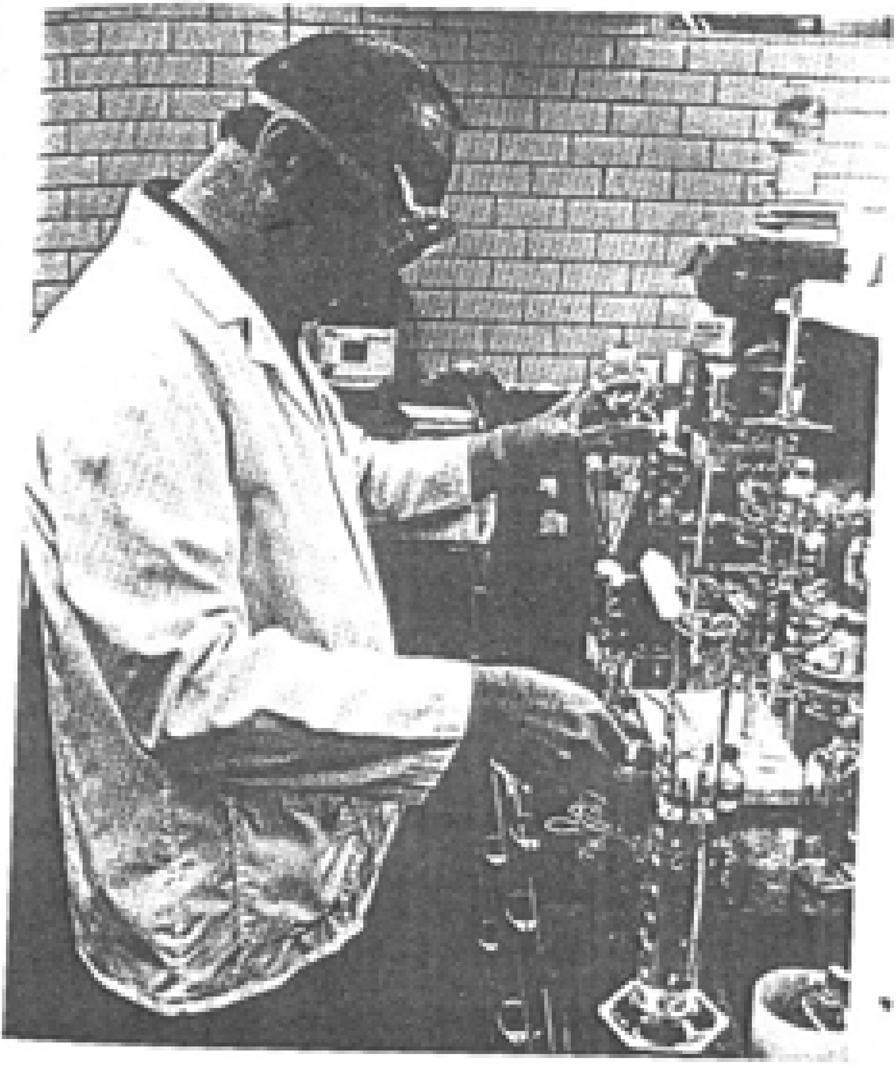


Photo Courtesy Du Pont
Many of the products we use every day began in a research laboratory like this one.

to the processing tank. Flowmeters usually show flow in gallons per minute, so five-hundred gallons might be added at fifty gal/min for ten minutes. Chemical B will be pumped from its storage tank in the same way. (The operator will probably pump both liquids into the processing tank at the same time unless there is a danger in mixing them this way.) Adding Chemical C—the powder—is not as

easy. If only a small amount is needed, it might be weighed into a container and dumped by hand into a mixture. If larger quantities are required, Chemical C will probably be stored in a *hopper* over the processing tank. The hopper will have some sort of measuring (usually weighing) device to ensure adding the proper amount.

Mixing a thousand-gallon tank cannot be done with a glass rod so the engineers will have provided a mechanical mixer, something like a ship's propeller driven by an electric motor. The tank will probably be heated by steam supplied to a *steam jacket* surrounding the tank. The mixture in the tank is stirred throughout the heating period to make sure it is heated uniformly. To cool the mixture, the steam will be shut off and cold water pumped into the jacket. Water cannot be cooled below 32°F (0°C) without turning to ice, but colder temperatures can be achieved by using a solution of salt water called brine. Finally, the mixture will have to be pumped into another tank for storage or the next stage of the process.

What has just been described is an example of a *batch process* in which a given amount of chemicals is processed in some way to yield a quantity of product. Batch processes are commonly used when relatively small quantities of materials are handled and are particularly common when the materials are expensive. For example, batch processes are very often employed in the manufacture of drugs, dyes, and foods.

Another widely used way of handling materials is the *continuous process* in which materials are constantly fed into one end of the equipment and finished product comes continuously out of the other end. All petroleum refining, for example, is done by continuous processes. In a refinery, crude petroleum is pumped into one end of the plant and a continuous stream of gasoline, kerosene, and fuel oil pours out of the other end. Let us look at the simple process we have been describing (mixing quantities of Chemicals A, B, and C, heating, and cooling) and see how it might be done as a continuous process.

The two liquid chemicals are pumped by a *proportioning pump* into a small mixing tank, where Chemical C is continuously added by a solids feeding device. The mixed chemicals are continuously drawn off the bottom of the mixer and passed through a *heat exchanger* where they are steam heated. They then pass into another heat exchanger where they are chilled by cold water or brine. The products flow out of the end of the cold heat exchanger.

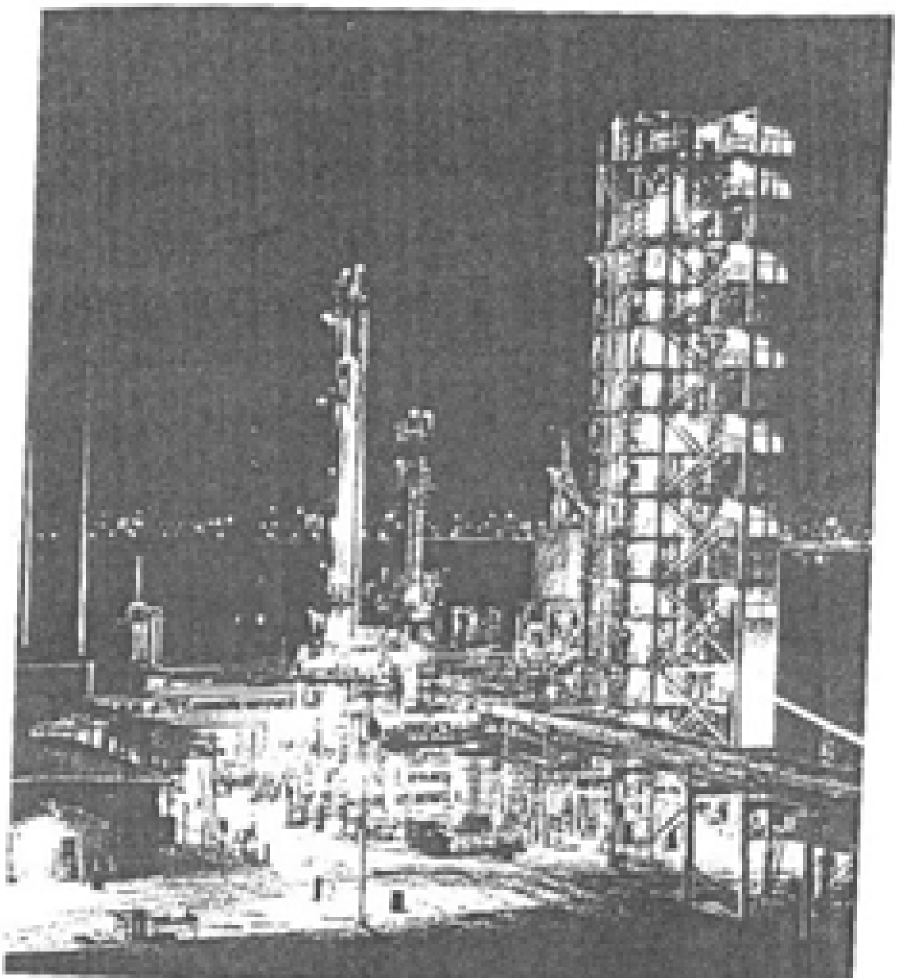


Photo Courtesy National Coal Association
This large scale pilot plant tests a process for making substitute natural gas from coal.

Because chemical plant equipment is so different from that used in the laboratory, one of the major jobs of R&D engineers is to decide what kinds of equipment must be used to carry out a commercial chemical process. They also determine the sizes of equipment needed—how big must the pumps be, how much power must the mixer have? Before designing the full-sized plant, the R&D engineer usually constructs a *pilot plant*—actually a small model of the final plant, containing small versions of the equipment. Pilot

plants are particularly useful when designing continuous process plants which are so different from the research laboratory. (It is usually impossible to run a continuous process in the standard laboratory glassware available to the chemist.)

A continuous process pilot plant will usually run twenty-four hours a day with three or four groups of operators and engineers, each group working for eight hours. This is called *shift work*, and each group is called a shift. Most often, shifts work from 8 a.m. to 4 p.m., 4 p.m. to midnight, and midnight to 8 a.m. A fourth shift is needed if the plant is to run during weekends, although many pilot plants shut down at that time. Usually there is a *group leader* in charge of each shift. The group leader may be a chemical engineer, a chemist, or a specially trained operator. This arrangement makes pilot plant experimentation unattractive to many chemical engineers who prefer to work during the day and leave the evening and night shifts to specially trained operators. However, a pilot plant is often so complicated that engineers are required on all shifts.

Since the basic purpose of the pilot plant is to gather information, there are frequent changes of flowrates, pressures, and temperatures. R&D engineers are always looking for that combination of conditions that will enable them to produce the maximum amount of product at the minimum price. As information is gathered, it is passed along to the company's management. This may be done by memoranda and telephone calls but in most companies, once a month, the R&D engineers write all they have learned during the past month in a *progress report*. These become their main record of accomplishment. The purpose of R&D is to gather information; since a company's management judges R&D engineers by the reports they submit, a great deal of work goes into the reports' preparation. When the research and development project is completed, information in the various progress reports is consolidated into a final report that details everything learned during the research. This final report is invaluable to the process design engineers who will design the full-scale plant.

There is one thing about R&D that many engineers find frustrating: a project is seldom finished. As with all research, there are always more ideas than time or manpower. Eventually, the work must end, even if the best possible design has not been reached. Otherwise no process would ever get into full-scale production. The decision to end a project is usually made by the head of the research laboratories in consultation with the executives of the company.

Discussion

1. What kind of work is done in a laboratory?
2. What kind of specialists usually do laboratory work?
3. Of what material is most laboratory equipment made?
4. How might a laboratory chemist mix materials?
5. What could a chemist use for heating or cooling chemicals in the laboratory?
6. What kinds of equipment might a chemical engineer design for mixing large quantities of materials? What might he use to measure these materials?
7. What is the device engineers use to heat tanks of materials?
8. What is a solution of salt in water called?
9. How does a batch process differ from a continuous process?
10. What kind of equipment is used for the continuous heating or cooling of streams of chemical materials?
11. What kind of equipment might a chemical engineer use for experimenting on a continuous process? Why doesn't a chemist usually run continuous process in the laboratory?
12. Why is shift work necessary in running a pilot plant?
13. What are the usual time periods for each shift?
14. Why is pilot plant work unattractive to some engineers?
15. What do chemical engineers look for when running a pilot plant?

16. How do R&D engineers pass on information to a company's management?

17. Who usually decides when a research project should be ended?

Review

A. List as many kinds of things as you can think of that are now made of plastics but were formerly made of natural materials.

B. Employees in the chemical process industries often have to work in shifts. What are some other kinds of jobs that require shift work?

C. Complete the following sentences with an appropriate word or phrase.

1. Ideas for new products are generally developed in a ______________.

2. A person experimenting in a laboratory is likely to be a ______________.

3. A chemical engineer uses a ______________ to measure large amounts of liquids.

4. A ______________ is used for storing and delivering powdered or granular materials.

5. A process plant mixer may look something like a ship's ______________.

6. A ______________ is often used to heat materials in a tank.

7. Batch processes are often used to process materials that are ______________.

8. Quantities of materials may be added in fixed ratios to a process by using a ______________.

9. A ______________ is employed for continuous heating or cooling of materials.

10. A ______________ is a miniature plant used for experimentation.

11. A ______________ plant will generally operate twenty-four hours a day.

12. People who operate continuous process plants generally do ______________ work.

13. ______________ shifts are usually needed if a plant is to work on weekends.

14. The basic purpose of a pilot plant is to ______________

15. Engineers write ______________ to inform management of their findings.

16. Progress reports are important because ______________
____.

UNIT THREE
PROCESS DESIGN

Special Terms

Scaleup: A mathematical technique whereby data from experiments on small-scale equipment can be used in designing plant equipment.

Vessels: The hollow structures containing liquid or gas. Tanks are the most common vessels used in CPI plants.

Kettle: A tank, usually open at the top, fitted for heating and cooling its contents.

Tank Farm: An area of a chemical process plant where there are a number of large tanks used for storing raw material or finished product.

Pipe Flange: A heavy metal disk which attaches to the end of a pipe to connect one pipe to another.

Gasket: An elastic material used for making joints tight. It is usually used between two mating pipe flanges.

Pipe Fitting: A specially made short length of pipe for such purposes as changing direction, joining pipe at various angles, or connecting pipe of unequal sizes.

Pipe Elbow (Ell): A pipe fitting used to change pipe direction by 90 degrees or by 45 degrees.

Pipe Tee: A T-shaped fitting used to connect pipes.

Pipe Cross: A pipe fitting used to connect four lengths of pipe at right angles to each other.

Pipe Reducing Fitting (Reducer): A pipe fitting used to join two pipes of unequal diameters. It comes in two types—eccentric and concentric.

Pipe Lateral: A fitting used to join two pipes at an acute angle.

Pressure Vessel: A closed vessel especially designed to contain its contents under pressure. Generally, any internal pressure above one atmosphere (100 kilopascals) requires a pressure vessel.

Pressure Vessel Code: A set of rules for designing and testing pressure vessels. In the United States the American Society of Mechanical Engineers (ASME) has devised such a set of rules—the ASME Pressure Vessel Code. Many governments require that pressure vessels conform to this code, thus giving it the force of law.

Materials of Construction: A term comprising various materials, such as metals and plastics, used in building structures and equipment. Selection of the proper material of construction for equipment is one of the jobs of the design engineer.

Corrosion: The attack on metals by various chemicals. Materials, such as acids, that attack metals are said to be corrosive. Special materials that withstand such attack are called corrosion resistant.

Alloy: A combination of metals (and sometimes other elements) that are melted together to produce another metal with special properties such as high strength or corrosion resistance.

Exotic Metals: The relatively rare and expensive metals that have special properties. They include titanium, tantalum, and zirconium.

Capital Investment: The total cost of land, building, and equipment for a plant or facility.

Operating Cost: The expense involved in running a plant. It includes such things as raw material, labor, maintenance, and replacement.

Return on Investment (ROI): A relationship between the cost of a plant and the profit made from that plant.

Vocabulary Practice

1. What is meant by *scaleup*?

2. What is a *vessel*?

3. What is a *kettle*?

4. Describe a *tank farm*.

5. What is a *pipe flange*? What is it used for?

6. What is a *gasket*?

7. What is a *pipe fitting*?

8. Describe a pipe *elbow*.

9. What is a pipe *tee* used for?

10. How is a *pipe cross* used?

11. What are *pipe reducing fittings*? What are they usually called? What are the two types of *reducers*?

12. What is a *pipe lateral*?

13. What is a *pressure vessel*? What pressures require such vessels?

14. Explain the meaning of *pressure vessel code*. Name such a code.

15. What are *materials of construction*? Who usually selects them?

16. What is *corrosion*? What are materials that resist corrosion called?

17. What is an *alloy*?

18. What are *exotic metals*? Name some.

19. What is meant by *capital investment*?

20. What is an *operating cost*? What items are included in this term?

21. What is *return on investment*? How is it abbreviated?

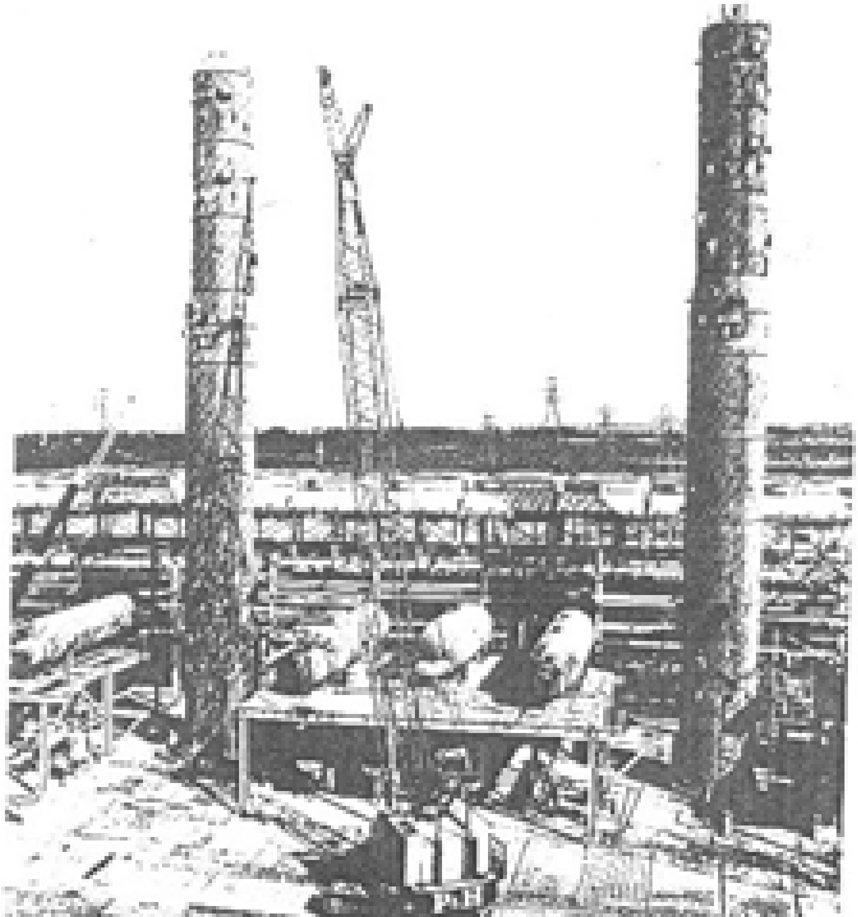


Photo Courtesy Dow Chemical
A Dow Chemical crude oil processing plant under construction.

Process Design

Many chemical engineers feel that process design is the most interesting kind of work in their profession. Certainly the training chemical engineers receive in college is more concerned with design

than with any other aspect of chemical engineering. Most of the information needed by the process design engineer is generated during the R&D phase, particularly from pilot plant data. But that information is based on small-sized equipment, whereas the production plant will contain full-sized equipment. Adapting that data is known as *scaleup*. This is always a mathematical technique but the exact procedures used depend on the type of equipment being scaled-up. Procedures for doing the job are available in textbooks and handbooks and may frequently be found in manufacturers' catalogues and other such literature.

Almost any chemical process plant includes a vast array of pipes and *vessels*, with another odd-shaped piece of equipment here and there. Open vessels are usually called tanks though, when heated, they are sometimes called *kettles*. Plants that process large quantities of liquid raw materials (such as petroleum refining plants) often have a number of enormous tanks arranged in an area known as a *tank farm*. When the contents of these tanks are flam-

A tank farm at a petroleum refinery.

mable, there are usually embankments of earth called dikes around them; if the tanks leak and the material catches fire, the flaming liquid cannot spread over the entire plant (as it did in early disasters).

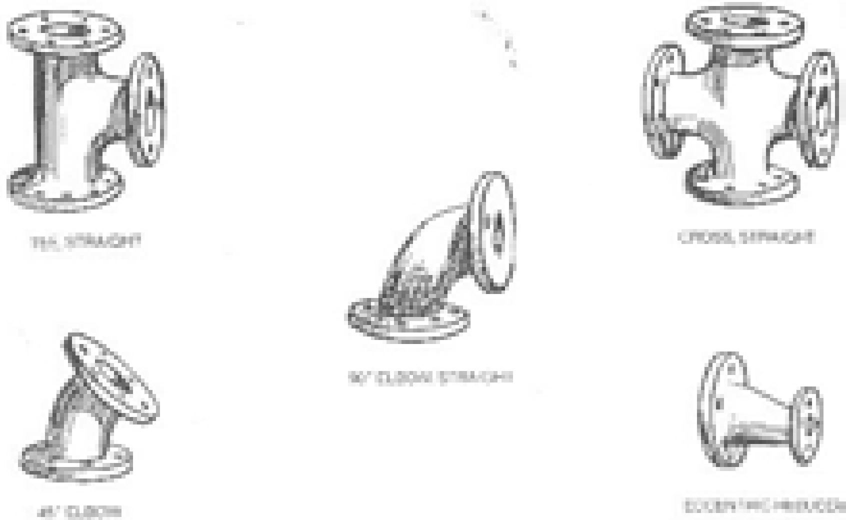
Piping is an important part of any chemical process plant because there is so much of it. Most home piping is of small size and is put together by screw threads cut into the pipe. Screwing sections of pipe together is easy to do with small-sized pipe because it can be easily handled. But the pipe used in process plants generally ranges in size from two to twelve inches in diameter and a section of such pipe may weigh many hundreds of pounds or kilograms.

Large-diameter pipe is put together by means of welding or *pipe flanges*. When flanges are used they are usually welded to the ends of the pipe. The flanges have a ring of holes around them so that two flanges can be bolted together with a *gasket* in between. Flanges have two advantages: first, welding can be done on the ground or in a shop; second, the pipe can be easily disassembled for inspection or replacement. The disadvantages are that the joints sometimes leak and the flanges are expensive. Welded pipe is harder to assemble because the welds must often be made while the pipe is high in the air or in awkward positions. A good welded joint will not leak and welding is a cheaper way of assembling pipe than flanges. However, the pipe must be cut and rewelded if it has to be opened for inspection or if it is necessary to replace faulty sections.

Pipe is made with walls of various thicknesses— thicker walls are required to carry material under higher pressure. Part of the design engineer's job is to calculate the pressures a pipe will have to withstand and to specify walls of the proper thickness.

There are a number of *pipe fittings* used with all piping systems. When a pipe must change 90 degrees in direction, a *pipe elbow*, or 90-degree *ell*, is employed; 45-degree ells change the direction by 45 degrees. When one pipe joins another at right angles, the juncture is made with a *pipe tee*. A *pipe cross* joins four pieces of pipe. Pipe of two different sizes can be connected by *reducers*, or *pipe reducing fittings*. When pipes must be joined at a sharp angle, a *pipe lateral* fitting is used.

As with pipes, vessels that withstand high pressure must have extra heavy walls. These are known as *pressure vessels* and must be carefully designed and constructed. Failure in pressure vessels may result in explosion with large pieces of the vessel flying around the



Flanged Pipe Fittings

plant—a circumstance exceedingly dangerous to personnel and destructive to equipment. Therefore the design and construction of pressure vessels (usually defined as those containing above 15 lb/sq. in., or 1 kilogram force/sq. cm., or 100 kilopascals) is usually regulated by laws known as *pressure vessel codes*. Any governmental body may write its own code. In the United States most areas adopt the pressure vessel code of the American Society of Mechanical Engineers (ASME) which is then enforced by Governmental pressure vessel inspectors. This code defines the way in which a design engineer must calculate vessel wall thicknesses and shapes, and also sets up fabrication procedures to be followed during construction. Welding, for example, must be done with extreme care and skill. Generally, welders who work on pressure vessels must pass a special test and are then known as certified welders. After a vessel has been designed and built, it must pass a pressure test conducted under conditions spelled out in the pressure vessel code. Because of the complications surrounding pressure vessels, the process design engineer usually designs only large or specialized vessels. Smaller ones can be purchased in standard sizes from manufacturers who specialize in such equipment. These vessels carry a special nameplate certifying that they were built according to the code and that they have passed the required tests.

Designing process plant equipment requires more than scaleup or following design codes; it also means specifying the materials to be used for equipment. Actually, the material must be selected before the equipment is designed because the design is related to the strength of the various *materials of construction*. Most chemical process equipment is built from ordinary steel, called mild steel or carbon steel. But many chemicals attack mild steel, causing *corrosion*. When this is a problem, the design engineer usually turns to stainless steel, an *alloy* of iron, nickel, and chromium. Some stainless steels contain other metals, such as molybdenum, that give the alloys greater strength, resistance to corrosion, or another desirable property. When corrosion problems are too severe for stainless steel, the engineer may choose alloys that contain large quantities of nickel known as high-nickel alloys. These special alloys are usually sold under trade names (some are Hastelloy, Incoloy, and Inconel) and may cost as much as several dollars a pound. Some process conditions require more specialized metals like titanium, tantalum, or zirconium. These are called *exotic metals* and are also very expensive.

In addition to metals, the design engineer has a large number of nonmetals to choose from. These include glass, plastics, graphite, and ceramics—alone or in combinations like glass-lined steel or rubber-lined plastic. The graphite used in process plants is usually impregnated with plastic and is known as impervious graphite. There are limitations to the use of nonmetals; most are not as strong as metals so they cannot be used for high pressure equipment, nor can they withstand high temperatures.

A process plant is usually designed in several stages. After the research and development has been done, and before the decision is made to build a full-sized plant, a final economic evaluation must be made. Of course, economic evaluations were made before and during the R&D work but they could be little more than educated guesses. The first time there is enough information to make a firm estimate of the cost of the plant and the cost of producing the product is when R&D is complete.

The cost of the final product is based on two things: *capital investment* and *operating cost*. The first is the cost of the land, the plant, and its auxiliaries such as roads, railroad spurs, electrical power lines, and sewage treatment facilities. Included here is the cost of equipment, materials, supervision, labor, and design. The

total of these costs—a large sum of money that must be available at one time—is the capital investment. The second, operating cost, includes the expense of running the plant after it is built—raw materials, labor and supervision, maintenance, shipping, and so on.

To determine whether or not an operation will be profitable, the design engineer must calculate the rate of return or *return on investment* (ROI) as follows:

$$\%\,\text{ROI} = \frac{\text{Net annual income - net annual depreciation}}{\text{Capital investment } + \text{ R \& D costs}} \times 100$$

Annual depreciation is the annual loss in value of the plant and its equipment owing to wear and obsolescence. In the chemical process industries, it is common to require that a project have an estimated ROI of at least 20% after income tax before it will be approved for construction.

Discussion

1. What aspect of the work do most chemical engineering college courses emphasize?
2. When does the design engineer get most of the information he or she needs for design?
3. What does a design engineer do to translate the pilot plant information into data for the full-scale plant?
4. Describe something of the appearance of a chemical process plant.
5. What does a tank farm look like?
6. How are pipes used in the home usually connected?
7. How are pipes connected in a chemical process plant? Why are these techniques used?

b 8. What are the advantages of connecting pipe by using flanges? By welding? What are the disadvantages of each method?

9. What are pipe fittings used for?

10. Name and describe five kinds of pipe fittings.

11. Why are pressure vessels used? What kind of pressure do they have to withstand?

12. Why may pressure vessels be dangerous if they are not properly designed and built?

13. Who writes pressure vessel codes? What is the most important pressure vessel code used in the United States?

14. What is special about the welders who work on pressure vessels?

15. Must the process design engineer design all the pressure vessels to be used in a plant? Why?

16. How can you tell if a purchased pressure vessel is safe?

17. What metals are used as materials of construction in chemical process plants?

18. What goes into the alloy known as stainless steel?

19. Name some high-nickel alloys.

20. What materials are called exotic metals?

21. Name several materials of construction that are not metals.

22. What is done to graphite to make impervious graphite?

23. What are some limitations of the nonmetallic materials of construction?

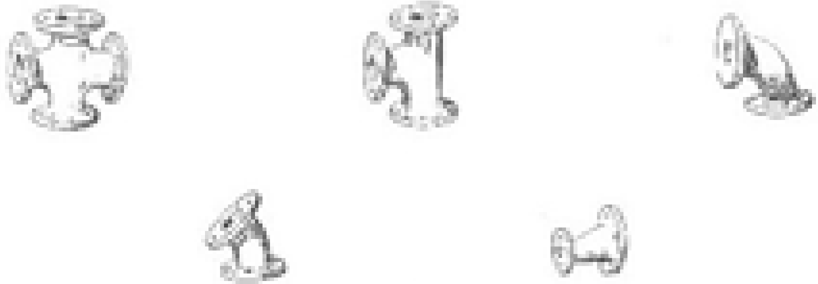
24. At what stages during the time a new process is being develop are economic evaluations usually made? When can such evaluation best be done?

25. What are the factors that go into the cost of the product of a CPI plant?

26. How does an engineer calculate return on investment?

27. What is a commonly required ROI before a plant will be approved for construction?

Review



A. Some commonly used pipe fittings are shown above. Name each one and explain how it might be used in a chemical process plant.

B. Corrosion is an important problem in chemical plant design. From your own experience, discuss the kinds of chemicals likely to cause corrosion. What kinds of corrosion might occur at home? In an automobile?

C. The ASME Pressure Vessel Code is the one most commonly used in the United States. What codes are used in your country? Discuss the reasons for having such codes.

UNIT FOUR
PLANT OPERATION

Special Terms

Foreman: A specially trained worker selected, because of work skills and leadership abilities, to supervise other workers.

Plant Efficiency: A comparison between the amount of product made in a plant and the cost of making it. The more efficient a plant is, the lower the cost of making a given quantity of product.

Plant Throughput: The amount of product manufactured in a particular length of time. A plant's throughput, or output, is usually given as tons/day or tons/yr.

Startup: The process by which a plant begins operations. The initial startup—the first time operation is attempted—may take months before all the equipment and the control system are working satisfactorily.

Shutdown: The process by which plant operation is stopped. Pieces of equipment must be stopped in a particular order, and sometimes in special ways, to avoid problems.

Column: A tall, narrow, closed vessel used for a particular purpose. It may have a height eight or ten times its diameter, and may be 100 feet (30 meters) tall, making it a striking feature of a process plant.

Reactor: A vessel (usually closed) in which a chemical reaction takes place. Reactors which work under high pressures—pressure vessels—are usually equipped for heating or cooling their contents.

Purging: The process of clearing liquids or gases out of pipelines and equipment. Flammable or dangerous materials are usually purged by displacing them with a safe material.

Instrument Tuning: The process of adjusting instruments that automatically control a plant's operation.

Lost-time Accident: A mishap that requires a worker to be away from the job for a day or more. Records of plant safety are usually based on the number of lost-time accidents.

Quality Control: The process of assuring that a plant's products have the required physical and chemical characteristics. The qualities checked may include such things as purity, strength, and color.

Rotating Shifts: A form of shift work in which each group of workers is changed at regular intervals from day work to evening work to night work.

Insulation: A material that provides a barrier to the passage of heat. It is used to keep hot things hot and cold things cold. Insulation contributes to plant safety by preventing contact with dangerously hot surfaces.

Vocabulary Practice

1. What is a *foreman*? On what basis are they usually selected?

2. What is *plant efficiency*? How is it usually calculated?

3. How is *plant throughput* determined?

4. What is meant by *startup*? What may be special about the first one?

5. What is *shutdown*?

6. Describe a *column*.

7. What is a *reactor*? What is it equipped to do?

8. What is meant by *purging*? How is equipment purged?

9. What is meant by *instrument tuning?*

10. What is a *lost-time accident?* Why is it recorded?

11. What is *quality control?* What may it check?

12. What are *rotating shifts?*

13. What is *insulation?* How does it contribute to safety?

Plant Operation

The function of the chemical engineer involved in plant operation is to see that the plant manufactures product. This sounds simple but includes a great many details. The engineer's two big responsibilities are the plant itself and the people who run it. The operations engineer is in charge of plant maintenance which is a continuing job in any chemical process plant, large or small. He or she is also responsible for having trained personnel on hand for plant operation. Since plant production often varies with the country's economy and sales of the plant's products, the size of the work force must also vary. Personnel are hired and laid off at various times. Sometimes workers can be recalled but often they have taken other jobs and new people must be hired and trained. In addition, personnel are discharged, quit, or retire, and some are sick or injured. Many CPI plants are unionized so operations engineers must be skilled in dealing with unions, both in day-to-day matters and in bargaining when union contracts expire.

The plant operation engineer is also responsible for the selection and training of *foremen*. A foreman (who may be a man or woman) is a specially trained person who is in charge of a group of workers. The plant operations engineer is always on the lookout for skillful workers with leadership qualities. A foreman is part of the plant's management personnel and may advance to higher levels of management.

An ongoing occupation of plant operation engineers is that of increasing the *efficiency* and *throughput* of their plants. Efficiency of plant operation is generally defined as producing product of the

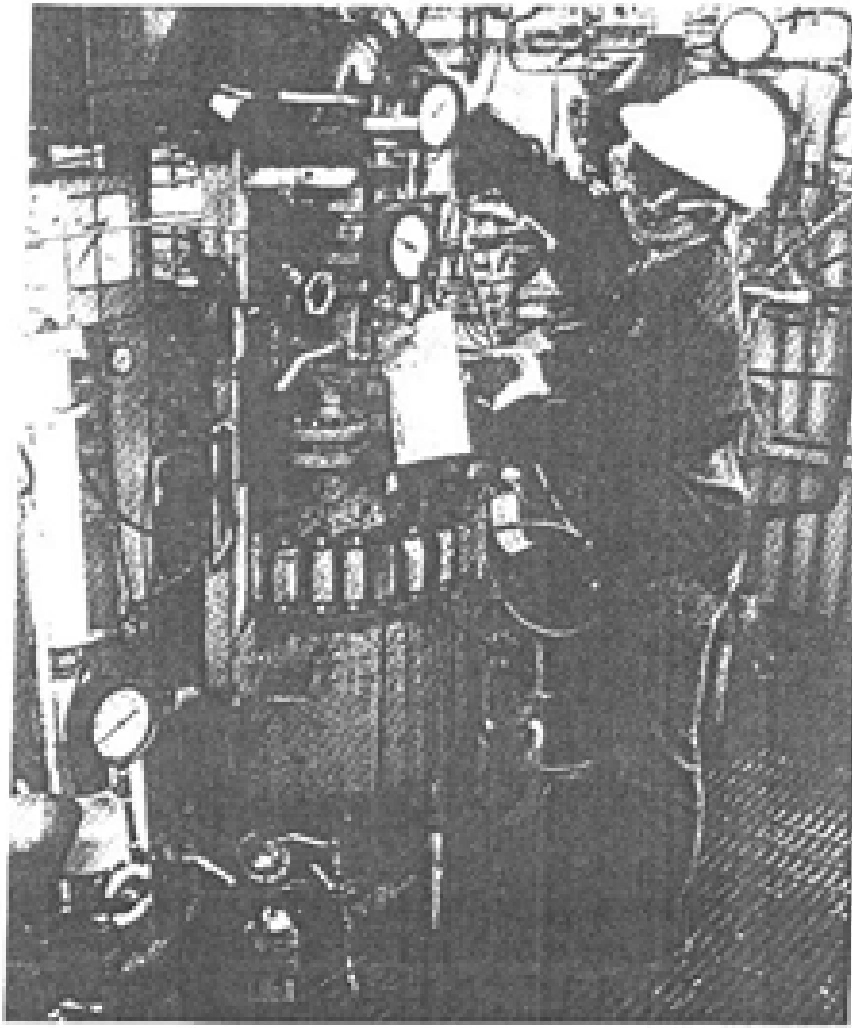


Photo Courtesy Dow Chemical
An engineer in a chemical plant takes a reading on a reactor.

required quality at the lowest possible cost. Sometimes, if there is a shortage of the product made by the plant, it may be important to increase the throughput even at increased cost. Hence, plant managers frequently experiment to find ways of increasing both efficiency and throughput. In theory, every process plant should always operate at the maximum efficiency possible, consistent with the required throughput.

Most large chemical process plants operate continuously; while the plant is running there is often little for plant personnel to do. Problems occur when some piece of equipment operates improperly or breaks down. But there are two occasions when plant personnel are always very busy: *startup* and *shutdown*. At the beginning of startup nothing is operating, so valves must be opened in the proper sequence to start the flow of materials; steam and cooling water must be started as required; *columns* and *reactors* must be brought to their proper operating temperatures. Some plants may take as much as a day before operating normally. Shutdown takes less time but also requires continuous attention from all plant personnel. This is particularly true of emergency shutdowns caused by equipment failures or by accidents such as fire and explosion. During shutdown it is often necessary to clear liquids or gases out of pipelines and equipment, particularly if they are flammable or corrosive. This is usually accomplished by displacing the dangerous material with a safer one—a process known as *purging*.

Perhaps the most laborious job in any plant is the very first startup. Inevitably, equipment is found to be defective or improperly installed. Pipe joints leak, pumps are improperly wired, and valves are jammed so they cannot be opened or closed. Often it takes several months of steady work before everything is corrected and the plant can run as it was designed to. Much of the work during an initial startup is devoted to what is known as *instrument tuning*. Most instruments used to make a plant run automatically have several adjustment knobs that must be set properly for the devices to work. These adjustments interact with each other—that is, changing one will change the action of the others. This means considerable trial and error before all are brought to the proper position.

Although chemical process plants use many dangerous materials, their accident rates are quite low as compared to other industries. Perhaps it is because the plants handle dangerous materials that everyone tends to be extremely conscious of safety. CPI plants generally carry on extensive safety campaigns. In many areas of a plant everyone, including management personnel and visitors, is required to wear a safety helmet (usually called a hard hat), or safety goggles, or both. Special safety showers and eyewash stations are provided to furnish emergency aid to any worker sprayed by a dangerous chemical. If poisonous gases are used, gas masks are kept

Photos Courtesy Dow Chemical

Safety is a primary concern of the chemical process industries. Above, laboratory animals used for testing the presence of air pollutants and below, a safety meeting held for Spanish-speaking workers at a Dow Chemical plant in Texas.

available. Every plant keeps bandages, burn dressings, and first-aid equipment readily available. Since many of the materials used in the CPI are highly flammable, there is always danger of fire. Smaller plants have fire-alarm boxes connected to the local fire department; large plants often have their own fire departments.

One way to determine the safety record of a plant over a period of time is to calculate the number of *lost-time accidents*—those serious enough for the one injured to be unable to work for a day or more. Many plants have large signs at the plant entrance indicating the number of days since the last lost-time accident.

Another plant responsibility is that of *quality control*. Every product of the CPI must meet certain specifications before it is sold. Enforcing these is the job of the quality control laboratory and its personnel. They check raw materials bought by the plant to determine if they are of the proper grade and check samples of product at specified times to see if the quality is being maintained. Quality-control personnel usually report only to the plant manager—not to other production supervisors—so that their standards and judgment cannot be influenced by production personnel.

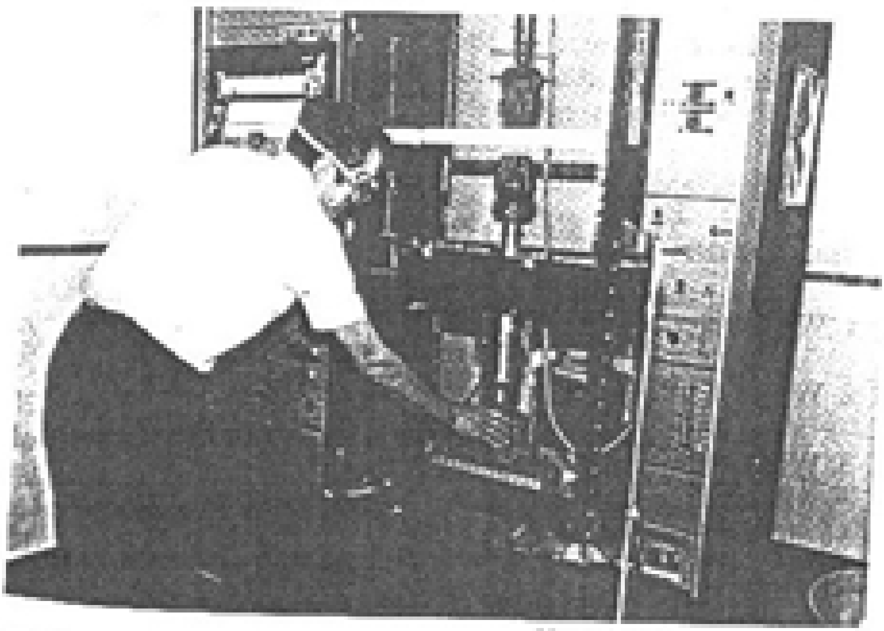


Photo Courtesy Dow Chemical

The flexural strength of a cured resin is tested as part of quality control.

Since continuous process plants are generally staffed by four shifts, there must be four workers available for each production job. Consequently a plant's workforce is much larger than can be seen—only a quarter of the workers are in the plant at any one time. Most workers prefer the day shift, so the evening and night shifts are compensated by higher rates of pay. But shifts are usually changed every few weeks so that each worker has an equal share of the desirable and undesirable conditions; this is known as *rotating shifts*. Scheduling the four shifts can be very complicated and take up a considerable part of the operations engineer's time.

There are still some parts of the world where energy is comparatively cheap, but in most places it is a considerable part of the cost of producing chemical products. Energy conservation has become a major way of decreasing costs in most process plants. Hot pipes and equipment have always been insulated because they would otherwise be a safety hazard, but the modern trend is to use much more *insulation* in order to conserve heat. Chemical reactors frequently operate at high temperatures so they are prime candidates for thick insulation. High pressure steam lines also need heavy layers of insulation. In older plants it may be difficult to use as much insulation as is now desirable because the equipment and pipelines are so close together that there is insufficient room. There are some newer insulation materials that provide good protection with relatively thin layers, but they are expensive.

Discussion

1. What is the primary job of plant operation engineers?
2. What are some of their responsibilities?
3. What kinds of personnel problems does the plant engineer deal with?
4. What kind of worker might become a foreman?
5. Are foremen part of management?

6. When is it desirable to increase plant throughput even at lower efficiency?

7. Is a plant always operated at its highest efficiency?

8. What are the most frequent causes of operating problems in process plants?

9. When are plant personnel busiest?

10. What must be done during a plant startup?

11. What things must be done during a plant shutdown?

12. What are some types of process plant equipment brought up to operating temperature during a startup?

13. What may cause an emergency shutdown?

14. Why do pipelines and equipment sometimes have to be purged? How is this done?

15. What kinds of problems may occur during a plant's first startup?

16. Why is instrument tuning needed during an initial startup?

17. Do chemical process plants have high accident rates? What may be a reason for this?

18. What kinds of safety equipment do most plants have?

19. How do CPI plants fight fire?

20. Discuss lost-time accidents.

21. What is the purpose of quality control?

22. To whom do quality control personnel usually report? Why?

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