# UNIT THREE
# PROCESS DESIGN

*Special Terms*

**Scale-up:** 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 pipes 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 of 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 the plant.

### *Vocabulary Practice*

1. What is meant by *scale-up*?
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 *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?

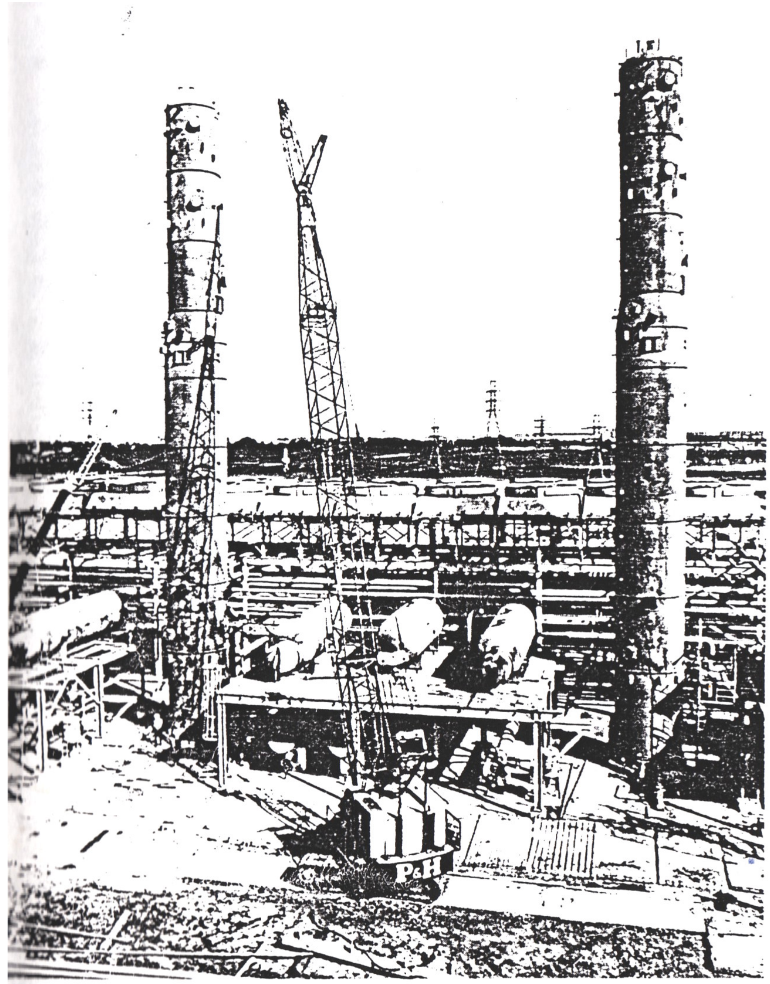


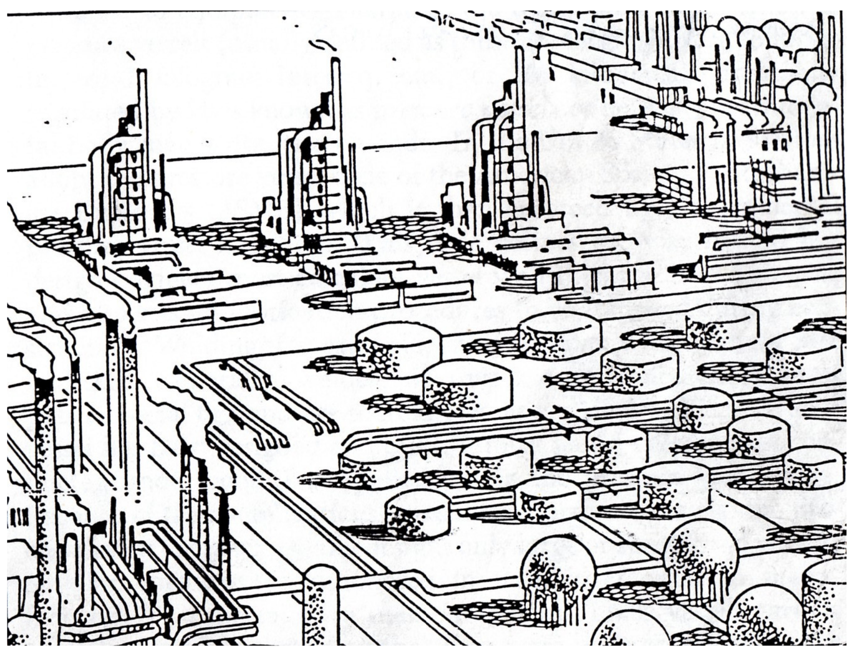

*Photo Courtesy Dow Chemical*

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 ***scale-up***. 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



A tank farm at a petroleum refinery.

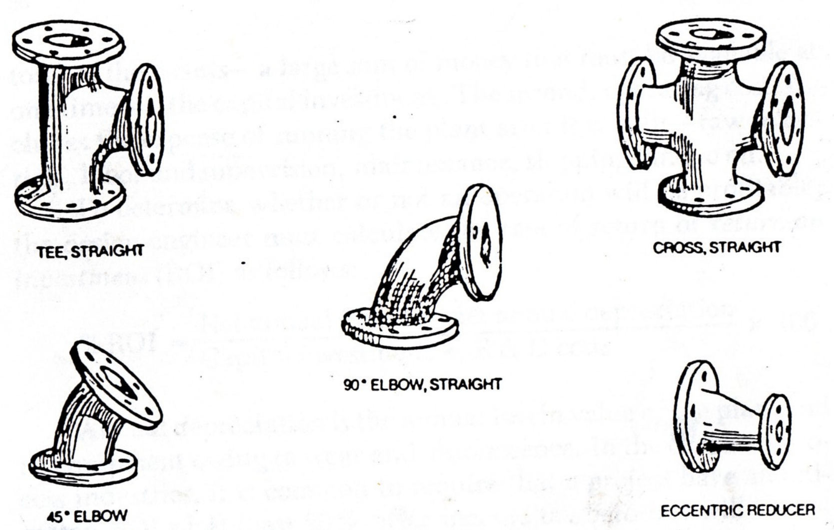
flammable, there are usually embankments of earth called dikes around them; if the tanks leak and the material catches fire, the flaming liquid cannot spread over the entire plant (as it did in early disasters).

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 re-welded 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.




Flanged Pipe Fittings

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 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., 0,01 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 scale-up 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-lines 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 the return or *return on investment* (ROI) as follows:

$$\%\ ROI = \frac{Net\ annual\ income - net\ annual\ depreciation}{Capital\ investment + R\ \&\ D\ \cos ts}\ x\,100$$

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.

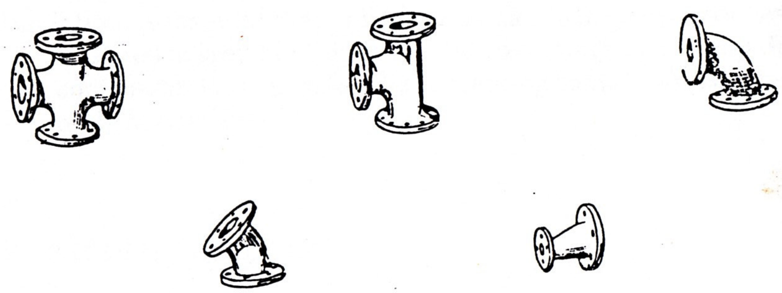
## *Discussion*

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 to do 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?
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 developed are economic evaluations usually made? When can such an 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.