

# PROCESS TECHNOLOGY EQUIPMENT & SYSTEMS

FOURTH EDITION



**CHARLES E. THOMAS**

# **Process Technology**

## **Equipment and Systems**

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## **Equipment and Systems**

**Fourth Edition**

**Charles E. Thomas**



**Process Technology Equipment and Systems,  
Fourth Edition**  
Charles E. Thomas

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*Dedication*

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# preface

It should come as no surprise to anyone who knows the important role process technicians play in modern chemical manufacturing to discover the prominence that process technology programs have taken in U.S. and international community colleges and universities. Still, the controversial question remains, “what is process technology?” Process technology is a field of study offered at community colleges or universities that prepare students to take entry-level positions as technicians in the chemical processing industry. The curriculum can be categorized as the study and application of the scientific principles associated with the operation and maintenance of the CPI. Typically, there are 8 to 12 core classes that cover theory and hands-on operation, including safety, quality, equipment, instrumentation, physics, chemistry, math, process systems, unit operations, and troubleshooting. Hands-on training may include drawing P & IDs, operating bench-top units, starting-up, operating, and shutting down DCS simulations and small scale pilot plants. The first process technology program was offered at a Jr. college in Baytown Texas in 1938 by employees of Humble Oil, now Exxon Mobil.

This text is the product of many years of research in the field of process technology and operator training. It is unique and designed to enhance the learning sequence needed by adult learners. The materials in this text are the foundation topics for operator training.

Educators, of course, do their best to provide well-thought-out and illustrated textbooks, classroom lectures, computer-aided simulations and instruction, hands-on activities, bench-top and pilot units, CD/DVD materials, and the like. They take into consideration learning styles/strategies and find teaching approaches that work best—that is, how both an instructor and an individual approach the learning process and, given my experience in teaching process technology, there is a marked preference for teachers and students alike to emphasize self-study, of being responsible for this discipline on their own. This is the approach taken in the fourth edition of *Process Technology: Equipment and Systems*.

Recently, the industry has noticed a sharp increase in the number of women choosing process technology as an occupation. This text provides a balanced foundation for the rich diversity of students choosing to prepare for occupations in the chemical processing industry. This includes a much younger group of adult learners who will need to take the place of the baby boomer generation, as people from the latter retire in massive numbers.



As with the previous three editions, *Process Technology: Equipment and Systems* empowers the adult learner to accomplish the learning process. It covers the basic equipment and technology associated with the chemical processing industry.

### *What's New in This Edition?*

The fourth edition includes new material on distillation, reactions, and process diagrams and equipment startups. This includes vapor liquid equilibrium diagrams, McCabe-Thiele method, detailed descriptions of plate and packed columns, calcium carbonate reactions, sodium phosphate reactions, ammonia reaction, reformers, and new detail on fluid catalytic cracking. The new edition also includes start-up procedures on the following systems: heat exchangers, cooling towers, boilers, furnaces, reactors, and distillation.

New features include:

- Process Diagrams: PFDs, PFIIDs, P & IDds, and Control Loops
- Distillation: vapor-liquid phase diagrams & McCabe-Thiele method
- Distillation: reflux ratio, bubble point, dew point, mole fraction
- Distillation: plate and packed column detail, column loading
- Reactions: calcium carbonate, sodium phosphate, ammonia
- Reactions: fluid catalytic cracking, reformers
- Start-up Procedures: heat exchangers, cooling tower, boilers, furnace, reactor, distillation

Key concepts and learning features include:

- Valves, piping, tanks, and vessels
- Pumps, compressors, and simple systems
- Turbines and motors
- Heat exchangers, cooling towers, and simple systems
- Steam generation, fired heaters, and systems
- Process symbols, diagrams, and instrumentation
- Utility and separation systems
- Reactor, distillation columns, and systems
- Plastics systems

Each chapter in the text moves from simple to complex topics. Learning objectives are identified at the front of each chapter. Photographs and line drawings provide a rich visual documentation on which to see the concepts and equipment discussed in the narrative. A summary and a set of open-ended review questions end each chapter. This text also includes a short list of equipment symbols and diagrams discussed in a specific chapter. This allows new technicians to gradually build a good understanding of basic symbols and diagrams that are part of the visual lexicon of process technology around the world.

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## *Acknowledgments*

There are many individuals—too many to count—to thank for their contribution to process technology as an ongoing and developing discipline in higher education. I would like to extend my gratitude to the expert reviewers who read the early versions of this book and made recommendations to improve the final text, namely Gary Denson, Bryant Dyer, Paul Chance, Mike LaGrone, John Purdin, and Sharon Disspayne.

Charles E. Thomas, Ph.D.

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# Introduction to Process Equipment

## OBJECTIVES

*After studying this chapter, the student will be able to:*

- Describe the basic hand tools used in industry.
- Explain the basic elements of rotary equipment.
- List the various types of stationary equipment.
- Identify the primary operation of a centrifugal pump.
- Explain the operation of a positive displacement pump.
- Describe dynamic and positive displacement compressors.
- Identify the purpose of a steam turbine.
- Describe the importance of equipment lubrication.
- Identify the various types of storage and piping equipment used in the chemical-processing industry.
- Describe the function of three types of industrial valves.
- Explain the purpose of a heat exchanger.
- Identify the primary function of a cooling tower.
- Identify the primary function of a boiler.
- Identify the purpose of a fired heater.
- Explain how a mixing reactor converts raw materials to useful products.
- Name the purpose of a distillation column.

## Key Terms

**Axial bearings**—devices designed to prevent back-and-forth movement of a shaft; also called *thrust bearings*.

**Basic hand tools**—the typical tools process technicians use to perform their job activities.

**Belt**—used to connect two parallel shafts—the drive shaft and the driven shaft—each of which has a pulley mounted on the end; belts fit in the grooves of the pulleys.

**Boiler**—a type of fired furnace used to boil water and produce steam; also known as a *steam generator*.

**Centrifugal force**—the force exerted by a rotating object away from its center of rotation. Often referred to as a *center-seeking force*, centrifugal force is usually stated as the force perpendicular to the velocity of fluid moving in a circular path.

**Chain drive**—a device that provides rotational energy to driven equipment by means of a series of sprocket wheels that interlink with a chain; designed for low speeds and high-torque conversions.

**Compressors**—mechanical devices designed to accelerate or compress gases; classified as positive displacement or dynamic.

**Cooling tower**—a simple, rectangular device used by industry to remove heat from water.

**Coupling**—a device that attaches the drive shaft of a motor or steam turbine to a pump, compressor, or generator.

**Distillation column**—a cylindrical tower consisting of a series of trays or packing that provide a contact point for the vapor and liquid. The contact between the vapor and liquid in the column results in a separation of components in the mixture based on differences in boiling points.

**Driven equipment**—a device such as a compressor, pump, or generator that receives rotational energy from a driver.

**Driver**—a device designed to provide rotational energy to driven equipment.

**Filter**—a porous medium used to separate solid particles from a fluid by passage through it.

**Fired heater**—a high-temperature furnace used to heat large volumes of raw materials.

**Gearbox**—a power transmission mechanism consisting of interlocking toothed wheels (gears) inside a casing.

**Heat exchanger**—an energy-transfer device designed to transfer energy in the form of heat from a hotter fluid to a cooler fluid without physical contact between the two fluids.

**Pumps**—devices used to move liquids from one place to another; classified as positive displacement or dynamic.

**Radial bearings**—devices designed to prevent up-and-down and side-to-side movement of a shaft.

**Reactor**—a device used to combine raw materials, heat, pressure, and catalysts in the right proportions to form chemical bonds that create new products.

**Rotary equipment**—industrial equipment designed to rotate or move.

**Rotor**—the shaft and moving blades of rotary equipment or the moving conductor of an electric motor.

**Seals**—devices that prevent leakage between internal compartments in a rotating piece of equipment.

**Stationary equipment**—industrial equipment designed to occupy a stationary or fixed position.

**Steam generator**—see Boiler.

**Steam turbine**—an energy-conversion device that converts steam energy (kinetic energy) to useful mechanical energy; used as drivers to turn pumps, compressors, and electric generators.

**Tanks and pipes**—vessels and tubes that store and convey fluids.

**Thrust bearing**—see *Axial bearings*.

**Torque**—the turning force of rotating equipment.

**Valve**—a device used to stop, start, restrict (throttle), or direct the flow of fluids.

**Viscosity**—a measure of a fluid's resistance to flow.

**Volute**—the discharge chute of a centrifugal pump; a widening cavity that converts velocity to pressure.

## Basic Hand Tools

The chemical processing industry is composed of refineries and petrochemical, paper and pulp, power generation, and food processing plants. Process technicians inspect and maintain equipment, place and remove equipment from service, complete checklists, control documentation, respond to emergencies, and troubleshoot system problems. To fulfill those responsibilities, the process technician must have a thorough understanding of tools, equipment, and systems.

Process technicians use hand tools to perform simple maintenance functions on operating units. The preventive maintenance role of process technicians is important because, in some cases, a little minor maintenance can prevent major equipment damage. **Basic hand tools** (Figure 1.1) used by process technicians include:

- Allen wrenches
- Wrenches: English and metric
- Pipe wrench
- Crescent wrench
- Valve wrench
- Channel locks
- Needle-nose pliers
- Pliers
- Vise grips
- File
- Tubing benders
- Broom or brush
- Electrical tape
- Measuring tape
- Water hose
- Hammer
- Ratchet and socket sets
- Wire brush
- Phillips screwdriver
- Flathead screwdriver
- Pencil or markers
- Wire cutter and strippers
- Utility knife

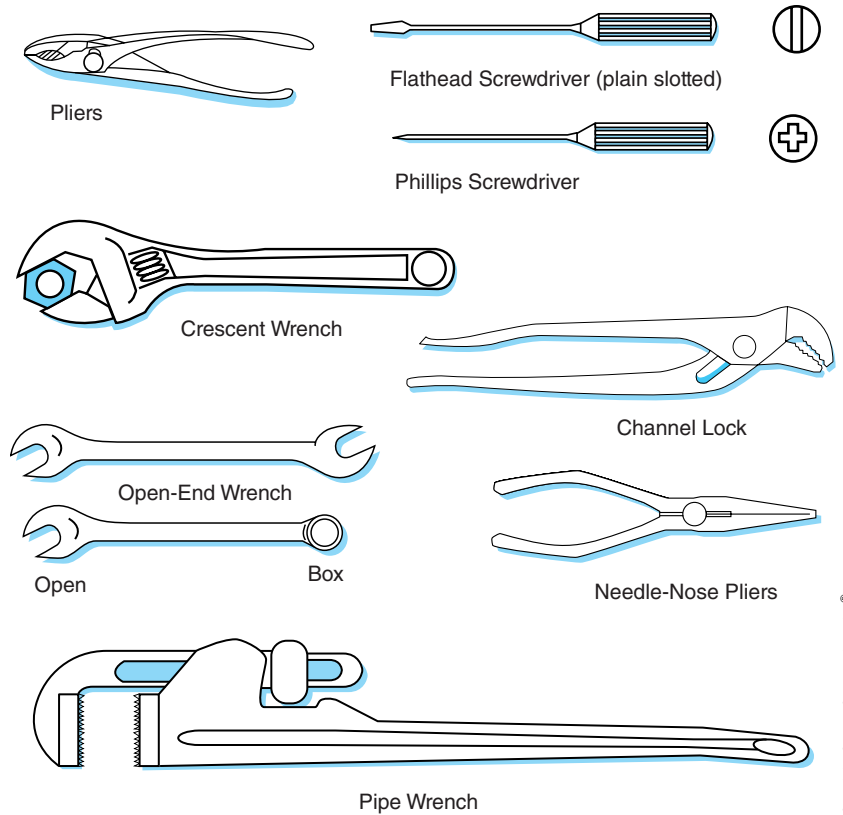


Figure 1.1 Basic Hand Tools

- Chisels
- Level
- Hacksaw
- Tubing cutters
- Dustpan
- Table vice
- Square
- Flash light

## Rotary Equipment

The chemical processing industry has a wide variety of rotary, reciprocating, and **stationary equipment**. A circular movement characterizes **rotary equipment**. Examples can be found in motors, **pumps**, **compressors**, fans, blowers, turbines, conveyors, and feeders. Shaft rotation is typically measured in RPM, or revolutions per minute. Many motors run in excess of 3,000 RPM. A protective cover is typically placed over the moving shaft to minimize accidents.

**CAUTION:** Severe injuries can result when loose clothing, shoelaces, jewelry, or long hair get tangled around rotating parts.

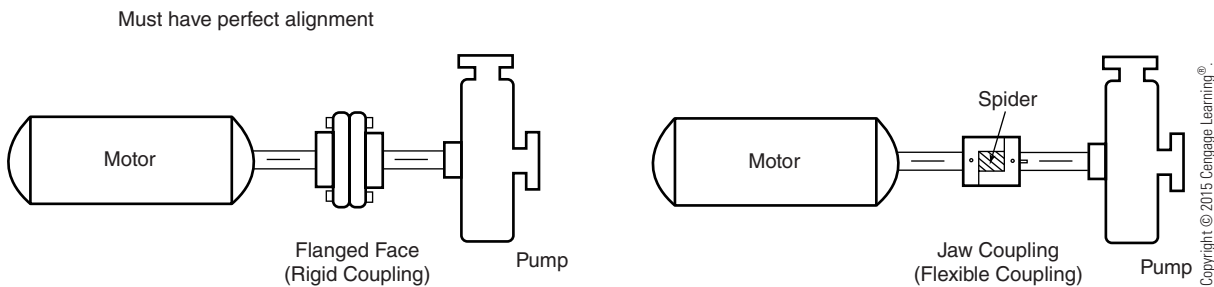
Rotary equipment is composed of a driver, a connector, and the **driven equipment**.

### Drivers and Driven Equipment

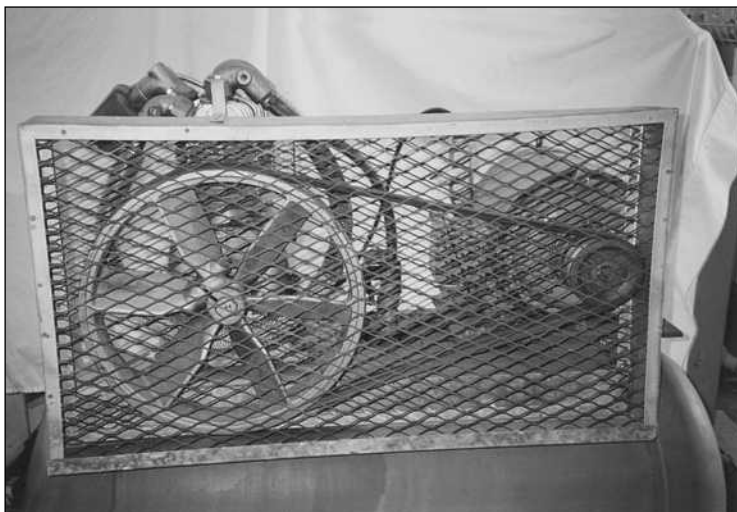
A **driver** is a device designed to provide rotational energy to another piece of equipment, the driven equipment. The most common drivers are electric motors and turbines. Examples of driven equipment include pumps, compressors, generators, fans, conveyors, and solids feeders. **Couplings**, **belts**, or chains connect drivers and driven equipment.

Couplings come in a variety of shapes and designs. The most common styles are fixed-speed couplings (rigid and flexible) and variable-speed couplings (hydraulic and magnetic). Figure 1.2 shows a rigid and a flexible coupling.

Belts are used to connect two parallel shafts: the drive shaft and the driven shaft. A pulley is mounted on the end of each shaft. Belts fit in the grooves of the pulley. The sizes of the pulleys allow the driver and driven equipment to operate at different speeds. When the drive pulley and the driven pulley are the same size, the speeds of the two shafts are virtually identical. Belts come in a variety of shapes and sizes and are made of durable material designed to withstand operating conditions. Belt drives (Figure 1.3)



**Figure 1.2** Fixed Couplings: Rigid and Flexible



**Figure 1.3** Belt Drive



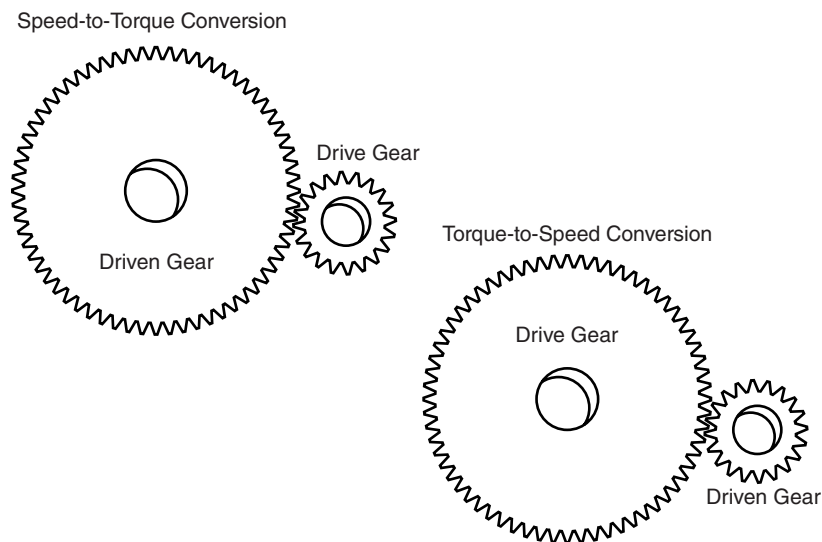
require less space than fixed-speed or variable-speed couplings. A belt drive can make speed-to-torque and torque-to-speed conversions. (**Torque** is the turning force of rotating equipment.) Process technicians frequently inspect belts during rounds to ensure that safety guards are in place, that belt tension is correct, and that the belts are still mounted on the pulleys. Flopping, squealing, or smoking belts indicate wear, tension, or driven-equipment problems.

**Chain drives** are very similar to belt drives. Instead of using pulleys, however, a chain drive has a series of sprocket wheels that interlink with the chain. Chain drives are designed for low speeds and high torque conversions. In this type of system, slippage is minimal, chain replacement is rare, and temperature variations are not a factor as long as the chain is kept lubricated.

### Gearboxes and Power Transmission

**Gearboxes** are often used between the driver and the driven equipment. A gearbox takes its name from the different-sized gears (toothed wheels) inside the casing. Inside the gearbox, the drive gear meshes with a larger or smaller gear, the driven gear. As the drive gear rotates, the interlocked gears in the box turn, transmitting power to the driven equipment. Smaller gear size is associated with speed. Larger gear size is associated with torque. Power transmission in rotating equipment is classified as speed-to-torque conversion or torque-to-speed conversion. Speed-to-torque conversion is accomplished with a small drive gear that has a large driven gear. Torque-to-speed conversion uses a large drive gear that has a small driven gear. Figure 1.4 illustrates the power transmission principle.

**Figure 1.4**  
*Power Transmission*



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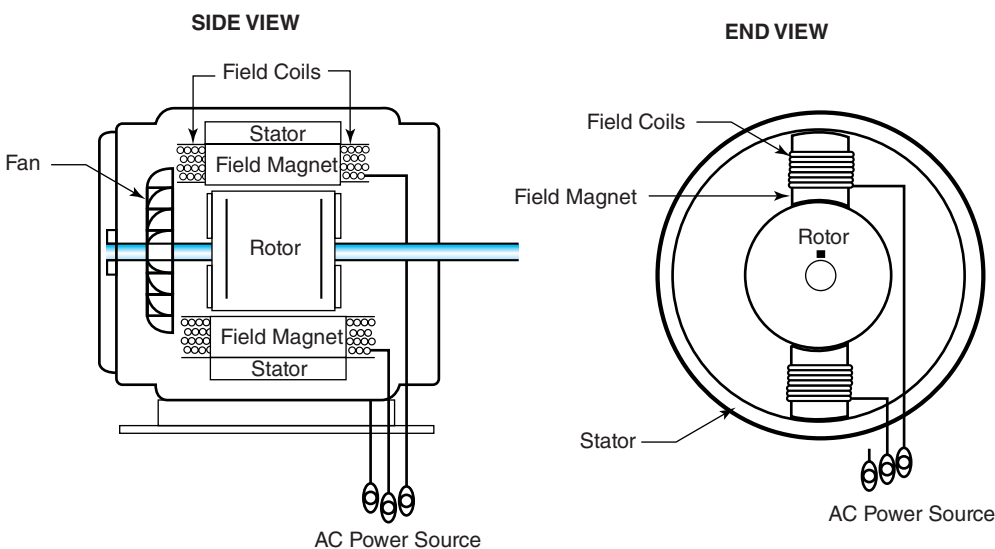
## Electric Motors

The process industry uses electric motors to operate pumps, generators, compressors, fans, blowers, and other equipment. Electric motors are either direct current (DC) or alternating current (AC). The operation of an electric motor is based on three principles: Electric current creates a magnetic field; opposite magnetic poles attract each other, and like magnetic poles repel each other; and current direction determines the magnetic poles. An electric motor consists of a stationary magnet (stator) and a moving conductor (rotor). A permanent magnetic field is formed by the lines of force between the poles of the magnet. When electricity passes through the conductor in a DC motor, the conductor becomes an electromagnet and generates another magnetic field. The twin fields increase in intensity and push against the conductor. The direction of rotation in a motor is determined by these strong magnetic fields.

The **rotor** in an AC motor (Figure 1.5) is a slotted iron core. Copper bars are fitted into the slots. Two thick copper rings hold the bars in place. Unlike the electric current in a DC motor, electric current in the AC motor is not run directly to the rotor. Alternating current flows into the stator, producing a rotating magnetic field. The stator artificially creates an electric current in the rotor, which generates the second magnetic field. When the two fields interact, the rotor turns.

## Centrifugal Pumps

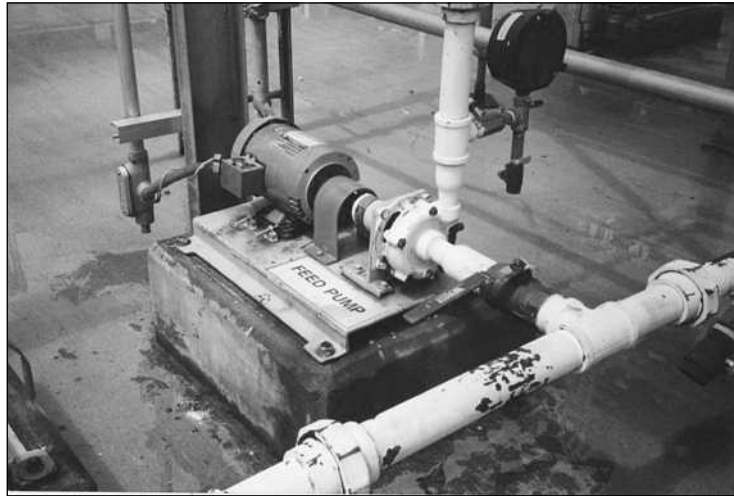
Centrifugal pumps (Figure 1.6) are devices that move fluids by **centrifugal force**. Centrifugal force is the force exerted by a rotating object away from its center of rotation; it is usually referred to as a “center-seeking force.” The primary principle involves spinning the fluid in a circular motion that propels it outward and into a discharge chute known as a **volute**. The basic



**Figure 1.5**  
AC Motor

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**Figure 1.6**  
*Centrifugal Pump*



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components of a centrifugal pump are the casing, motor or driver, coupling, volute, suction eye or inlet, impellers, wear rings, **seals**, bearings, discharge port, and suction and discharge gauges.

### **Positive Displacement Pumps**

Positive displacement pumps displace a specific volume of fluid on each stroke or rotation. Positive displacement pumps can be classified as rotary or reciprocating. Rotary pumps displace fluids by means of rotating screws, gears, vanes, or lobes. Reciprocating pumps move fluids by drawing them into a chamber on the intake stroke and displacing them by means of a piston, diaphragm, or plunger on the discharge stroke. Reciprocating pumps are characterized by a back-and-forth motion. The basic components of a reciprocating pump are a connecting rod, a piston, plunger, or diaphragm, seals, check valves, motor, casing, and bearings.

### **Dynamic Compressors**

Dynamic compressors operate by accelerating gas and converting kinetic energy (the energy of movement) to pressure. These compressors are classified as centrifugal or axial. Centrifugal compressors use the principles of centrifugal force. Gases are drawn into a suction eye, accelerated in the impeller, and discharged out the volute. Gases move in a rotary motion from the center of the compressor to the discharge outlet.

An axial flow compressor is composed of a rotor that has rows of fanlike blades. Unlike centrifugal compressors, axial compressors do not use centrifugal force to increase gas velocity. Air is moved axially along the shaft. Rotating blades attached to a shaft push gases over stationary blades called stators. The stators are mounted on or attached to the casing. As the rotating blades increase the gas velocity, the stator blades slow it down. As the gas slows, kinetic energy is released in the form of pressure. Gas



**Figure 1.7**  
*Blower*

velocity increases as the gas moves from stage to stage until it reaches the discharge port. Jet engines and gas turbines contain axial flow compressors. Figure 1.7 Blower, illustrates how a centrifugal blower is used in a refrigeration system to evenly distribute ice on the exterior of tubes by bubbling air up from the bottom of the thermal ice bath to the top.

### Positive Displacement Compressors

Positive displacement (PD) compressors operate by trapping a specific amount of gas and forcing it into a smaller volume. They are classified as rotary or reciprocating. PD compressors and PD pumps operate under similar conditions. The primary difference is that compressors are designed to transfer gases, whereas pumps move liquids. Rotary compressor design includes a rotary screw, sliding vane, lobe, and liquid ring. Reciprocating compressors include a piston and diaphragm. Figure 1.8 is an example of a typical PD compressor found in industry.

### Steam Turbine

A **steam turbine** (Figure 1.9) is a device that converts kinetic energy to mechanical energy. Steam turbines have a specially designed rotor that