Lesson 5

Steam Turbines, Condensers, and Cooling Towers

Lesson Goal and Objectives

Goal

To familiarize you with the operation of a turbine used to produce electricity and with the operation of auxiliary equipment in a power plant.

Objectives

Upon completing this lesson, you should be able to—

1. describe the operation of a turbine in producing electricity,
2. recall the location of condensers in a power plant and the reason they are used,
3. recognize two types of cooling towers and the difference in their operation, and
4. recall the locations of steam turbines, condensers, cooling towers, feedwater heaters, and reheaters in a complete steam generation system.

Introduction

Boilers produce steam for many different purposes. Some industries design their facilities to use steam in the processes, to heat the facility during colder months, and occasionally to generate electricity for in-plant use. Utilities use steam to drive large turbines that generate electricity. The design and complexity of a boiler system will vary depending on the size and ultimate use of the steam produced by the boiler.

Steam Turbines

Steam contains a tremendous amount of heat energy. Heat energy is transformed into mechanical energy to drive a steam turbine. The turbine in turn rotates a generator which changes the mechanical energy into electrical energy, or electricity.

A steam turbine has two main parts—the cylinder and the rotor. The cylinder, or stator, is made of steel or cast iron and contains the fixed blades, vanes, or nozzles that direct steam into the movable blades. The rotor is a shaft that carries the movable blades. High-temperature, high-pressure steam enters one end of the turbine through an inlet valve into the steam chest. The steam chest contains control valves that regulate the flow of steam into the turbine. Steam flows through a set of stationary blades, or nozzles. As the steam passes through the nozzles, it expands in volume, and its velocity increases. The steam moving at high velocity strikes the first set of moving blades, causing the shaft to rotate (Figure 5-1). The steam enters the next set of fixed blades and then into the set of moving blades, continually causing the shaft to rotate.

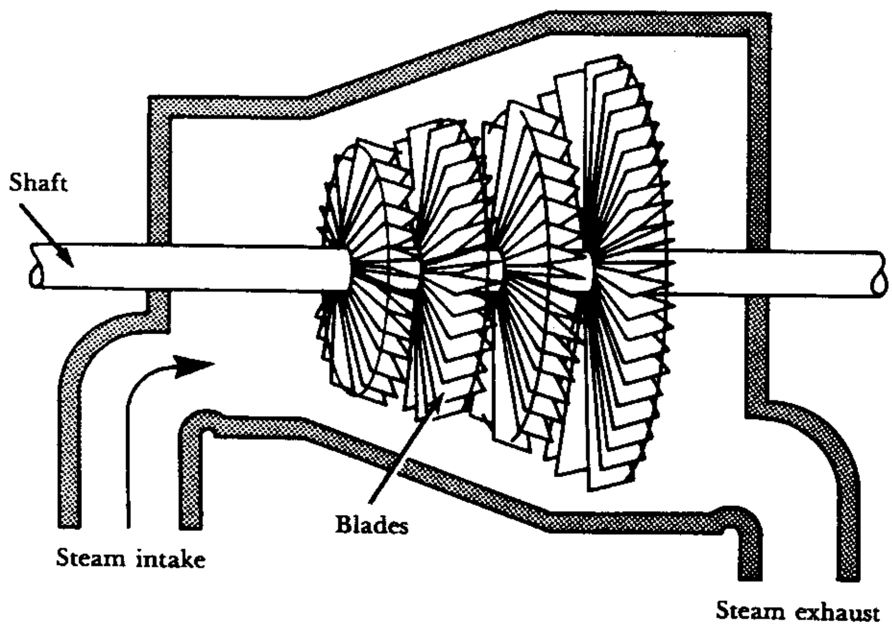

Figure 5-1. Typical steam turbine.

As the steam moves through the turbine its pressure and temperature decrease, while its volume increases. A pound of steam will expand over 800 times its original volume as it moves from the steam header through the turbine. The turbine, therefore, increases in diameter from the inlet to the outlet. This allows the volume of steam to increase as it moves through the turbine without reducing the efficiency of the system.

A turbine that uses the impact force of a steam jet on the blades to turn the shaft is called an *impulse turbine*. Its action is analogous to that occurring with a windmill. As the wind strikes the blades, the impact force causes the windmill to turn. The harder the wind blows, the faster the windmill blades will turn. The steam flow through the blades in an impulse turbine is shown in Figure 5-2. Steam expands as it passes through the nozzles where its pressure decreases and its velocity increases. As steam flows through the moving blades, its pressure remains the same and its velocity decreases because the steam does not expand here. The nozzles, or fixed blades, expand the steam again as the steam moves into the next stage. The pressure decreases in each stage as the steam expands through the fixed blades.

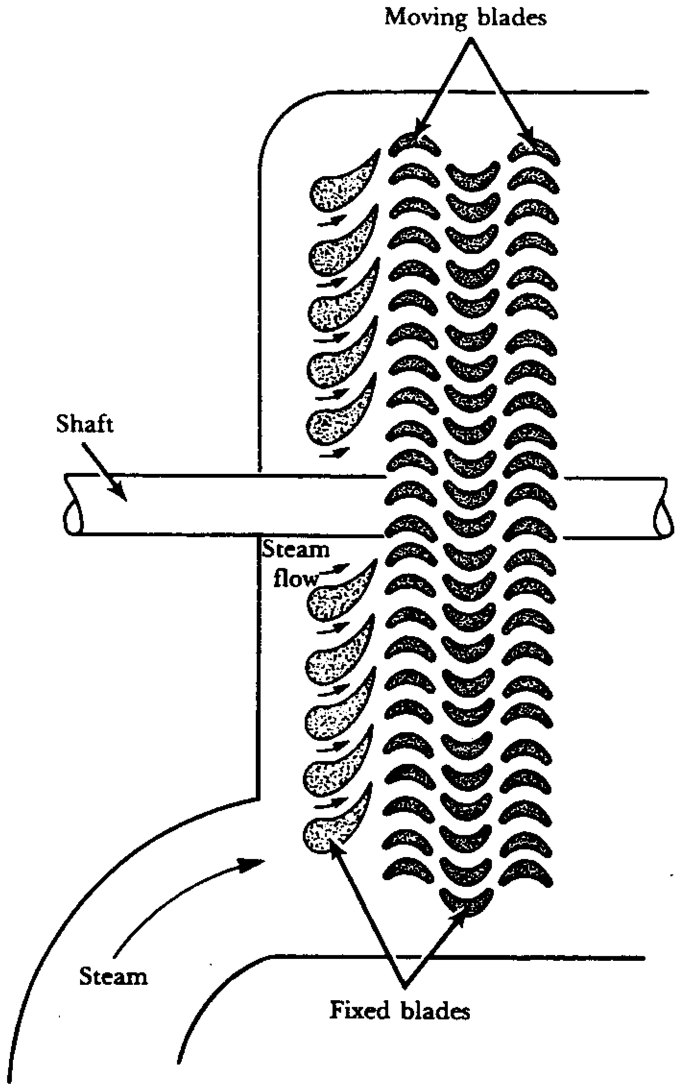

Figure 5-2. Steam flow through the blades of an impulse turbine.

In a *reaction turbine,* the pressure decreases and the velocity increases while the steam flows through both the fixed and moving blades. The action is analogous to the kickback that an individual receives when shooting a shot gun. The reaction turbine uses the kickback force from the steam as it leaves the moving blades to rotate the shaft. All of the blades are the same shape and therefore act like nozzles (Figure 5-3).

Many utilities use turbines that have both impulse and reaction blade arrangements. These turbines usually have impulse blades at the high-pressure end and reaction blades at the low-pressure end of the turbine. The length and size of the blades increase from front to back to use the expanding steam efficiently.

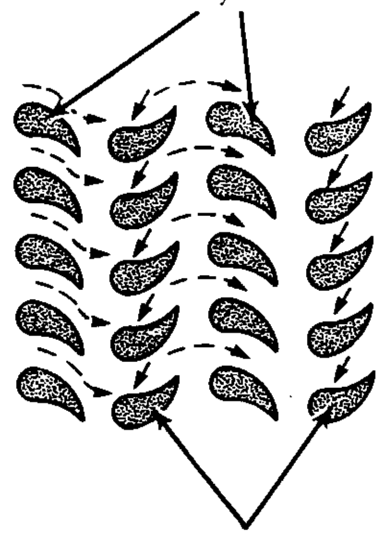

Figure 5-3. Steam flow through the blades of a reaction turbine.

Large steam turbines usually have high-pressure, intermediate-pressure, and low-pressure sections (Figure 5-4). Steam, from the superheater, goes to the main steam header. It flows into the high-pressure section of the turbine, rotates the shaft, and looses some of its pressure and temperature. The steam then goes back to the boiler where it is heated in the reheater. Steam flows from the reheater to the intermediate-pressure turbine where it turns the rotor. Part of the steam is extracted from the intermediate-pressure turbine and is used to heat water in the boiler feed-water heaters. The rest of the steam flows through a crossover pipe to the low-pressure turbine and continues to turn the rotor. In the low-pressure turbine, the last bit of work is extracted from the steam. Some steam from the high-pressure and low-pressure turbines is also extracted to heat boiler feedwater. The spent steam from the low-pressure turbine is sent to the condenser.

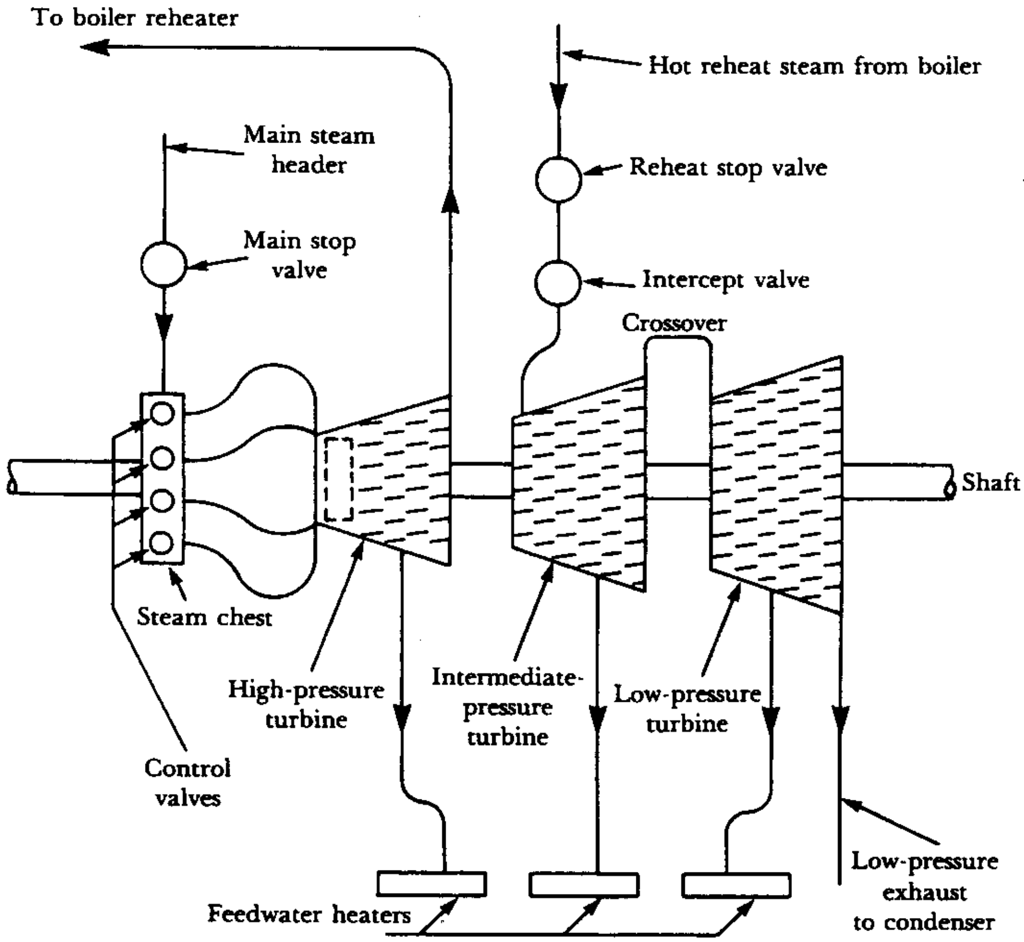

Figure 5-4. Steam flow through high-pressure, intermediate-pressure, and low-pressure turbines.

The shaft arrangements can be single, tandem-compound, and cross-compound as shown in Figure 5-5. A single turbine consists of one steam turbine coupled to a generator. In a tandem-compound turbine, a high-pressure turbine and a low-pressure turbine are joined to a common shaft that is coupled to a single generator. In a cross-compound turbine, a high-pressure and an intermediate-pressure turbine are joined to a common shaft and a low-pressure turbine is on a separate shaft. Each shaft drives its own generator.

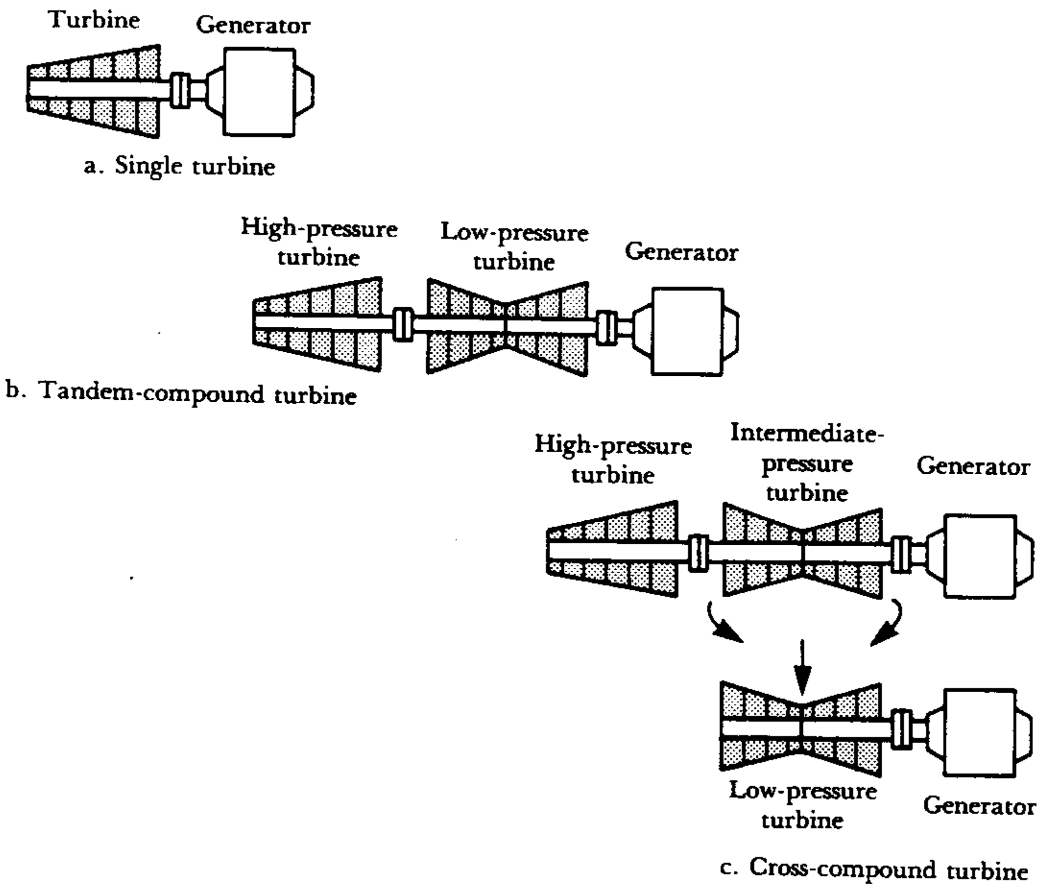

Figure 5-5. Turbine and generator shaft arrangements.

Condensers

Condensers are used in connection with steam turbines for two reasons: (1) to produce a vacuum at the turbine exhaust and (2) to recover the condensate, condensed steam, so it can be used again. Because condensed steam is pure distilled water, it is very suitable for use as boiler feedwater. Condensed steam, at the turbine exhaust, produces a vacuum to remove the back pressure that would otherwise hinder the flow of steam from the turbine. Because the condensed steam is at a lower temperature than the exhausted steam, the overall efficiency is increased.

Two types of condensers are the direct contact and indirect contact. In a *direct contact* condenser, steam is mixed with sprays of cooling water (Figure 5-6). The cooling water condenses the steam and both are collected at the bottom of the vessel, called the hotwell. Few power plants use direct contact condensers because the cooling water, usually pumped from nearby lakes, rivers, or ponds, contaminates the pure condensed steam. Thus, the condensate is unsuitable to be used as boiler feedwater without first being treated extensively.

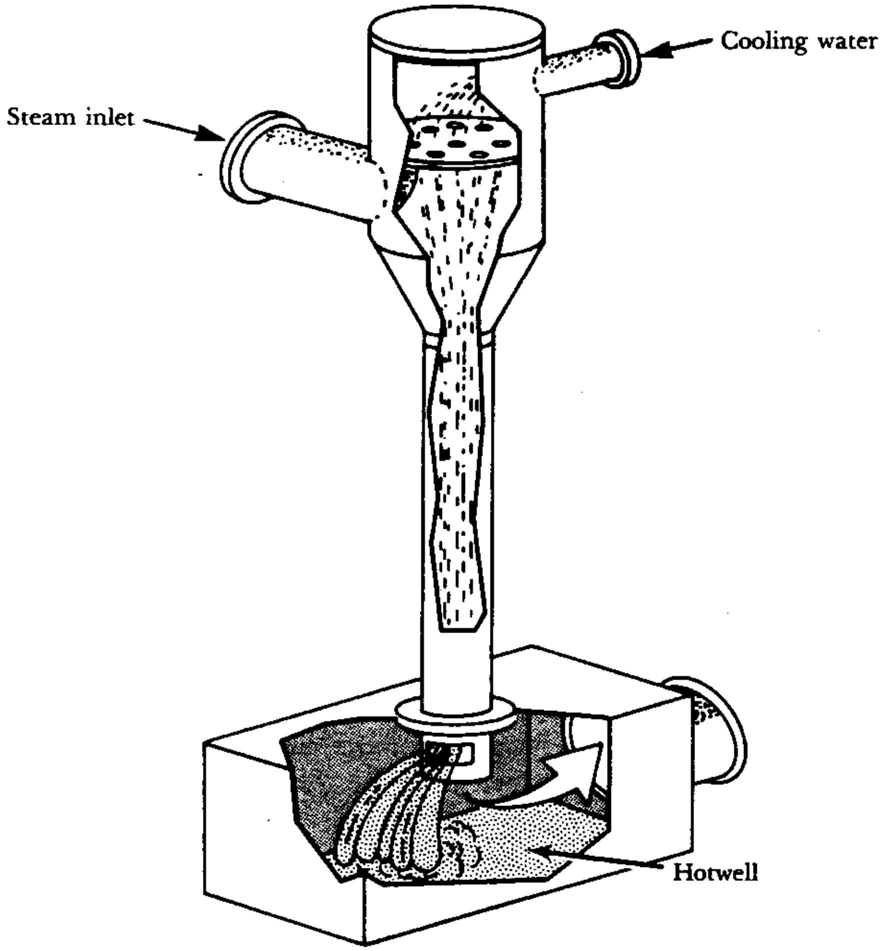

Figure 5-6. Direct-contact condenser.

Most power plants use indirect, or surface, condensers, commonly called shell-and-tube heat exchangers. The surface condenser is a closed vessel containing many small-diameter tubes (Figure 5-7). Cooling water passes through individual tubes while steam flows over and around tube bundles. Condensed steam collects at the condenser bottom or hotwell. The condensate is pumped from the hotwell, through the feedwater heaters, into the economizer, and finally back into the boiler steam drum where the cycle begins again. Depending on the design, the cooling water can make one or more passes through the tubes before being discharged. Warmed cooling water is returned to the rivers or lakes or is sent to a cooling tower. Because the cooling water does not actually come in contact with the steam, the pure condensed steam is not contaminated as it is in the direct contact condenser.

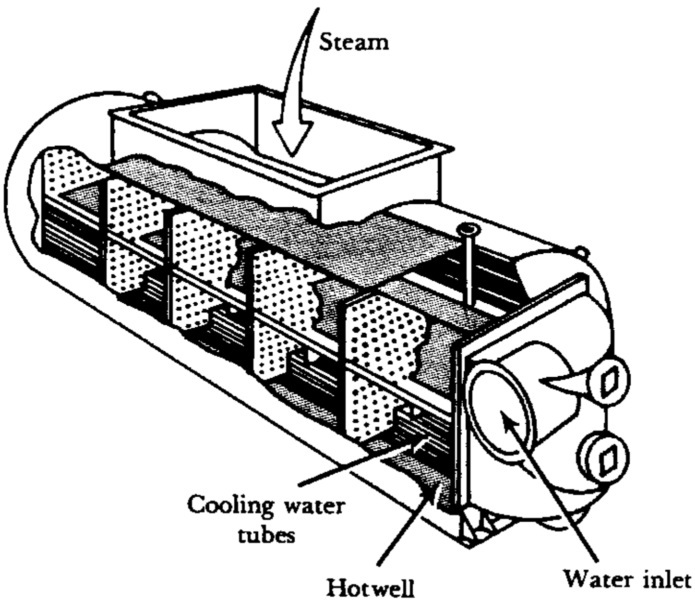

Figure 5-7. Surface condenser.

Condensers require large quantities of cooling water. A condenser uses approximately 9 to 12 gallons of water (75 to 100 lb) to condense each pound of steam (TPC, 1975).

The water pumped from nearby rivers, lakes, and streams passes through intake screens located at the water source to remove sticks, leaves, and other suspended solids from it. Screens can become plugged, and therefore, must be periodically checked and maintained to remove collected debris. Otherwise, waterflow to the condenser may be restricted.

Condenser tubes become dirty after continual use. Tube fouling occurs when scale, slime, and algae collect on the inside of the tubes. These deposits can reduce both heat transfer and water flow through the condenser. Tubes can be cleaned by using a hydraulic gun, chemicals, or backwashing. In the hydraulic gun technique, rubber plugs are shot by water jets through the condenser tubes. The rubber plugs rub against the tube walls to remove slime and soft scale. In chemical cleaning, chlorine or chlorine compounds are added regularly to the water supply. The chlorine dissolves algae and reduces slime buildup. In backwashing, the water flow through the condenser is reversed, flushing out the tubes.

Cooling Water Systems

The cooling water system through the condenser can be a once-through or a recirculating system. Water is pumped from the source and flows through large pipes or channels. The intake of the pipe has a screen or a set of closely-spaced bars to prevent solids from entering the pipe. Water is pumped through the condenser and is returned to the source with an increased temperature occasionally as high as 20°F above the water source's temperature. This can cause thermal pollution to the water source, possibly injuring fish and other organisms.

Power plants having limited water supplies or those with high-temperature return water from the condenser use a recirculating cooling water system. This system uses one or more cooling towers to remove heat from the warmed cooling water and returns the water to the condenser. A recirculating system only requires a small amount of additional cooling water (approximately 5 to 10%) to replace any losses that occur during the cooling operation.

One type of cooling tower, a mechanical draft tower, uses either a forced-draft fan that is located at the bottom of the tower or an induced-draft fan that is located at the top of the tower. In a tower using a forced-draft fan, air is blown up through the tower while the warm water from the condenser is sprayed at the top of the tower. Water descends over wood, ceramic, or fiberglass slats and collects in a basin at the tower bottom. In an induced-draft cooling tower, air enters louvers in the side of the tower and is pulled upward by the fan (Figure 5-8). In both of these towers, the water temperature decreases as water evaporates and heat is transferred to the air. A pump in the basin returns cooled water back to the condenser.

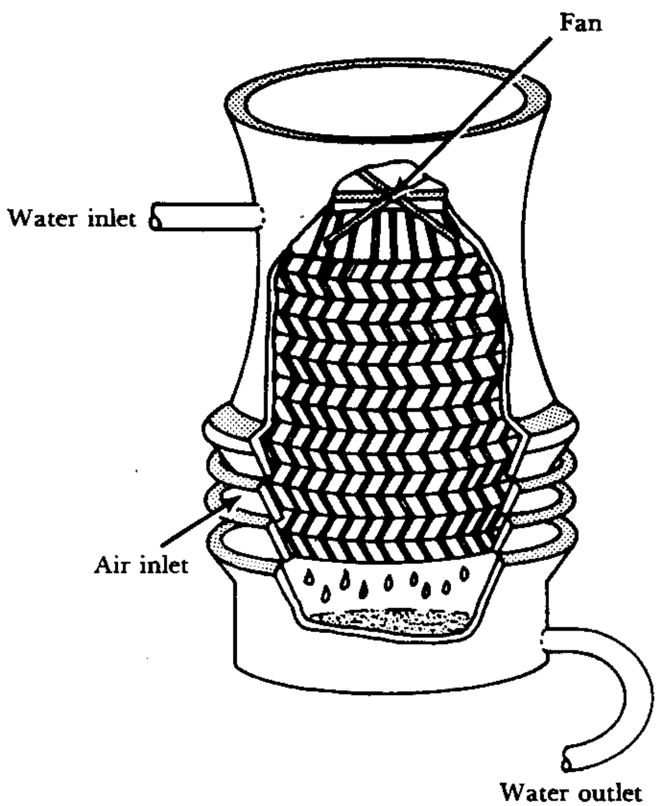

Figure 5-8. Induced-draft cooling tower.

A hyperbolic natural-draft cooling tower is shown in Figure 5-9. Water is sprayed at the tower top and falls over slats of wood, ceramic, or fiberglass contained in the tower. Air enters the bottom of the tower and rises up through the tower because of the natural draft. Cooled water collects in a concrete basin and is returned to the condenser.

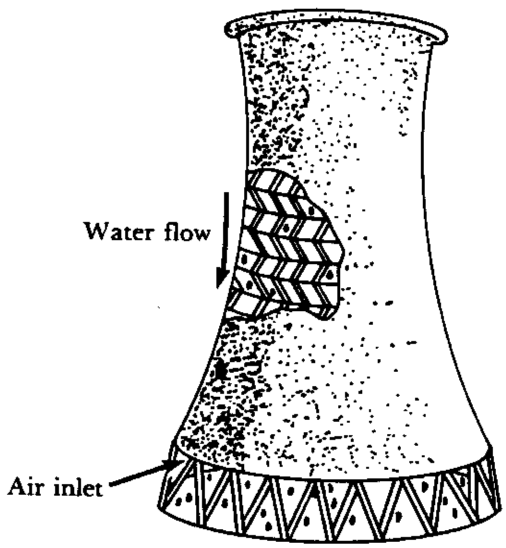

Figure 5-9. Hyperbolic natural-draft cooling tower.

In cooling towers, the dissolved solids concentration increases as the cooling water evaporates. Buildups of minerals in the water can cause scale, corrosion, and plugging in the condensers, pumps, and piping. Scale formation can be reduced by adding phosphates to the water. Phosphates react with scale-forming impurities precipitating them into a sludge. The sludge settles in the tower basin and is removed during blowdown. Phosphates can cause algae to grow, but the algae growth can be controlled by adding chlorine. The pH of the cooling water can be adjusted by adding either sulfuric acid or lime. Dissolved oxygen in the cooling water can be reduced by adding corrosion inhibitors.

Summary

This lesson briefly covered steam turbines, condensers, and cooling towers. A complete steam generation system that generates electricity contains a boiler, turbine, generator, and auxiliary equipment. Figure 5-10 shows the schematic diagram of a coal-fired boiler system.

Pulverized coal is fed into the burners of the boiler by a forced-draft fan. Steam produced in the boiler tubes collects in steam drums where moisture is removed by separators. Steam is then sent to the superheater where it is further heated. High-pressure, high-temperature steam leaves the superheater through steam headers. Steam enters the steam chest in the turbine where control valves regulate the flow through the turbine. The high-pressure turbine, containing fixed and moving vanes, is turned as the high-pressure steam strikes the blades. Steam is exhausted from the high-pressure turbine and piped back to the reheat section of the boiler to be heated again. Reheated steam flows through the intermediate-pressure turbine and/or the low-pressure turbine. Some steam is extracted from the turbines to heat boiler feedwater in the feedwater heaters. Boiler feedwater is further heated in the economizer before it flows to the steam drum as makeup water. Steam is exhausted from the low-pressure turbine into the condenser to create a vacuum and to condense steam into high quality water to be used again in the boiler. Condenser cooling water is cooled by using cooling towers. Fresh makeup water for the boiler is treated by chemicals and by an evaporator or demineralizer before it goes to the feedwater heaters. Flue gas produced in the boiler goes through the boiler tube sections, the economizer, air preheater, and finally through air pollution control devices to remove pollutants before it enters the atmosphere.

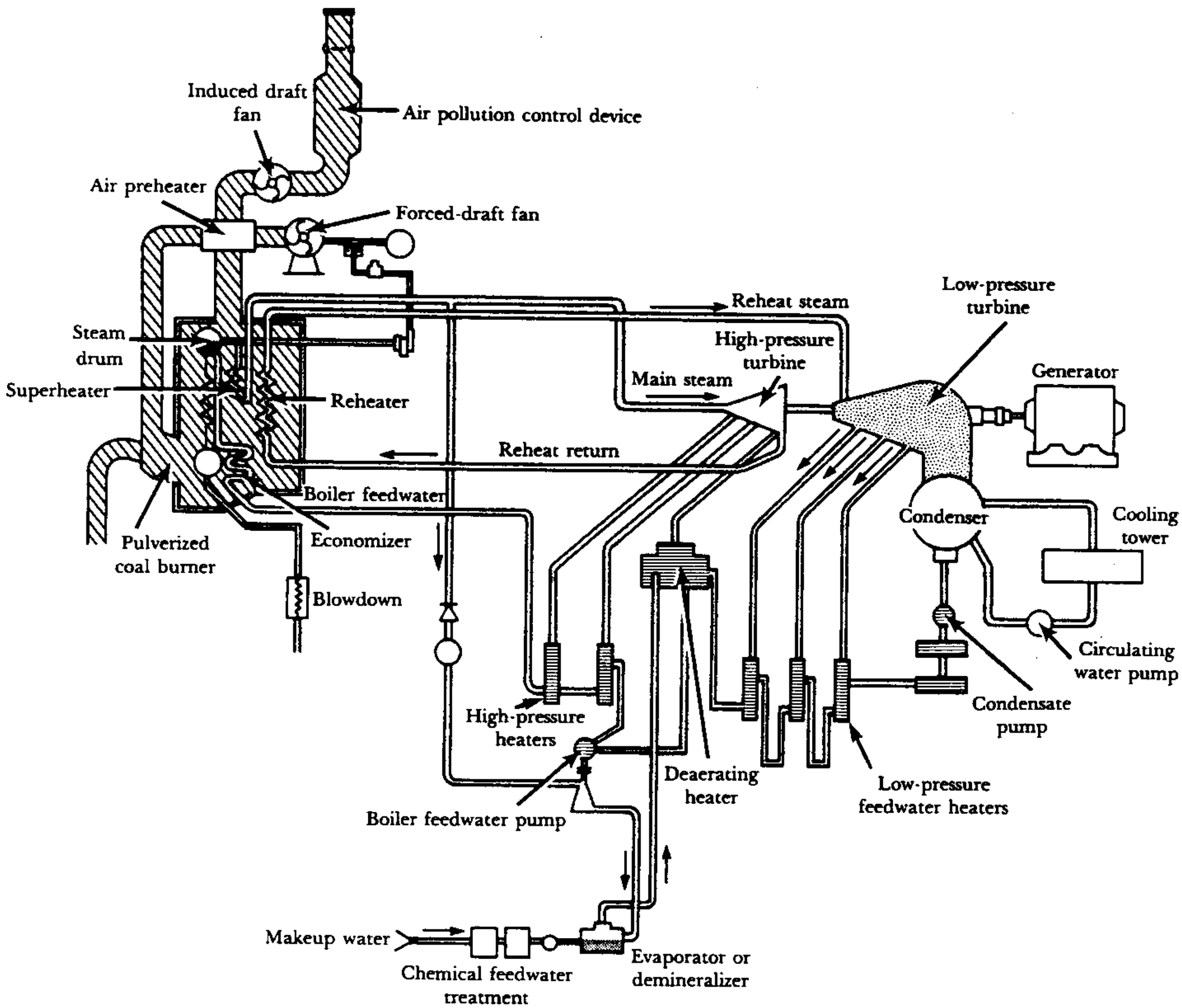

Figure 5-10. Layout of a steam generation system.

Review Exercise

1. High-temperature, high-pressure steam enters a turbine through an inlet valve into the a. steam chest. b. reheater. c. condenser.	
2. In a turbine, fixed or stationary blades are called a. stators. b. nozzles. c. rotors.	1. a. steam chest.
3. As steam moves through a turbine and is exhausted, its pressure ________, its volume ________, and its temperature ________. a. increases, decreases, decreases b. decreases, decreases, decreases c. decreases, increases, decreases	2. b. nozzles.
4. A ________ uses the kickback force from steam as it leaves the moving blades to rotate the shaft. a. impulse turbine b. impact turbine c. reaction turbine	3. c. decreases, increases, decreases
5. In a steam turbine, steam is sent from the high-pressure turbine to the ________ before it enters the low-pressure turbine. a. economizer b. reheater c. superheater d. condenser	4. c. reaction turbine
6. Condensers are used in connection with steam turbines to a. cool water before it is returned to rivers or lakes. b. produce a vacuum at the turbine exhaust. c. recover condensed steam. d. b. and c. above e. all of the above	5. b. reheater
	6. b. and c. above

7. Power plants generally use ________ so that cooling water is not contaminated. a. direct contact condensers b. spray ponds c. surface condensers	
8. Cooling towers that use fans located in the top of the tower are called a. hyperbolic natural-draft towers. b. induced-draft towers. c. forced-draft towers.	7. c. surface condensers
9. In cooling towers, the water temperature decreases as the water ________, thus transferring heat to the air. a. condenses b. evaporates c. diffuses	8. b. induced-draft towers
10. In cooling towers, dissolved solids can be removed by a. blowdown b. blowback c. deaerators	9. b. evaporates
	10. a. blowdown

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