CHAPTER 3

BASIC STEAM CYCLE

To understand steam generation, you must know what happens to the steam after it leaves the boiler. A good way to learn the steam plant on your ship is to trace the path of steam and water throughout its entire cycle of operation. In each cycle, the water and the steam flow through the entire system without ever being exposed to the atmosphere. The four areas of operation in a main steam system are generation, expansion, condensation, and feed. After studying this chapter, you will have the knowledge and ablity to describe the main steam cycle and the functions of the auxiliary steam systems.

MAIN STEAM SYSTEM

The movement of a ship through the water is the result of a number of energy transformations. Although these transformations were mentioned in the last chapter, we will now discuss these transformations as they occur. Figure 3-1 shows the four major areas of operation in the basic steam cycle and the major energy transformations that take place. These areas are A—generation, B—expansion, C—condensation, and D—feed.

GENERATION—The first energy transformation occurs in the boiler furnace when fuel oil burns. By the process of combustion, the chemical energy stored in the fuel oil is transformed into thermal energy. Thermal energy flows from the burning fuel to the water and generates steam. The thermal energy is now stored as internal energy in steam, as we can tell from the increased pressure and temperature of the steam.

EXPANSION—When steam enters the turbines and expands, the thermal energy of the steam converts to mechanical energy, which turns the shaft and drives the ship.

For the remainder of the cycle, energy is returned to the water (CONDENSATION and FEED) and back to the boiler where it is again heated and changed into steam. The energy used for this purpose is the thermal energy of the auxiliary steam.

The following paragraphs will explain the four major areas of operation in the basic steam cycle shown in figure 3-1.

GENERATION

When a liquid boils, it generates a vapor. Some or all of the liquid changes its physical state from liquid to gas (or vapor). As long as the vapor is in contact with the liquid from which it is being generated, it remains at the same temperature as the boiling liquid. In this condition, the liquid and its vapors are in equilibrium contact with each other. Area A of figure 3-1 shows the GENERATION area of the basic steam cycle.

The temperature at which a boiling liquid and its vapors may exist in equilibrium contact depends on the pressure under which the process takes place. As the pressure increases, the boiling temperature increases. As the pressure decreases, the boiling temperature decreases. Determining the boiling point depends on the pressure.

When a liquid is boiling and generating vapor, the liquid is a SATURATED LIQUID and the vapor is a SATURATED VAPOR. The temperature at which a liquid boils under a given pressure is the SATURATION TEMPERATURE, and the corresponding pressure is the SATURATION PRESSURE. Each pressure has a corresponding saturation temperature, and each temperature has a corresponding saturation

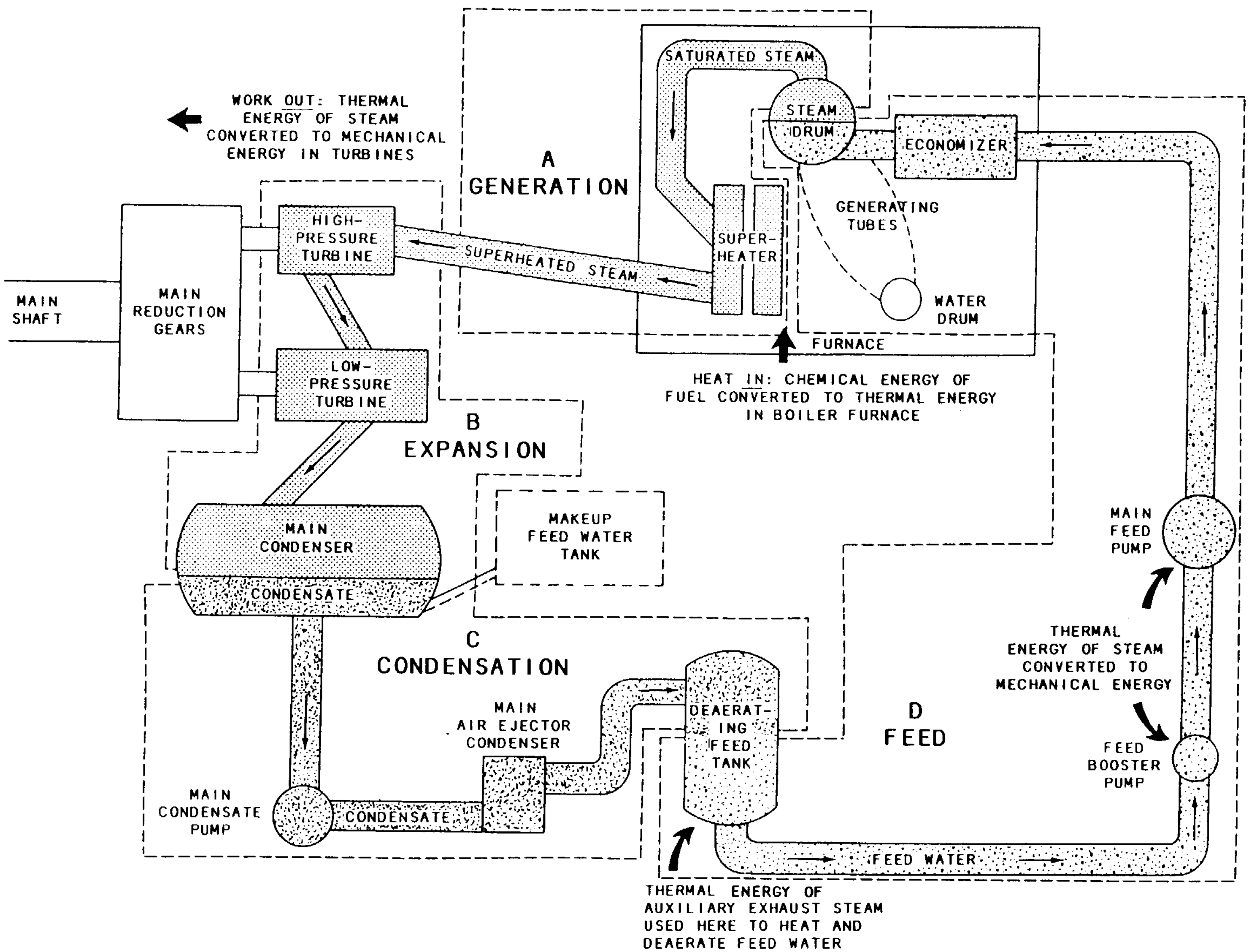

Figure 3-1.—Basic steam cycle.

pressure. A few saturation pressures and temperatures for water are as follows:

Pounds Per Square Inch Absolute (psia)	Degrees Fahrenheit (°F)
11	198
14.7	212
110	335
340	429
630	567
1200	596
2000	636
3000	695
3206.2	705.40

We know that atmospheric pressure is 14.7 psia at sea level and lesser at higher altitudes. Boiling water on top of a mountain takes a lot longer than at sea level. Why is this? As noted before, temperature and pressure are indications of internal energy. Since we cannot raise the temperature of boiling water above the saturation temperature for that pressure, the internal energy available for boiling water is less at higher altitudes than at sea level. By the same lines of reasoning, you should be able to figure out why water boils faster in a pressure cooker than in an open kettle.

A peculiar thing happens to water and steam at an absolute pressure of 3206.2 psia and the corresponding saturation temperature at 705.40°F. At this point, the CRITICAL POINT, the vapor and liquid are indistinguishable. No change of state occurs when pressure increases above this point or when heat is added. At the critical point, we no longer refer to water or steam. At this point we cannot tell the waterer steam apart. Instead, we call the substance a fluid or a working substance. Boilers designed to operate at pressures and temperatures above the critical point are SUPERCRITICAL boilers. Supercritical boilers are not used, at present, in propulsion plants of naval ships; however, some boilers of this type are used in stationary steam power plants.

If we generate steam by boiling water in an open pan at atmospheric pressure, the water and steam that is in immediate contact with the water will remain at 212°F until all the water evaporates. If we fit an absolutely tight cover to the pan so no steam can escape while we continue to add heat, both the pressure and temperature inside the vessel will rise. The steam and water will both increase in temperature and pressure, and each fluid will be at the same temperature and pressure as the other.

In operation, a boiler is neither an open vessel nor a closed vessel. It is a vessel designed with restricted openings allowing steam to escape at a uniform rate while feedwater is brought in at a uniform rate. Steam generation takes place in the boiler at constant pressure and constant temperature, less fluctuations. Fluctuations in constant pressure and constant temperature are caused by changes in steam demands.

We cannot raise the temperature of the steam in the steam drum above the temperature of the water from which it is being generated until the steam is removed from contact with the water inside the steam drum and then heated. Steam that has been heated above its saturation temperature at a given pressure is SUPERHEATED STEAM. The vessel in which the saturated steam is superheated is a SUPERHEATER.

The amount by which the temperature of superheated steam exceeds the temperature of saturated steam at the same pressure is the DEGREE OF SUPERHEAT. For example, if saturated steam at 620 psia with a corresponding saturation temperature of 490°F is superheated to 790°F, the degree of superheat is 300°F (790 – 490 = 300).

Most naval propulsion boilers have superheaters. The primary advantage is that superheating steam provides a greater temperature differential between the boiler and the condenser. This allows more heat to be converted to work at the turbines. We will discuss propulsion boilers and component parts more extensively in the next chapter. Another advantage is that superheated steam is dry and therefore causes relatively little corrosion or erosion of machinery and piping. Also, superheated steam does not conduct or lose heat as rapidly as saturated steam. The increased efficiency which results from the use of superheated steam reduces the fuel oil required to generate each pound of steam. It also reduces the space and weight requirements for the boilers.

Most auxiliary machinery operates on saturated steam. Reciprocating machinery, in particular, requires saturated steam to lubricate internal moving parts of the steam end. Naval boilers, therefore, produce both saturated steam and superheated steam.

EXPANSION

The EXPANSION area of the main steam system is that part of the basic steam cycle in which steam from the boilers to the main turbines is expanded. This removes the heat energy stored in the steam and transforms that energy into mechanical energy of rotation.

The main turbines usually have a high-pressure (HP) turbine and a low-pressure (LP) turbine. The steam flows into the HP turbine and on into the LP turbine. Area B of figure 3-1 shows the expansion area of the main steam system. This portion of the main steam system contains HP and LP turbines.

CONDENSATION

Each ship must produce enough feedwater for the boilers and still maintain an efficient engineering plant. Therefore, feedwater is used over and over again.

As the steam leaves or exhausts from the LP turbine, it enters the CONDENSATE system. The condensate system is that part of the steam cycle in which the steam is condensed back to water. Then it flows from the main condenser toward the boilers while it is being prepared for use as feedwater.

The components of the condensate system are (1) the main condenser, (2) the main condensate pump, (3) the main air ejector condenser, and (4) the top half of the deaerating feed tank (DFT). These components are shown in area C of figure 3-1.

The main condenser receives steam from the LP turbine. It condenses the steam into water. We will explain this process in the next chapter on boilers. The main condensate pump takes suction from the main condenser hot well. It delivers the condensate into the condensate piping system and through the main air ejector condenser. As its name implies, the air ejector removes air and noncondensable gases from the main condenser that leak or are discharged into it during normal operation. The condensate is used as a cooling medium for condensing the steam in the inter and after condensers of the main air ejector.

FEED

The DFT (fig. 3-2) is the dividing line between condensate and feedwater. The condensate enters the DFT through the spray nozzles and turns into feedwater in the reservoir section of the DFT. The DFT has three basic functions:

- To remove dissolved oxygen and non-condensable gases from the condensate
- To preheat the water
- To act as a reservoir to store feedwater to take care of fluctuations in feedwater demand or condensate supply

The condensate enters the DFT through the condensate inlet. There it is sprayed into the dome of the tank by nozzles. It is discharged in a fine spray throughout the steam-filled top. The fine spray and heating of the condensate releases trapped air and oxygen. The gas-free condensate falls to the bottom of the tank through the water collecting cones, while the air and oxygen are exhausted from the tank vent.

The collected condensate in the storage section of the DFT is now called feedwater and becomes a source of supply for the main feed booster pump. The main feed booster pump takes suction from the DFT and maintains a constant discharge pressure to the main feed pump.

The main feed pump receives the water (delivered from the booster pump) and discharges it into the main feed piping system. Area D of figure 3-1 shows the path of the water from the DFT to the economizer. The discharge pressure of the main feed pump is maintained at 100 to 150 psig above boiler operating pressure on 600-psi plants. On 1200-psi plants, it is maintained at 200 to 300 psig above boiler operating pressure. The discharge pressure is maintained throughout the main feed piping system. However, the quantity of water discharged to the economizer is controlled by a feed stop and check valve or automatic feedwater regulator valve.

The economizer is positioned on the boiler to perform one basic function. It acts as a preheater. The gases of combustion flow around the economizer tubes and metal projections that extend from the outer tube surfaces. The tubes and projections absorb some of the heat of combustion and heat the water that is flowing through the economizer tubes. As a result, the water is about 100 °F hotter as it flows out of the economizer to the boiler.

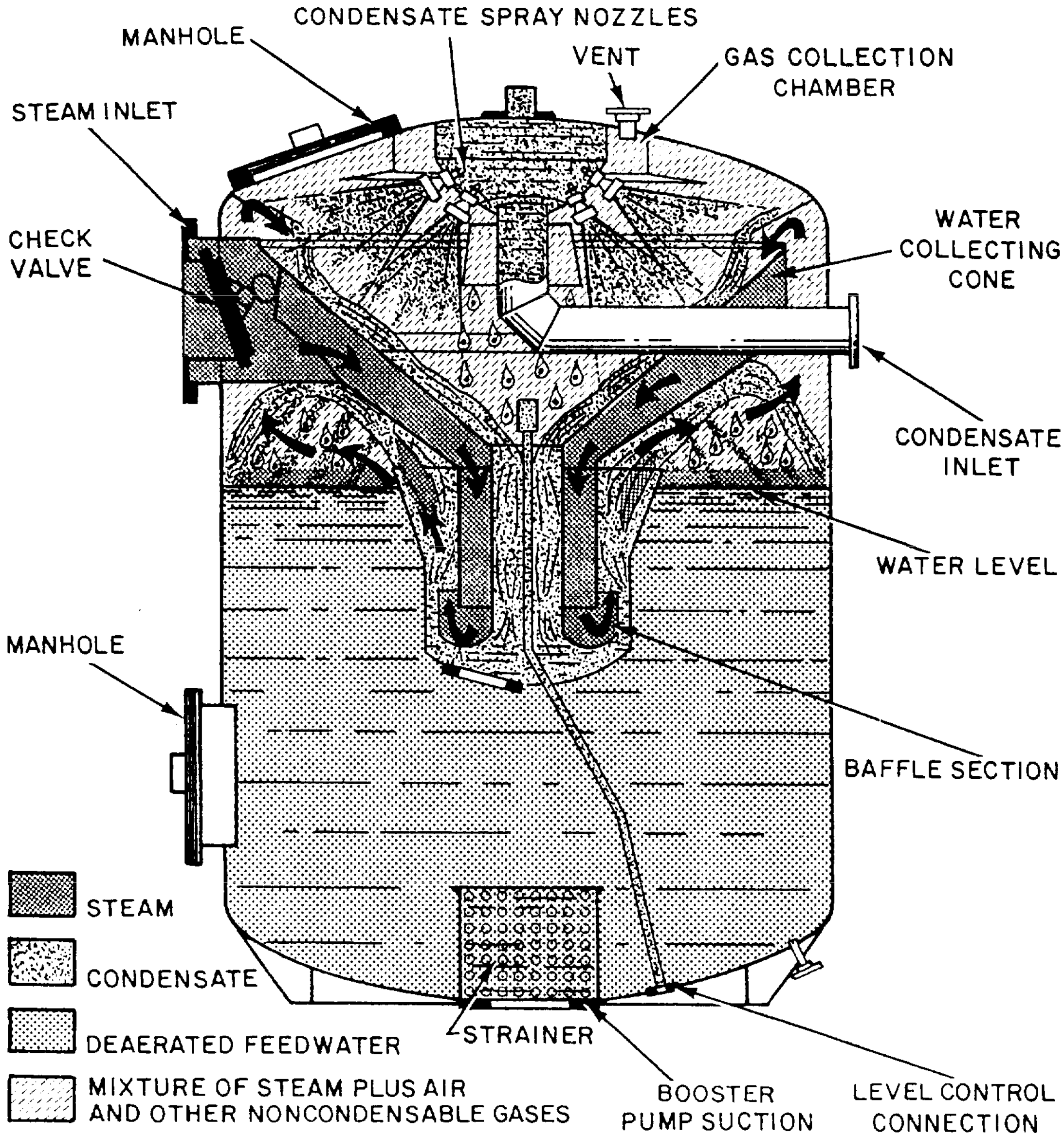

Figure 3-2.—Deaerating feed tank.

AUXILIARY STEAM SYSTEM

Auxiliary steam systems supply steam at the pressures and temperatures required cooperate many systems and machinery, both inside and outside engineering spaces. As discussed previously, auxiliary steam is often called saturated steam or desuperheated steam.

Many steam systems and machinery receive their steam supply from auxiliary steam systems on most steam-driven ships. Some typical examples are constant and intermittent service steam systems, steam smothering systems, ships' whistles, air ejectors, forced draft blowers, and a wide variety of pumps. Some newer ships use main steam instead of auxiliary steam for the forced draft blowers and for some pumps. Aboard some ships, turbine gland sealing systems receive their steam supply from an auxiliary steam system. Other ships may receive their supply from the auxiliary exhaust system. Gland sealing steam is supplied to the shaft glands of propulsion and generator turbines to seal the shaft glands against leakage. This leakage includes air leaking into the turbine casings and steam leaking out of the turbine casings. More use of electrically driven (rather than turbine-driven) auxiliaries has simplified auxiliary steam systems on newer ships.

SUMMARY

In this chapter, you have learned about the main steam system, the auxiliary steam system, and the use of steam after it leaves the boiler. Remember, steam and feedwater are recycled over and over again to provide heat and power to operate machinery. It is important that you understand the terminology associated with steam and feedwater systems. You will use these terms in your day-to-day routine aboard ship. Some of the subjects will be discussed in greater detail in later chapters. All of these areas are important in their own right. As you learn this information, you will become a more proficient and reliable technician.