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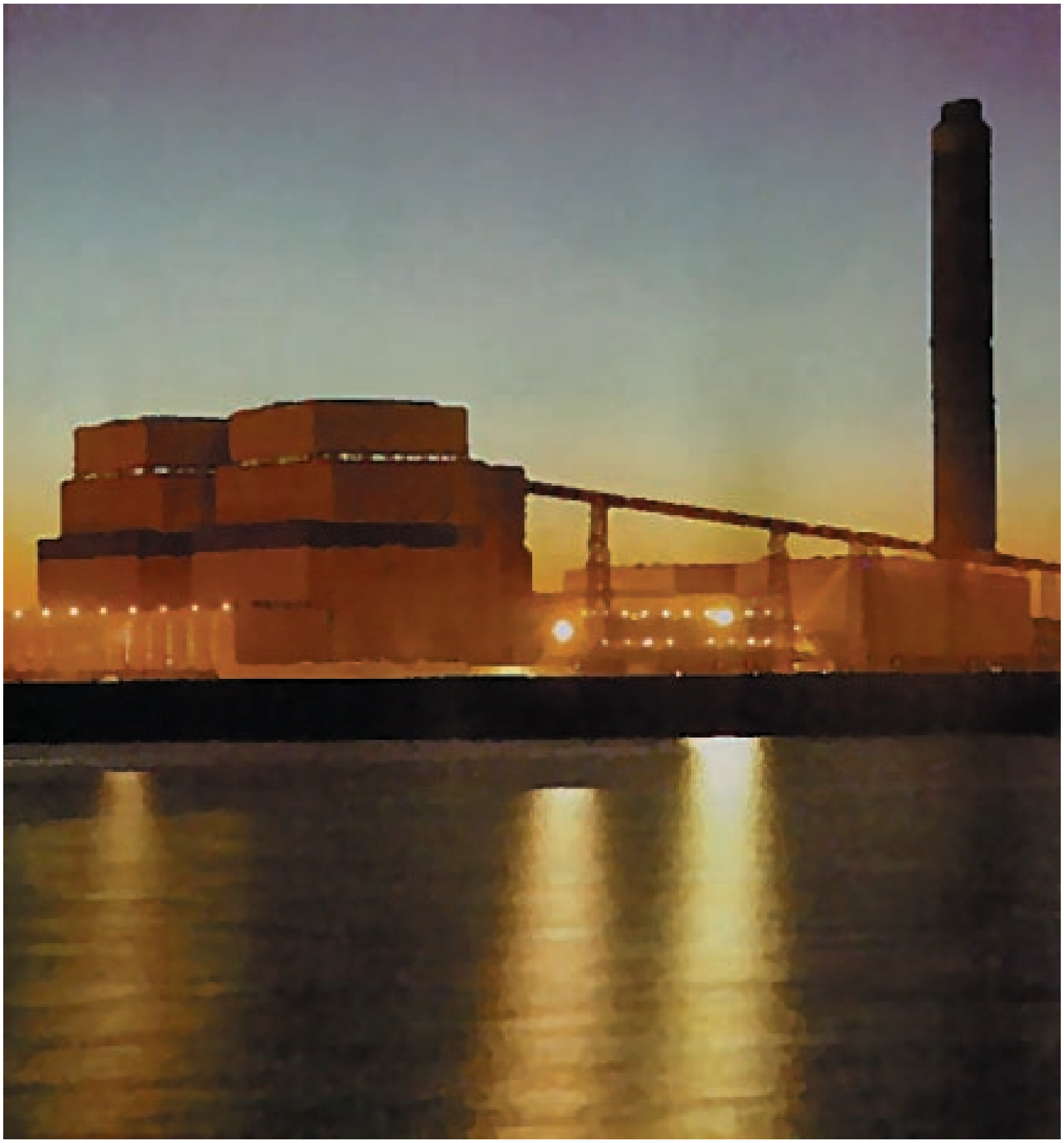

Power Industry Guide

Valtek Control Products

Flowserve Power Industry Guide

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Introduction

Electric power can be generated by a number of different processes, systems and components; however, most electricity is generated through the use of a rotating electric generator. An electric generator operates on the principle that a small electric current can be generated in a wire by passing it through a magnetic field. By using many wires in a coil, the currents are added to one another to generate usable electric current.

Commercial power generation can be broken down into three categories based upon the energy source used: thermal (coal, gas, and oil), renewable (hydro, biomass, geothermal, solar, and wind), and nuclear. Total generation in 1996 by U.S. electric utilities was 3,077 billion kilowatt-hours. Of the total generation, 68 percent was thermal, 10 percent renewable, and 22 percent nuclear. Coal fired units accounted for 84 percent of the thermal generation or 57 percent of the total. Non-utility generators produced 383 billion kilowatt hours in 1995. Approximately 76 percent of the non-utility generation is thermal and 24 percent renewable. Natural gas accounts for 74 percent of the thermal generation or 56 percent of the total non-utility generation.

Consumption of electricity worldwide is estimated at 11.4 trillion kilowatt-hours and expected to grow to 20 trillion kilowatt-hours by 2015. This represents approximately a three percent increase in power consumption.

In a conventional thermal process, a steam turbine converts steam energy into usable, rotational energy to turn the generator. Boilers produce steam to operate the turbine. Windmills, water turbines, internal combustion engines and other motive forces can be used in place of the steam turbine to turn the generator.

Although coal is the most common fuel to fire a boiler in a power plant, natural gas, oil or even biomass can be utilized as fuel to replace the coal to fire the boiler, and the majority of the process remains unchanged. Exhaust gas and ash disposal systems are dependent on the type of fuel being used. Figure 1 provides an overall view of a coal- fired power plant and the power generation process.

This guide offers the reader a general understanding of the major systems in a power plant utilizing a conventional boiler fired by coal, oil, gas or biomass to produce subcritical steam, which drives a steam turbine connected to a generator. A brief discussion of variations of this process such as nuclear, gas turbine, and supercritical plants are also described and covered individually under their own section. Rather than give a complete description of each of these variations, the major differences between them and the conventional thermal processes are explained.

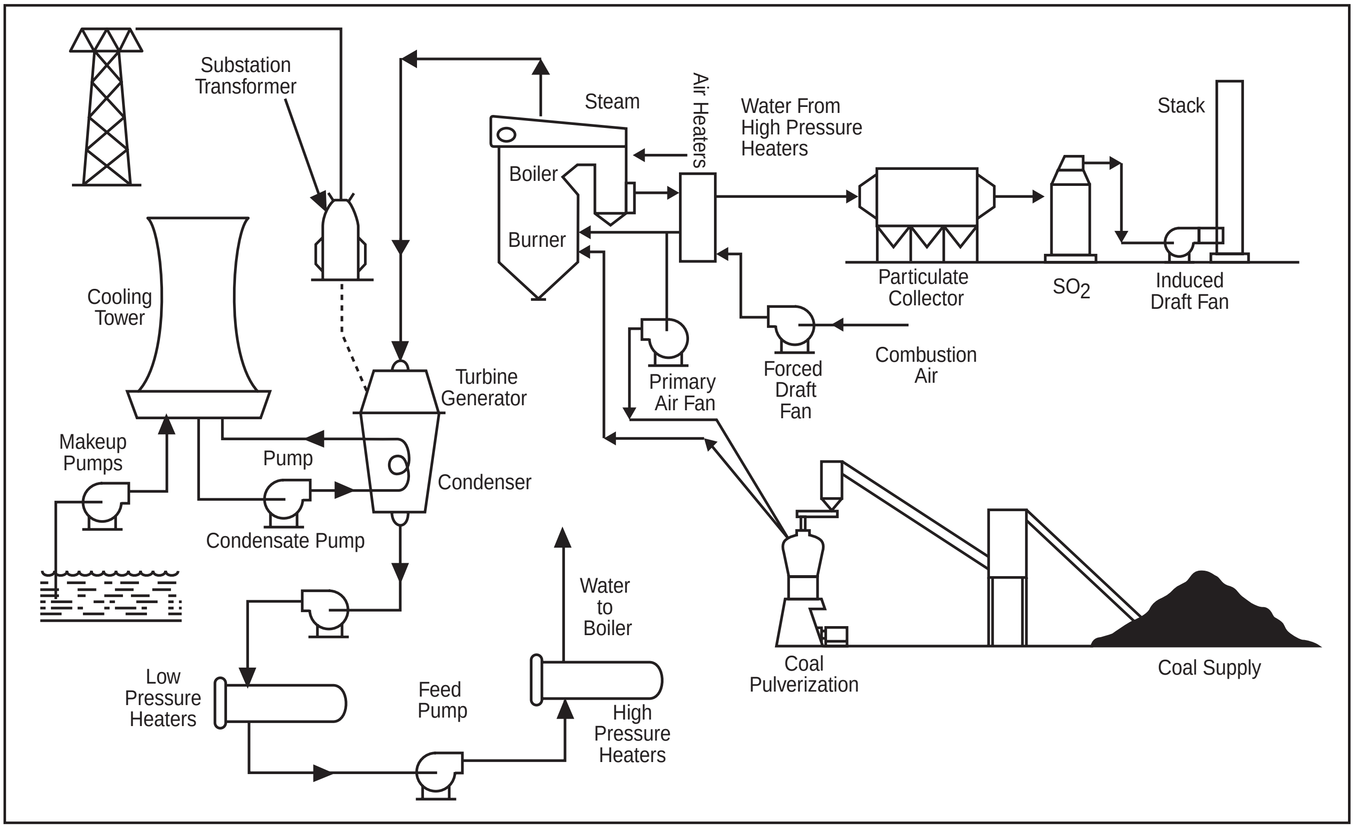


Figure 1: Coal-fired Power Plant

Conventional Subcritical Coal-Fired Power Plant

Actual power generation facilities are very complex and involve numerous processes and components. Steam power plants can be classified as subcritical and super-critical. If a plant operates below the critical point of water (3208.2 psia) , it is classified as subcritical.

This section is intended to provide a description of the processes and major components in a subcritical power plant (see Figure 2). Although similar in many ways, the super-critical power plant has some variations that are covered in greater detail in a separate section.

The conventional power generation process is a continuous cycle; therefore, discussion can begin at any point in the cycle. Because each part of the cycle builds upon the previous process in a continuous loop, the entire power generation cycle must be explained before each process becomes clear.

This discussion begins at the condenser. Water from the condenser is heated and the pressure increases through the feedwater system. The boiler adds more heat energy, and the superheated steam expands through a series of turbine blades that turn the generator. The expanded steam exits the turbine to the condenser, and the cycle continues.

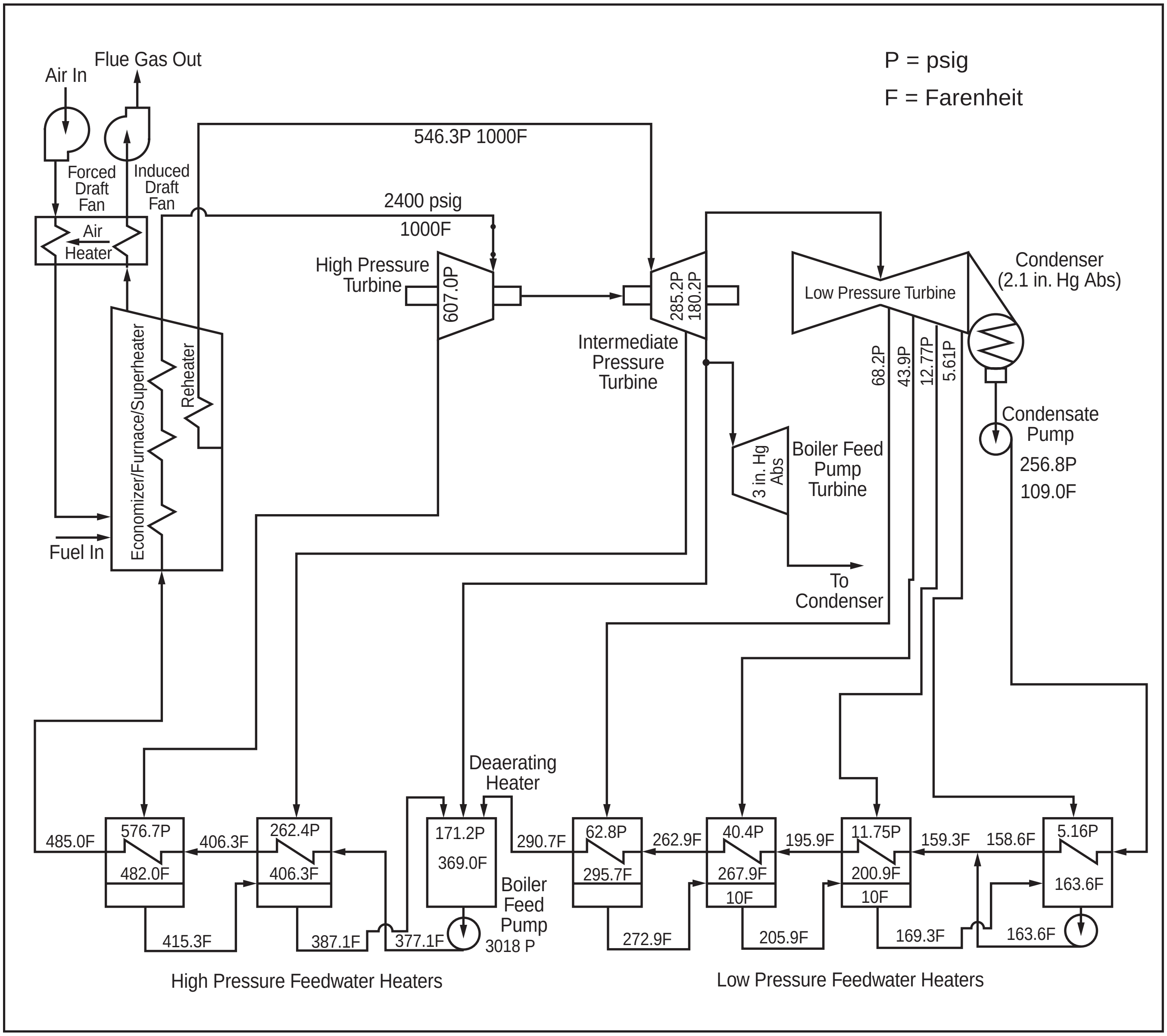


Figure 2: Heat Balance for a Subcritical Power Plant

Condensate System

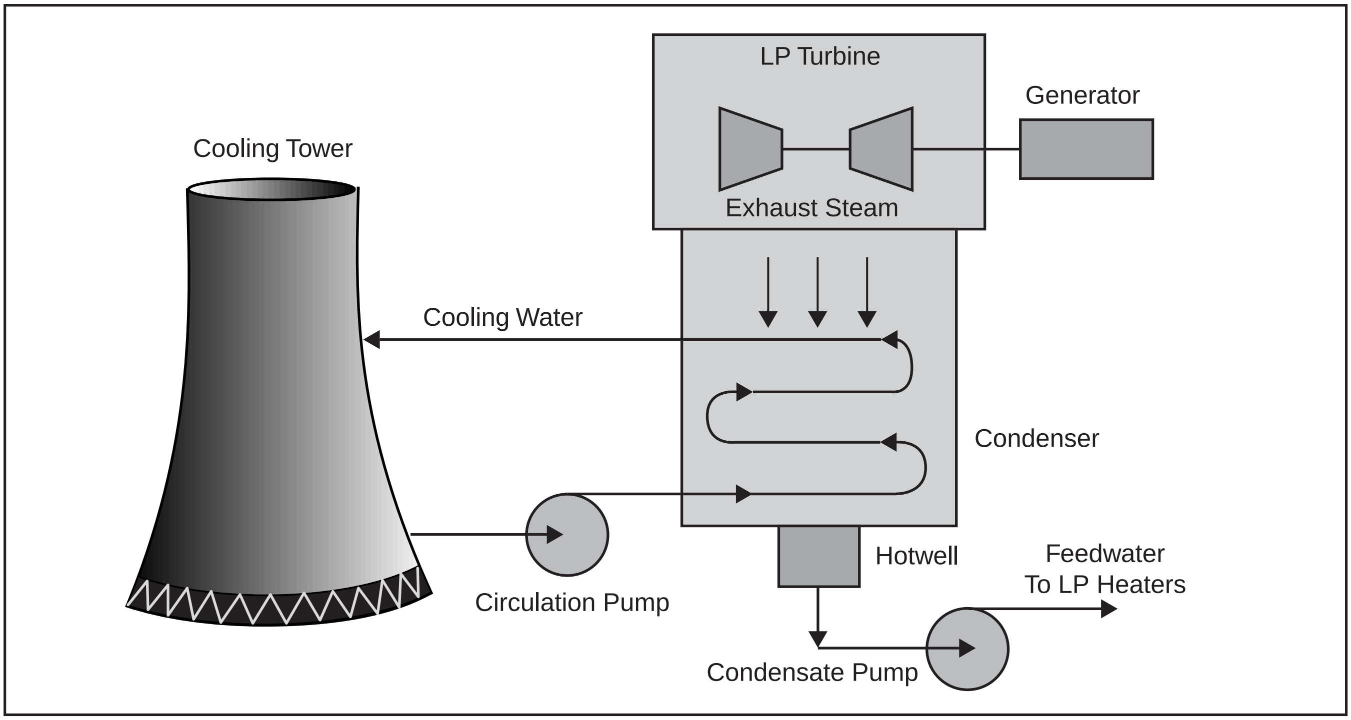


Figure 3: Condensate System

Condenser

The condenser operates on the principle that a mass of liquid occupies significantly less space than an equal mass of gas. For example, a pound of steam at 212° F and atmospheric pressure would occupy 26.8 cubic feet. The same pound of steam, if condensed, would occupy only about 0.017 cubic feet. That is a volumetric reduction of almost 99.94 percent. In a condenser, the exhaust steam from the turbine is passed through a heat exchanger where cool water running through tubes condenses steam into a liquid. This reduction in volume forms a vacuum in the condenser. Reducing the pressure in the condenser allows the steam from the turbine to condense at a lower temperature. The lower the pressure and temperature that can be achieved in the condenser, the greater the overall efficiency of the plant.

Cooling water is brought into the condenser through tubes and the exhaust steam passes by them. In this manner, the heat is transferred from the steam to the cooling water and the steam condenses and is collected in the 'hotwell' to be used again as feedwater. The warm cooling water is then circulated to a cooling tower where it is cooled to near ambient conditions (Figures 3 and 4).

Makeup Water

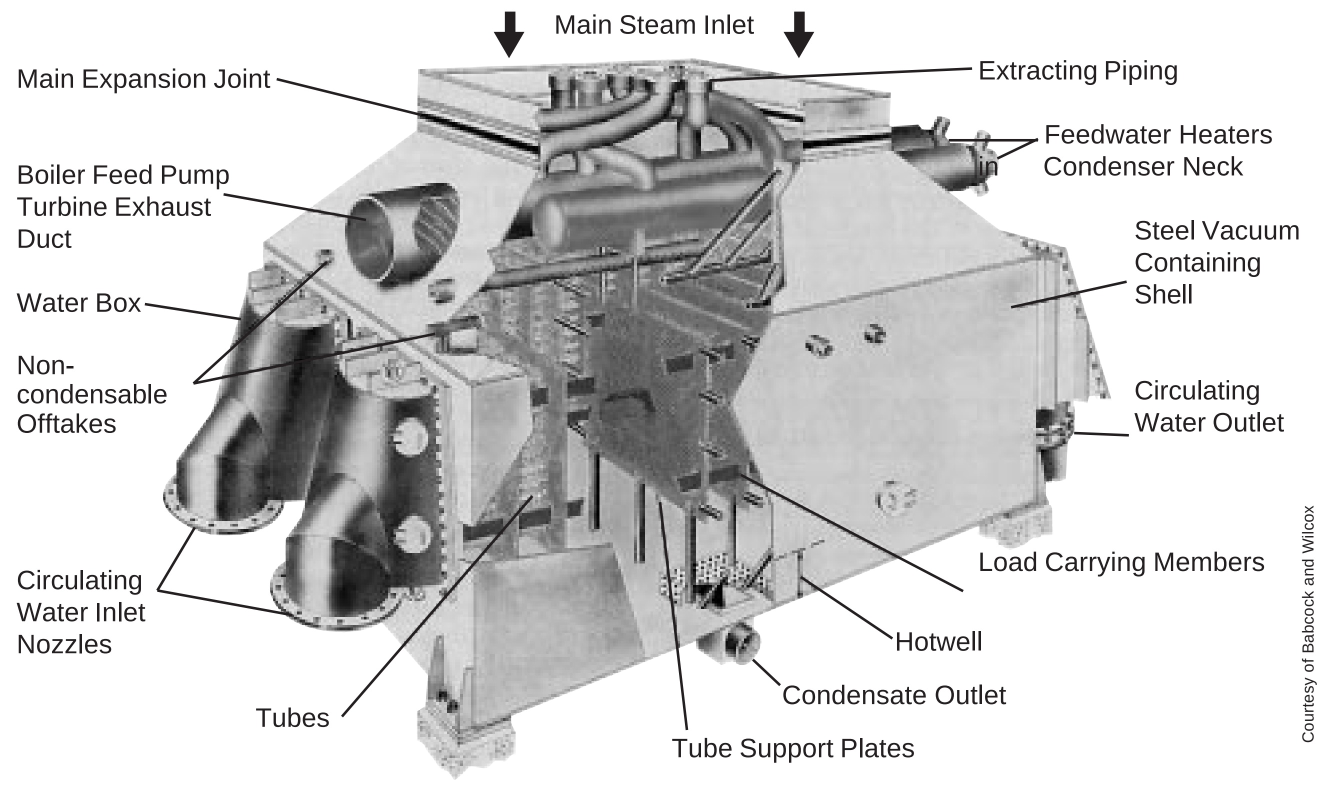
A power plant is a continuous cycle; therefore, theoretically, very little water should have to be added. In every system, however, leaks and evaporation occur, requiring a small amount of water to be added to the system. This water is referred to as makeup water.

Water Treatment

Impurities in feedwater can cause serious corrosion problems and adversly affect the efficiency and operation of a power plant. Pure water rarely exists naturally; thus, raw water for makeup needs to be treated to reduce contaminants that cause corrosion and leave deposits throughout the system. No water treatment is completely effective in removing impurities. Those impurities not removed from the makeup water prior to entering the system concentrate in the feedwater and boiler. These impurities are often removed in a process referred to as 'blowdown.' Blowdown can be either a continuous or intermittent process and involves using a valve to release water from the boiler.

Water contains both dissolved and suspended solids of various types and concentrations, depending upon its source. Suspended solids can be removed by filtration or settling. Dissolved solids cannot be removed by filtration and are in solution with water. Examples of suspended solids include mud, silt, sand, clay, organic matter and some metallic oxides. Examples of dissolved solids include iron, calcium, silica, magnesium and sodium.

If left in the system, dissolved solids form scale on the boiler internal surfaces and reduce heat transfer. This can result in overheating of the tubes and failure or damage of other downstream equipment. Dissolved solids can be removed from the system using a variety of processes including evaporation, ion exchange, reverse osmosis, electrodialysis and ultrafiltration.



Courtesy of Babcock and Wilcox

Figure 4: Condenser Condensate Outlet

Condensate Pump

Condensate collected in the hotwell will be at the same pressure as the condenser (approximately 0.5 psia) and must be pressurized before moving on to the feedwater system. During start-up, little if any flow is circulating through the system. For this reason, it is necessary for the condensate pump to have a recirculation system similar to the main feedpump. In the condensate pump case, however, the water to be recirculated is at significantly lower pressure and temperature than the main feedpump. Recirculation prevents overheating and cavitation of centrifugal pumps. A control valve known as the condensate pump recirculation valve provides the required minimum flow. After passing through the condensate pump, the condensate enters the feedwater system.

In order to make usable energy to turn the steam turbine, water needs to be pressurized and heated until it vaporizes into steam. After vaporizing, the steam temperature is elevated (superheated) to maximize the energy content of the steam and to protect the turbine from water damage. The boiler provides the energy to vaporize and superheat steam. The boiler is also used to reheat steam between turbine sections.

Major water quality problems associated with boiler systems

Major Problem	Deaerator	Feedwater System	Boiler	High-pressure Boiler	Turbine	Super-heater	Steam-Using Equipment	Condensate System
Scale								
Hardness		X	X					
SiO_2		X		X				
Corrosion								
Oxygen	X	X	X	X	X	X		
Alkalinity/CO_2			X	X		X	X	X
Ammonia		X						
Chelate		X	X					
Deposits								
Metal Oxides		X	X	X				
Organics		X	X	X				
Carryover								
Entrained liquids			X	X	X	X		
Dissolved solids						X	X	X

Feedwater System

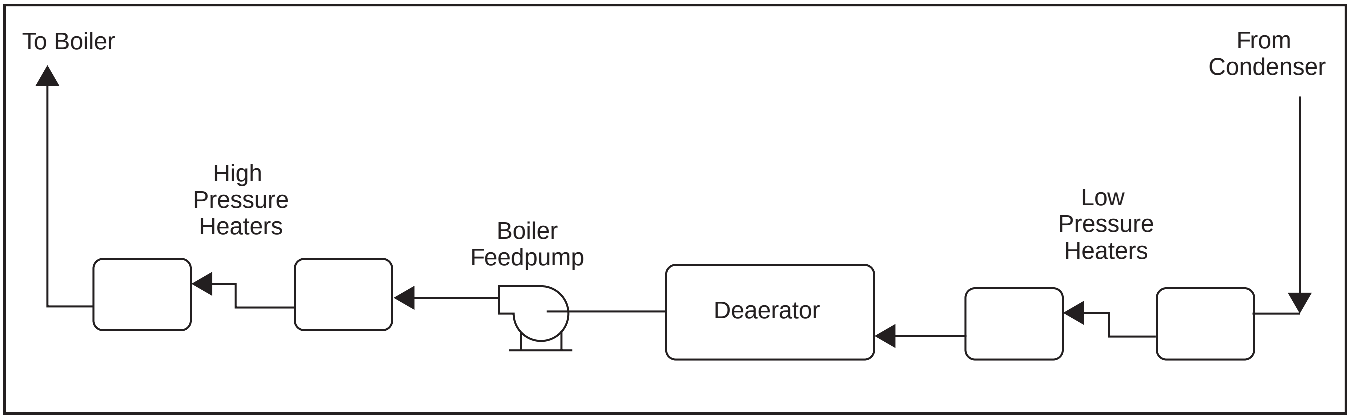


Figure 5: Feedwater System

The feedwater system provides the boiler with water in the proper volume and at the design pressure and temperature. The feedwater system includes the low and high pressure feedwater heaters, deaerator and boiler feedpump (see Figure 5). If the feedwater is delivered at the incorrect temperature or pressure, the boiler tubes and downstream equipment can be damaged. Improper temperatures also adversely affect the efficiency and reliability of the process. In a typical subcritical plant, the feedwater is delivered to the boiler at approximately 2400 - 3200 psig and 300 - 500° F. Too low of a flow to the boiler can result in overheating of the tubes, while too high of a flow can result in wet steam entering the turbine, causing water damage to the turbine blades.

Boiler Feedpump

Pressurization of the feedwater is accomplished through the use of a boiler feedpump that is commonly steam driven. Large plants may have a smaller motor-driven feedpump for start-ups. Also, smaller power plants may utilize a motor-driven main feedpump. Boiler feedpumps require a minimum flow to protect against overheating and cavitation. Minimum circulation for the feedpumps is provided by a feedwater recirculation system. The recirculation system diverts the minimum flow from the discharge of the pump back to either the condenser or the deaerator. Because both the condenser and the deaerator are at relatively low pressures as compared to the high discharge pressures of the pump, severe cavitation can be expected in the valve diverting this flow. This valve is referred to as the 'boiler feedpump recirculation valve,' 'feedpump minimum bypass valve' or 'automatic recirculation control valve' and is one of the most severe applications in the power plant. During normal plant operation, sufficient flow is passing through the feedpump to the boiler without any recirculation, so the valve will be closed. Figure 6 is a steam driven, boiler feedpump.

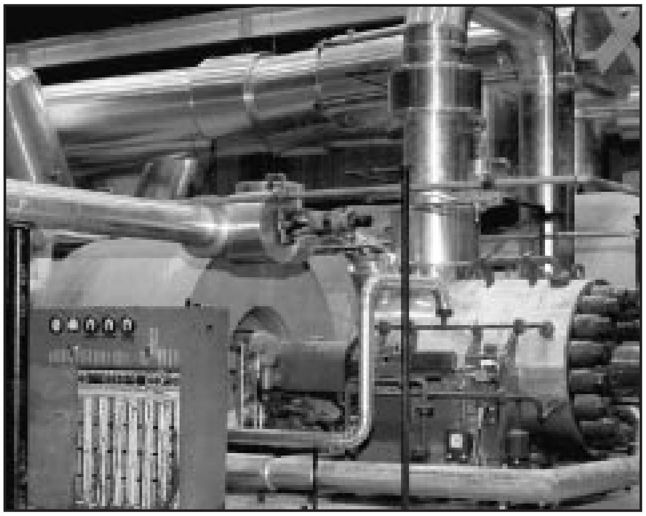


Figure 6: Boiler Feedpump

Feedwater Heaters

In the feedwater system, water passes through a series of heaters referred to generically as feedwater heaters, which utilize steam extracted from various stages of the turbine to raise the temperature of the boiler feedwater. The heat energy from the steam is transferred to the feedwater in these heaters through a tube and shell type heat exchanger or through direct mixing of the steam and the feedwater. Feedwater heaters that mix the steam and water are referred to as 'open' while those utilizing a tube and shell type heat exchanger are 'closed.' A closed type feedwater heater is depicted in Figure 7.

Open feedwater heaters serve a dual function of feedwater heating and removing non-condensable gases. The function of removing non-condensable gases is covered in greater detail in the *Deaerator* section.

Feedwater heaters are further categorized as either low or high pressure. The difference between the two is that the low-pressure units are heating water that has not yet passed through the boiler feedpump or the

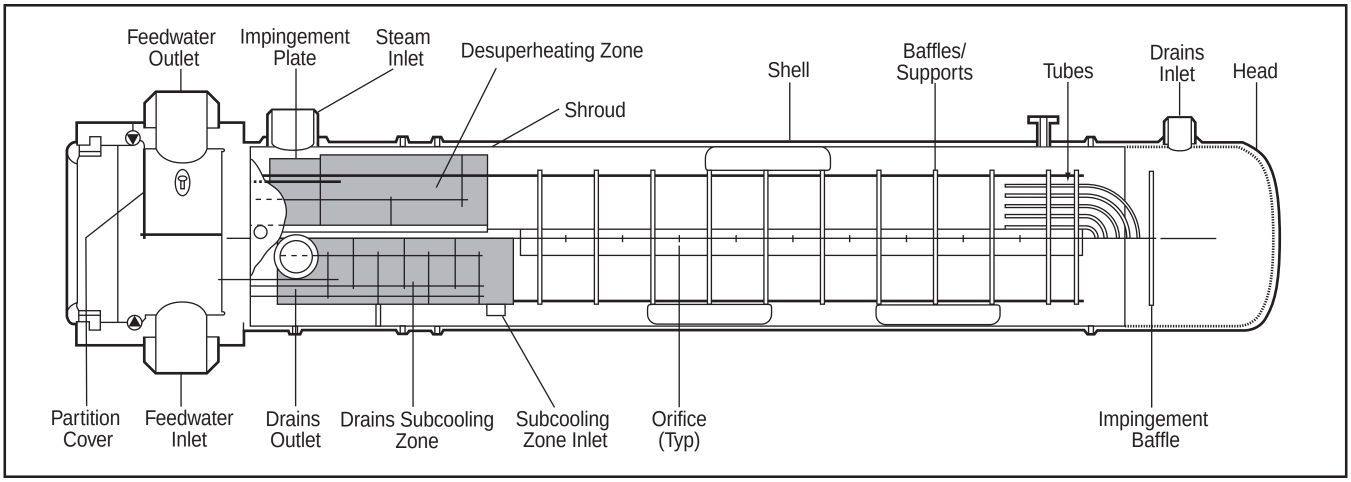
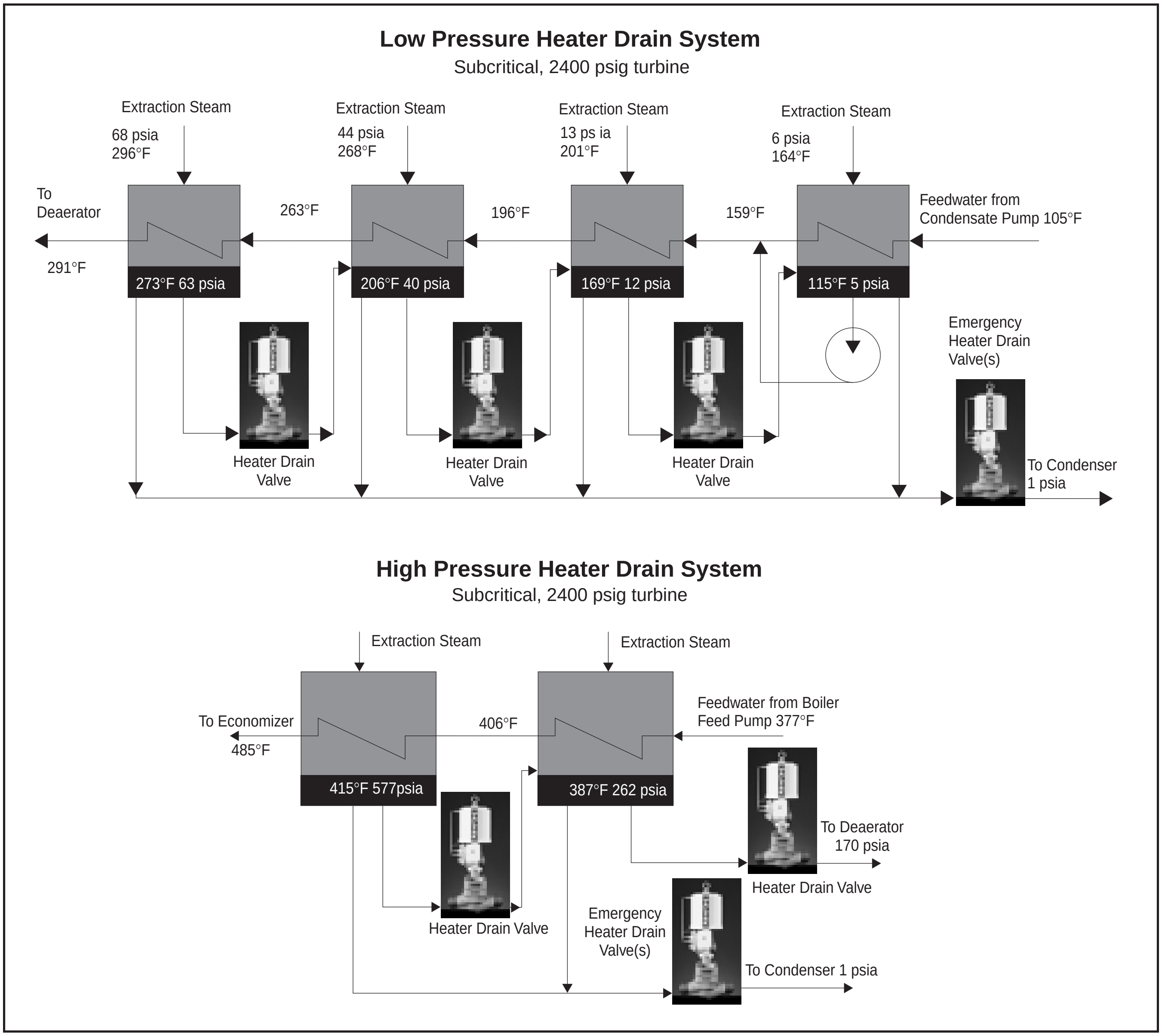


Figure 7: Closed Feedwater Heater


Low Pressure Heater Drain System

Subcritical, 2400 psig turbine

High Pressure Heater Drain System

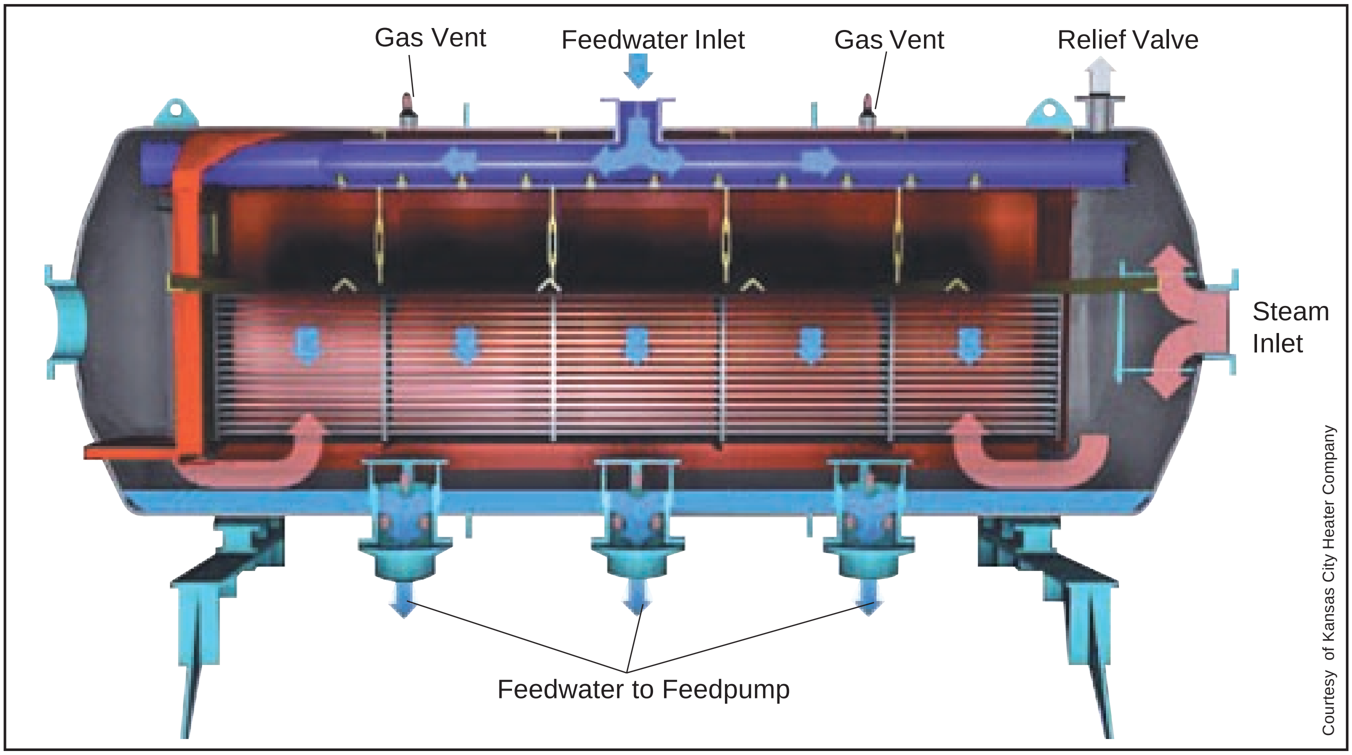
Subcritical, 2400 psig turbine

Figure 8: Low and High Pressure Heater Drain Systems

deaerator. High-pressure feedwater heaters are located after the main feedpump and are closed while the low-pressure heaters can be either open or closed.

Steam for the low-pressure heaters is commonly extracted from the low pressure section of the turbine. High-pressure heaters are located downstream of the boiler feed pump and utilize steam extracted from the high or intermediate pressure sections.

In closed feedwater heaters, as the steam gives up its heat to the feedwater it loses energy and often condenses. Control valves referred to as 'heater drain valves' control the condensate level in each of the heaters. Condensate from one heater is cascaded down to the next heater. Condensate from the heaters can be returned to the condenser, deaerator or mixed with the feedwater, depending upon the plant design (see Figure 8).



Courtesy of Kansas City Heater Company

Figure 9: Deaerator

Deaerator

After the feedwater leaves the last of the low-pressure heaters, it is directed to a device known as the deaerator to remove the non-condensable gases in the feedwater. The deaerator operates on the principle that hot water can hold considerably less dissolved gases than cold water. Using extraction steam, the feedwater is heated in the deaerator to near saturation temperatures, and the water releases the dissolved gases which are then vented off. The deaerator is actually an open feedwater heater.

Feedwater is a combination of makeup water and water condensed from steam that has passed through the boiler and into the condenser. Because the condenser is operated at a vacuum, some atmospheric gases can leak into the system. Also, water holds dissolved gases such as oxygen and nitrogen that are referred to as non-condensable. These gases do not condense at the same temperature as steam, and if they are not removed they can build up in the condenser , causing the pressure to rise. Also, dissolved gases left in the system can lead to corrosion of the boiler and piping. If the pressure rises in the condenser, the plant will not run efficiently and the turbine could be damaged.

Boiler

The boiler converts the energy in the fuel to heat and transfers this heat energy to the feedwater, combustion air and steam. Heat transfer in the boiler takes place in the economizer, air heater, boiler tubes, drum, superheaters and reheater.

Economizer

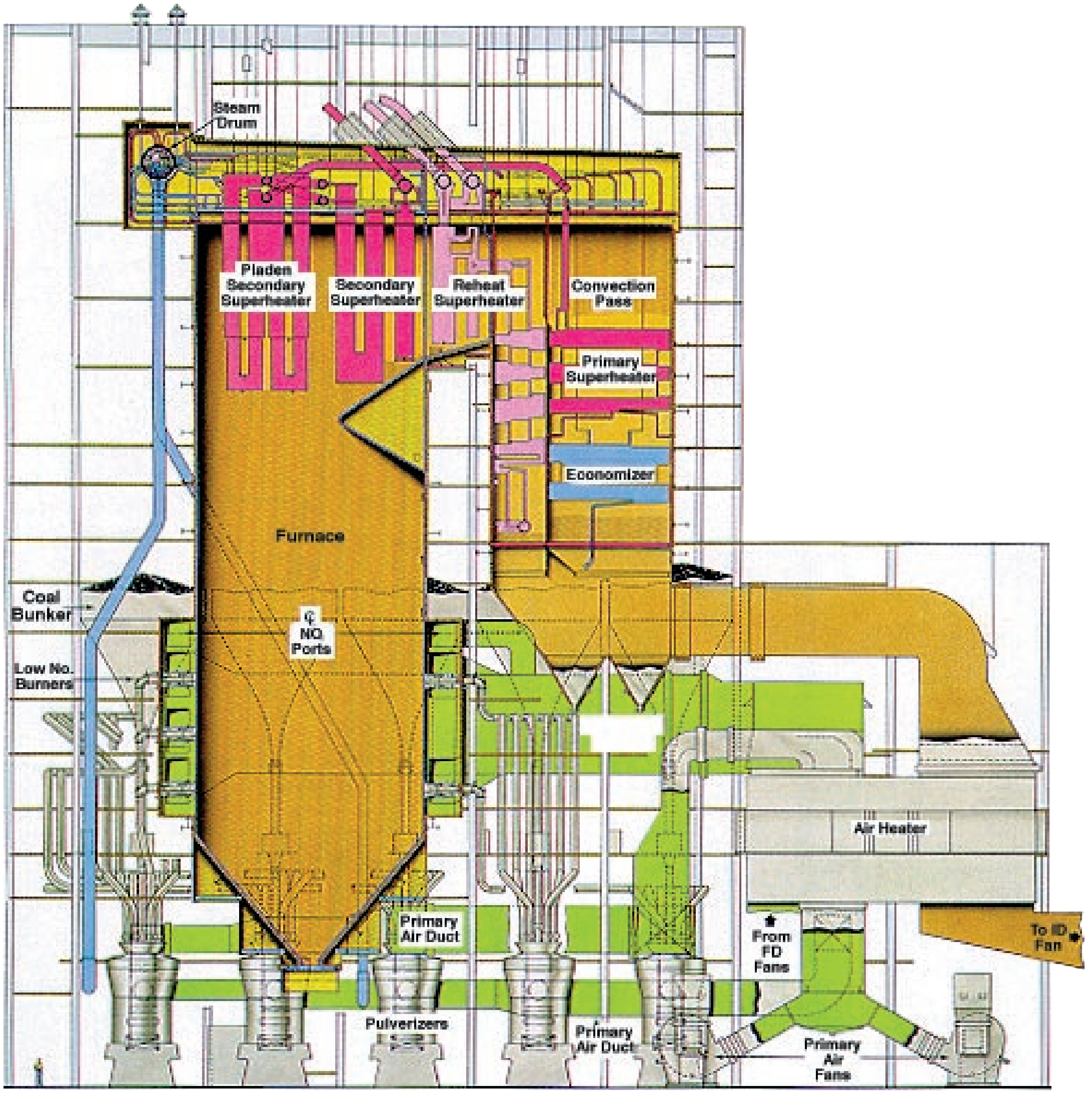
The economizer is a bank of tubes through which the feedwater passes before it goes into the main tube section of the boiler. Heat that is remaining in the combustion gases in the boiler after passing through the tubes, superheaters and reheaters is directed through the economizer. The economizer reduces energy consumption and thermal strain on the boiler tubes.

Air Heater

The air heater or 'pre-heater' heats the combustion air to the boiler in order to improve efficiency and improve combustion. The air heater is the last heat exchanger mechanism in the boiler before the flue gases are vented. Because the flue gas is relatively low in temperature by the time it reaches the air heater, a large surface area is often required in the air heater to facilitate heat transfer.

Drum

After the boiler feedwater has passed through the economizer, it is directed to the boiler tubes and drum where it finally becomes steam. The drum provides an area where the steam separates from the feedwater. The drum is connected to many sections of tubes that circulate the feedwater in the boiler. These steel tubes are arranged to maximize the exposure to the heat from the boiler. As steam bubbles form, they collect in the drum before passing further on. It is important to keep a constant liquid level in the upper drum to provide the



Courtesy of Babcock and Wilcox

Figure 10: Carolina Type 455 MW Boiler

proper quality of steam. Control valves called feedwater regulator valves, control the liquid level in the drum. Requirements for the feedwater can vary greatly so the flow rate to the drum must be constantly adjusted. Modern boilers have high heat rates and if new feedwater is not introduced, they can actually boil dry and damage boiler tubes in a matter of a few minutes.

Superheaters

Superheaters are used to raise the temperature of the steam coming from the drum to the design temperature of the turbine. To understand the reason for increasing steam temperature, one must first understand how the maximum thermal efficiency of a power plant is affected by the maximum and minimum operating temperatures. Energy is proportional to absolute temperature so maximum efficiency can be calculated with:

$$E = \frac{T_1 - T_2}{T_1}$$

Because these temperatures are absolute temperatures, you must add 460 to degrees Fahrenheit to get the absolute temperature in degrees Rankine. As an example, for a plant that operates with a maximum temperature of 500° F and a minimum temperature of 160° F, the maximum thermal efficiency would be:

$$E = \frac{960 - 620}{960} = 35.4\%$$

If the maximum temperature were to be raised to 1000° F and the minimum temperature remained the same, the maximum thermal efficiency becomes:

$$E = \frac{1460 - 620}{1460} = 57.5\%$$

This example demonstrates the benefit from operating at higher temperatures and a major reason for adding a superheater. In reality, power plants have significant inefficiency and even the best conventional steam power plants have an actual efficiency of about 40 percent.

The superheater consists of alloy steel tubes through which the steam from the drum passes. These tubes are located in the boiler in the path of the hot gases. As the steam passes through these tubes it is heated to a temperature higher than the saturation temperature it achieved in the drum. In addition to improving the thermal efficiency of the plant, adding a superheater also helps insure that the steam does not condense in the lower pressure stages of the turbine and cause damage. It is not uncommon for the boiler to include two sets of superheaters called the primary and secondary superheaters.

Reheater

In addition to the superheaters, steam is often returned to the boiler to be reheated after it has passed through the high-pressure or intermediate stages of the turbine. Besides a considerable drop in pressure, steam leaving the high-pressure stages of the turbine has also cooled significantly. By returning the steam to the boiler, the reheater brings the steam temperature back up to nearly the same temperature as it was before entering the high-pressure stage of the turbine. By reheating, the efficiency of the lower pressure stages of the turbine can be significantly improved.

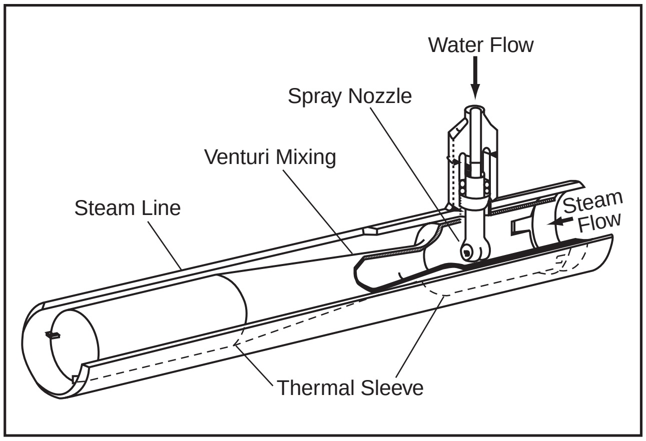


Figure 11: Spray Attemperator

Attemperator

Attemperators are used to control the temperature of the steam to the turbine. Allowing too high of a temperature can cause turbine overheating, while too low of temperature affects plant efficiency and can result in water droplets forming in the lower pressure stages of the turbine. Water droplets will quickly erode the turbine blades.

Several types of attemperators are available but most contemporary power plants utilize some type of spray attemperator. Spray attemperators function by adding high purity water to the steam through a spray nozzle located at the throat section of a venturi in the steam line.

Attemperators are normally located between the primary and secondary superheaters and also before the reheat superheater. Placing the attemperators in these locations helps protect the turbine from water that may not vaporize immediately upon spraying it into the steam (see Figure 11).

Turbine

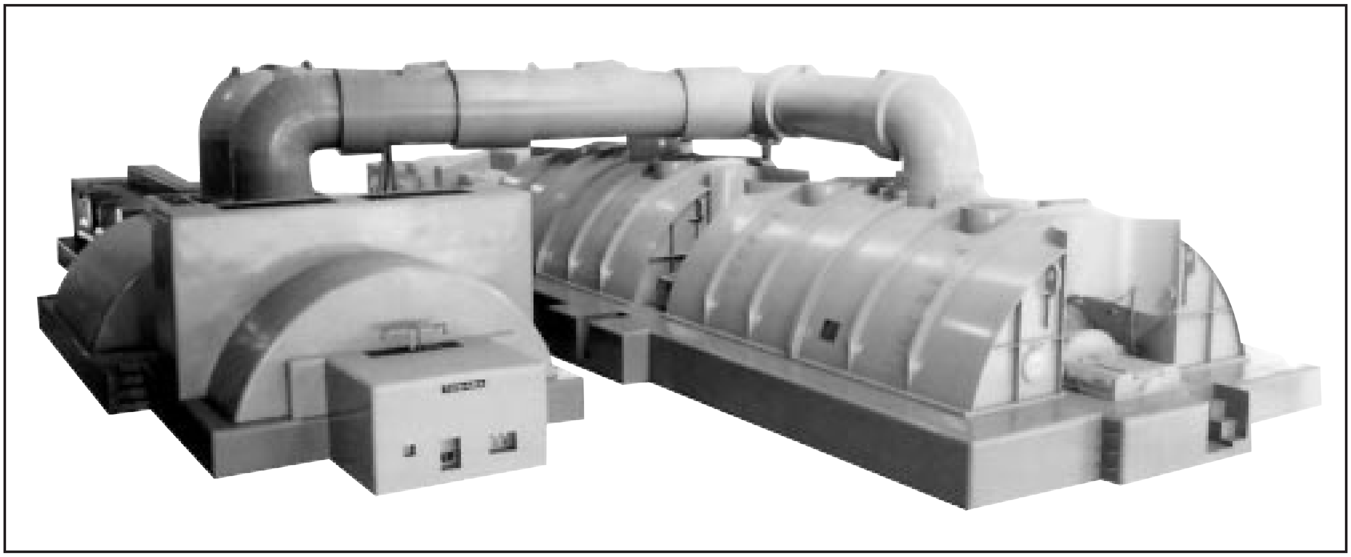
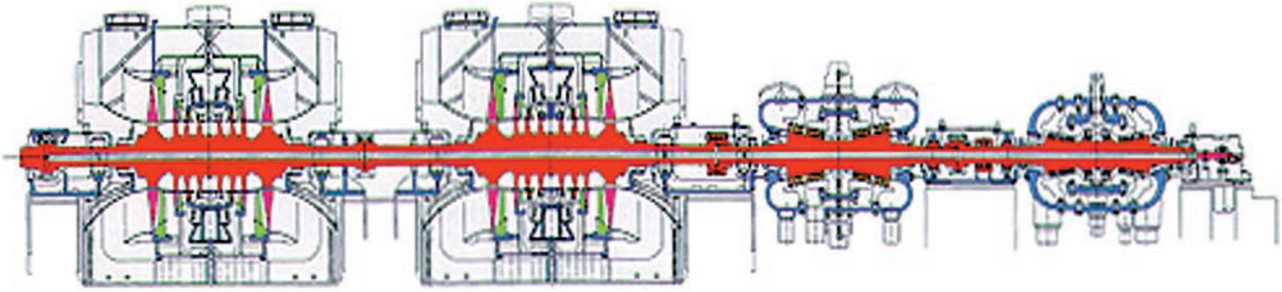


Figure 12: Steam Turbine Generator

The turbine is essentially a complex windmill or fan with many blades that converts the thermal energy of the steam to useful mechanical energy. Steam turbines in thermal generating plants can range in generating capacity from 1 megawatt to more than 1,000 megawatts. As high-energy steam passes through the various stages of the turbine, its energy is converted to rotating the turbine. It is common for a turbine to have both high and low pressure sections with a reheat cycle in between. An intermediate stage can also be included, which may or may not include an additional reheat cycle.

After passing through the high-pressure section of the turbine, the steam may be returned to the boiler reheat superheater to increase the steam temperature before entering the next turbine section. This is done to improve the efficiency of the turbine and to reduce the potential of condensate forming in the lower pressure stages of the turbine. The reheat steam is heated to approximately the same temperature as the superheated steam entering the high-pressure turbine. However, the reheat steam pressure is much lower than that of the main steam. Superheated steam pressures might be as high as 2700 psi while reheat steam pressures might be below 600 psi. Steam is also extracted at various points in the turbine for use in other areas of the plant for heating feedwater, operating auxiliary equipment, and space heating. Figure 2 is an example of a plant employing high, low and intermediate pressure turbines with one reheat cycle.

After exiting the low-pressure turbine, the steam returns to the condenser. At this point, one complete cycle in the power generation process has been completed.



Courtesy of Mitsubishi Heavy Industries

Figure 13: Cutaway view of Steam Turbine

Super-critical Power Plants

A variation of the conventional power generation process is the super-critical or 'once-through' boiler. Super-critical plants operate at pressures exceeding the critical point of water. The term 'once through' comes from the identifying feature of the super-critical boiler which has no drum for the separation of the steam and water. While all super-critical plants are once-through, not all once-through plants are super-critical.

The main difference between a conventional and super-critical boiler is that the super-critical boiler is designed to produce steam at temperatures and pressures higher than the super-critical temperature and pressure of water. Figure 14 is a heat balance for a typical super-critical power plant. Operating in the super-critical region increases thermal efficiency, reduces fuel consumption and produces fewer emissions. Because of the higher operating pressures and temperatures, equipment construction, operation and reliability become even more important factors for super-critical plants.

Once-through boilers lack a drum for steam and water separation and heat storage. For this reason, they have a start-up system that includes either a flash tank or separators. The flash tank or separators serve much the same function as a drum while the boiler is coming up to operating temperature, pressure and flow. Figure 15 shows a simplified schematic of a Babcock & Wilcox Universal Pressure Boiler Bypass System.

After start-up of the once-through boiler, the flash tank is bypassed and flow through the plant is as shown in the schematic pictured in Figure 14. Notice that the schematic now becomes similar to a conventional thermal power cycle except that the pressures and temperatures are higher.

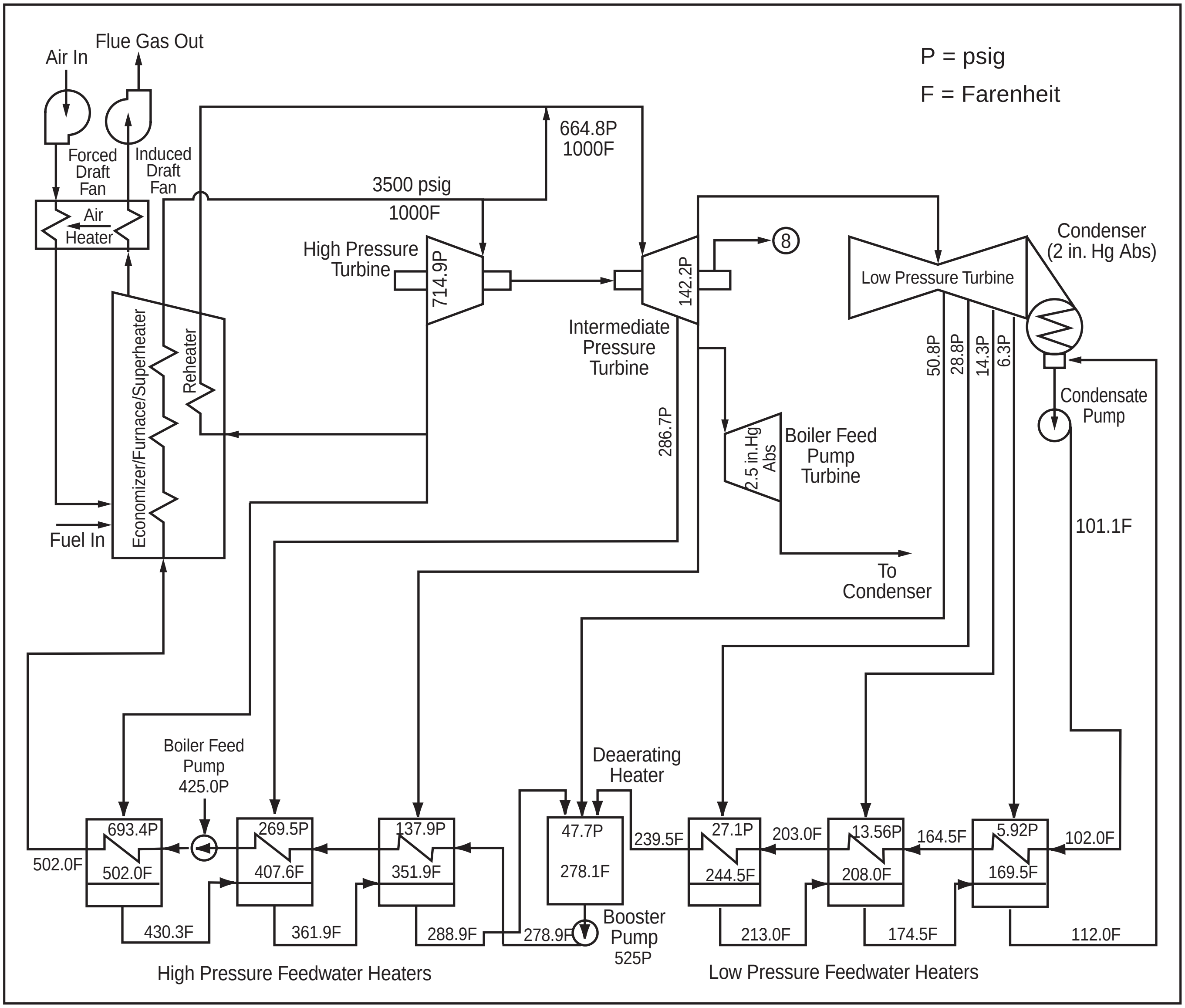


Figure 14: Heat Balance for a Super-critical Power Plant

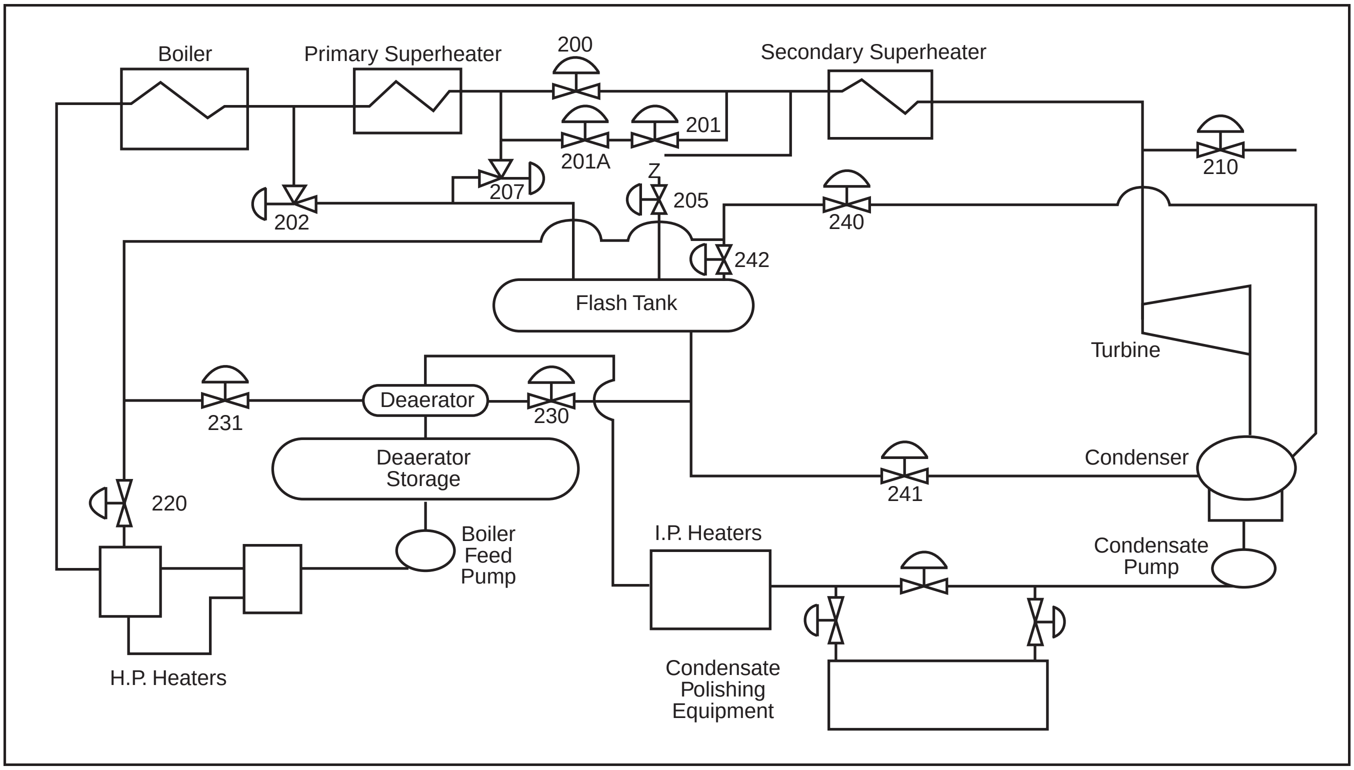


Figure 15: Pressure Control of Power Plants

Sliding Pressure Control

A term heard frequently when referring to once-through boilers is "sliding pressure control." Surplus power generating capacity, and the inclusion of many nuclear plants as base load units increased the necessity of throttling once-through power plants during low demand times. Sliding pressure control was developed as a method of allowing once-through boilers to cycle their load during off-peak hours.

Regulating the pressure of the steam entering the turbine controls the generator speed. Turbine control valves, located on the inlet of the turbine, normally perform this function for moderate changes in demand. However, if demand swings often or widely, a different control strategy is necessary to protect the turbine.

Flow through a valve can be considered a constant enthalpy (h - btu/lbm) process. By referring to the steam tables it can be easily demonstrated that when the pressure is reduced through a valve, in order to maintain the same enthalpy, the temperature of the outlet steam must also be reduced. This means that large demand swings can result in significant steam temperature changes that can cause turbine damage and reduce the thermal efficiency of the plant.

Sliding pressure control allows the turbine load to vary with demand while supplying the turbine with constant temperature steam. This is accomplished by opening the turbine control valve and controlling the turbine with a control valve located between the primary and secondary superheaters. Even though the steam temperature downstream of the sliding pressure control valve may vary as a result of its throttling, the secondary superheater can smooth out the resulting temperature changes of the steam prior to entering the turbine. Figure 16 illustrates normal and sliding pressure control.

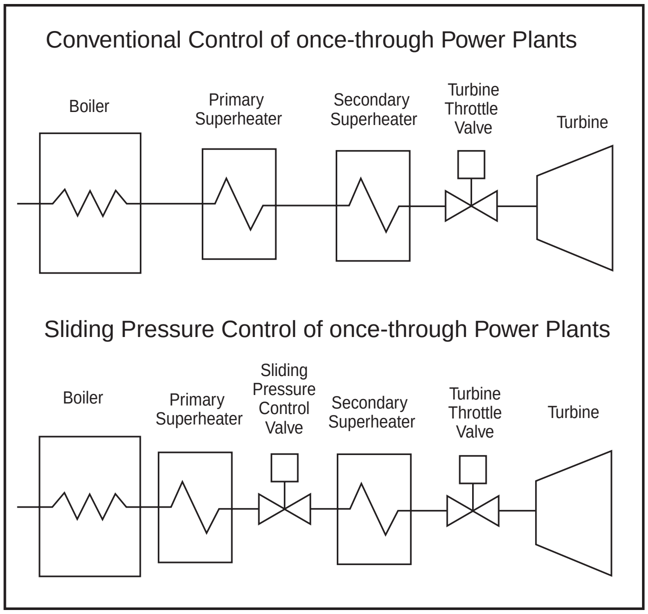


Figure 16: Pressure Control

Nuclear Power Plants

Although not currently as popular as some alternatives, nuclear power plants can be found in 32 countries worldwide and account for over 20 percent of the power generated in these countries.

Nuclear power plants utilize a controlled chain reaction of fissionable material to produce heat. This reaction takes place in the nuclear core. A nuclear core and steam generator can be used to replace the boiler and associated systems and the rest of the power generation cycle would be similar to a conventional thermal power plant. Nuclear generating units range in size from 75 megawatts to more than 1,400 megawatts.

Moderator

Conventional nuclear reactors utilize water around the core as a moderator. The moderator serves two functions. First, it slows down the neutrons so when they collide with fuel molecules they will be absorbed and cause them to fission. Second, as the fission process occurs, the heat of the core rises. The moderator is used to transfer this heat from the core to produce steam. The moderator in all water modulated plants is 'heavy water' or deuterium oxide. Deuterium is a hydrogen isotope that has an extra neutron. The increased size of the nucleus of the deuterium oxide makes it more effective than normal water in slowing down the fission neutrons.

NUCLEAR REACTOR TYPES

Boiling Water Reactor (BWR)

Some nuclear power plants heat the moderator until it becomes steam. This type of nuclear plant is referred to as a "Boiling Water Reactor" or BWR. The steam produced in the BWR core is then used to turn the turbine. One disadvantage of this type of system is that the steam is radioactive and the equipment it comes in contact with becomes radioactive. An advantage of the BWR is its simplicity and ability to operate at slightly higher steam temperatures than alternative designs. Figure 17 is a cutaway of a BWR reactor.

Pressurized Water Reactor (PWR)

Nuclear power plants that use water as a moderator but do not boil it are referred to as a “Pressurized Water Reactor” or PWR. PWR’s pressurize the moderator so it does not boil at the high core temperatures. The moderator is then circulated through a heat exchanger where the process water/steam is heated (see Figure 18).

Most operating nuclear reactors are PWR’s and use the moderator to heat the process steam by means of a heat exchanger. This keeps the process steam separate from the radioactive water surrounding the nuclear core.

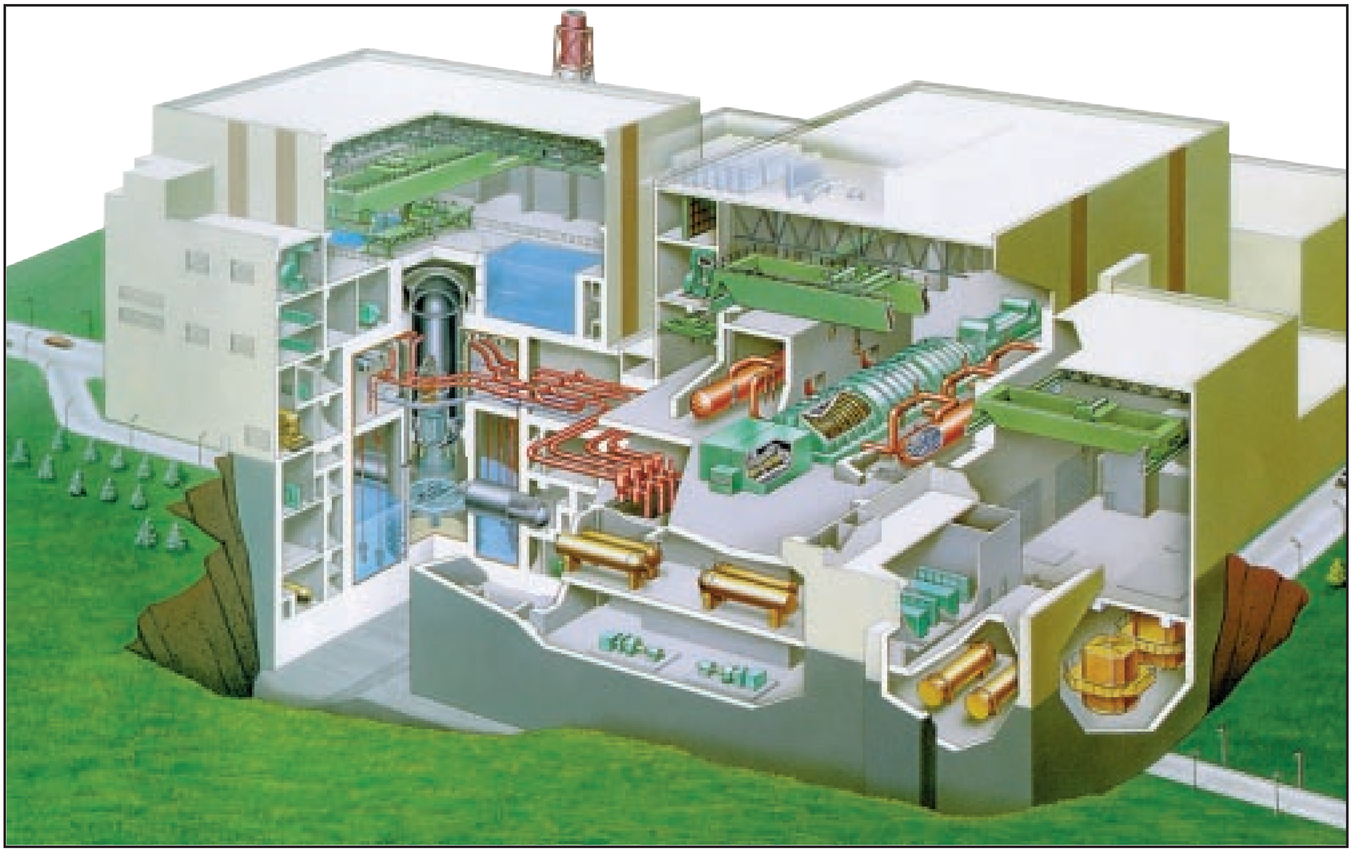


Figure 17: Cutaway view of a BWR Reactor

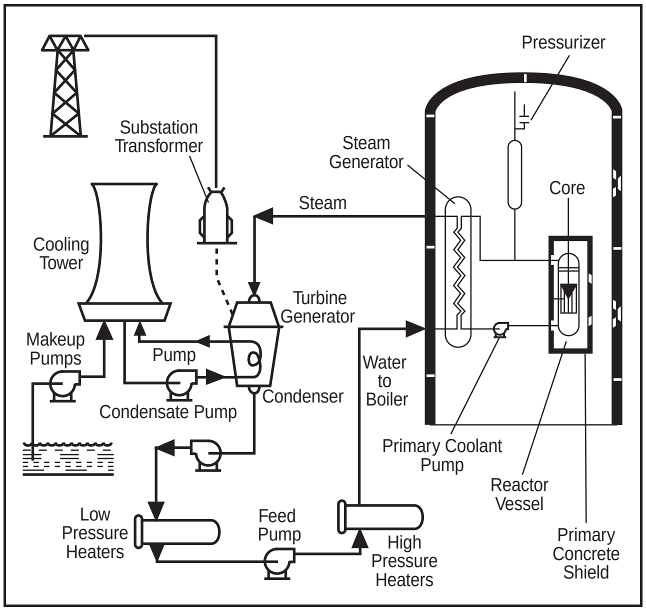


Figure 18: Nuclear Reactor

Nuclear power plants operate at lower temperatures and pressures than typical fossil powered units and therefore have some subtle differences. Because of the lower temperatures and pressures in the nuclear steam cycle, the limits on oxygen and other non-condensable gases in the feedwater are less stringent and can normally be controlled through condenser hotwell deaerators. For this reason, most U.S. nuclear plant feedwater systems are totally enclosed and do not incorporate a classic deaerating heater.

Breeder Nuclear Reactors

The conventional nuclear reactor requires a highly refined uranium-235 or plutonium fuel and accounts for virtually every commercial nuclear power plant in operation. Uranium-235 accounts for less than one percent of the naturally occurring uranium. Most uranium exists as the isotope uranium-238. Breeder reactors were developed to utilize the more plentiful uranium-238 as fuel. Breeder reactors get their name from their characteristic of actually producing more fissionable material than they use. This is accomplished by building a core of fissionable plutonium-239 with an outer layer of uranium-238. As the plutonium-239 undergoes the fission process, it releases neutrons that when added to the nucleus of a uranium-238 atom, transform it to plutonium-239. The plutonium can then be used in the fission process.

Because plutonium is used to make nuclear weapons, has a half-life of 24,000 years and is extremely toxic, breeder reactors have been the center of much controversy. Breeder reactors also require liquid sodium as a core coolant. Liquid sodium is very reactive and actually is flammable in contact with air or water. A problem with leaks of sodium at existing breeder reactors has also slowed the expansion of this technology.

Boiling Water Reactor Safety Systems

In addition to the typical systems used in power generation, nuclear power plants utilize many auxiliary systems specific to nuclear power generation. These auxiliary systems can be broken into two general categories: systems necessary for normal operations and systems that provide backup or support during upset conditions. Brief descriptions of some of the auxiliary systems for a BWR are given below. Although specific to a BWR, many identical or similar systems would be found in a PWR.

SYSTEMS FOR NORMAL PLANT OPERATIONS

Reactor Water Cleanup System

The reactor water cleanup system provides continuous purification of a portion of the reactor coolant in order to reduce the concentration of fission products.

Shutdown Cooling Function of the Residual Heat Removal System

The shutdown cooling function of the residual heat removal system removes heat from the nuclear system during shutdown and prior to refueling.

SYSTEMS FOR ABNORMAL PLANT OPERATIONS

Standby Liquid Control System

The standby liquid control system is a redundant control system capable of shutting the reactor down from rated power operation to the cold condition. Operation of this system has not been required in any commercial boiling water reactor. This system consists of a large storage tank filled with sodium pentaborate, pumps, valves, piping and instrumentation. This equipment injects the sodium pentaborate into the reactor core and shuts down the reactor without the use of additional systems.

Reactor Core Isolation Cooling System

The reactor core isolation cooling system maintains sufficient water in the reactor pressure vessel to cool the core in the event the vessel becomes isolated from the turbine steam condenser accompanied by a loss of feedwater flow. The system also allows for complete plant shutdown under conditions of loss of the normal feedwater system. This is accomplished by maintaining the necessary reactor water inventory until the reactor vessel is depressurized, allowing the operation of the shutdown cooling function of the residual heat removal system.

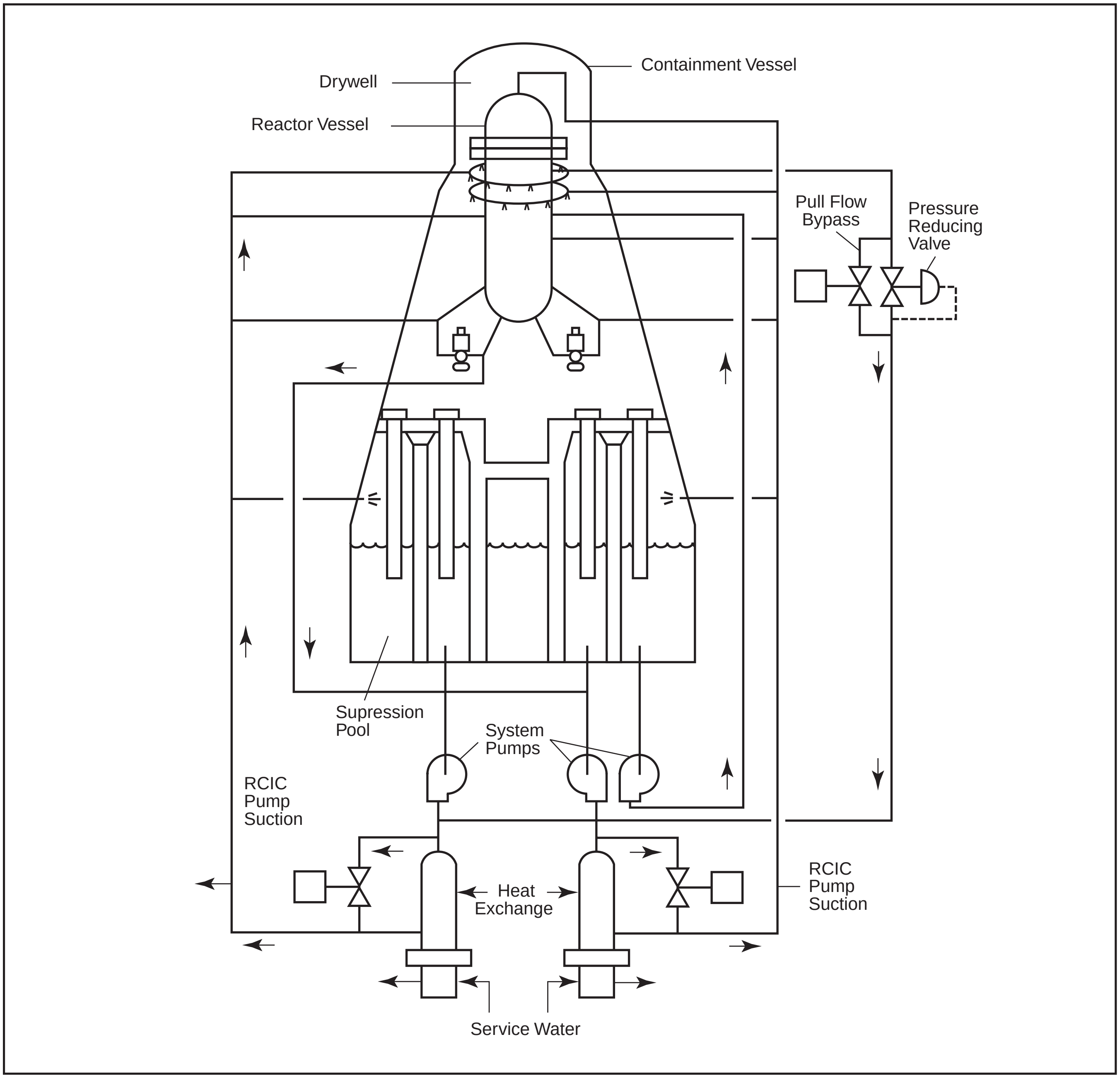


Figure 19: Residual Heat Removal System

High Pressure Core Spray System

The high pressure core spray system depressurizes the nuclear boiler system and provides makeup water in the event of a loss of reactor coolant. It also prevents fragmentation of the nuclear core in the event the core becomes uncovered.

Low Pressure Core Spray System

The low pressure core spray system prevents fragmentation of the nuclear core in the event the core is uncovered by loss of coolant by directing jets of water down into the fuel assemblies.

Residual Heat Removal System

The residual heat removal system removes post-power energy from the nuclear boiler under normal and abnormal conditions. The residual heat removal system consists of several subsystems, including low pressure coolant injection, suppression pool cooling, containment spray cooling, reactor steam condensing and nuclear boiler shutdown cooling. A simplified schematic of the residual heat removal system is shown in Figure 19.

Gas Turbines

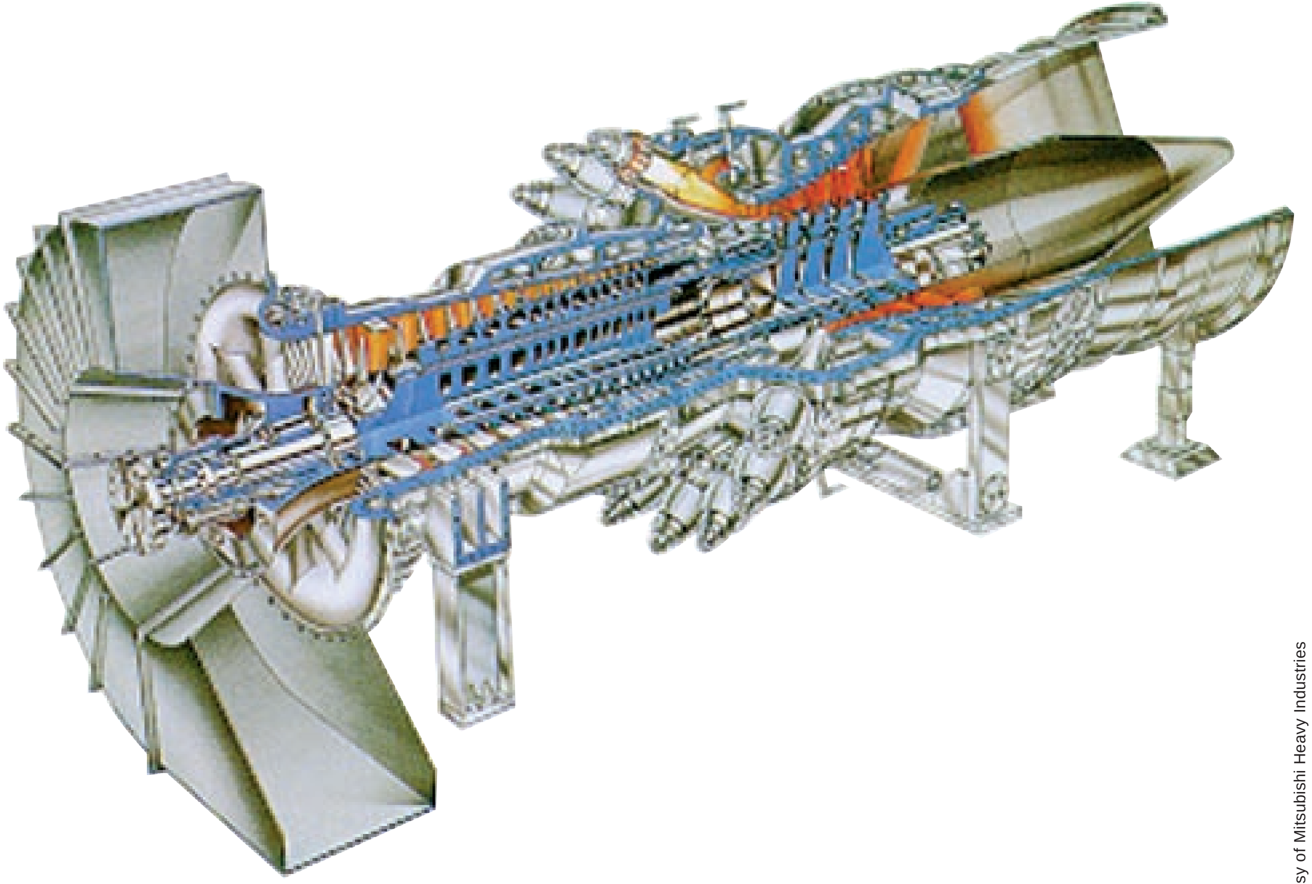
Gas turbines are often utilized to turn the generator rather than a steam turbine. Due to an abundance of inexpensive natural gas, a relatively easy permitting process, and a short construction cycle, gas turbines have become a very popular way of adding generating capacity. Gas turbines have quick start-up times and as a result are popular for peaking, remote, emergency and reserve power requirements. Gas turbines are available in a variety of sizes and configurations with modern turbines being delivered with generating capacity in excess of 200 MW and firing temperatures exceeding 2000° F.

Gas turbines can be designed and built specifically for power generation purposes or may be adapted from other applications. An example of an adapted turbine is the aeroderivative turbine. An aeroderivative turbine is one that was originally designed for aviation use that has been converted for power generation.

Combined Cycle

Often, in order to increase efficiency of a gas turbine, a heat recovery steam generator (HRSG) is utilized to make use of the waste heat in the turbine exhaust to generate steam. The steam generated can then be routed through a steam turbine and associated cycle to generate even more power. In this case, the waste heat from the gas turbine provides the same function as the coal, oil or gas, while the remainder of the process remains relatively unchanged. When a HRSG is utilized, the turbine is referred to as operating as a “combined cycle." A typical HRSG is illustrated in Figure 21.

Gas turbines without heat recovery boilers are called “simple cycle," while those operating with heat recovery are “combined cycle” (see Figure 22). Valve applications for a combined cycle installation have most of the same engineering challenges and concerns as those

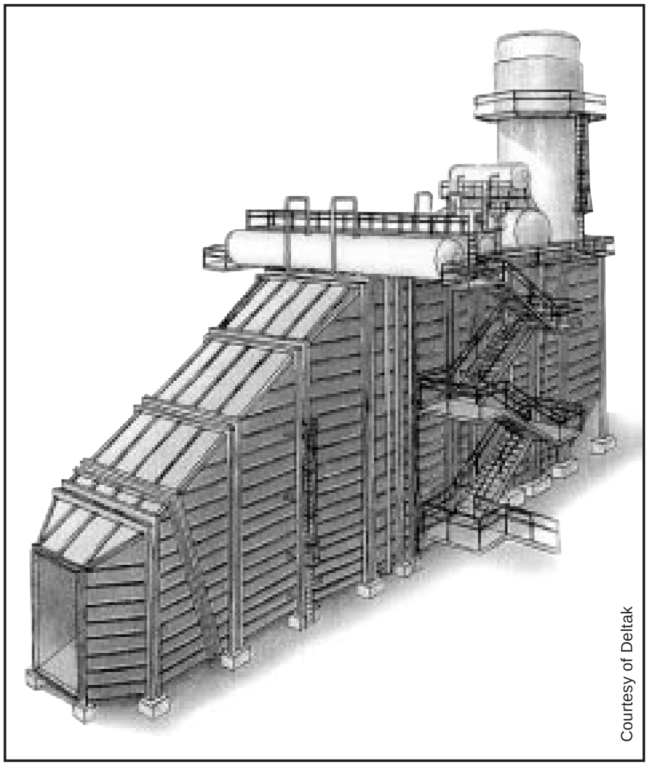


Courtesy of Mitsubishi Heavy Industries

Figure 20: Gas Turbine

found in a conventional fossil-fuel power plant. In addition to the control valves found on the HRSG, the turbine requires valves for fuel control and shut-off. It is not uncommon for gas turbines to operate under a 'dual fuel' control scheme that allows the use of either liquid or gaseous fuel. Dual fuel systems allow power generators to utilize inexpensive natural gas when it is available and switch over to petroleum when the natural gas is unavailable or higher in cost than the alternative petroleum fuel.

Gas turbines also often use control valves to inject DI (deionized) water or steam for power augmentation or as a means of controlling NOx emissions. Gas turbine control valves are usually specified by the turbine manufacturer and commonly have hydraulic or electric operators. For additional information on gas turbines and associated control valve applications, contact the Flowserve specialist assigned to the specific gas turbine manufacturer.



Courtesy of Deltak

Figure 21: HRSG

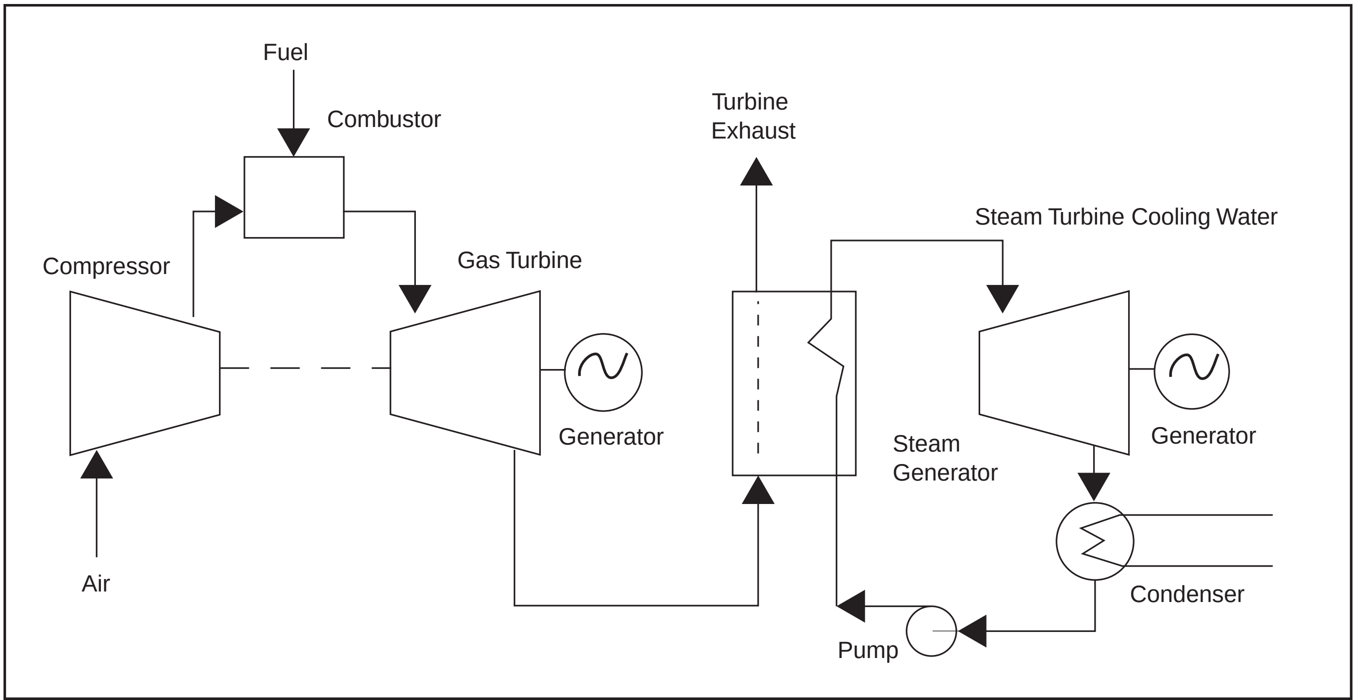


Figure 22: Combined Cycle Schematic

Glossary

Air Heater A heat exchanger for the recovery of energy from the flue gas. Preheats combustion air prior to entering the boiler. This is last heat exchanger in the flue gas prior to the stack.

Attemperator A device that controls steam temperature by diluting high temperature steam with low temperature water.

Atom The smallest component of an element having all the properties of the element, consisting of an aggregate of protons, neutrons, and electrons such that the number of protons determines the element.

Baseload The minimum amount of electric power or natural gas delivered or required over a period of time at a steady rate. The minimum continuous load or demand in a power system over a given period of time usually not temperature sensitive.

Biomass Organic material such as wood waste or garbage.

Blowdown Water that is bled from the boiler drum or steam supply system to control the concentration of total solids in the boiler water.

Boiling Water Reactor (BWR) A nuclear reactor that utilizes the moderator as the primary process fluid.

Boiler A device for generating steam for power, processing or heating purposes or for producing hot water for heating purposes or hot water supply.

Boiler Feedpump The main pump in a power plant.

Breeder Nuclear Reactor A nuclear reactor that utilizes Uranium-238 in the fission process and as a result produces fissionable plutonium. Because they create more fuel than they use, they are given the name breeder.

Closed Feedwater Heater A feedwater heater incorporating a tube and shell type heat exchanger to prevent direct mixing of the feedwater and extracted steam.

Cogeneration When a power plant produces both steam and electricity as end products.

Combined Cycle The combination of one or more gas turbine and steam turbines in an electric generation plant.

Condenser An extended surface heat exchange for the purpose of extracting the heat of a fluid.

Condensate Polishing The process removing minerals from the condensate.

Constant Enthalpy Process A process in which the enthalpy of the fluid at the beginning of the process is equal to the enthalpy of the fluid at the end of the process.

Condensate The liquid resulting when a vapor is subjected to cooling and/or pressure reduction.

Deaerator An open feedwater heater used to remove non-condensable gases from the feedwater.

Deionization The removal of all charged atoms or molecules from some material such as water. The process commonly employs one resin that attracts all positive ions and another resin to capture all negative ions.

Dissolved Solids Mineral impurities in the condensate, feedwater or makeup water that are in solution.

Drum A large vessel in the boiler where steam is separated from the water.

Economizer A heat exchanger prior to the air heater for preheating feedwater.

Evaporation The change of state from liquid to vapor.

Electron An elementary subatomic particle having a rest mass of 9.107 x 10^{-28}g and a negative charge of 4.802 x 10^{-10} statcoulomb. Also known as negatron. A subatomic particle of identical weight and positive charge is termed a positron.

Electrodialysis A method of purifying water where an applied electrical charge draws impurity through permeable membranes.

Extracted Steam Steam that is extracted from the turbine at intermediate locations between the entrance and the exit to the condenser.

Feedwater Heater A device used to preheat feedwater prior to entering the boiler.

Flash Tank A device, similar to a drum, used on start-up systems for once-through boilers to separate water and steam.

Flue Gases The products of combustion in the boiler.

Fossil Fuel Fuel such as coal, crude oil or natural gas, formed from fossil remains of organic material.

Generator A machine that converts mechanical energy into electrical energy. Generally rated in terms of real power (megawatts) and reactive power (Megavars) output or in terms of real power (megawatts) and power factor. Generators require a source of mechanical energy output (typically a turbine) and ancillary equipment to interface with the transmission network.

High Pressure Feedwater Heater A feedwater heater located after the main pump.

Half-life The time span necessary for the atoms of a nuclide to disintegrate by one-half.

Hotwell The area in a device such as a condenser or feedback heater where condensate collects.

Ion Exchange A demineralization process in which the cations in solution are replaced by hydrogen ions and the anions in solution are replaced by hydroxide ions.

Isotope Any of two or more forms of a chemical element, having the same number of protons in the nucleus, or the same atomic number, but having different numbers of neutrons in the nucleus, or different atomic weights.

Kilowatts A unit of electrical power equal to one thousand watts.

Kilowatt-Hour (kWh) One thousand watt hours.

Low Pressure Feedwater Heater A feedwater heater located prior to the main pump.

Makeup Water Treated raw water added to the system to compensate for that lost due to leakage, process requirements, evaporation, sampling, venting or blowdown.

Megawatt A unit of electrical power equal to one million watts or one thousand kilowatts.

MW Abbreviation for Megawatt.

Non-Condensable Gas Gases such as nitrogen and oxygen that do not condense at condenser pressures and temperatures.

NOx Abbreviation for Nitrous Oxide.

Nucleus The positively charged core of an atom; it contains almost all of the mass of the atom but occupies only a small fraction of its volume.

Nuclear Power Plant A facility in which heat produced in a reactor by the fissioning of nuclear fuel is used to drive a steam turbine.

Nuclear Reactor A device in which a fission chain reaction can be initiated, maintained and controlled. Nuclear reactors are used in the power industry to produce steam for electricity.

Neutron An elementary particle having no charge, mass slightly greater than that of a proton, and spin of $^{1}/_{2}$.

Open Feedwater Heater A feedwater heater that uses direct mixing of the feedwater with extracted steam.

Peaking When a facility is operated on a cyclic basis to provide for fluctuating demand.

Plutonium A fissionable material used in nuclear power plants and weapons.

Preheater A heat exchanger for the recovery of energy from the flue gas. Preheats combustion air prior to entering the boiler. Located prior to the preheater and after the superheaters and reheaters.

Pressurized Water Reactor (PWR) A nuclear reactor that separates the moderator from the process through the use of a heat exchanger.

Proton An elementary atomic particle of mass number 1 and a positive charge equal in magnitude but opposite in sign to the charge on an electron.

Recirculation System Systems designed to provide centrifugal pumps with a minimum flow to prevent overheating, cavitation and damage.

Reheater A heat exchanger, where steam that has already passed through part of the turbine, is reheated.

Reverse Osmosis A method of purifying water by applying hydraulic pressure to an impure stream and forcing it through a semipermeable membrane.

Rankine An absolute scale of temperature in which the degree intervals are equal to those of the Fahrenheit scale in which 0° Rankine equals -459.7° F.

Saturation Temperature The temperature at which vaporization takes place at a given pressure (saturation pressure).

Saturation Pressure The temperature at which vaporization takes place at a given temperature (saturation temperature).

Scale Mineral deposits on the inner walls of boiler piping.

Separator A device used on start-up systems for once-through boilers to separate water and steam.

Simple Cycle When gas turbines are used to generate electricity without heat recovery and steam generation, they are operating in a "Simple Cycle."

Sludge Boiler water solids which settle out in headers, drums and boiler surfaces.

Subcritical Operating temperatures and pressures are below the critical point of water (3203.6 psia.)

Super-Critical Operating temperatures and pressures are above the critical point of water (3203.6 psia.)

Superheat The process of raising the steam temperature above the saturation temperature.

Superheater A heat exchanger where main steam is heated beyond the saturation temperature.

Suspended Solids Mineral or organic impurities in the condensate, feedwater, or makeup water that are not dissolved.

Turbine The part of a generating unit usually consist of a series of curved vanes or blades on a central spindle, which is spun by the force of water, steam or hot gas to drive an electric generator. Turbines convert the kinetic energy of such fluids to mechanical energy through the principles of impulse and reaction, or a measure of the two.

Ultrafiltration A method of purifying water by forcing it through a filtering membrane.

Uranium-235 A highly refined and rare isotope of Uranium. Uranium-235 is the primary fission material for boiling water and pressurized water reactors.

Uranium-238 The most plentiful isotope of Uranium.

Venturi A constricted area in the flow passage vacuum that causes an increase in fluid velocity and a corresponding decrease in pressure.

Watthour (Wh) An electrical energy unit of measure equal to 1 watt of power supplied to, or taken from, an electrical circuit steadily for 1 hour.

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