7

Thermal Power Station (Components and Working)

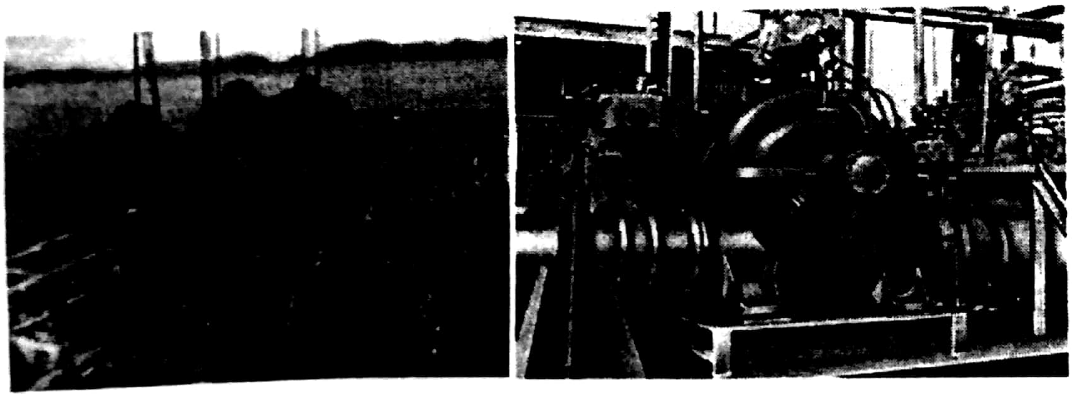
7.1. Overview

The thermal power station is a complex electro-mechanical system with a larger share of mechanical devices, providing power to drive the generator to produce electric power. In a typical large thermal electric power station different components are connected to form a complex network of pipes and gadgets, which work in a coordinated manner. The major components of a thermal power station are:

1. Feed water pump.
2. Boiler (steam generator)
3. Steam turbines.
4. Condensation unit and cooling tower.
5. Generator (Alternator).

7.2. Feed-Water Pump

A pump is a mechanical device using suction or pressure to raise, move, compresses or force fluids. Pumps generally fall into three major groups: direct lifting pumps, displacement pumps and gravity pumps. Boiler feed water pump is used to supply water to the boiler drum at desired pressure and temperature and is located at the inlet of boiler. Boiler feed pump extract water from a water source (river, lake or a pond) through de-aerator and feed it to the boiler drum via pre-heaters or economizer. Feed-water often has oxygen dissolved in it at objectionable levels, which comes from air in-leakage from the condenser, pump seals, or from the condensate itself. The oxygen is removed in a de-aerator. De-aerators function on the principle that oxygen is decreasingly soluble as the temperature is raised. This is done by passing a stream of steam through the feed-water. De-aerators are generally a combination of spray and tray type. One problem with the control of de-aerators is ensuring sufficient temperature difference between the incoming water temperature and the stripping steam. If the temperature is too close, not enough steam will be available to exclude oxygen from the 'make-up' water.



(a) (b)

Figure 7.1: (a) Intake Pipes (b) Pumping Unit

Figure 7.1(a) is a photograph of intake pipes of pumping units, which draws water from a river and figure 7.1(b) is a photograph of a pumping unit.

Boiler feed pumps usually rotates at a high speed, typically with 5000 rpm and can deliver about 300 tons of water per hour. The most common type of feed water pump used in thermal power plants is centrifugal; both single and multi-stage, depending on the duty to be performed and size of the plant. Typical feed water pumps are shown in figure 7.2.

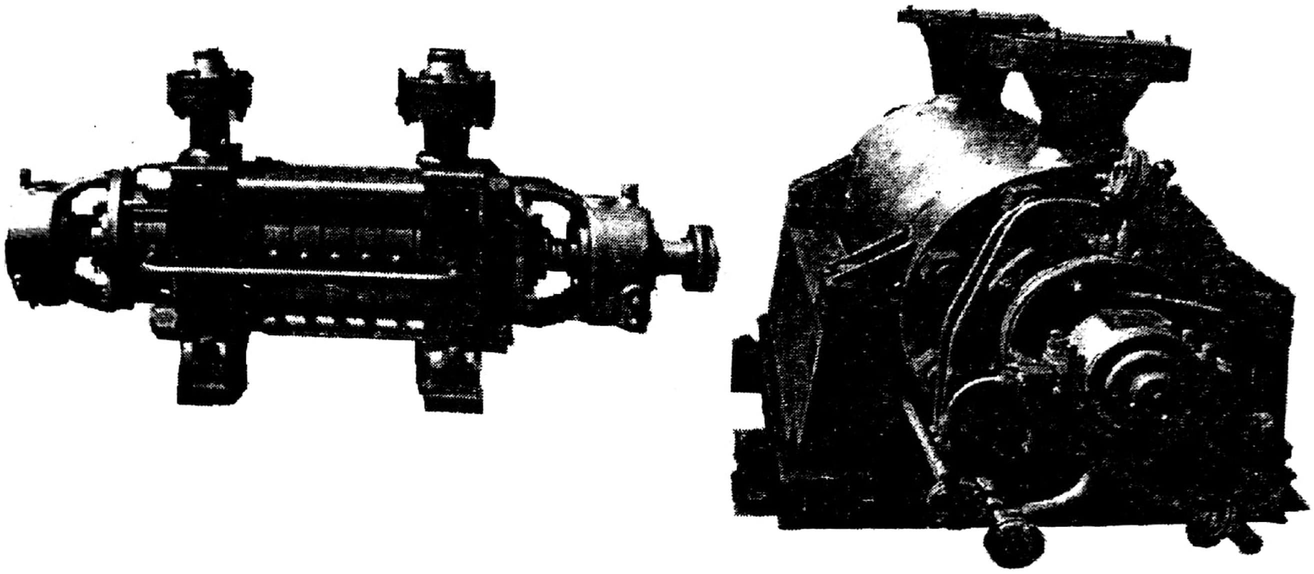
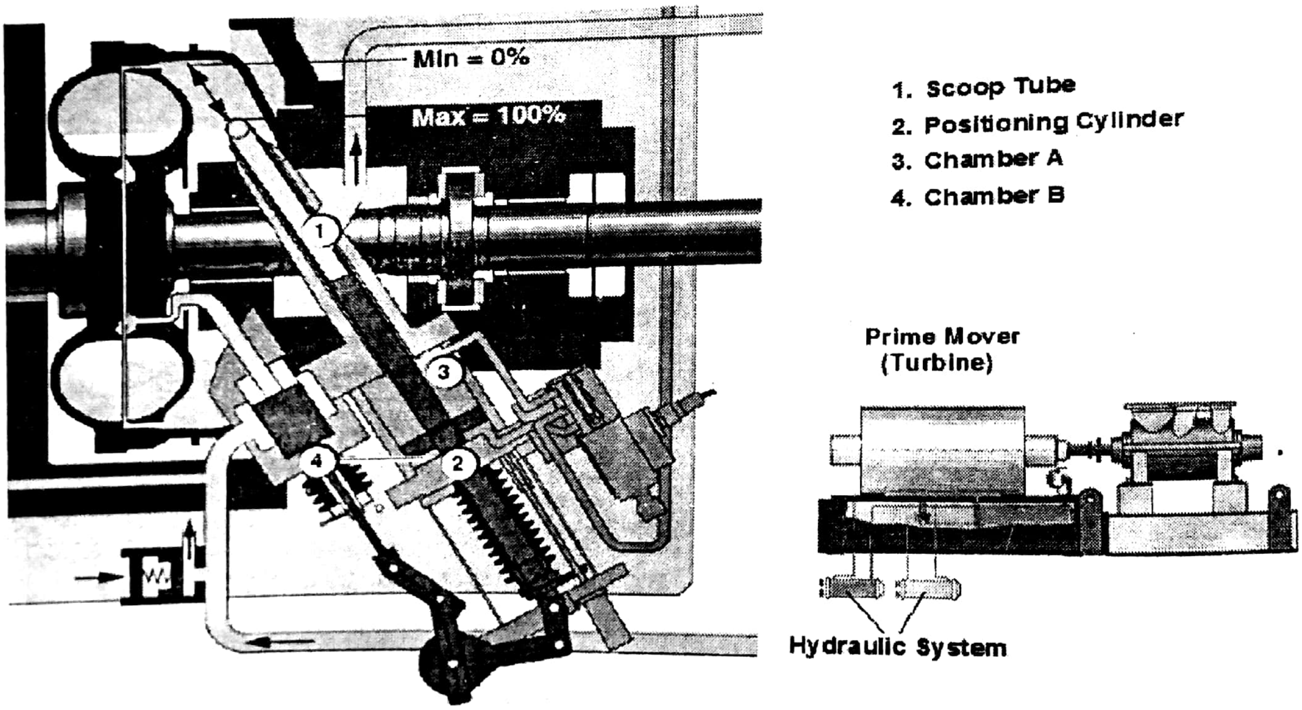


Figure 7.2: Feed Water Pumps

The most common pump used in large thermal power plants to feed water to the boiler is a multistage centrifugal. The main parts of this pump are impeller, stainless steel two-piece twin volute and stage pieces, combination of balancing drum and disc, shaft and gland packing. A heavy cylindrical forged steel barrel is an integral part for the stages to be stacked and closed at one end by a bolt on the head. The stages inside barrel casing are split radially. In few pumps, the stages are also split axially. The advantage of barrel type feed pump is that it has smaller number of joints to be sealed against the high pressure action and this minimize leaking. As the stages multiply, the boiler feed pump has an increased length and to attain radial rigidity, bigger shaft is designed and installed for reliability. Although, in these pumps where the stages are less, the reliability is high but efficiency is affected; the reason being increase in diameter of the shaft. The driving power to the feed water pump is generally provided by mechanical means incorporating servo-mechanism hydraulic system shown in figure 7.3(a). Hydraulic coupling is used to transmit power in a wear-free manner from a prime mover (steam turbine) to a pump as shown in figure 7.3(b). The power is transmitted by the following methods:

1. By means of a connecting coupling between the prime mover and geared variable speed coupling.
2. By means of a step-up gear unit between the input shaft of the prime mover and primary shaft of the pump.
3. Hydro-dynamically by means of the working oil between the primary wheel and the secondary wheel.



(a)

(b)

Figure 7.3: (a) Hydraulic Control System (b) Hydraulic System incorporated with Turbine and Pump

The control at the hydraulic coupling is done by the scoop tube, which provides variable adjustment of the driven machine's (pump) speed. The power from the driving machine (turbine) is transmitted to the primary wheel of the hydraulic system to the working oil. The working oil is accelerated in the primary wheel, and the mechanical energy is converted into the energy of fluid flow. The secondary wheel picks up the flow energy and converts it into mechanical energy. This energy is transmitted to the driven machine. The speed of the driven machine is controlled by varying the amount of oil in the coupling during operation with the aid of the adjustable scoop tube as follows: Scoop tube advances as far as possible into the scoop chamber of the coupling (0% position), indicating minimum oil ring and minimum speed. Scoop tube retracted as far as possible out of the scoop chamber of the coupling (100% position), indication maximum oil ring and maximum output speed.

7.2.1. Selection of Feed Water Pump

The selection of boiler feed water pump is dependent on the capacity of the boiler. The operation of the pump may be continuous or intermittent that depends on the water level control of the boiler. A float type switch is provided in boilers with capacity 4500 kg/hr or lesser which ensure the programmed level of water in the boiler, which is intermittent operation. The boilers having capacity higher than 4500 kg/hr will have modulating feed water regulator to feed the water continuously at diverse flow rates to satisfy the need of maintaining designed water level in the boiler, which is a continuous operation. Boiler feed water pumps can usually handle temperature up to 110°C. For higher temperatures, an external water cooling method is employed. The de-aerator pump used in power plants is, however, designed for higher temperatures.

7.2.2. Seals and Supports

As mentioned earlier, the most common pump used in thermal power plants is a multistage centrifugal pump for feeding water to boilers. In view of reliability, the bearing used in these boiler feed pumps is 'Kingsbury Thrust' or

'Journal' type bearing. Categorically, in low pressure installations, horizontal single stage volute type centrifugal pumps are more in use. For medium pressure below 100 bars, split case multistage twin volute diffuser pumps are common because of the difficulties found in sealing the case joint surfaces. The seals used in boiler feed pumps are generally stuffing box type and injected condensate to avoid leakage of feed water. Asbestos gland packing is out-dated due to health hazards and is replaced by non-asbestos braided gland packing which include graphite and poly-tetra fluoro-ethylene (PTFE), Aramid (portmanteau of aromatic polyamide) or in combination due to their self-lubricating properties. Hence the scoring of shaft is avoided, leakages are reduced and the life of shaft is enhanced. The selection of gland packing depends on the temperature, flow rate etc. In some power plants, mechanical seals are also used but rubbing speed is always a problem due to the large diameter and high speed shafts.

7.3. Boiler (Steam Generator)

Boiler is an essential component of a thermal power plant, which is an enclosed container or vessel where heat energy due to combustion of fuel is used to convert fluid from liquid to vapor phase (water into steam) and is sometimes referred to as a phase changer. Boiler, together with its associated systems is referred to as a steam generator. The essential components of a steam generator are as follows:

1. Steam drum
2. Primary Superheater, Secondary Superheater and Tertiary Superheater
3. Re-heater
4. Attemperators
5. Economizer
6. Draft fans
7. Ducts and flues

8. Burner system
9. Piping and valves

The basic working principle of a boiler is simple and easy to understand. The boiler is essentially a closed vessel inside which water is stored. Fuel (generally coal) is bunt in a furnace and combustion process produces hot gases. These hot gases come in contact with water where the heat of these hot gases transfers to the water and consequently steam is produced. In boilers designed for thermal power plants, differential heating takes place, and each area of the boiler is at different temperature. The water which is heated is therefore made to flow in tubes on the surface of the boiler. The steam produced is then piped to the turbine of thermal power plant. Thermal power plant boilers are different because of the complexity of the process and different types of system involve in the entire combustion process. The main objective of boiler in thermal power plant is to maximize the efficiency that is, the ratio of net output energy obtained from input energy.

To maximize efficiency it is important to construct / assemble water tube in the way to maximize heat absorption by conduction, which gives rise to different process. The following sub-systems are involved that are; economizer, pre-heater and re-heater and these sub-systems along with the boiler is then referred to as steam generator. Most of the boiler structure is made up of steel. Firstly, water is taken into the boiler through a water source. If water is available in a plenty in the region, then the source is an open pond or river. If water is in limited availability, then it is recycled and the same water is used over and over again; of course along with make-up water. The boiler is heated with the help of oil, coal or natural gas as fuel. A furnace is used to combust the fuel and supply the heat produced to the boiler. The increase in temperature helps in the transformation of water into steam. An economizer uses the heat from the exhaust gases to heat the feed water. An air pre-heater heats the air sent into the combustion chamber to improve the efficiency of the combustion process. There is a separate residue and ash collection system in place to collect all the waste materials from the combustion process and to prevent them from escaping into the atmosphere. Apart from this, there are various other monitoring systems and instruments in place to keep track of the functioning of all the devices.

7.3.1. Types of Boiler

Boilers can be classified according to the end use, such as for heating, power generation or other processes. They can be classified according to pressure, materials of construction, size tube contents (for example, waterside or fireside), firing, heat source or circulation. Boilers are also distinguished by their method of fabrication. Accordingly, a boiler can be pack-aged or field-erected. Sometimes boilers are classified by their heat source. For example, they are often referred to as oil-fired, gas-fired, coal-fired, or solid fuel–fired boilers. There are mainly two types of boilers that are used in thermal power stations; fire tube boiler and the water tube boiler. In fire tube boiler, there are numbers of tubes through which hot gases are passed and water surrounds these tubes. Water tube boiler is reverse of the fire tube boiler. In water tube boiler the water is heated inside tubes and hot gases surround these tubes.

Fire Tube Boiler: Figure 7.4 shows the simple schematic and cut-away view of a fire tube boiler. As is indicated from the name, the fire tube boiler consists of series of straight tubes that are housed inside a water-filled outer shell through which hot gases are passed. The tubes are arranged so that hot combustion gases flow through the tubes. These hot gas tubes are immersed into water, in a closed vessel and as such they heat the water surrounding the tubes, thus convert water into steam; the steam remains in same vessel. The water is confined by the outer shell of boiler. As the water and steam both are in same vessel a fire tube boiler cannot produce steam at very high pressure. To avoid the need for a thick outer shell, fire tube boilers are used for lower pressure applications. Fire tube boilers typically have a lower initial cost, are more fuel efficient and are easier to operate, but they are limited generally to capacities of

25 tons per hour and pressures of 17.5 kg/cm^2. However, in recent years the size of fire tube boilers has increased.

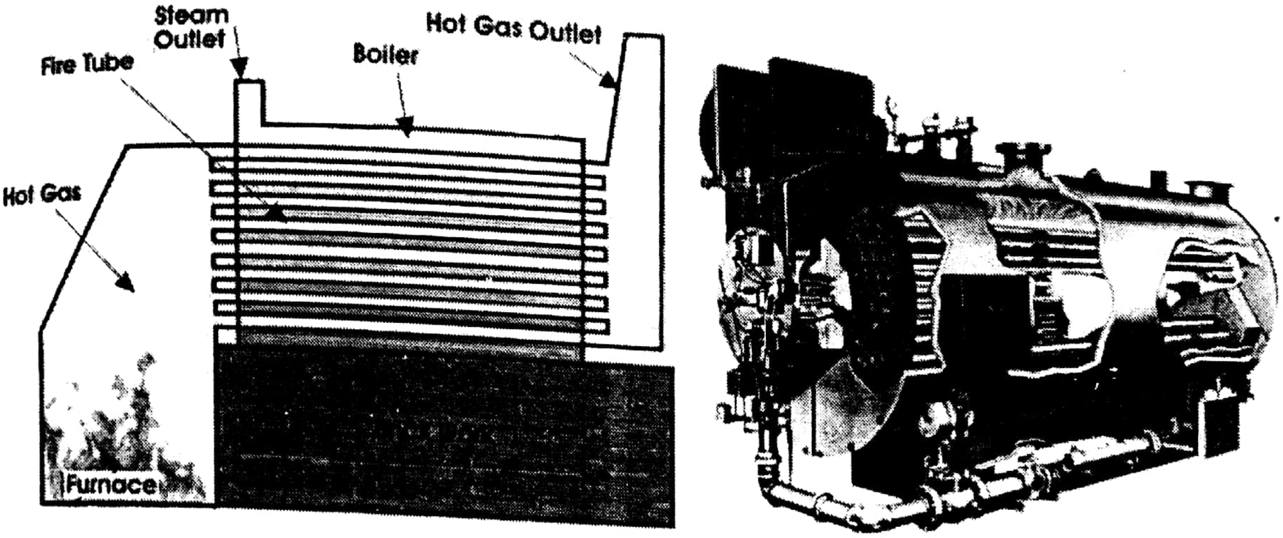


Figure 7.4: Illustration and Cut-away View of a Fire Tube Boiler

Most recent modern fire tube boilers have cylindrical outer shells with a small round combustion chamber located inside the bottom of the shell. Depending on the construction details, these boilers have tubes configured in one, two, three, or four pass arrangements. Because the design of fire tube boilers is simple, they are easy to construct and can be transported fully assembled as a package unit. There are different types of fire tube boiler likewise, external furnace and internal furnace fire tube boiler. External furnace boiler can be again categorized into three different types

1. Horizontal return tubular boiler.
2. Short fire box boiler.
3. Compact boiler.

Again, internal furnace fire tube boiler has also two main categories such as horizontal tubular and vertical tubular fire tube boiler. Normally horizontal return fire tube boiler is used in thermal power plant of low capacity. It consists of a horizontal drum into which there are number of horizontal tubes submerged in water. The fuel (normally coal) is burnt below these horizontal drum and the combustible gases move to the rear from where they enter into fire tubes and travel towards the front into the smoke box. During this travel of gases in tubes, they transfer their heat into the water and steam bubbles come up. As steam is produced, the pressure of the boiler develops in the closed vessel. The advantages of fire tube boilers are:

1. It is simple and compact in construction and has low cost.
2. Fluctuation of steam demand can be met easily.

The disadvantage of fire tube boiler

1. As the water required for operation of the boiler is quite large, it requires long time for raising steam at desired pressure.
2. As the water and steam are in same vessel the very high pressure of steam is not possible.
3. The steam received from fire tube boiler is not very dry.

Water Tube Boiler: In a water tube boiler, sometimes referred to as 'water in tube', the water is heated inside tubes and the hot gases surround them. Figure 7.5 shows a schematic and cut-away view of a typical water tube boiler. In water tube boilers, the conditions are reversed with the water passing through the tubes and the hot gases passing outside the tubes. These boilers can be of a single or multiple-drum type. They can be built to any steam capacity and pressures, and have higher efficiencies than fire tube boilers. Water tube boilers are designed to circulate hot combustion gases around the outside of a large number of water filled tubes. The tubes extend between an upper header, called a steam drum, and one or lower headers or drums. In the older designs, the tubes were either straight or bent into simple shapes. Modern boilers of this type have tubes with complex and diverse bends. Because the pressure is confined inside the tubes, water tube boilers can be fabricated in larger sizes and used for higher-pressure applications.

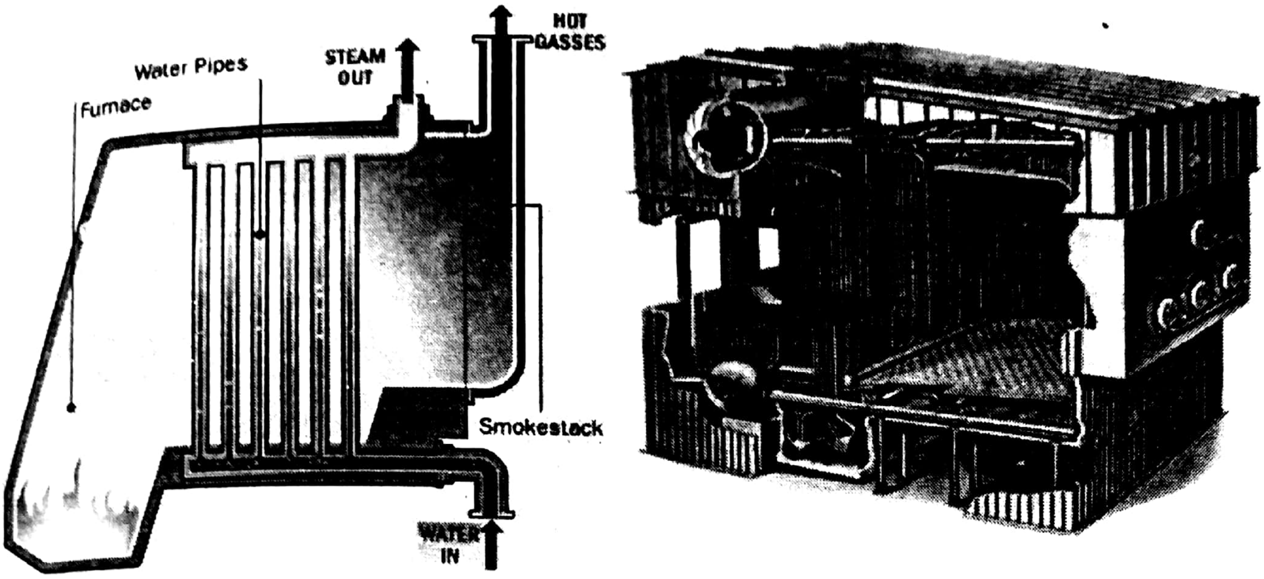


Figure 7.5: Illustration and Cut-away View of a Water Tube Boiler

Small water tube boilers, which have one and sometimes two burners, are generally fabricated and supplied as full packaged units. Because of their size and weight, large water tube boilers are often fabricated in pieces and assembled in the field. Almost any solid, liquid or gaseous fuel can be burnt in a water tube boiler. The common fuels used are coal, oil and natural gas. Besides, biomass and other solid fuels such as municipal solid waste, tyre-derived fuel and wood. However, design of water tube boilers that burn these fuels can be significantly different. Coal-fired water tube boilers are used in thermal power plants and are classified into three major categories; such as:

1. Horizontal Straight Tube Boiler.
2. Bent Tube Boiler.
3. Cyclone Fired Boiler.

Horizontal Straight Tube Boiler can be further sub-divided into two different types:

1. Longitudinal Drum Water Tube Boiler.
2. Cross Drum Water Tube Boiler.

Bent Tube Boiler also can be further sub-divided into four different types:

1. Two Drum Bent Tube Boiler.
2. Three Drum Bent Tube Boiler.
3. Low Head Three Drum Bent Tube Boiler.
4. Four Drum Bent Tube Boiler.

There are many advantages of water tube boiler due to which these types of boiler are essentially used in large thermal power plant.

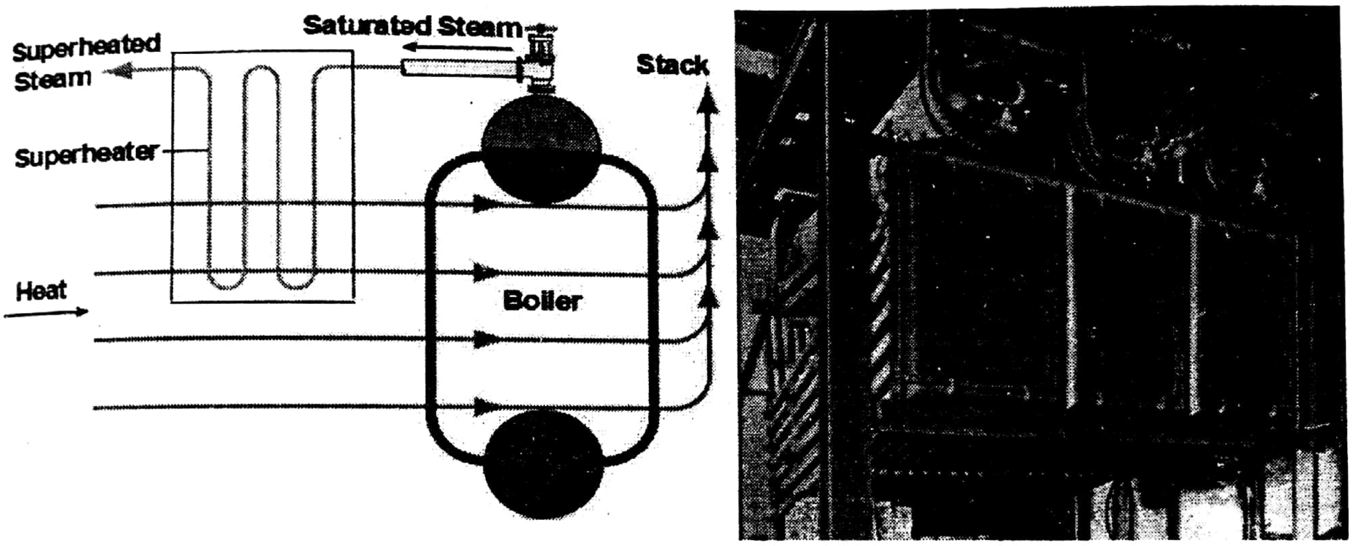
1. Larger heating surface can be achieved by using more numbers of water tubes.
2. Due to convectional flow, movement of water is much faster than that of fire tube boiler; hence rate of heat transfer is high which results into higher efficiency.
3. Very high pressure in order of 140 kg/cm^2 can be obtained smoothly.

The disadvantage of water tube boilers are:

1. Being of large size and heavy, it is not compact in construction.
2. Cost wise, water tube boilers are expensive.
3. Because of large size, it is difficulty to transport and therefore it is usually assembled on-site.

7.3.2. Superheater

A superheater is a device incorporated in boilers that is used to convert wet saturated steam into dry steam at high temperature and pressure. Superheaters are a very beneficial part of the steam cycle, because dry steam contains more thermal energy and increases the overall efficiency of the thermodynamic cycle. Dry steam is also less likely to condense within the cylinders of a reciprocating engine or the casing of a steam turbine. Figure 7.6 shows a schematic diagram and a photograph of a typical superheater. As shown in figure 7.6(a), the steam produced in the boiler is further heated by passing it through a superheater coil on its way to the turbine in a thermal power plant. A common superheater is a group of parallel pipes with their surfaces exposed to the hot gases in the boiler furnace.



(a) (b)

Figure 7.6: Superheater (a) Schematic Diagram (b) Photograph

By means of superheaters the greatest output of work in relation to the heat supplied is secured by using a low condenser temperature and a high boiler pressure. Superheaters have many advantages, the most notable being reduced fuel consumption and increased efficiency. The only disadvantage is increased maintenance costs, but superheaters still generally are considered to be worth any extra costs. If accurate control of the degree of superheat is required, as would be the case if the steam is to be used to drive turbines, then a device known as attemperator or de-superheater is fitted. This is a device is usually located at the exit of the superheater, but may be placed in an intermediate position. Attemperator primarily controls the degree of superheat in a boiler with superheater by partially de-superheating the steam by the controlled injection of water into the superheated steam flow. This process is called attemperation. The degree of superheat will, however, depend on the steam load and the heat available, given the design of the superheater. The degree of superheat of the final exiting steam is generally not subject to wide variation because of the design of the downstream processes. Usually, boiler feed-water is used for attemperation. A direct contact attempaerator injects a stream of high purity water into the superheated steam. The water must be free of non-volatile solids to prevent objectionable buildup of solids in the main steam tubes and on turbine blades. Since attemperator water comes from the boiler feed-water, provision for it has to be made in calculating flows. The calculation is based on heat balance. The total enthalpy (heat content) of the final superheat steam must be the mass weighted sum of the enthalpies of the initial superheat steam and the attemperation water. Boiler superheaters can be found in two major varieties; radiant superheaters and convection superheaters.

Radiant Superheaters: Radiant super heaters are located directly within the combustion chamber of the boiler. This arrangement allows for the burner from the boiler to heat both the boiler tubing and the super heater tubes, making radiant superheater a highly effective device. These are most commonly found in modern steam power plants and also were widely used in steam automobiles in the past.

Convection Superheaters: Convection superheaters are most commonly found on steam powered locomotives. Much like a convection oven, this type of superheater utilizes the hot gases from the burner to reheat the steam. A convection superheater can be extremely efficient, because most of the thermal energy is given only to the boiler tubing, and what would normally be exhaust instead heats the superheater tubes. This type of superheater is also incorporated with the some of the boilers used in thermal power plants. On steam locomotives, convection superheaters are slightly different from what one would find in thermal power plants. Both use the same principle of utilizing hot gases, but locomotive superheaters usually are somewhat separate from the boiler itself.

Instead, they are positioned in front of the boiler, and hot gases from the boiler tubing go through tubing of the superheater. The general specifications of the boilers are listed in table 7.1.

Table 7.1: Specification of Boiler (Babcock-Hitachi Single Drum, Radiant-Natural Circulation Boiler)

Parameter	Specifications
Evaporation (BMRC)	1094.4 Ton/hour
Steam Pressure at SH outlet	181.1 bar(g)
Steam Temperature at SH outlet	541^0C
Feed water temperature	275.8^0C
Reheat steam flow	941.4 Ton/hour
Steam pressure at RH outlet	37.6 bar(g)
Steam temperature at RH outlet	541^0C
Steam temperature at RH inlet	328.6^0C
Ambient air temperature	34.8^0C
Draught system	Forced draught
Fuel	Natural gas, Mazout Oil

7.3.3. Economizer

The economizer is a heat exchanger device associated with the boiler through which the feed-water is pumped before entering the boiler. The economizer is installed in the feed-water circuit and is located between the main boiler water inlet and the exhaust gas circuit, but is a part of the boiler as shown in figure 7.7. The feed-water is pre-heated by the hot exhaust gases, which raises its temperature. The feed-water after passing through the economizer thus arrives in the boiler at a higher temperature than would be the case if no economizer was fitted. Less energy is therefore required to produce steam at sufficient temperature. Alternatively, if the same quantity of energy is supplied, then more high temperature steam is produced. The flue gases, having passed through the main boiler and the superheater are still at a high temperature. A boiler economizer captures the 'lost or waste heat' from the hot flue gases escaping from the hot stack or chimney of the boiler. The economizer typically transfers this waste heat to the boiler's feed-water or return water circuit, but it can also be used to heat domestic water or other process fluids. Boiler economizer improves boiler's efficiency by extracting heat energy from the flue gases discharged. Roughly, a 10°C increase in feed-water temperature will give an efficiency improvement of 2%. Because the economizer is on the high-pressure side of the feed pump, feed water temperatures in excess of 100°C are possible. The feed-water thus boils in the economizer before entering the boiler. The boiler water level controls should be of the 'modulating' type, (not 'on-off') to ensure a continuous flow of feed-water through the heat exchanger.

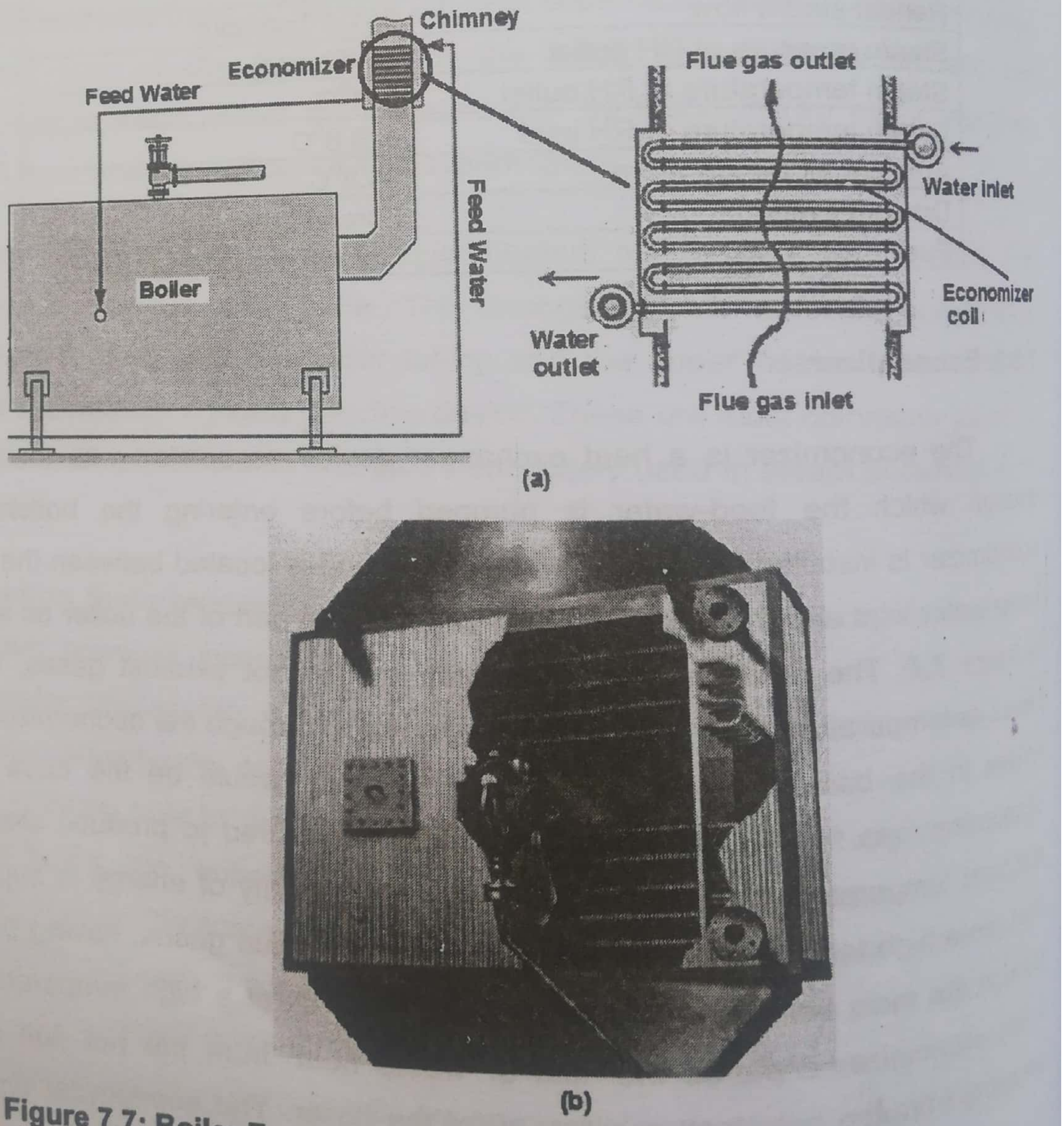


Figure 7.7: Boiler Economizer (a) Schematic (b) Cut-away View

In addition, capturing this normally lost heat by the use of economizer thus reduces the overall fuel requirements for the boiler. This is possible because the boiler feed-water or return water is pre-heated by the economizer therefore the boilers main heating circuit does not need to provide as much heat to produce a given output quantity of steam or hot water. Less fuel therefore result is savings, which reduces the overall cost of operation as well as fewer emissions; since the boiler now operates at a higher efficiency.

7.3.4. Re-heater

In modern high pressure steam power plants, steam exhausting the high pressure section of the turbine at around 41 bars and 310^{0}C is often returned to the boiler to be reheated back to the superheat temperature. The section of the boiler where this occurs is known as the reheat section shown in figure 7.8 and is usually located between the secondary and primary superheat sections. They are the same as the superheaters but their exit temperature is a little less, with pressure about 20-25% less than the superheater.

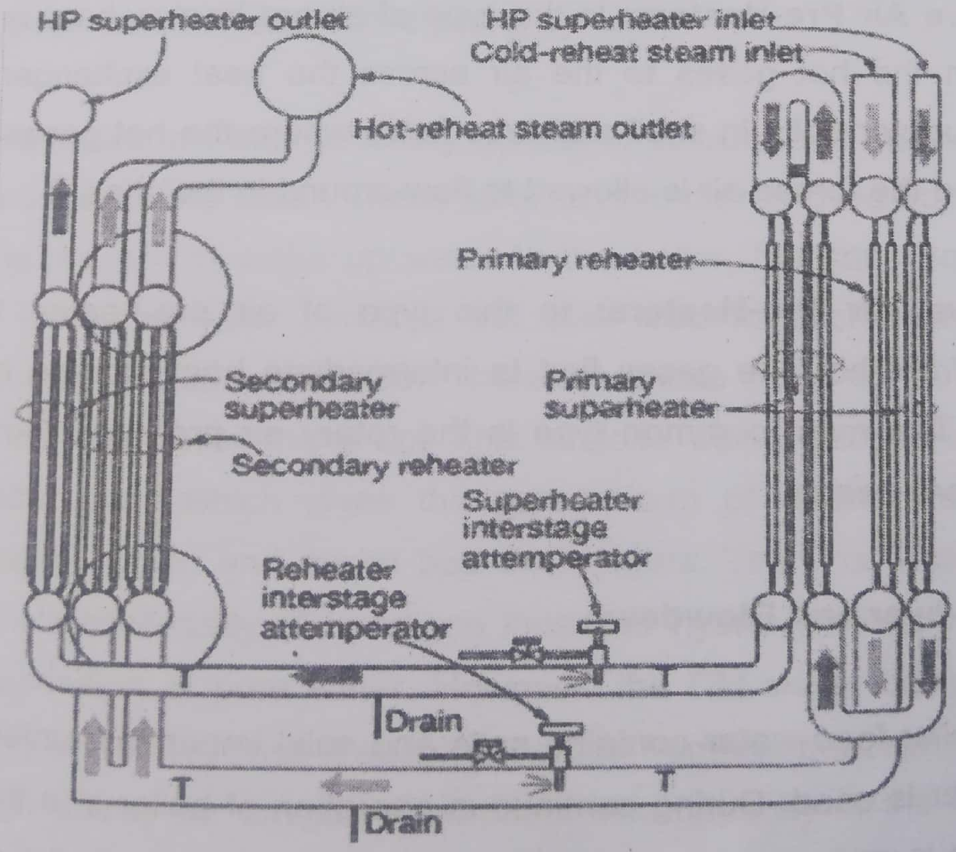


Figure 7.8: Re-heater System

Reheat temperature control is similar to that in the superheater section in that feed-water is sprayed into the steam path to control outlet temperature. In re-heaters, the attemperation spray is generally to the inlet rather than the outlet to reduce the potential for thermal stresses.

7.3.5. Air Pre-heaters

Air pre-heating is also a requirement for the operation of pulverized coal furnaces to dry the fuel, which is accomplished by using device known as air pre-heater. Air pre-heater is a simple heater or combination of heaters that heats the air before it enters the combustor, resulting in improved combustion and less fuel consumption thereby increasing the thermal efficiency. The fuel savings are nearly directly proportional to the air temperature rise in the pre-heater. Typical fuel savings are 4% for 1100^{0}C air temperature rise and about 11% for a 2760^{0}C temperature rise in the pre-heater. Air pre-heaters are of the following two types:

Recuperative Air Pre-Heaters: In this type of air pre-heater, heat is transferred directly from the hot gases to the air across the heat exchanger. They are commonly tubular units in shell and tube form, where the hot gases flow inside the tubes and the forced air is allowed to flow around in the shell.

Regenerative Air Pre-Heaters: In this type of air pre-heater, the heat is transferred from hot flue gases first to intermediate heat storage medium and then to air. The most common type is the rotary air pre-heater known as the Ljungstorm pre-heater.

7.3.6. Carry-over and Blowdown

All boiler feed-water contains salts and solid impurities, unless treated or distilled water is used. During continuous operation of boiler in a thermal power plant, water is converted to steam leaving behind concentrates in the boiler water. When the amount of concentrates exceeds a certain limit, it impairs steam purity. In order to keep concentrates within safe limits, the boiler water carrying excessive concentration of solid particles must be discharged and replaced by fresh feed-water. This process is called blowing down operation of the boiler and the discharged water is referred to as blowdown. The required blowdown B in percentage can be calculated by knowing the weight of feed-water W_F and the blowdown water W_B using:

$$B = \frac{W_B}{W_F} \times 100 \tag{7.1}$$

Modern boiler operation requires that the flow of impurities in the power plant steam-water circuit must be known to ensure safe operation. Water treatment should be made an essential practice by power plant operation engineers to avoid salts and solid impurities entering in the feed-water circuit. These are referred to as carry-over and such impurities produce scales and algae in the boiler and the associated piping system.

The impurities in water generally consist of calcium and magnesium salts imparting hardness to the water. These salts have to be removed from the water. If hardness is present in make up water to the boiler, the salts not only form deposits on the tube water surfaces but also lead to overheating in those localities resulting in tube fractures. Therefore these have to be completely removed for use as boiler make up. This is done using dematerialized (DM) water treatment plant which gives the purest form of water. This generally consists of cation, anion and mixed bed exchangers. The final water from this process consists essentially of hydrogen ions and hydroxide ions which is the chemical composition of pure water. However, the DM water being very pure becomes highly corrosive, once it absorbs oxygen from the atmosphere because of its very high affinity for oxygen absorption. The capacity of the DM plant is dictated by the type and quantity of salts in the raw water input. The storage tank for DM water is made from materials not affected by corrosive water, such as poly-vinyl chloride (PVC). The piping and valves are generally of stainless steel. Sometimes on top of the water in the tank a steam blanketing arrangement or stainless steel doughnut float is provided to avoid contact with atmosphere. DM water make up is generally added to the boiler at the steam space of condenser that is vacuum side. This arrangement not only sprays the water but also DM water gets de-aerated, with the dissolved gases being removed by the ejector of the condenser itself.

7.4. The Steam Turbine

A steam turbine is a device that converts the thermal energy of steam into mechanical energy by using it to turn the blades of a rotor. High-temperature, high-pressure steam passes through a nozzle or fixed blades and spurts out and expands, or has its direction altered into a high-speed jet that is directed against rotor blades which spin the shaft to which they are attached, creating rotational energy. In simple terms, the steam turbine's rotors are turned by the force of the steam in just the same way that a waterwheel is turned by the force of the flowing water.

The first device that may be classified as a steam turbine of reaction type was the classic Aeolipile, described in the 1st century by Greek mathematician at Alexandria in Roman Egypt. In 1551, a steam turbine was used in practical rotational applications by Taqi Al-Din in Ottoman Egypt. Later steam turbines were also described by Italian Giovanni Branca (1629) and John Wilkins in England (1648). In 1884 Sir Charles Parsons, used his first model of reaction type steam turbine to rotate a dynamo that generated 7.5 kW of electricity. The invention of Parson's steam turbine revolutionized power generation by producing cheap and plentiful electricity possible. Parsons had the satisfaction of seeing his invention adopted for all major power stations of the world. During a short time the size of generators had increased from his first 7.5 kW set up to units of 50 MW capacity. Steam turbines are made in a variety of sizes ranging from small of order of 0.75 kW (less than a horse-power) units used as mechanical drives for pumps, compressors and other shaft driven equipment, to 1500 MW (2000 Mhp) turbines used to generate large scale electricity. A typical power plant steam turbine rotates at 1800–3600 rpm; about 100–200 times faster than the blades spin on a typical wind turbine, which needs to use a gearbox to drive a generator quickly enough to make electricity. Steam turbines also need some form of control mechanism that regulates their speed, so they generate as much or as little power as needed at any particular time. Thus the demand on a power station can be fulfilled relatively quickly. Steam turbines therefore need to cope with fluctuating output even though their steam input may be relatively constant.

Energy in the steam after leaving the boiler is converted into rotational kinetic energy as it passes through the turbine. Stationary blades convert the potential energy of the steam (temperature and pressure) into kinetic energy (velocity) and direct the flow onto the rotating blades. The rotating blades convert the kinetic energy into forces, caused by pressure drop, which results in the rotation of the turbine shaft. The turbine shaft is connected to a generator, which produces the electrical energy. There are several classifications for modern steam turbines. These types include condensing, non-condensing, reheat, extraction and induction. Condensing or atmospheric turbines are most commonly found in electrical power plants. These turbines exhausts steam in a partially condensed state, typically of a quality near 90%, at a pressure well below atmospheric to a condenser. Non-condensing or back pressure turbines are most widely used for process steam applications. The exhaust pressure is controlled by a regulating valve to suit the requirements of the process steam pressure. These are commonly found at refineries, heating units, pulp and paper plants, and desalination facilities where large amounts of low pressure process steam are available. Reheat turbines are also used almost exclusively in electrical power plants. In a reheat turbine, steam flow exits from a high pressure section of the turbine and is returned to the boiler where additional superheat is added. The steam then goes back into an intermediate pressure section of the turbine and continues its expansion. Extracting type turbines are common in all applications. In an extracting type turbine, steam is released from various stages of the turbine, and used for industrial process or sent to boiler feed water heaters to improve overall cycle efficiency. Extraction flows may be controlled with a valve, or left uncontrolled whereas induction turbines introduce low pressure steam at an intermediate stage to produce additional power.

An ideal steam turbine is considered to be an isentropic device incorporating constant entropy process, in which the entropy of the steam entering the turbine is equal to the entropy of the steam leaving the turbine. Steam enthalpy is converted into rotational energy as it passes through a turbine stage. However, actual steam turbines are not purely isentropic, with typical isentropic efficiencies ranging from 20–90% based on the application of the turbine. The interior of a turbine comprises several sets of stationary (fixed) and rotating (movable) blades also referred to as buckets. One set of stationary blades is connected to the casing and one set of rotating blades is connected to the shaft.

Steam turbine systems are essentially heat engines for converting heat energy into mechanical energy by alternately vaporizing and condensing a working fluid in a closed system known as the Rankine cycle already discussed in chapter 6. This is a reversible thermodynamic cycle in which heat is applied to a working fluid in a boiler, first to vaporize and then superheated to increase its temperature and pressure. The high temperature vapour is then fed to a steam turbine, where it expands (pressure and temperature drops) thus imparting its energy to the rotor blades causing the rotor to turn. The vapour leaving the turbine is then condensed and pumped back in liquid form as feed-water to the boiler. The working fluid in a Rankine cycle thus follows a closed loop and is re-used constantly. The efficiency of a heat engine is determined only by the temperature difference of the working fluid between the input and output of the turbine. According to Carnot thermodynamic cycle the maximum efficiency available is:

$$\eta = 1 - \frac{T_C}{T_h} \qquad 7.2$$

Where T_h is the temperature in degrees Kelvin of the working fluid in its hottest state (after heat has been applied) and T_c is its temperature in its coldest state (after the heat has been removed). To maximize efficiencies, the temperature of the steam fed to the turbine can be as high as 900°C, while a condenser is used at the output of the turbine to reduce the temperature and pressure of the steam to as low a value as possible by converting it back to water. The condenser is an essential component necessary for maximizing the efficiency of the steam engine by maximizing the temperature difference of the working fluid in the machine.

Example 7.1: Use Carnot's law to calculate the efficiency of a steam turbine system with an input steam temperature of 543°C and a temperature of the condensed water of 23°C.

Given that: $T_C = 23^0\text{C}$ or 296^0K

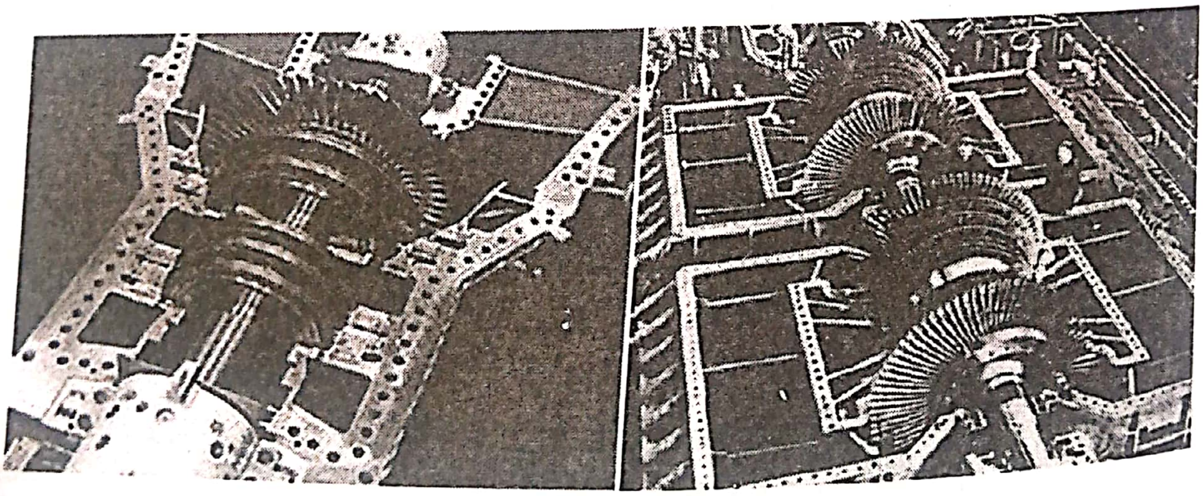
$T_h = 543^0\text{C}$ or 816^0K

Using: $$\eta = 1 - \frac{T_C}{T_h}$$

$$\eta = 1 - \frac{296}{816} = \mathbf{0.6373 \text{ or } 63.73\%}$$

The above situation does not take into account; heat, friction and pressure losses in the system. A more realistic value for the efficiency of the steam turbine would be about 50%.

To maximize turbine efficiency the steam is expanded, doing work, in a number of stages. Large machines are usually built with multiple stages to maximize the energy transfer from the steam. These arrangements include single casing, tandem compound and cross compound turbines. Tandem compound are used where two or more casings are directly coupled together to drive a single generator. A cross compound turbine arrangement features two or more shafts not in line driving two or more generators that often operate at different speeds. A cross compound turbine is typically used for many large applications. The sets of stationary and rotating blades intermesh with certain minimum clearances, with the size and configuration of sets varying to efficiently exploit the expansion of steam at each stage. These stages are characterized by how the energy is extracted from them and are known as either impulse or reaction turbines. Most steam turbines use a mixture of the reaction and impulse designs; each stage behaves as either one or the other, but the overall turbine system uses both. Typically, higher pressure sections are reaction type and lower pressure stages are impulse type. Figure 7.9 shows photograph of a single and multi-stage steam turbine used typically in thermal power plants.



(a) (b)

Figure 7.9: (a) Single-Stage Turbine (b) Multi-Stage Turbine

In a typical larger power stations, the steam turbines are compounded (see Appendix C) by splitting into three separate stages, the first being the High Pressure (HP), the second the Intermediate Pressure (IP) and the third the Low Pressure (LP) stage as shown in figure 7.10.

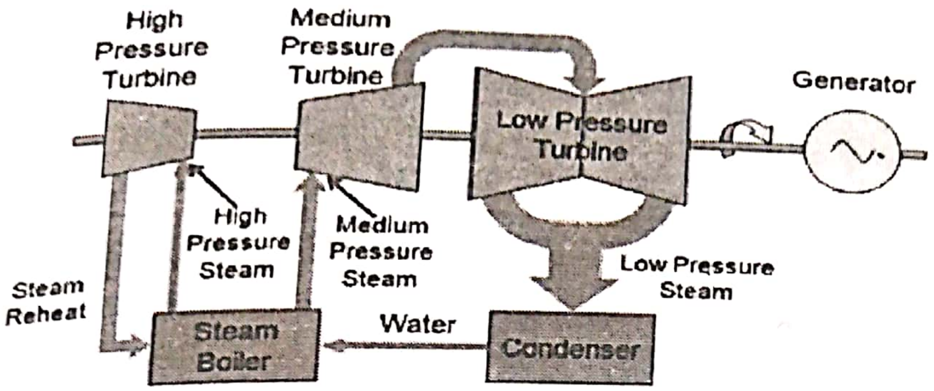


Figure 7.10: Three-Stage Turbine System (Source: Electropedia)

After the steam has passed through the HP stage, it is returned to the boiler to be re-heated to its original temperature although the pressure remains greatly reduced. The reheated steam then passes through the IP stage and finally to the LP stage of the turbine. Steam turbines can be configured in many different ways. Several IP stages can be incorporated into the one steam turbine. A single shaft or several shafts coupled together may be used. To reduce axial forces on the turbine rotor bearings the steam may be fed into the turbine at the midpoint along the shaft so that it flows in opposite directions towards each end of the shaft thus balancing the axial load. Either way, the principles are the same for all steam turbines. The configuration is decided by the use to which the steam turbine is put, co-generation or pure electricity production. For co-generation, the steam pressure is highest when used as process steam and at a lower pressure when used for the secondary function of electricity production.

Steam turbines, essentially used in thermal power plants for the generation of electricity are either impulse type or reaction type turbines. In an impulse turbine, the rotating blades are like deep buckets. High-velocity jets of incoming steam from carefully shaped nozzles forced into the blades, pushing them around with a series of impulses, and bouncing off to the other side with a similar pressure but much-reduced velocity. This design is called an impulse turbine and is particularly good at extracting energy from high-pressure steam. In a reaction turbine, there is a second set of stationary blades attached to the inside of the turbine case. These help to speed up and direct the steam onto the rotating blades at just the right angle, before it leaves with reduced temperature and pressure but broadly the same velocity as it had when it entered. In steam turbines, both sets of blades have to be made from incredibly tough materials capable of rotating at very high speeds with high-pressure steam blowing at them the whole time. A distinction is made between impulse and reaction turbine designs based on the relative pressure drop across the stage. There are two measures for pressure drop, the pressure ratio and the percent reaction. Pressure ratio is the pressure at the stage exit divided by the pressure at the stage entrance. Reaction is the percentage isentropic enthalpy drop across the rotating blade or bucket compared to the total stage enthalpy drop. Some manufacturers utilize percent pressure drop across stage to define reaction.

7.4.1. Impulse Turbine

An impulse turbine has fixed nozzles that orient the steam flow into high speed jets. These jets contain significant kinetic energy, which is converted into shaft rotation by the bucket-like shaped rotor blades, as the steam jet changes direction as shown in figure 7.11. High-pressure steam is fed to the turbine and passes along, through multiple rows of alternately fixed and moving blades of the turbine. From the steam inlet port of the turbine towards the exhaust point, the blades and the turbine cavity are progressively larger to allow for the expansion of the steam. A pressure drop only occurs across the stationary blades, with a net increase in steam velocity across the stage. As the steam flows through the nozzle its pressure falls from inlet pressure to the exit pressure (atmospheric pressure, or more usually, the condenser vacuum), thus giving a high expansion ratio of steam. Due to this high ratio of expansion of steam, the steam leaves the nozzle with a very high velocity. The steam leaving the moving blades has a large portion of the maximum velocity of the steam when leaving the nozzle. The loss of energy due to this higher exit velocity is commonly called the carry over velocity or leaving loss.

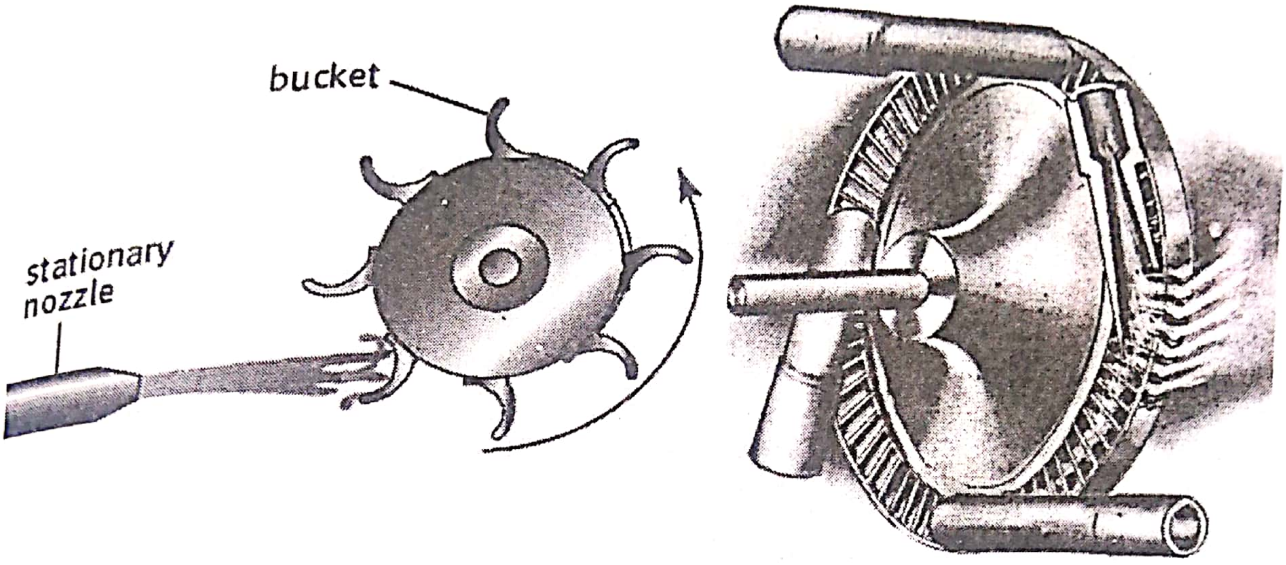
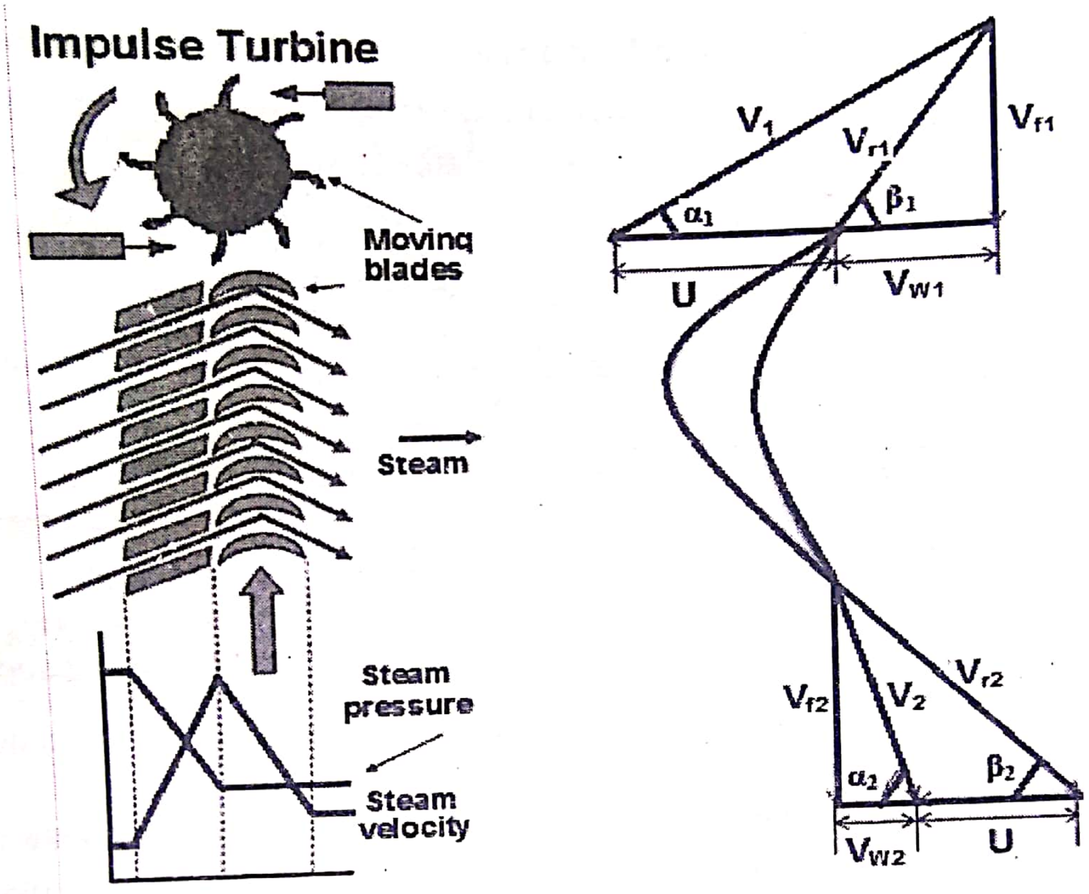


Figure 7.11: Simple Impulse Type Turbine

The stationary blades act as nozzles in which the steam expands and emerges at an increased speed but lower pressure (Bernoulli's conservation of energy principle: kinetic energy increases as pressure energy falls). As the steam impacts on the moving blades it imparts some of its kinetic energy to the moving blades. The principle and velocity diagram is shown in figure 7.12. The steam jets are directed at the bucket shaped rotor blades of the turbine where the pressure exerted by steam jets causes the rotor to rotate, resulting in the decrease of velocity of the steam as it imparts its kinetic energy to the blades. The blades in turn change the direction of flow of the steam; however, its pressure remains constant as it passes through the rotor blades since the cross-section of the chamber between the blades is constant. Impulse turbines are therefore also known as constant pressure turbines. The next series of fixed blades reverses the direction of the steam before it passes to the second row of moving blades. The law of moment of momentum applies, which states; that the sum of the moments of external forces acting on a fluid which is temporarily occupying the control volume is equal to the net time change of angular momentum flux through the control volume.



(a) (b)

Figure 7.12: Impulse Turbine (a) Principle (b) Velocity Diagram

A velocity triangle given in figure 7.12(b) helps in a better understanding of the relationship between the various velocities. The terminologies used are as follows:

V_1 and V_2 are the absolute velocities at the inlet and outlet respectively.

V_{f1} and V_{f2} are the flow velocities at the inlet and outlet respectively.

$(V_{W1} + U)$ and V_{W2} are the swirl velocities at the inlet and outlet respectively.

V_{r1} and V_{r2} are the relative velocities at the inlet and outlet respectively.

U_1 and U_2 are the velocities of the blade at the inlet and outlet respectively.

And α is the guide vane angle and β is the blade angle.

Then according to the law of moment of momentum, the torque T on the fluid of mass m is given by:

$$T = m(r_2 V_{W2} - r_1 V_{W1}) \qquad 7.3$$

For an impulse steam turbine: $r_2 = r_1 = r$. Therefore, the tangential force on the blades is:

$$F_U = m(V_{W1} - V_{W2}) \qquad 7.4$$

Work done per unit time or power P developed:

$$P = Tw \qquad 7.5$$

Where ω is the angular velocity of the turbine, then the linear speed of the blade U is $r\omega$. The work done per unit time or power developed is then:

$$P = mU(\Delta V_W) \qquad 7.6$$

Blade efficiency: Blade efficiency η_b can be defined as the ratio of the work done on the blades to kinetic energy KE supplied to the fluid, and is given by:

$$\eta_b = \frac{W}{KE} = \frac{mU(\Delta V_W)}{0.5mV_1^2}$$

Or

$$\eta_b = \frac{2U(\Delta V_W)}{V_1^2} \qquad 7.7$$

In order to obtain the expression for the stage efficiency of a steam turbine the effect of steam nozzle has to be considered. Figure 7.13 is a diagram of a typical convergent-divergent steam nozzle used with steam turbines. In a converging-diverging nozzle the pressure drops to a critical value at the throat and there can be a further pressure drop because the flow is accelerating out the back in the diverging section.

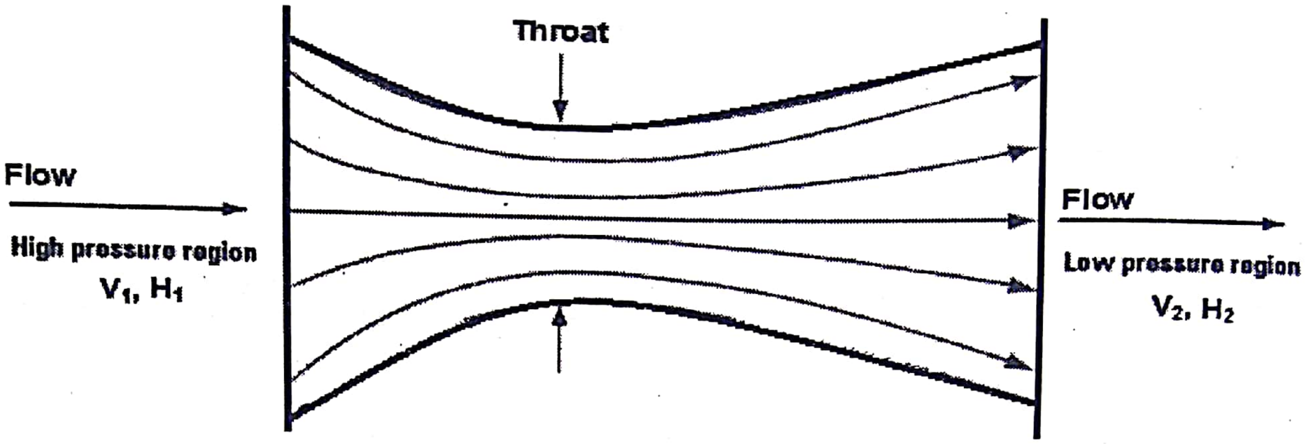


Figure 7.13: Convergent Divergent Nozzle

The enthalpy drop at the nozzle is then equal to the change in kinetic energy at the inlet and outlet:

$$H_1 - H_2 = \frac{1}{2}mV_2^2 - \frac{1}{2}mV_1^2$$

Where the enthalpy (in J/kg) of steam at the entrance of the nozzle is H_1 and the enthalpy of steam at the exit of the nozzle is H_2. $H_1 - H_2 = \Delta H$ is the specific enthalpy drop of steam in the nozzle. According to the first law of thermodynamics:

$$H_1 + \frac{V_1^2}{2} = H_2 + \frac{V_2^2}{2} \qquad 7.9$$

Assuming that V_1 is appreciably less than V_2, we get:

$$\Delta H \approx \frac{V_2^2}{2} \qquad 7.10$$

Stage efficiency: A stage of an impulse turbine consists of a nozzle set and a moving wheel. The stage efficiency η_{stage} is defined as the ratio of work done per unit time to the change in kinetic energy and is expressed as:

$$\eta_{stage} = \frac{P}{\Delta KE} = \frac{mU(\Delta V_W)}{0.5m(V_2^2 - V_1^2)}$$

Or
$$\eta_{stage} = \frac{U(\Delta V_W)}{0.5(V_2^2 - V_1^2)}$$

$$\eta_{stage} = \frac{U(\Delta V_W)}{\Delta H} \qquad 7.8$$

The stage efficiency defines a relationship between enthalpy drop ΔH in the nozzle and work done by the moving wheel. Furthermore, stage efficiency is the product of blade efficiency η_b and nozzle efficiency η_N, or $\eta_{stage} = \eta_b \times \eta_N$. Nozzle efficiency is given by:

$$\eta_N = \frac{V_2^2}{2(H_1 - H_2)} \qquad 7.11$$

The blade efficiency of the turbine is obtained from the velocity diagram of figure 7.12(b). Since:

$$\Delta V_W = V_{W1} - (-V_{W2})$$

$$\Delta V_W = V_{W1} + V_{W2} \qquad 7.12$$

$$\Delta V_W = V_{r1}\cos\beta_1 + V_{r2}\cos\beta_2$$

$$\Delta V_W = V_{r1}\cos\beta_1\left(1 + \frac{V_{r2}\cos\beta_2}{V_{r1}\cos\beta_1}\right) \qquad 7.13$$

The ratio of the cosines of the blade angles at the outlet and inlet can be denoted by *c* and is expressed as:

$$c = \frac{\cos\beta_2}{\cos\beta_1} \qquad 7.14$$

Similarly the ratio of steam velocities relative to the rotor speed at the outlet to the inlet of the blade is defined by the friction coefficient *k* as:

$$k = \frac{V_{r2}}{V_{r1}} \qquad 7.15$$

$k < 1$ depicts the loss in the relative velocity due to friction as the steam flows around the blades and for smooth blades without friction; $k = 1$. The blade efficiency from equation 7.7 can then be expressed as:

$$\eta_b = \frac{2U(\Delta V_W)}{V_1^2} = \frac{2U(\cos\alpha_1 - U/V_1)(1+kc)}{V_1} \qquad 7.16$$

The ratio of the blade speed to the absolute steam velocity at the inlet is termed as the blade speed ratio. It is denoted by ρ and is expressed as:

$$\rho = \frac{U}{V_1} \qquad 7.17$$

Using equation 7.17, the blade efficiency in equation 7.16 can be expressed in terms ρ as:

$$\eta_b = 2\rho(\cos\alpha_1 - \rho)(1+kc) \qquad 7.18$$

By taking the derivative of both sides of equation 7.18 with respect to ρ and then putting the derivative $\frac{d\eta_b}{d\rho} = 0$, the maximum blade efficiency can be determined as follows:

$$\frac{d}{d\rho}\eta_b = \frac{d}{d\rho}[(2\rho\cos\alpha_1 - 2\rho^2)(1+kc)] = 0$$

Or $$\rho = \frac{\cos\alpha_1}{2} \qquad 7.19$$

Comparing equation 7.17 and 7.19, we therefore have: $\frac{U}{V_1} = \frac{\cos\alpha_1}{2}$. For a single stage impulse turbine:

$$\rho_{out} = \frac{U}{V_1} = \frac{\cos\alpha_1}{2} \qquad 7.20$$

Thus the maximum blade efficiency of turbine occurs when ρ is equal to $\frac{\cos\alpha_1}{2}$, the situation is shown in figure 7.14.

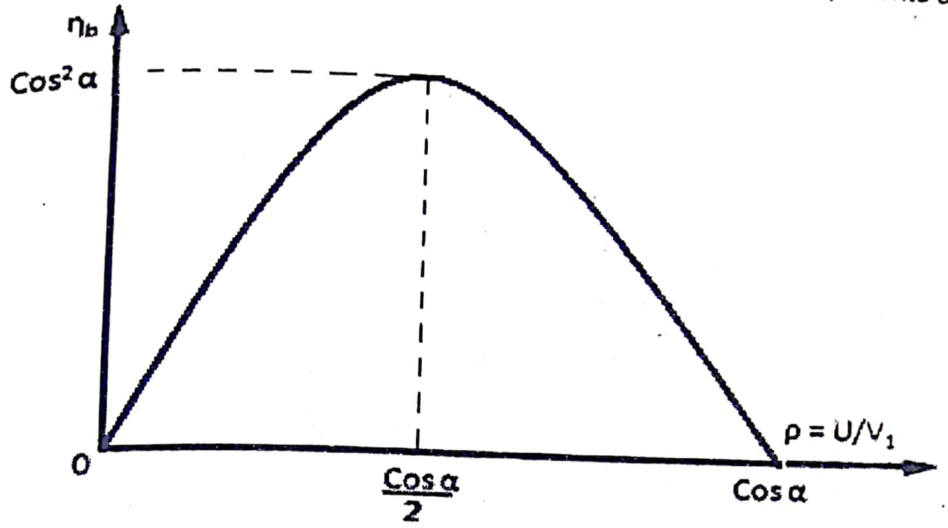


Figure 7.14: Efficiency versus Blade Speed Ratio for Impulse Turbine

Therefore the maximum value of stage efficiency is obtained by putting the value of $\frac{U}{V_1} = \frac{\cos\alpha_1}{2}$ in the expression 7.16, we obtain:

$$\eta_{b,\max} = \frac{\cos^2\alpha_1(1+kc)}{2} \qquad 7.21$$

For equiangular blades; $\beta_1 = \beta_2$ therefore $c = 1$. Substituting $c = 1$ in equation 7.21, we obtain:

$$\eta_{b,\max} = \frac{\cos^2\alpha_1(1+k)}{2} \qquad 7.22$$

In case when the friction due to the blade surface is neglected; then $k = 1$ and equation 7.22 can then be expressed as:

$$\eta_{b,\max} = \cos^2\alpha_1 \qquad 7.22$$

The following two conclusions can be drawn from the discussion:

1. For a given steam velocity, work done per kg of steam would be maximum when $\cos^2\alpha_1 = 1$ or $\alpha_1 = 0$.

2. As α_1 increases, the work done on the blades reduces, but at the same time surface area of the blade reduces, therefore there are less frictional losses.

7.4.2. Reaction Turbine

A reaction turbine consists of a set of fixed blades and set of rotating blades as shown in figure 7.15. This type of turbine makes use of the reaction force produced as the steam accelerates through the nozzles formed by the rotor. The rotor blades of the reaction turbine are shaped like an aerofoil, arranged in such a manner that the cross section of the champers formed between the fixed blades diminishes from the inlet side towards the exhaust side of the blades so that; as the steam progresses through the chambers its velocity increases while at the same time its pressure decreases, just as in the nozzles formed by the fixed blades of an impulse turbine.

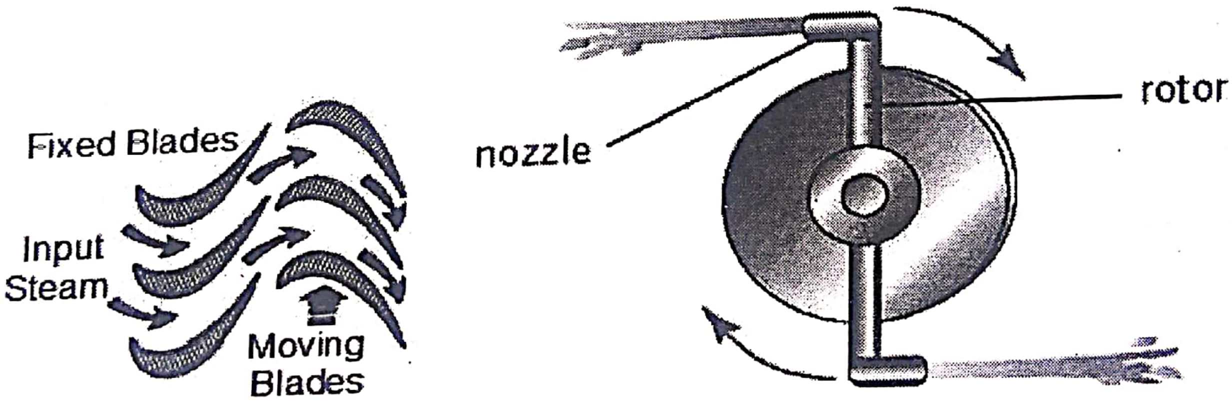
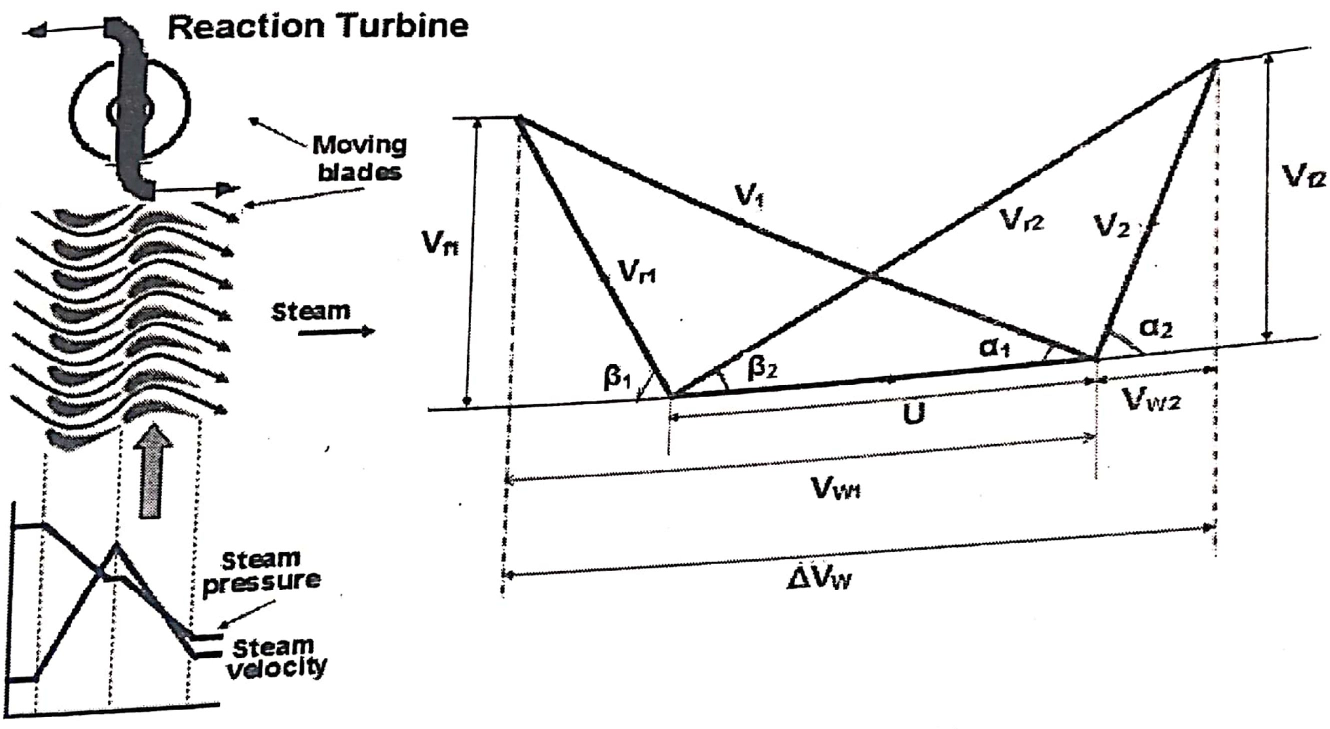


Figure 7.15: Reaction Turbine

Steam is directed onto the rotor by the fixed vanes of the stator also referred to as guide vanes and leaves the stator as a jet that fills the entire circumference of the rotor as shown in figure 7.15. The steam then changes direction and increases its speed relative to the speed of the blades and a pressure drop thus occurs across both the stator and the rotor. The steam accelerate through the stator and decelerate through the rotor, with no net change in steam velocity across the stage, but with a decrease in both pressure and temperature; reflecting the work performed in the driving of the rotor. Thus the pressure decreases in both the fixed and moving blades as illustrated in figure 7.16(a). As the steam emerges in a jet from between the rotor blades, it creates a reactive force on the blades, which in turn creates the turning moment on the turbine rotor. The exhaust steam from the low-pressure turbine is condensed to water in the cooling tower; extracting the latent heat of vaporization from the steam. The expression for blade efficiency of the reaction turbine can be obtained by considering the velocity diagram shown in figure 7.16(b).



(a)

(b)

Figure 7.16: Reaction Turbine (a) Principle (b) Velocity Diagram

Blade efficiency: Energy input E to the blades in terms of the change in enthalpy, in each stage is defined as:

$$E = \Delta h$$

This energy is equal to the sum of the kinetic energy supplied to the fixed blades and the kinetic energy supplied to the moving blades, which can also be defined in terms of enthalpy. This energy is thus the sum of enthalpy drop over the fixed blades (ΔH_f) and the enthalpy drop over the moving blades (ΔH_m). That is:

$$E = \Delta H_f + \Delta H_m \qquad 7.23$$

The effect of expansion of steam over the moving blades is to increase the relative velocity at the exit. Therefore the relative velocity at the exit V_{r2} is always greater than the relative velocity at the inlet V_{r1}. In terms of velocities, the enthalpy drop over the moving blades contributing to a change in static pressure is expressed as:

$$\Delta H_m = \frac{V_{r2}^2 - V_{r1}^2}{2} \qquad 7.24$$

The enthalpy drop in the fixed blades, with the assumption that the velocity of steam entering the fixed blades is equal to the velocity of steam leaving the previously moving blades is given by:

$$\Delta H_f = \frac{V_1^2 - V_0^2}{2}$$

Where V_0 is the inlet velocity of steam in the nozzle. Since V_0 is very small and can be neglected. Therefore:

$$\Delta H_f = \frac{V_1^2}{2} \qquad 7.25$$

Substituting ΔH_f and ΔH_m respectively from equation 7.24 and 7.25, we have:

$$E = \frac{V_1^2}{2} + \frac{V_{r2}^2 - V_{r1}^2}{2} \qquad 7.26$$

A very widely used design has half degree or 50% reaction and this type of design is known as Parson's turbine. This consists of symmetrical rotor and stator blades. For this type of turbine the velocity triangle is similar to that shown in figure 7.16(b), and therefore:

$\alpha_1 = \beta_2$, $\beta_1 = \alpha_2$, $V_1 = V_{r2}$ and $V_{r1} = V_2$

Assuming Parson's turbine and making use of the above mentioned conditions in equation 7.26, we obtain:

$$E = V_1^2 - \frac{V_{r1}^2}{2} \tag{7.27}$$

From the inlet velocity triangle shown in figure 7.16(b) we have:

$$V_{r1}^2 = V_1^2 + U^2 - 2UV_1\cos\alpha_1 \tag{7.28}$$

Substituting V_{r1} from equation 7.28 in equation 7.27, we have:

$$E = V_1^2 - \frac{V_1^2}{2} - \frac{U^2}{2} + \frac{2UV_1\cos\alpha_1}{2}$$

Or

$$E = \frac{V_1^2 - U^2 + 2UV_1\cos\alpha_1}{2} \tag{7.29}$$

Work done for unit mass flow per second *P* is then expressed as:

$$P = U(\Delta V_W)$$

From the velocity diagram of figure 7.16, we have:

$$P = U(2V_1\cos\alpha_1 - U) \tag{7.30}$$

Therefore the blade efficiency is given by:

Or

$$\eta_b = \frac{P}{E} = \frac{2U(2V_1\cos\alpha_1 - U)}{V_1^2 - U^2 + 2V_1U\cos\alpha_1} \tag{7.31}$$

Since: $\rho = \frac{U}{V_1}$ and $U = \rho V_1$. Substituting this value of *U* in equation 7.31, we obtain:

$$\eta_b = \frac{2\rho(\cos\alpha_1 - \rho)}{1 - \rho^2 + 2\cos\alpha_1} \tag{7.32}$$

For maximum efficiency: $\frac{d\eta_b}{d\rho} = 0$, we obtain:

$$\eta_{b,\max} = \frac{2\cos^2\alpha_1}{1+\cos^2\alpha_1} \qquad 7.33$$

Figure 7.17 shows the comparison of the blade efficiencies of reaction and impulse turbine. It can be seen from figure 7.17 that the efficiency of reaction turbine is greater than that of an impulse turbine for the same blade angle.

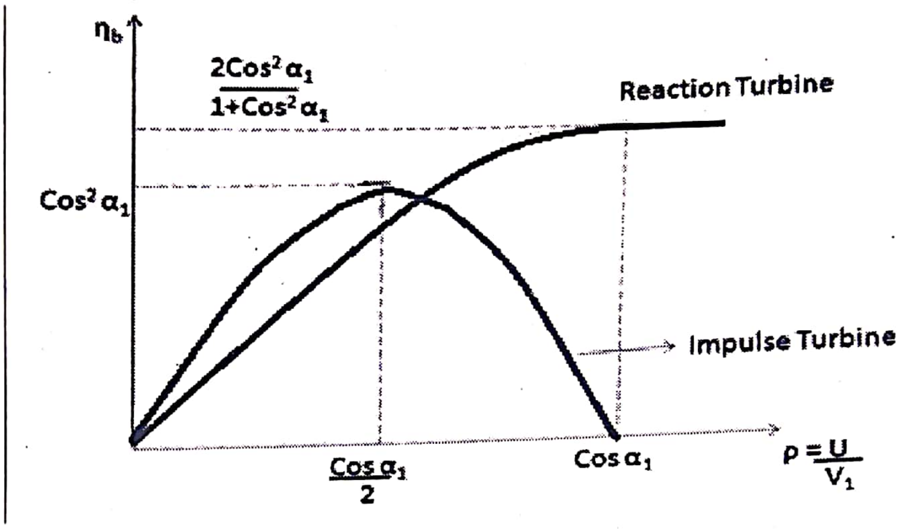


Figure 7.17: Comparing Efficiencies of Impulse and Reaction turbines

The volume of the steam goes to zero in the condenser, reducing the pressure dramatically to near vacuum conditions thus increasing the pressure drop across the turbine, which enables the maximum amount of energy to be extracted from the steam and hence maximum work done. The condensate is then pumped back into the boiler as feed-water to be used again, of course with make up water from the water source.

7.5. Steam Condenser

A steam condenser in its simplest terms is a heat transfer device which transforms a thermodynamic fluid from its vapor phase to its liquid phase (also known as phase transition). The main use of a condenser in thermal power plants is to receive exhausted steam from a turbine and condense the steam to water that can be re-used as feed water to the boiler. In the absence of a condenser excessive backpressure caused by the steam degrade the performance of turbine thus lowering its efficiency. Backpressure turbines, often used for electricity generation in process industries do not use condensers. These are called atmospheric or non- condensing turbines. Such type of turbines do not waste the energy in the steam emerging from the turbine exhaust, however, instead it is diverted this steam for use in applications requiring large amounts of heat such as refineries, pulp and paper plants, desalination plants, textiles and heating of buildings. These applications may also use the available steam to power mechanical drives for pumps, fans and materials handling. The boiler and turbine must of course be oversized for the electrical load in order to compensate for the power diverted for other uses.

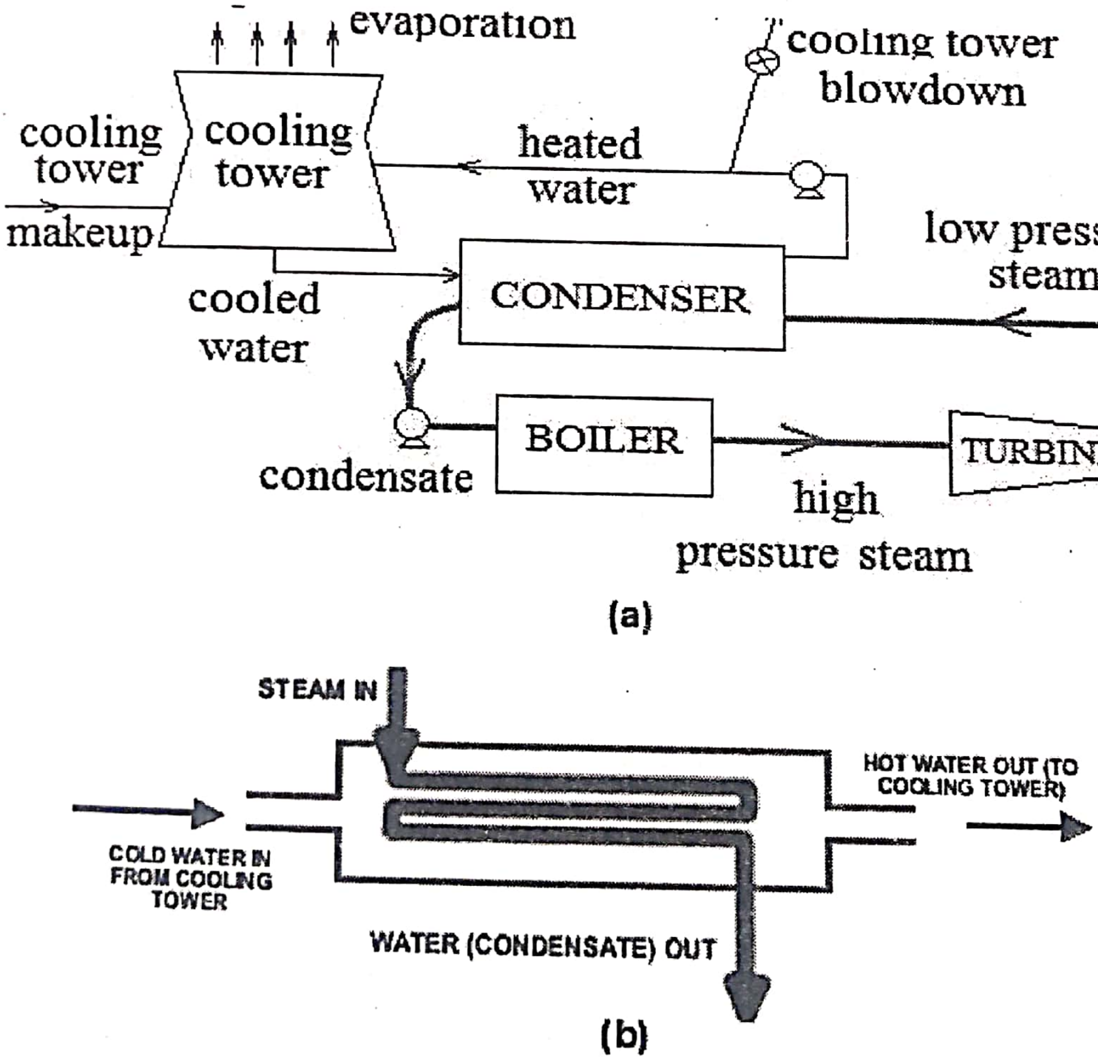


Figure 7.18: (a) Schematic Arrangement of Thermal Power Plant with Steam Condenser (b) Diagram of Steam Condenser

Figure 7.18(a) shows a schematic diagram of a thermal power plant incorporating a condenser and figure 7.18(b) is a diagram of a simple condenser. As shown in figure 7.18(b), a condenser in its simplest form is a shell and tube heat exchanger installed at the outlet of every steam turbine in thermal power stations. Shell and tube exchangers are the usual design, with steam usually on the shell side. The cooling water is allowed to circulate around the tubes in which steam is flowing. The heat exchanged between the steam in the tubes and circulating water converts steam into water. The steam thus enters as superheated or saturated and leaves as superheated, saturated, or as liquid water, depending on the initial steam conditions and the design load of the exchanger. A steam condenser generally condenses the steam to a pressure significantly below atmospheric pressure, which also allows the turbine to do more work. The difference between the heat of steam per unit weight at the inlet to turbine and the heat of steam per unit weight at the outlet to turbine represents the heat given out (or heat drop) in the steam turbine which is converted to mechanical power. By condensing the exhaust steam of turbine, the exhaust pressure is brought down below atmospheric pressure from above atmospheric pressure, increasing the steam pressure drop between inlet and exhaust of steam turbine. This further reduction in exhaust pressure gives out more heat per unit weight of steam input to the steam turbine, for conversion to mechanical power. The heat drop per unit weight of steam is also measured by the enthalpy drop. Therefore the more the conversion of heat per unit weight of steam to mechanical power in the turbine, the better is its performance or otherwise known as efficiency as depicted by equation 7.2 of the Carnot cycle. In addition, decreasing the condensate temperature will also result in a lowering of the turbine backpressure. Within limits, decreasing the turbine backpressure will in turn increase the thermal efficiency of the turbine. The condenser also converts the discharge steam back to water which is returned to the boiler as feed-water. In the condenser the latent heat of condensation is conducted to the cooling medium flowing through the cooling tubes.

Most of the heat liberated due to condensing that is; latent heat of steam is carried away by the cooling medium (water or air). In so doing, the latent heat of steam is given out inside the condenser. Where water is in short supply an air cooled condenser is often used. In water cooled condensers, water from a cooling pond, lake or river flows through the inlet canal into the condenser. This cool water condenses the low pressure steam into water. An air cooled condenser is, however, significantly more expensive and cannot achieve as low a steam turbine backpressure and is therefore less efficient. Plants operating in hot climates may have to reduce output if their source of condenser cooling water becomes warmer; unfortunately this usually coincides with periods of high electrical demand for air conditioning.

The purpose of the condenser is to condense the exhaust steam from steam turbine to obtain maximum efficiency and also to get the condensed steam in the form of water (condensate), back to steam generator or boiler. Condensate is usually returned to the boiler as part of the feed-water. Accordingly, one must take into account the amount and quality of the condensate when calculating boiler treatment parameters. Condensate tanks and pumps are major points for oxygen to enter the condensate system and cause corrosion. These points should be monitored closely for pH and oxygen ingress and proper condensate treatment applied. Condensers also provide a negative pressure at the turbine exit, thereby making heat transfer much more effectively thus increasing the efficiency. Condensers are classified as Jet condensers or contact condensers and surface condensers, which are discussed as follows:

Jet Condenser: Figure 7.19 shows a jet condenser. In jet condensers the steam to be condensed mixes with the cooling water and thus heat transfer is by direct conduction. The temperature of the condensate and the cooling water is same when leaving the condenser; and the condensate cannot be recovered for use as feed water to the boiler. This type of condenser has a large area of cooling surfaces compared to the system volume.

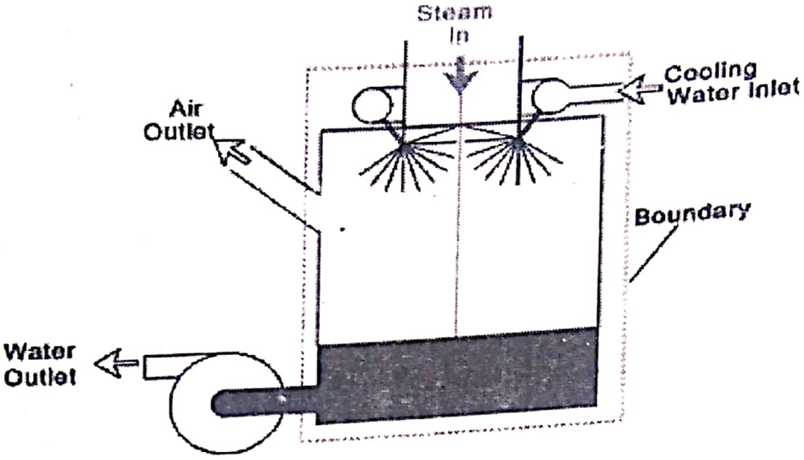


Figure 7.19: A Jet Condenser

This type of condenser is suitable where conditions permit condensation of exhaust steam by direct contact with the cooling water. A typical jet condenser can maintain a pressure of less than 0.07 bars and can condense over 12000 kg/hr of steam. The vacuum is created in the chamber by an air ejector. As shown in figure 7.19, the cooling water is sprayed into the chamber. The fine spray comes into contact with the steam. The steam condenses and the condensate falls to the bottom of the condenser chamber with the injection water. The condensate and injection water is withdrawn using a centrifugal extraction pump. The jet condenser is generally provided with safety features to guard against flooding. The heat transfer process in the condenser is such that the energy lost by the steam equals the energy gained by the water. Thus under steady state conditions the energy equation for the condenser for the system is:

$$m_S(H-H_d)=m_W(t_0-t)+H_r \qquad 7.34$$

Where: m_s = mass flow rate for steam (kg/s)

m_w = mass flow rate for water (kg/s)

H = specific enthalpy for vapor (kJ/kg)

H_d = specific enthalpy for outlet water (kJ/kg)

t = cooling water temperature (^{0}C)

t_o = Water outlet temperature (^{0}C)

H_r = radiated heat (kJ/s)

Neglecting heat radiation, the ratio of the mass of jet water to the mass of steam condensed from equation 7.34 is:

$$\frac{m_W}{m_S} = \frac{H - H_d}{t_0 - t} \qquad 7.35$$

Equation 7.34 can also be expressed as:

$$m_S(H) + m_S(t_{sat} - t_d) = m_W(t_0 - t) + H_r \qquad 7.36$$

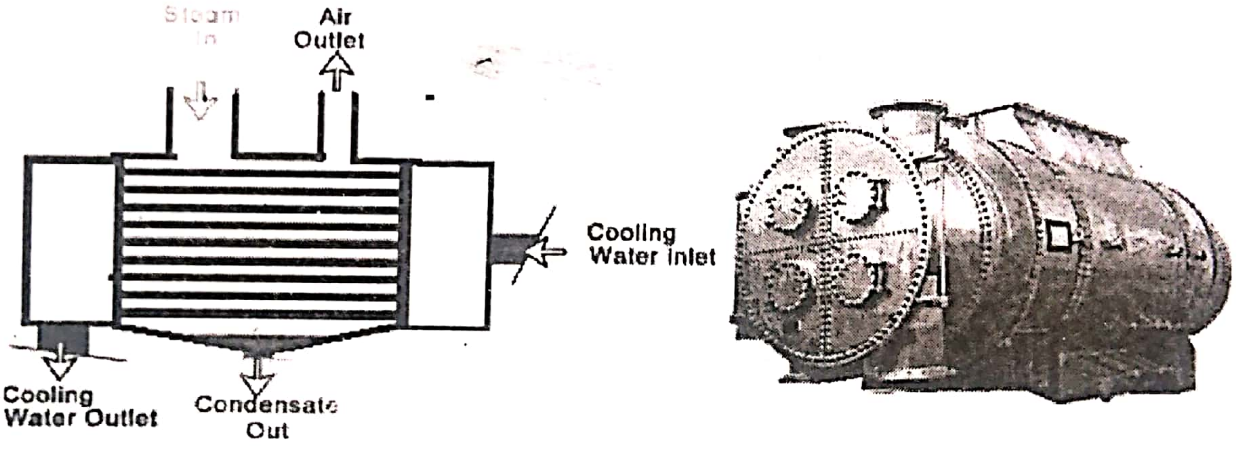
Where t_{sat} is the saturation temperature of steam in ^0C and t_d is the Condensate outlet temperature in ^0C. If H_f is the specific enthalpy for saturated water in (kJ/kg), H_{fg} is the specific enthalpy for vapor (kJ/kg) and x is the dryness fraction, then:

$$H = H_f + xH_{fg}$$

Thus neglecting H_r, the ratio of the mass of cooling water to the mass of steam condensed from equation 7.36 is:

$$\frac{m_W}{m_S} = \frac{H_f + xH_{fg} + (t_{sat} - t_d)}{t_0 - t} \qquad 7.37$$

Surface Condenser: Figure 7.20 shows a diagram and an image of a surface condenser. The surface condenser is a shell and tube type heat exchanger in which cooling water is circulated through the tubes. The exhaust steam from the low pressure turbine enters the shell where it is cooled and converted to water by flowing over the tubes. Such condensers use steam ejectors or rotary motor-driven exhausters for continuous removal of air and gases from the steam side to maintain vacuum. In surface condensers there is no direct contact between the steam to be condensed and the circulating cooling water. The heat is convectively transferred to the cooling water. As such; the temperature of the condensate may be higher than the temperature of the cooling water at outlet, and the condensate is recovered as feed water to the boiler. Both the cooling water and the condensate are separately withdrawn. Because of this advantage surface condensers are used in thermal power plants. Final output of condenser is water at low temperature, which is passed to high pressure feed water heater, where it is heated and again passed as feed water to the boiler. Since water is being passed at high temperature as feed water the temperature inside the boiler does not decrease and boiler efficiency is maintained.



(a) (b)

Figure 7.20: Surface Condenser (a) Diagram (b) Image

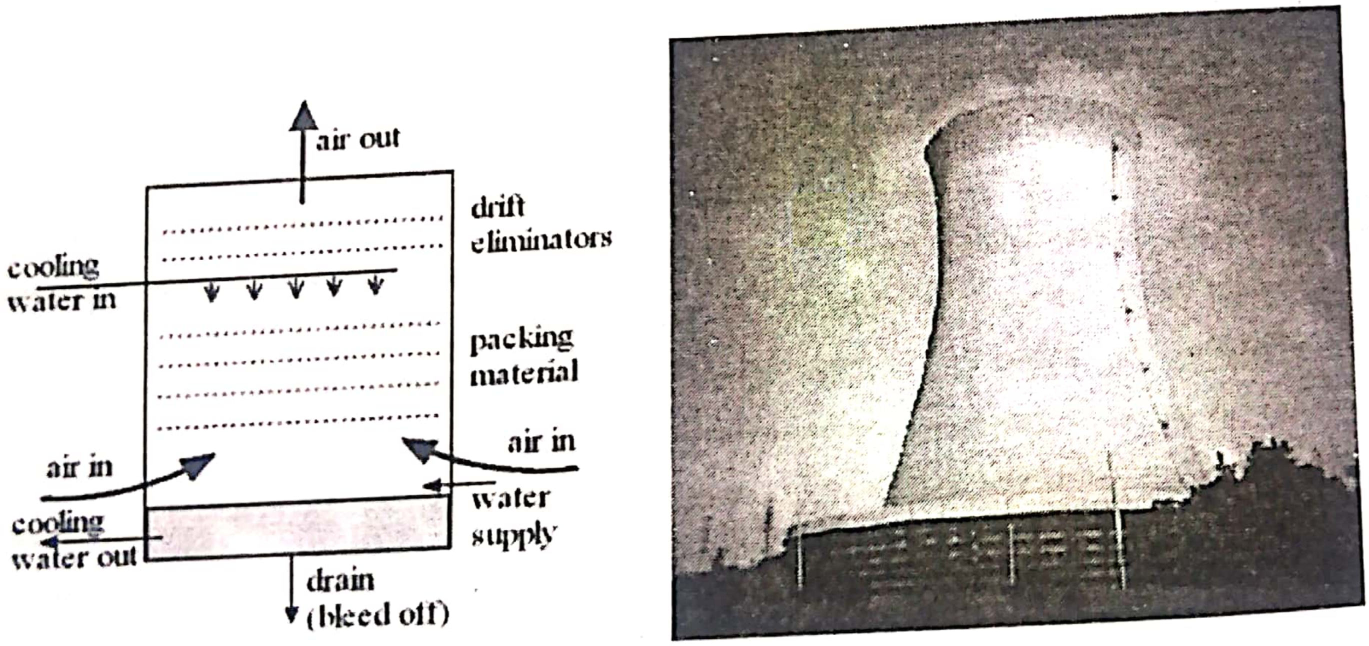
The surface condenser is the most important type of condenser in present day use. Its main functions are to condense low pressure steam exhausted from turbines and also to maintain the vacuum at the exhaust end of the turbines. It has the advantage that the condensate and the cooling water are entirely separate. The condensate is thus delivered to the boiler feed system as distilled water and is at a higher temperature compared to the discharge of in jet condenser.

7.6. Cooling Tower

As discussed in the previous section, cooling water is supplied to the condenser from natural or artificial sources, which condenses steam to water though still heated by several degrees. The temperature of the cooling water must be ultimately restored to the previous level plus evaporation of part of the water, accounting for water loss. When there are no sources of water of sufficient size, the cooling water is circulated through a closed loop and subjected to air cooling in evaporative coolers of the tower type structures called cooling towers, the schematic of which is shown in figure 7.21(a). A cooling tower is a heat rejection device in which atmospheric air (the heat receiver) circulates in direct or indirect contact with warmer water (the heat source), which is thereby cooled. A cooling tower thus extracts waste heat to the atmosphere through the cooling of a water stream to a lower temperature. The type of heat rejection in a cooling tower is termed evaporative in that it allows a small portion of the water being cooled to evaporate into a moving air stream to provide significant cooling to the rest of that water stream. Steam is condensed in the condenser using the cooled water coming out of the cooling tower. The heat from the water stream transferred to the air stream raises the temperature of the air and its relative humidity to 100%, which is then discharged to the atmosphere. Water vapour seen billowing from power plants is evaporating cooling water from cooling towers, not the working fluid as shown in figure 7.21(b). Cooling towers are commonly used to provide significantly lower water temperatures than achievable with 'air cooled' or 'dry' heat rejection devices, like the radiator in a car, thereby achieving more cost-effective and energy efficient operation of systems in need of cooling.

A cooling tower also serves as the heat sink in a conventional thermodynamic process, such as refrigeration or steam power generation, and when it is convenient or desirable to make final heat rejection to atmospheric air. Water, acting as the heat-transfer fluid, gives up heat to atmospheric air, and thus cooled, is re-circulated through the system, affording economical operation of the process. Two basic types of cooling towers are commonly used. One transfers the heat from warmer water to cooler air mainly by an evaporation heat-transfer process and is known as the evaporative or wet cooling tower. Evaporative cooling towers are further classified according to the means employed for producing air circulation through them: atmospheric, natural draft, and mechanical draft.

The other transfers the heat from warmer water to cooler air by a sensible heat-transfer process and is known as the non-evaporative or dry cooling tower. Non-evaporative cooling towers are also known as air-cooled heat exchangers, and are further classified by the means used for producing air circulation through them. These two basic types are sometimes combined, with the two cooling processes generally used in parallel or separately, and are then known as wet-dry cooling towers.



(a)

(b)

Figure 7.21: Cooling Tower (a) Schematic Diagram (b) Photograph

Evaluation of cooling tower performance is based on cooling of a specified quantity of water through a given range and to a specified temperature approach to the wet-bulb or dry-bulb temperature for which the tower is designed. Because exact design conditions are rarely experienced in operation, estimated performance curves are frequently prepared for a specific installation, and provide a means for comparing the measured performance with design conditions.

7.7. Working and Operation of Thermal Power Station

Figure 7.22 shows a layout of a thermal electric power station. Electrical energy generation in thermal power stations essentially involves three energy conversions:

1. Extracting thermal energy from the combustion of fuel such as coal, oil or gas and using it to raise steam to desired temperature and pressure in the steam generator.
2. Converting the thermal energy of the steam into kinetic energy (mechanical energy) by the turbine.
3. Using a generator to convert the turbine's mechanical energy into electrical energy.

In thermal electric power plants, also referred to as fossil fuel plants; use mostly coal but also oil and gas, is burnt in a combustion chamber, which produces heat at high temperature. Recently, these fuels have been supplemented by limited amounts of renewable biofuels and agricultural waste. Fuel such as coal is passed from storage and coal handling plant to the boiler's furnace, where it is burnt by procedure already discussed in chapter 6. The boiler furnace has mounted on it the coal nozzles and igniter guns, soot blowers, and water lancing. Necessary ports on furnace walls with safety covers for manual observation inside the furnace are also provided. Air and gas path equipment are: forced draught (FD) fan, air pre-heater, boiler furnace, induced draft (ID) fan, dust separators and the stack or chimney. For thermal units of about 200 MW capacity, FD fan, air pre-heater, dust collectors and ID fan are duplicated with necessary isolating dampers. The forced draft (FD) fan takes air from atmosphere and injects it into the air nozzles through the air pre-heater mounted on the boiler furnace to give sufficient hot air for better combustion. The induced draft (ID) fan draws out the combustible gases from the furnace to assist FD fan and to maintain always slightly negative pressure in the furnace to avoid backfiring through any opening. Just at the outlet of furnace and before the furnace gases are handled by ID fan, fine dust carried by the outlet gases are removed to avoid atmospheric pollution (environmental limitations prescribed by law) as well as to minimize erosion of ID fan rotors.

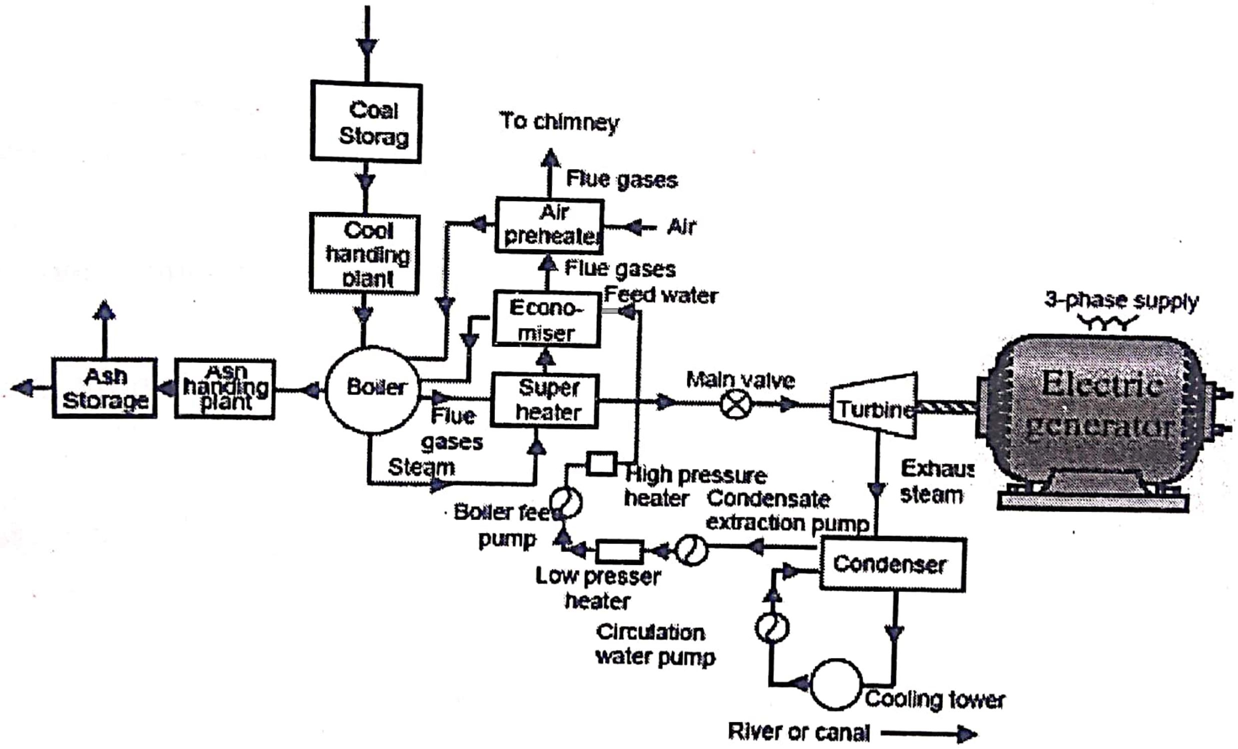


Figure 7.22: Thermal Electric Power Plant

The dust separator system is shown in figure 7.23. Dust separators are provided immediately at the outlet of the furnace and before the ID fan. They are of mechanical type or electrical type, sometimes mechanical followed by electrical type to reduce the load on the electrical type. The dust is normally collected in hoppers below them. Dust separators are emptied periodically by water jet ejectors or by air suction depending on how they are further disposed off. In case of further use of this fine ash, it is generally handled dry by air and taken to a silo located at a higher level for loading the fine ash in trucks from bottom of silo. In case of these being dumped in the yard, then wet method by water jet injectors is employed.

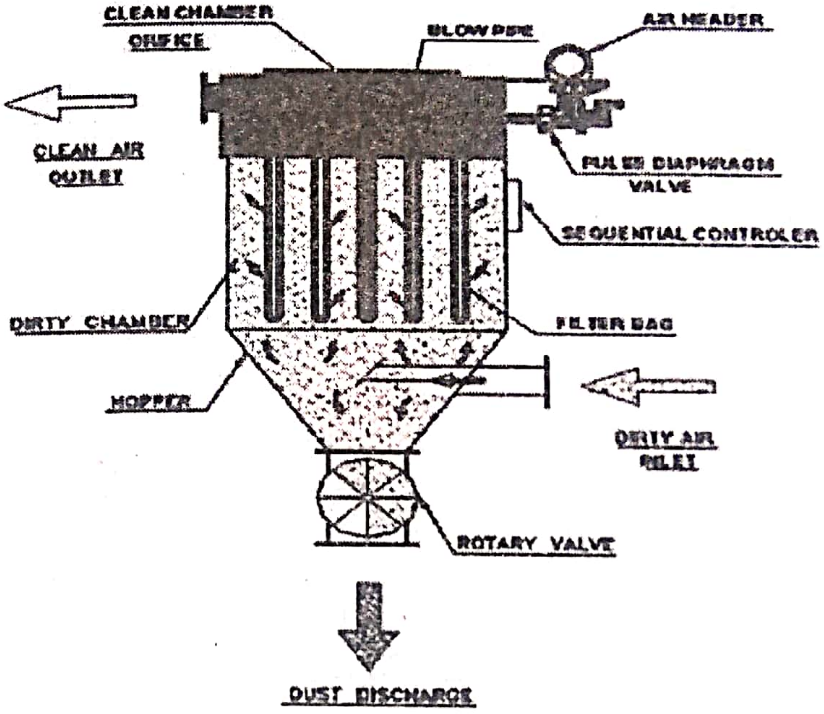


Figure 7.23: Dust Separator

In order to avoid furnace or boiler explosions due to accumulation of combustible gases after a trip out, these gases are flushed out from the combustion chamber before starting igniters. The chemical process of burning the fuel releases heat by chemical transformation (oxidation) of the fuel, which can never be perfect. There will be losses due to impurities in the fuel, incomplete combustion and heat and pressure losses in the combustion chamber and boiler. Typically these losses would amount to about 10% of the available energy in the fuel. The heat of combustion of fuel is used by the water in the steam generator to produce steam. This is made up of economizer, the boiler with all internal and external fittings and chemical dosing arrangement, generating tubes (with necessary headers for uniform distribution of water flow) and super-heater coils. Necessary safety valves are located at suitable points to avoid excessive pressures. The steam generator unit has to produce steam at highest purity, and at high pressure and temperature required for the turbine. Necessary air vents and drains are provided on boiler, super-heater coils and headers etc. for initial start up and for maintaining the boiler water concentration. Since steam is taken out continuously and returned to the boiler, losses due to blow-downs and leakages have to be made up for maintaining designed boiler water quantity. For this, continuous make up water is added to the boiler water system. Since this make up requires pure water this quality water is obtained by a dematerialized (DM) water treatment plant. However some storage is essential as DM plant may be down for maintenance. For this purpose a storage tank is installed from which continuously DM water is drawn for boiler make up.

The boiler internals provided are such that the wet steam entering the boiler from the generating tubes is removed of moisture, and then the dry steam enters the superheater coils. Superheated steam at a temperature of about 600^{0}C and is at a pressure of about 250 bars is allowed to enter the turbine system through nozzles. The sides of the nozzles are highly finished to afford the least possible resistance to the flow of steam. This high pressure fluid is diverted onto the blade of the turbine, forcing the turbine to spin. Thus energy in the steam after it leaves the boiler is converted into rotational mechanical energy as it passes through the turbine. The turbine normally consists of several stages with each stage consisting of a stationary blade (or nozzle) and a rotating blade. Stationary blades convert the potential energy of the steam (temperature and pressure) into kinetic energy (velocity) and direct the flow onto the rotating blades. The rotating blades convert the kinetic energy into forces, caused by pressure drop, which results in the rotation of the turbine shaft. In a large thermal power station, turbine system consists of three stage turbine arrangement; low pressure, intermediate pressure and the high pressure turbine as shown in figure 7.24. After expansion and doing the necessary work at the turbine system, the steam is condensed to water in a condenser through circulating water either directly from the water source of from a cooling tower. The turbine shaft is connected directly to an electric generator, which produces electrical energy.

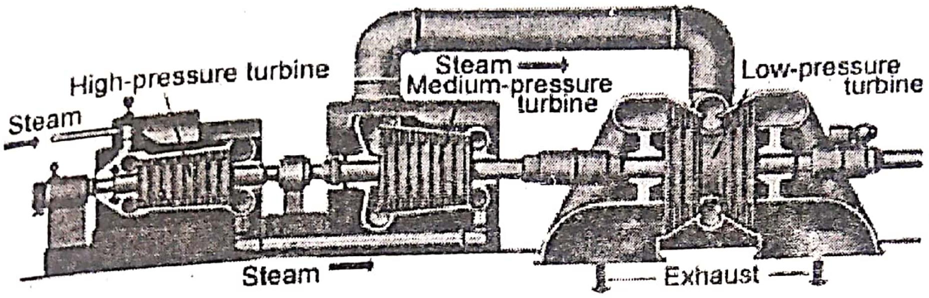


Figure 7.24: Three-stage Turbine System

From condenser the condensate is pumped through LP (low pressure) feed heaters to de-aerator and then it drops to feed tank. In order to increase the thermal efficiency the feed water is pumped by feed water pumps, through the HP (high pressure) feed heaters to the boiler through economizer where the feed water is further heated by the hot exhaust gases. At the bottom of every boiler a hopper has been provided with a sealing arrangement with water between boiler furnace and this hopper. This is to give a seal against slightly negative pressure maintained in the furnace and also for the expansion of the furnace walls downwards on furnace heat-up. This hopper is always filled with water, overflowing continuously at the top seal to quench the ash and clinkers falling down from the furnace. Some arrangement to crush these clinkers, then for removal outside and conveying to ash dump yard is made. In some designs clinker crushers are provided submerged in water to crush the clinkers and then convey the crushed pieces by means of hydraulic jets. For long distance disposal, ash sluice pumps are also provided for conveying to ash yard. In another design the clinker crushers are provided outside submerged in water with clinker inside the hopper being removed by chain conveyors.

The steam turbine drives a generator, to convert the mechanical energy into electrical energy. Typically the generator is a rotating field synchronous machine producing electrical energy at 50Hz or 60Hz. A cut-away view of a typical steam turbine driven generator is shown in figure 7.25. Since the generator is driven by steam turbines rotating at very high speed, for producing power at typically 50Hz with a 4 pole machine would require rotating speed of 1500 rpm and for a two pole machine 3000 rpm. The synchronous machines or alternators used in thermal power stations are having large sizes lengthwise and relatively smaller diameters as compared to hydro-generators, which have a larger diameter relative to its length in order to accommodate large number of poles for relative low rotating speeds. The energy conversion efficiency of these high capacity generators can be as high as 98% or 99% for a very large machine.

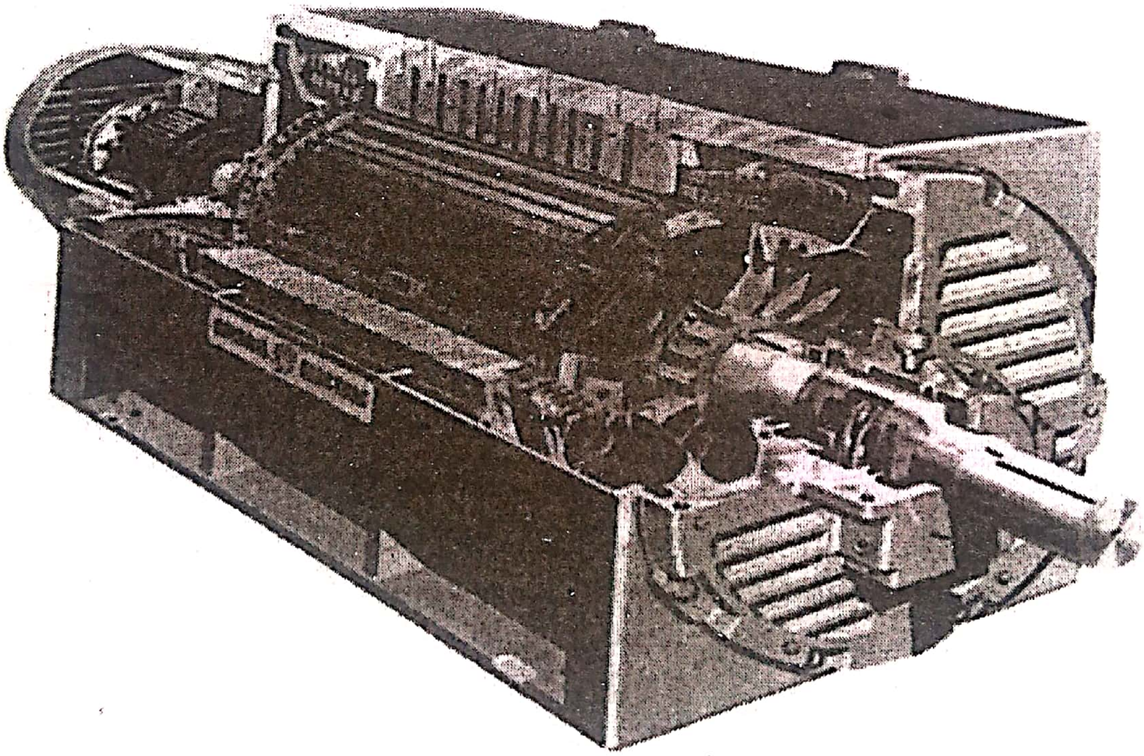


Figure 7.25: Steam Turbine Driven Generator (General Electric)

The power handling capacity of a brushed machine is usually constrained by the current handling capability of the slip rings in an AC machine (or even more by the commutator in a DC machine). Since the generator load current is generally much higher than the field current, it is usually desirable to use the rotor to create the field and to take the power off the generator from the stator to minimize the load on the slip rings. Rotating field machines are used for the high power generating plant in most of the world's national electricity grid systems. The field excitation power needed for these huge machines can be as much as 2.5% of the output power (25 KW in a 1.0 MW generator) though this reduces as the efficiency improves with size so that a 500 MW generator needs 2.5 MW (0.5%) of excitation power. If the field voltage is 1 kV, the required field current will be 2.5 kA. Providing such excitation through slip rings is an engineering challenge, which has been overcome by generating the necessary power within the machine itself by means of a pilot, three phases, and stationary field generator on the same shaft. The AC current generated in the pilot generator windings is rectified and fed directly to the rotor windings to supply the excitation for the main machine. Because of high rotating speeds of the synchronous machines used with steam turbines, they are referred to as turbo-alternators. Turbo-alternators, because of their large length compared to their diameter have long shafts and therefore special design considerations are exercised in order to avoid sub-synchronous resonance (SSR).

The generator coupled to the turbine does require some arrangement for cooling to dissipate the heat generated inside, depending on the size of the unit. Though in small size units it is mostly natural air cooling through air filters at inlet, in larger units generally found in power generating utilities now a day, special closed circuit cooling arrangements are incorporated. A typical 1000 MW generator must dissipate 20 MW of waste heat and such generators require special cooling techniques. As mentioned earlier, the efficiency of a very large generator can be as high as 98% or 99% but for a 1000 MW generator, an efficiency loss of just 1% means 10 MW of losses must be dissipated, mostly in the form of heat. To avoid overheating, special cooling precautions must be taken and two forms of cooling are usually employed simultaneously. Many large generators are cooled by hydrogen gas rather than air.

Hydrogen gas has the advantages that its density is only about 7% of the density of air resulting in fewer windage losses due to the rotor churning up the air in the machine and its thermal capacity is 10 times that of air giving it superior heat removal capability. The hydrogen gas is used because mainly of its higher affinity for heat absorption, lowest density to give less friction in a rotating medium, and being non self igniting. However, it should be noted that hydrogen gas is explosive in presence of air. The hydrogen gas pressure is therefore maintained slightly higher than atmosphere pressure say at about 1.5 kgf/cm² (150 kPa), to avoid outside air ingress. Due to this higher pressure than outside pressure and to avoid leakage to outside atmosphere where shaft emerges out of the casing, some form of sealing arrangement has to be provided. This is accomplished by providing mechanical seals around the shaft with a very small annular gap in-between to avoid rubbing between shaft and seal. To avoid gas leakage from this very small annular gap and also to avoid heat generation beyond limit, oil under pressure is provided in such a way that part of the oil flows to inside and part to outside. The oil flowing inside prevents the hydrogen gas leakage to atmosphere. This oil is called seal oil and should always be present as long as gas pressure inside is above atmosphere. Some manufacturers provide carbon rings in housing as seal and some provide other types known generally as 'labyrinths'. The seal oil entering the seal oil housings is therefore split in to two parts; one going inside the casing and the other coming out. The coming out oil is taken to bearing drain itself. The oil going inside the casing, which is under pressure, requires some sort of seal system to remove this oil to outside of casing as no oil should accumulate inside the casing, having conductors stressed to high voltage. Different manufacturers have their own designs for removing oil through a loop seal arrangement.

Since hydrogen gas is explosive with atmospheric air under certain conditions, a system has to be incorporated for its handling. For the first filling of hydrogen, purging out of the same for any inspection inside, for normal make up for losses during running and to maintain desired pressure and purity continuously, a separate system is provided. Also firefighting arrangement for inside generator explosions is incorporated with monitoring and control equipment. This system includes hydrogen gas cylinders and carbon dioxide gas cylinders suitably located with pressure reduction locations and piping to the generator casing, and purging piping. In order to avoid explosions, all purging pipe connections lead to open air at highest level to dilute the purged gases.

Cooling water is circulated through copper bars in the stator windings and hydrogen is passed through the generator casing. The generator conductors are made hollow to take water for cooling to remove further heat from coils. The generator coils being at about 22 kV, and water being conductive with and from safety point of view, some form of insulating barrier material (such as Teflon™ tubing) is used for interconnection of cooling water line and the generator high voltage coils. The DM water of lowest conductivity and without any impurities is used for passing through the coils. The DM water used for this purpose must be in a closed circuit, because of its affinity to absorb oxygen from the atmosphere which would otherwise make it highly corrosive. It is also provided with its own mixed bed ion exchangers and magnetic and mechanical filters to maintain highest purity and free of any foreign material.

The summary of energy conversion process in thermal electric power plants is summarized as follows:

Stage 1: The first conversion of energy takes place in the boiler. Coal is burnt in the boiler furnace to produce heat. Carbon in the coal and oxygen in the air combine to produce carbon dioxide and heat.

Stage 2: The second stage is the thermodynamic process.

1. The heat from combustion of the coal boils water in the boiler to produce steam. In modern power plant, boilers produce steam at a high pressure and temperature.
2. The steam is then piped to a turbine.
3. The high pressure steam impinges and expands across a number of sets of blades in the turbine.

4. The impulse and the thrust created rotate the turbine.
5. The steam is then condensed and pumped back into the boiler to repeat the cycle.

Stage 3: In the third stage, rotation of the turbine rotates the generator rotor to produce electricity based of Faraday's principle of electromagnetic induction.

7.8. Ancillary Systems

Apart from the basic steam raising and electricity generating plant, there are several essential automatic control and ancillary systems, which are necessary to keep the plant operating safely at its optimum capacity. These include:

1. Matching the power output to the demand (current controls).
2. Maintaining the system voltage and frequency.
3. Keeping the plant components within their operating pressure, temperature and speed limits.
4. Lubrication systems.
5. Feeding the fuel to the combustion chamber and removing the ash.
6. Pumps and fans for water and air flow.
7. Separating harmful products from the combustion exhaust emissions (pollution control).
8. Cooling the generator.
9. Electricity transmission equipment. Transformers and high voltage switching.
10. Emergency shut down and load shedding (overload protection).

7.9. Site Requirements for Thermal Power Plants

As the name implies the power plant is meant for generating power which obviously means that it will consume huge quantities of water and fuel. Water is used in two ways in thermal power plants: Firstly, internal steam cycle in which steam is produced via heat energy source and convey it to an electricity-generating turbine. Secondly, cooling cycle which cool and condense the after-turbine steam thus dramatically decreases the volume of the expanded steam, creating a suction vacuum which draws it through the turbine blades, and then to discharge surplus heat to the environment. However, due to the large quantities of water involved and the many competing uses for water, the water usage in thermal power plants is coming under increasing scrutiny.

Site selection and location of thermal power station plays a key role in the power system operation. The followings must be considered in planning for a large thermal power station.

Land Area: Before any other consideration, the minimum area and size required for the construction of power plant should be defined. Some land cover areas such as forests, orchards, agricultural land, and pasture are sensitive to the pollutions caused by a power plant. The effect of the power plant on such land types surrounding should be counted for. Parameters of the region such as temperature, humidity, wind direction and speed affect the productivity of a power plant and always should be taken into account. Usually, a power plant has high towers and chimneys for large volume of exhaust gases. Consequently for security reasons, they should be away from airports. Due to excessive vibrations of turbo alternators and turbines and smoke emission, historical building are fragile and at same time very valuable. Therefore the vibration and smoke resulting from thermal power plant can damage them, and a defined distance should be considered.

Geology and Soil Type: The power plant should be built in an area with soil and rock layers that could stand the weight and vibrations from the power plant. In addition, the seismic activity of the area must be considered. Even weak and small earthquakes can damage many parts of a power plant intensively. Therefore the site should be away enough from the natural faults and previously earthquake hit areas.

Water Resources: For the construction and operating of power plant different volumes of water are required. Large amount of water is also required for cooling purposes in the power plant hence it is better water source is available nearby. This could be supplied from either surface water or underground water resources. Best location is near a river or a lake, where feed water is available in ample quantity throughout the year. Therefore having enough water supplies in defined vicinity can be a factor in the selection of the site. However, the power plant should have a reasonable distance from permanent and seasonal rivers and floodways. It is recommended to build a thermal power plant near a large hydroelectric station with huge storage of water behind the dam. Both can work in coordination.

Transportation Facilities: The major issue in thermal power plants is the transportation of fuel, such as; coal. In the case of gas fuel, the power plant must be situated to the source such that the length and cost of piping system is less in order to reduce losses. The exact quantity of fuel needed would depend on the size of the plant and its capacity but it is a general fact that ample quantities of fuel must be available either in the vicinity or it should be reasonably economical to transport the fuel to the power plant. It is therefore recommended that a large thermal power plant should be situated near to a coal mine or gas field to reduce losses and transportation cost. Since most thermal power plants use coal (they can use other fuels as well) it must be ensured that sufficient coal is available round the clock. Just to give you a rough idea a power plant with 1000 MW capacity approximately would require more than ten thousand tons of coal per day hence the necessity for continuous supply and storage capability of coal in the power station. Thus the best site in this regard would be to allow easy and enough access to transportation network in both power plant construction and operation periods.

Topography: Studies have proved that high elevation has a negative effect on the production efficiency of gas turbines. Higher altitudes, where pressure is less, will result in poor efficiencies. In addition, changing of a sloping area into a flat site for the construction of the power plant needs extra budget. Therefore, the parameters of elevation and slope should be considered.

Power Transmission Network: To transfer the generated electricity to the consumers, the plant should be connected to electrical transmission system. Therefore the nearness to the load centre can play a role in economical transportation of the generated energy. In general, the site should be near the areas that there is more need for generation capacity, to decrease the amount of power loss and transmission expenses.

Environmental Issues: Thermal power station must be located at a suitable distance from residential area and townships due to emissions. Operation of a power plant has important impacts on environment. Therefore, priority will be given to the locations that are far enough from national parks, wildlife, protected areas, etc. For the same reasons as above, the site should have an enough distance from population centers.

Apart from these major requirements there are also other requirements which are equally important such as the availability of skilled people to work for the plant and good transport facilities in the vicinity and compensation for the affected. Hence we see that setting up a thermal power plant requires a lot of factors to be considered simultaneously.

Summarizing, a thermal power station is located at a site of water source near to large industrial estate, where needs of energy can be easily fulfilled by supplying energy through transmission line. Further since both industries and thermal power station can cause environmental pollution, they are situated away from the residential areas, commercial centre, public buildings and schools. There must be ample space for the storage of coal, disposal of ash, building of the power plant, and residential colony of workers, markets and so forth. An approximate analysis suggests that for every megawatt of power generated there must be at least three acres of land available for the purpose. Hence the power plant site needs to have good amount of land and this land should have good bearing capacity in order to survive the static and dynamic loads during the operation of the plant.