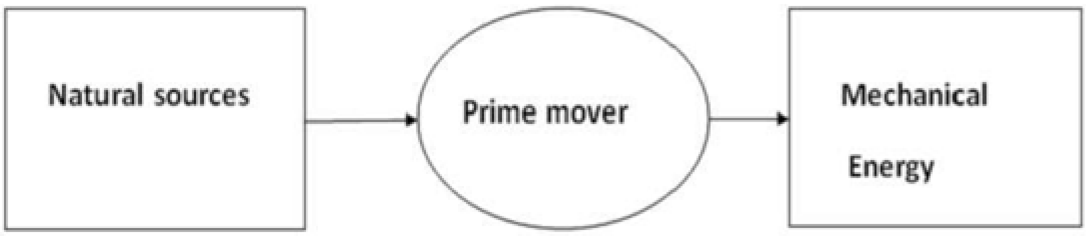
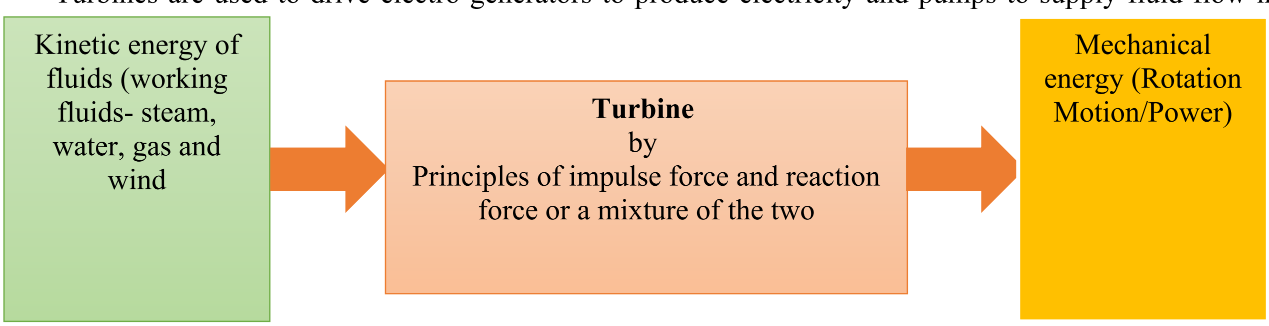
TURBINES

PRIME MOVER: Prime mover is a self-moving device which converts the available natural source of energy into mechanical energy of motion to drive the other machines. The various types of prime movers which convert heat energy produced by the combustion of fuels into mechanical energy.

Eg: Turbines, Internal combustion Engines, External combustion Engines, etc……



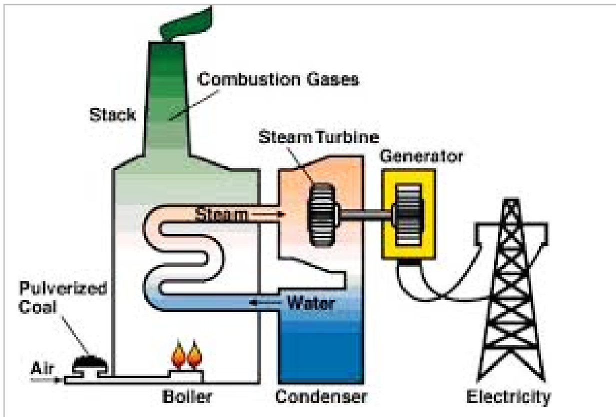
Turbine: A turbine can be defined as a power producing machine. The device generates power by converting the kinetic energy of a stream of fluid (such as water, steam, or hot gas) into mechanical energy (in the form of rotation of shaft) through the principles of impulse and reaction. Turbines are used to drive electro generators to produce electricity and pumps to supply fluid flow in a



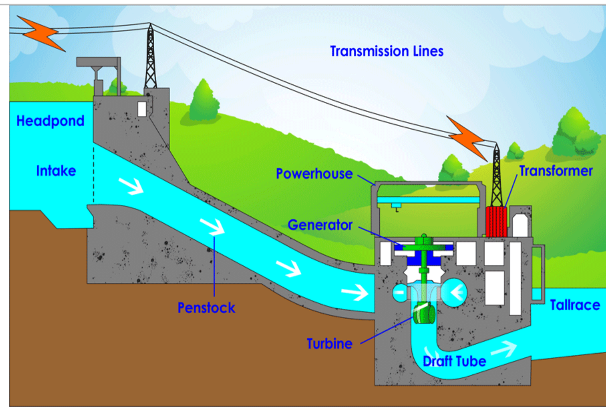
Turbines are classified based on the medium used to run the rotors of turbine:

1) Steam turbine – The steam is used to run the turbine.
2) Gas turbine – Here the gases of the burnt fuel is used to run the turbine.
3) Water Turbine – Here the water is used as a medium to run the turbine.

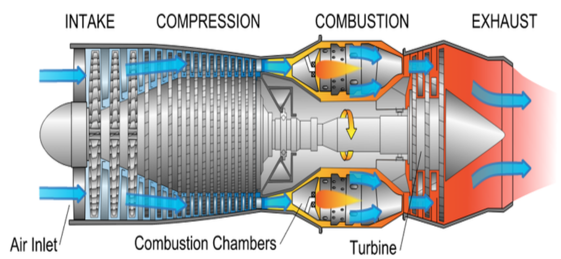
4) Wind Turbine - Here the wind (air blowing over the earth surface) is used as a medium to run the turbine.



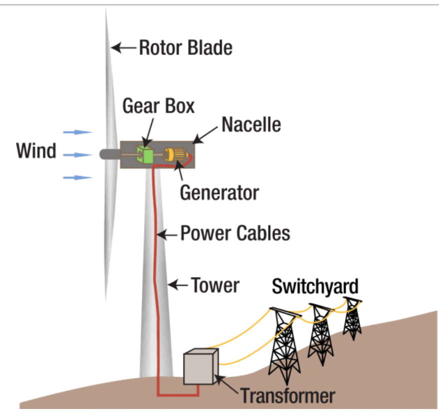
Steam Turbine:



Water Turbine

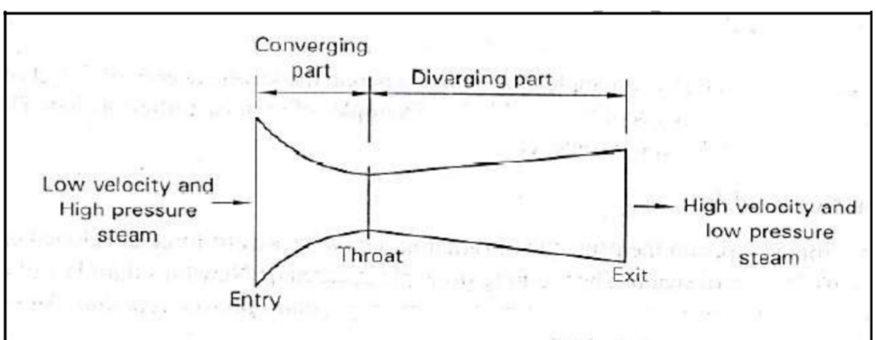


Gas Turbine



Wind Turbine

EXPANSION OF STEAM IN THE NOZZLE:

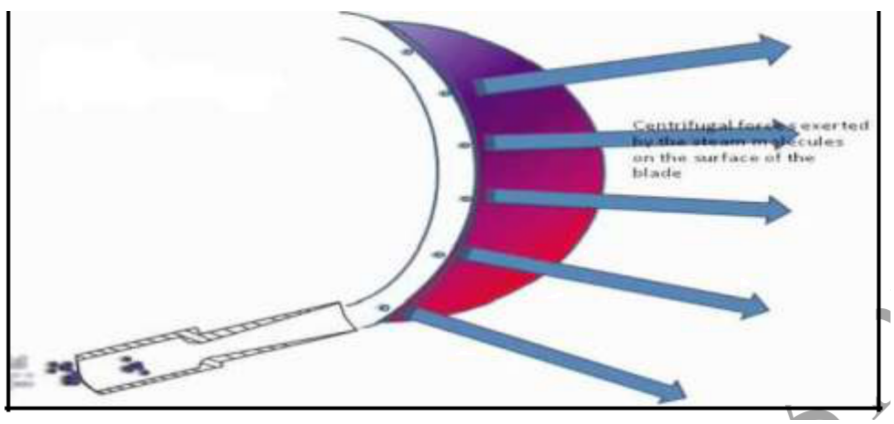


Convergent – Divergent nozzle

A nozzle is a passage of varying cross-section through which steam flows. Figure shows a convergent-divergent nozzle in which the cross-sectional area of the nozzle diminishes from the entry to throat, and thereafter diverges to the exit as shown in the figure. Steam is expanded in a nozzle to increase its kinetic energy. The high pressure and low velocity steam generated in a boiler enters the nozzle, and as it passes between the entry and the throat, the pressure of the steam drops to a lower value. In other words, steam expands to a low pressure. This drop in pressure reduces the enthalpy (heat content) of steam.

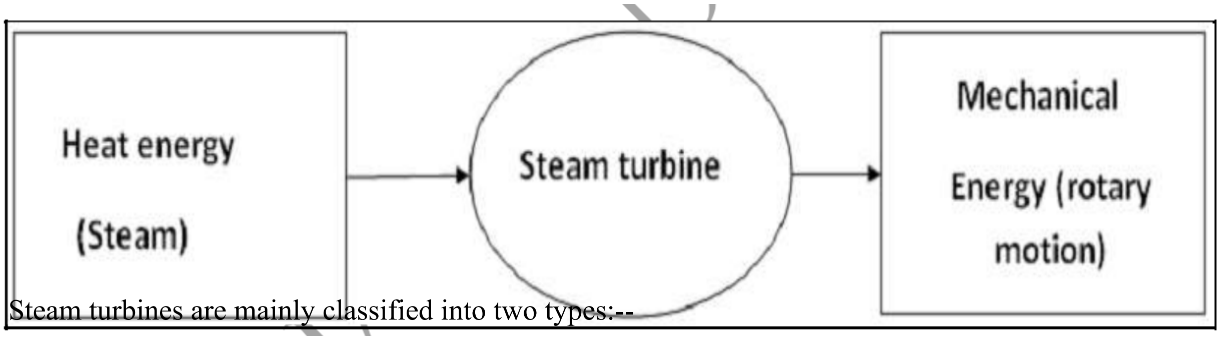
Since there is no external work and heat transfer in the nozzle, the reduction in the enthalpy of steam must be equal to the increase in velocity (kinetic energy) of the steam. In other words, the steam performs work upon itself by accelerating itself to a high velocity. Hence, the steam comes out of the nozzle with low pressure, and high velocity. Beyond the throat, the nozzle diverges to a certain length, so as to allow any incomplete expansion of the steam to take place.

PROPELLING FORCE IN THE STEAM TURBINE: The high pressure steam is made to pass through a nozzle. The steam expands in the nozzle i.e. its pressure falls & the heat energy is converted into kinetic energy which makes the steam to flow with a greater velocity. This high velocity steam enters the rotating part of the turbine & undergoes a change in direction of motion which gives rise to a change of momentum & therefore a force. This constitutes the driving force of the turbine.



STEAM TURBINES

A steam turbine is defined as a prime mover that converts the heat energy of the steam into mechanical energy in the form of rotary motion. Finally the rotary motion is used to generate electricity in the generator. It is used for driving electric generators, ship propellers, pumps, fans, compressors, etc.



Steam turbines are mainly classified into two types:--

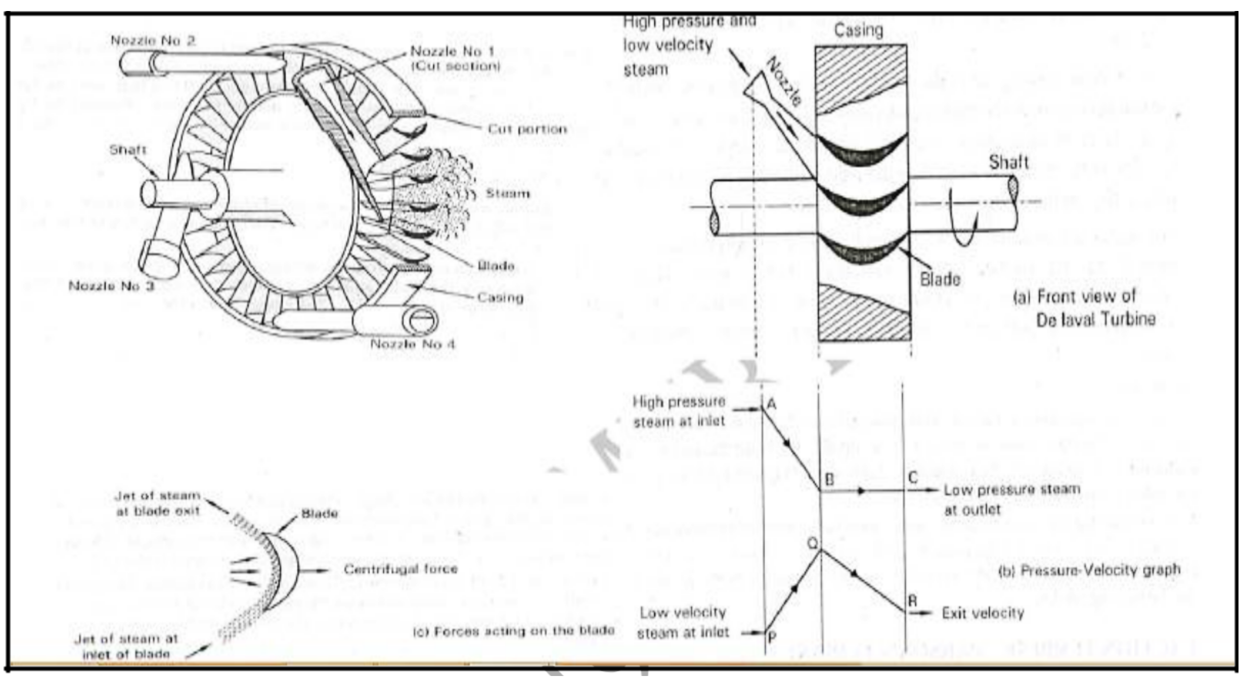
1. Impulse Turbine (De-Laval Turbine): In impulse turbine the steam expands in nozzles and its pressure does not alter as it moves over the blades.

2. Reaction Turbine (Parson's Turbine): In reaction turbine, the steam expands continuously as it passes over the blades and thus there is a gradual fall in the pressure during expansion.

1) IMPULSE TURBINE (DE-LAVAL TURBINE)

The turbine consists of a series of curved blades fixed on the circumference of a single wheel called rotor. The rotor in turn is connected to a shaft as shown in fig a.

In operation, the high pressure, low velocity steam generated in a boiler is made to flow through a convergent-divergent nozzle. As the steam passes through the nozzle, expansion takes place and the pressure of the steam decreases.



This drop in pressure of the steam results in the increase in the velocity (kinetic energy) of steam. The change in pressure and velocity of steam is shown in figure b. The high velocity jet of steam coming out of the nozzle is directed towards the moving blades of the turbine.

The steam flowing over the blades undergoes a change in its velocity and direction thereby resulting in change of momentum. The force due to the change of momentum is the impulse force that acts in the direction normal to the blades, thereby pushing the blade in its direction. The force acting on the blade is shown in figure b. Since a number of blades are fixed on the wheel, each blade comes in contact with the high velocity jet of steam. As a result, the wheel rotates continuously at high speeds. Hence, the shaft connected to the rotor also rotates. Thus, the kinetic energy of steam is converted into mechanical work. The output (rotation) at the shaft can be utilized for driving generators to produce electricity, or any other devices.

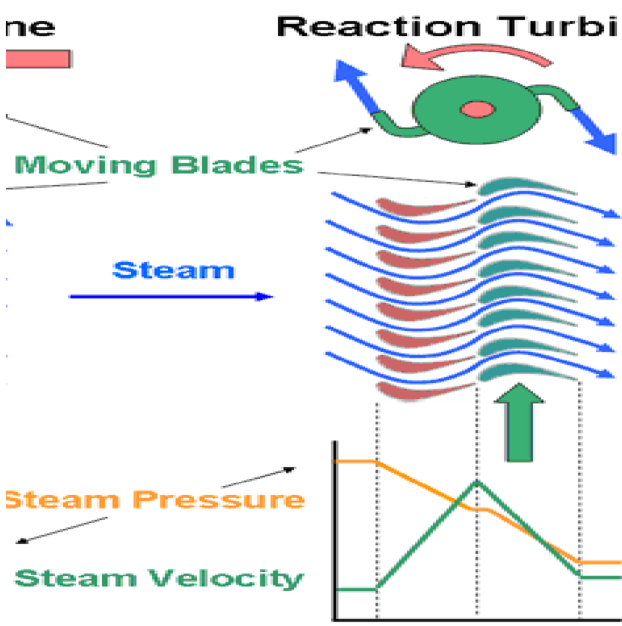
Important note on Impulse turbine:

1. Since all the kinetic energy is absorbed by one row of the moving blades only, the speed of the wheel is too high varying from 25000 to 30000 rpm. Such a high speed produces large centrifugal forces, increases vibration, causes over heating of the bearings, etc., and this makes it impossible for direct coupling to other machines.

2. Loss of energy due to higher exits velocity of steam.

2) REACTION TURBINE (PARSON'S TURBINE)

Reaction turbine was invented by Sir Charles Parson and hence widely called Parson's turbine. The turbine runs by the reactive force of the jet of steam, rather than the direct push or impulse as is in the case of impulse turbine Figure a shows the arrangement of blades in a reaction turbine & the change in pressure and velocity of steam. Reaction turbine consists of alternate rows of fixed and moving blades. The fixed blades are fastened (fixed) to a stationary casing and hence the name, while the moving blades are mounted on the periphery of a rotating wheel called rotor. The rotor in turn is connected to a shaft.



In reaction turbines, there are no nozzles. Instead, the blades are designed in such way that, the spaces between the blades have the shape of a nozzle. Hence in reaction turbines, pressure drop takes place gradually and continuously over both the moving and fixed blades. Pressure velocity graph shown in figure. Also, the blades used in reaction turbines are asymmetrical in shape being thicker at one end. In operation, the high pressure, low velocity steam generated in a boiler passes over the first row of fixed blades. The space between the fixed blades acts as nozzle due to which the steam gets expanded to a low pressure and high velocity. The fixed blades guide the high velocity jet of steam to move on to the moving blades.

The high velocity jet of steam now glides over the moving blades where it undergoes a change in its velocity and direction, thereby resulting in change of momentum. This gives impulse force to the blade and hence the rotor to rotate. Thus the kinetic energy of the steam is converted into mechanical energy of rotation of the rotor. Also, the steam while passing through the moving blades suffers further drop in pressure, as the moving blades too act as nozzles. When the steam leaves the moving blade, a reactive force is set up. Thus, the net force acting on the moving blade is the impulse force of the incoming steam and the reactive force of the outgoing steam. For this reason, reaction turbines are also called as impulse-reaction turbine.

The process continues in the next row of fixed and moving blades. Thus, the steam expands and does work on the blades causing the rotor to rotate at high speeds. Hence, the shaft connected to the rotor also rotates, thereby doing useful work.

Difference between IMPULSE and REACTION steam turbines:

	Impulse turbine	Reaction turbine
1	The steam completely expands from high pressure to low pressure in the nozzle before it enters the moving blades	The high pressure steam continuously expands successively in both the fixed and moving blades
2	Because of the large pressure drop in the nozzle, the steam speed and as well as the rotor speeds are high	Due to smaller pressure drop over both fixed and moving blades, both the steam speed and rotor speed are low
3	Occupies less space per unit power	Occupies more space for the unit power
4	Suitable for small power generation prime movers	Suitable for medium and high power generation prime movers
5	Due to high rotor speeds compounding is required to reduce the speed	The speeds are relatively less and hence no compounding is required
6	**The blades are symmetrical hemispherical Profile**	**The blades are unsymmetrical and aero foil profile**
7	**Lower efficiency due to high losses (Only once steam, striking the blades)**	**Higher efficiency due to less losses (Almost complete expansion of steam, while passing over fixed & moving blades)**
8	**Nozzle is required**	**Fixed blade act as nozzle**

Advantages of steam turbines over other prime movers:

a) Steam turbines can work at high temperatures and very high steam pressures. Hence the thermal efficiency is higher compared to other prime movers.

b) Steam turbines are rotary engines and hence do not have any reciprocating parts. Hence, less vibration and noise.

c) No wear and tear of the parts. Also lubrication is not required.

d) Turbine rotor can be balanced accurately.

e) Power generation in a steam turbine is at a uniform rate. Hence, a flywheel is not required.

f) Higher speeds with greater speed range is possible.

g) Steam turbines can take considerable over-load with only a slight reduction in its efficiency.

h) Steam turbine can be designed in sizes ranging from a few kW to over 1000 MW in a single unit. This enables to use steam turbines as prime movers in large power plants. i) Steam turbines are extensively used to propel ships of high tonnage and also to drive high speed generators, compressors, etc.

Compounding of Impulse Steam Turbine:

To improve the thermal efficiency of any power plant, generally high pressure (near about 120 to 140 bar), high temperature and high-velocity steam is used. Steam expands from boiler pressure to the condenser in one stage. So, steam's pressure drop and it will increase its velocity. This high-velocity strikes the turbines rotor and the speed of the rotor becomes high.

The method used to reduce the rotor speed - **Compounding of impulse steam Turbine**

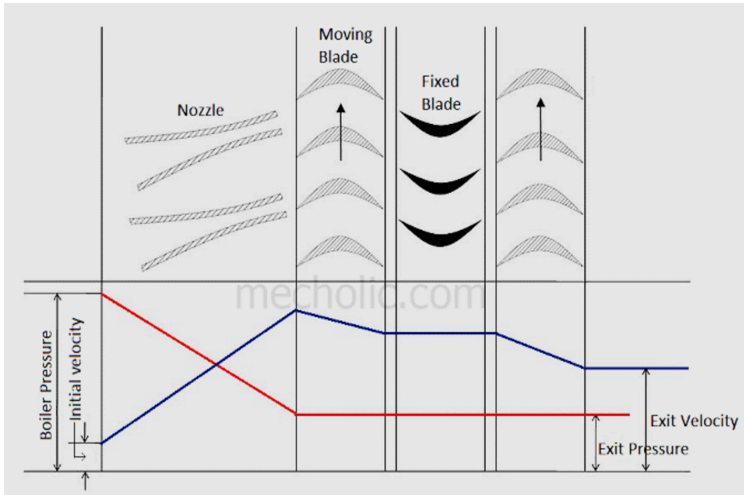
Compounding is achieved by using more than one set of nozzles, blades, rotors, in a series, keyed to a common shaft; so that either the steam pressure or the jet velocity is absorbed by the turbine in stages

Generally, three different types of compounding are used to reduce the rotor speed of steam turbine.

1. **Velocity Compounding,** 2. **Pressure Compounding,** 3. **Pressure Velocity Compounding**

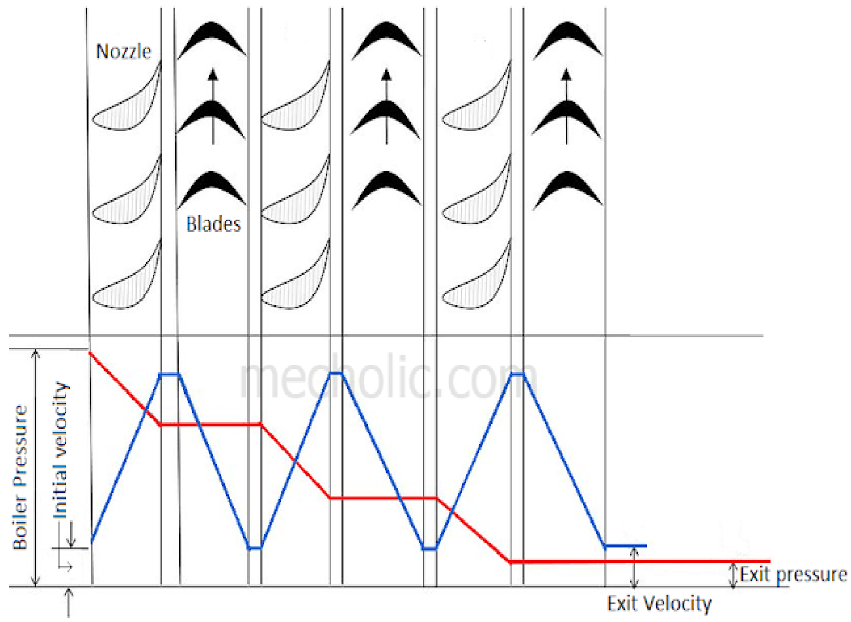
1. **Velocity Compounding**

The turbine has adjacent rows of moving blades and fixed blades. The moving blades are keyed to the same shaft. Here the working fluid is a steam. Initially, the steam from boiler having high pressure and low velocity is directed to moving blades through a stationary nozzle. The steam completely expands in the nozzle, as steam passes through the nozzle the total enthalpy drop and hence the pressure of steam drops. At the same time, the velocity or kinetic energy of steam increases according to the Bernoulli's principle. The portion of the kinetic energy is then absorbed by the row of moving blades, impart a rotation on shaft. The velocity of steam is decreases and pressure remains the same while it passing over the moving blades. The steam is then pass through the fixed blades without any change in velocity and the pressure (the velocity will slightly drop in practical application). The purpose of fixed blade is to redirect the steam to the next rows of moving blades where again work is done on rotor with dissipating kinetic energy. Finally, the low-velocity steam leaves the turbine.



2. **Pressure Compounding**

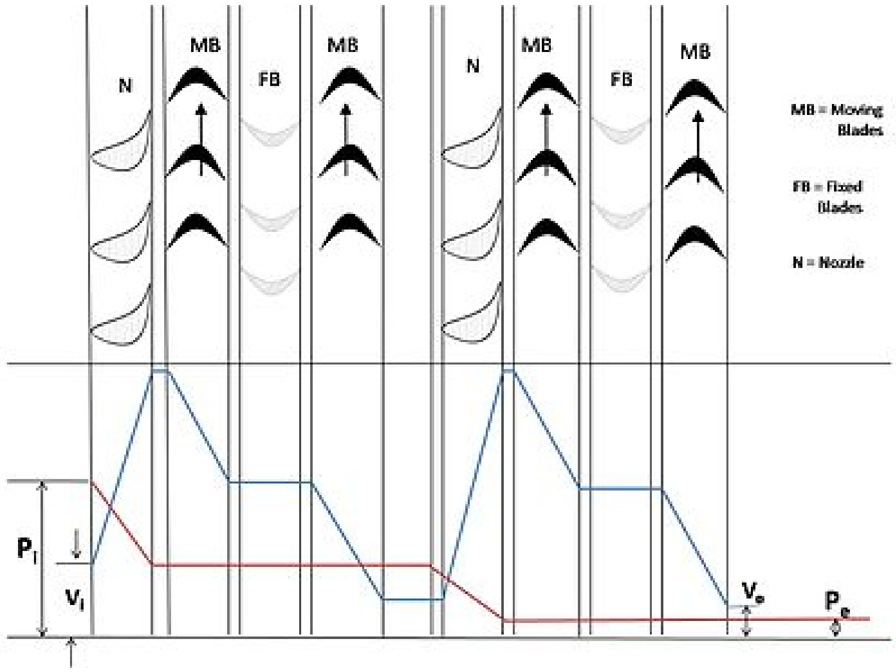
The pressure compounding is a type of turbine in which the pressure energy of steam is extracted in multiple stages instead of single stages. Figure shows that pressure compounding arrangement of a turbine. It has rows of moving blades and fixed nozzle arranged adjacently. Since it operates at high pressure the whole turbine should be air tight. Here the steam is first directed to moving blades through the main nozzle. While pass through the main nozzle, steam partially get expanded, the pressure drops, and velocity increase. Approximately all of the gained kinetic energy is then absorbed by the first set moving blades. The pressure remains constant while steam passes through the blades. The steam then moves through the second set of nozzle, where it again partially get expanded. The result will be decreasing pressure and increase velocity. Then the steam move to the second set blades, there it continue the similar process happened in first set of blades. Here set of one nozzle and blade consider as one stage. The process will repeat in each step and finally steam leaves the turbine at low velocity and pressure. In curves of velocity and pressure shows that the absorption of pressure energy in multiple steps.



3. **Pressure Velocity Compounding**

It is a combination of the above two types of compounding. The total pressure drop of the steam is divided into a number of stages. Each stage consists of rings of fixed and moving blades. Each set of rings of moving blades is separated by a single ring of fixed blades. In each stage there is one ring of fixed blades and 3-4 rings of moving blades. Each stage acts as a velocity compounded impulse turbine.

The fixed blades act as nozzles. The steam coming from the boiler is passed to the first ring of fixed blades, where it gets partially expanded. The pressure partially decreases and the velocity rises correspondingly. The velocity is absorbed by the following rings of moving blades until it reaches the next ring of fixed blades and the whole process is repeated once again.



WATER TURBINES

A water turbine is a hydraulic prime mover that converts the energy of falling water into mechanical energy in the form of rotation of shaft. The mechanical energy in turn is converted into electrical energy by means of an electric generator.

Water turbines are classified based on the following factors:

Based on type of energy available at the inlet of the turbine/working principle:

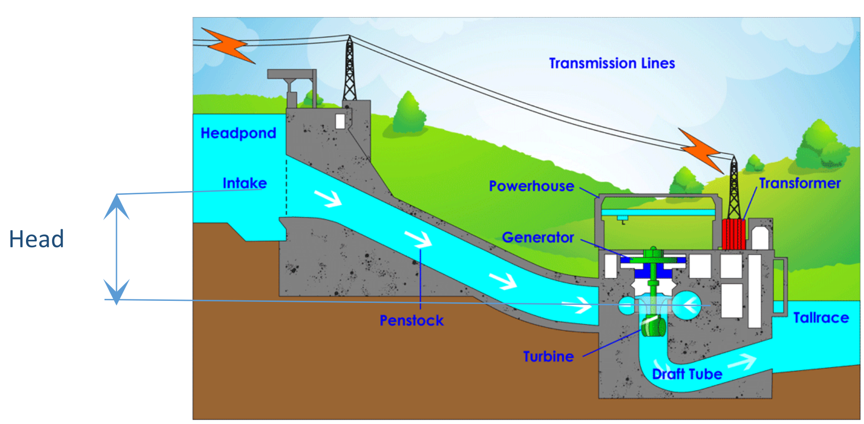
(a) Impulse turbine: The energy available at the inlet of the turbine is only kinetic energy.

Example: Pelton wheel, Girad turbine, Banki turbine, etc.

(b) Reaction turbine: Both pressure energy and kinetic energy is available at the inlet of the turbine.

Example: Kaplan turbine, Francis turbine, Thomson turbine, etc.

Based on the head under which turbine works:



a) High head turbine: Head of water available at the inlet of the turbine ie, above 400 m. Example: Pelton wheel.

b) Medium head turbine: Head of water available at the inlet of the turbine ranges from 50 m to 400 m. Example: Francis turbine.

c) Low head turbine: Head of water at the inlet will be less than 50m. Example: Kaplan Turbine.

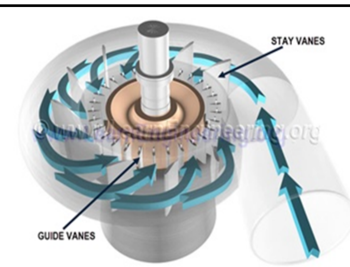
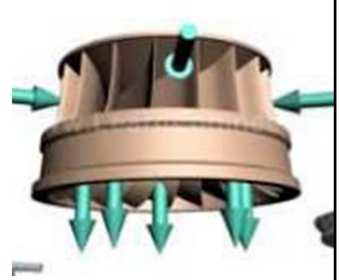
Based on the direction of flow of water through the runner:

a) Tangential flow turbine: Water flows along the tangent to the runner. Example: Pelton wheel.

b) Axial flow turbine: Water flows in a direction parallel to the axis of rotation of the runner. Example: Kaplan turbine.

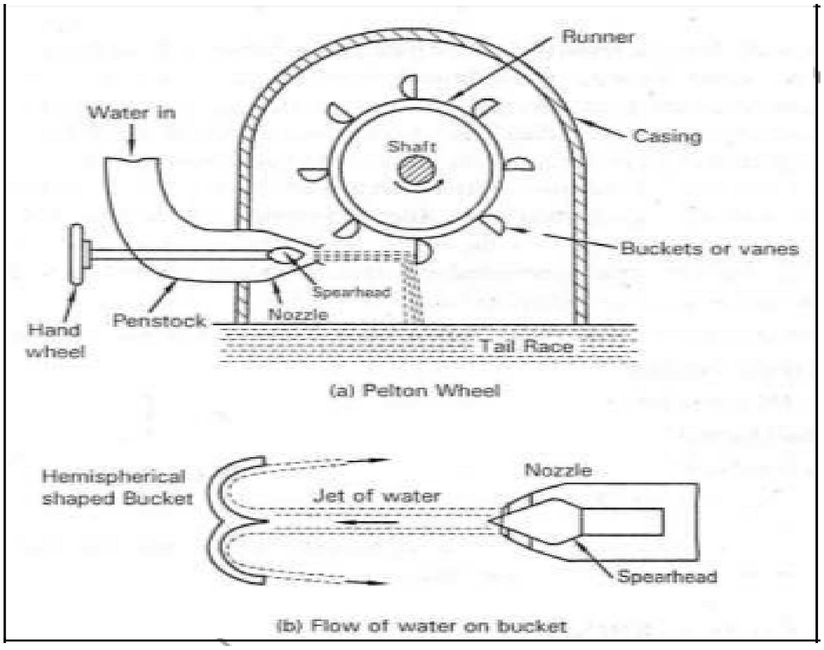
c) Radial flow turbine: Water flows in a radial direction through the runner. Radial flow turbines are further classified into inward radial flow and outward radial flow turbines. Example: Thomson turbine, Girad turbine, Old Francis turbine.

d) Mixed flow turbine: Water flows racially into the runner and leaves axially, Example: Modern Francis turbine.

Tangential flow Turbine Ex: Pelton Wheel	**Axial flow Turbine** Ex: Kaplan Turbine	**Radial flow Turbine** Ex: old Francis Turbine	**Mixed flow Turbine** Ex: Modern Francis Turbine
			

1) PELTON WHEEL TURBINE

Pelton wheel is a tangential flow impulse turbine, used for high heads and small quantity of water flow. Figure shows the schematic diagram of a Pelton wheel. The Pelton wheel consists of the following parts: nozzle with spear head, shaft, rotor, buckets, casing, and tailrace.



Working: In operation, water from the reservoir (dam) having potential energy flows through the penstock and enters the nozzle. As water flows through the nozzle, the potential energy of water is completely converted into kinetic energy in the nozzle. The high velocity jet of water issuing from the nozzle impinges on the curved blades fixed around the runner wheel. The impulse force due to the high velocity jet of water sets the runner wheel into rotary motion. Hence, the shaft coupled to the runner wheel also rotates thereby doing useful work. Thus, the potential energy of the water is converted into mechanical work. After performing work, the water freely discharges to the tailrace. The work produced at the output shaft is used to drive a generator to produce electricity the electricity is then transmitted to a substation where transformers increase voltage to allow transmission to homes, office, and factories.

Advantages:

1) Simple in construction and easy maintenance.

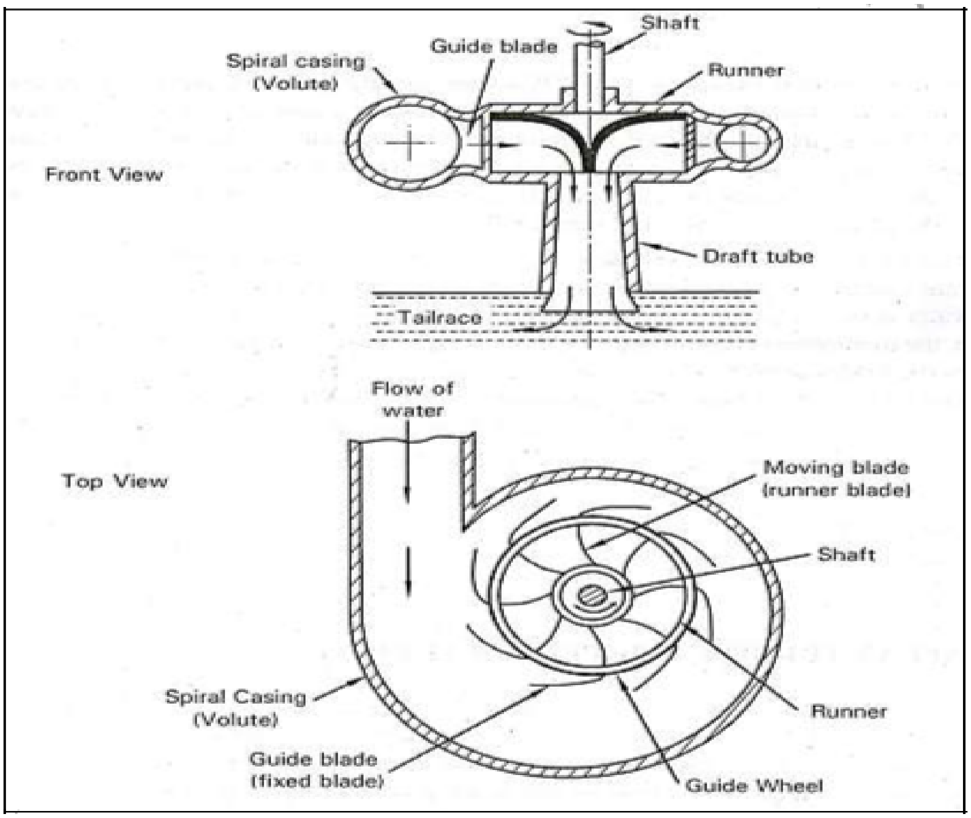
2) To drive more power multiple jets (2 to 6) Pelton wheel may be used.

Disadvantages:

1) A lot of head loss occurs when the river discharge is low.

2) FRANCIS TURBINE

Francis turbine is a mixed flow reaction turbine used for medium heads. It was the first Hydraulic turbine with radial flow, designed by American scientist James Francis. Figure shows the front and top views of a Francis turbine. Francis turbine consists of the following parts: spiral casing (volute), runner, shaft, guide blade (fixed blade), guide wheel, moving blade (runner blade).



Working:

In operation, water from the reservoir (dam) flows through the penstock and enters the spiral casing. As the water flows through the tapered spiral casing, a part of its potential energy is converted into kinetic energy. Water flows through the guide blades, gets deflected and then flows radially inwards to the outer periphery (outer diameter) of the runner. The water then moves over the moving blades in the radial direction and is finally discharged to the tailrace axially from the centre of the runner via a draft tube.

During its flow over the runner blades, the blade passages act as nozzle, and the remaining part of the potential energy is converted into kinetic energy. It is important to note at this point, that the jet of water does not impinge on the runner. In fact, they are leaving the runner at high velocity. So, the momentum is converted into force as in the case of impulse turbine. Since the water leaves the blades at high velocity, there is a reaction force on the runner. This force sets the runner into rotary motion. Hence the shaft connected to the runner also rotates thereby doing useful work. The shaft in turn drives the generator to produce electricity.

Advantages:

1) No head loss occurs even at low discharge of water.

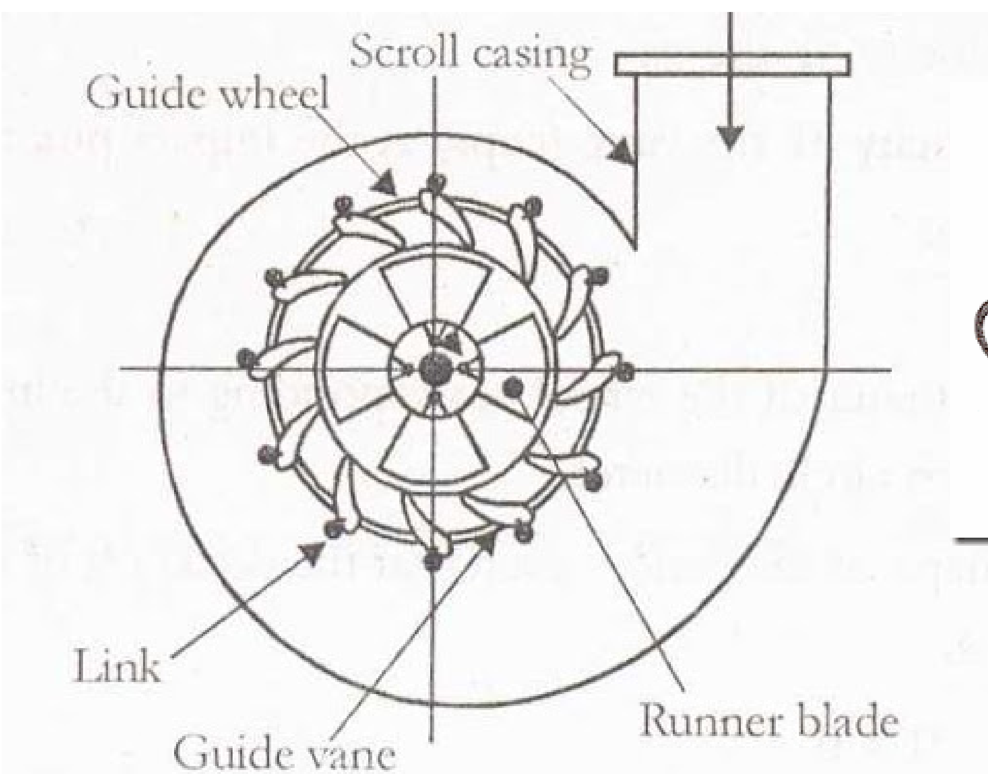
Disadvantages:

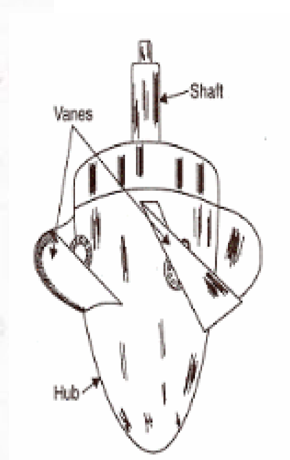
1) Eddy losses are more

2) Since the spiral casing is grounded, runner is not easily accessible. Hence dismantling is difficult.

3) KAPLAN TURBINE

The Kaplan turbine is a low head reaction turbine in which water flows axially, Figure shows the rotor and front view of a Kaplan turbine. Kaplan turbine consists of the following parts: guide vanes, runner vanes, shaft, spiral casing, tailrace, hub, and blade.





Working:

Kaplan turbine is an axial flow reaction turbine and is used where large quantity of water is available at low heads. The turbine consists of a hub or boss fixed to a vertical shaft. The runner blades attached to the hub are adjustable, and can be turned about their axis to take care of change of load. The runner has only 4 to 8 blades. Similar to Francis turbine, Kaplan turbine also has a ring of fixed guide blades at the inlet to the turbine. The inlet is a scroll shaped tube surrounding the fixed blades. In operation, water from the reservoir flows through the penstock and enters the spiral casing. A part of the potential energy of water is converted into kinetic energy in the spiral casing.

The water then moves through the guide blades (fixed blades), gets deflected and then flows axially through the runner blades as shown in figure. During its flow over the runner blades, the blade passages act as nozzle, and the remaining part of the potential energy is converted into kinetic energy. The water leaves the runner blades at high velocity, and as a result, a reaction force is set up causing the runner to rotate at high speeds. Hence the shaft connected to the runner also rotates thereby doing useful work. The shaft in turn drives the generator to produce electricity. The water discharging at the centre of the runner enters the draft tube whose end is immersed into the tailrace as in Francis turbine.

Advantages:

1) Simple in construction and requires less space.

2) Eddy losses are almost eliminated.

Disadvantages:

1) Cavitation is likely to occur due to high velocity flow of water.

Difference between impulse water turbine and reaction water turbine:

Differences between Impulse and Reaction Turbines:

S.No	Impulse Turbine	Reaction Turbine
1	In impulse turbine all hydraulic energy is converted into kinetic energy by a nozzle and it is is the jet so produced which strikes the runner blades.	In reaction turbine only some amount of the available energy is converted into kinetic energy before the fluid enters the runner.
2	The velocity of jet which changes, the pressure throughout remaining atmosphere.	Both pressure and velocity changes as fluid passes through a runner. Pressure at inlet is much higher than at outlet.
3	Water-tight casing is not necessary. Casing has no hydraulic function to perform. It only serves to prevent splashing and guide water to the tail race.	The runner must be enclosed within a watertight casing.
4	Water is admitted only in the form of jets. There may be one or more jets striking equal number of buckets simultaneously.	Water is admitted over the entire circumference of the runner.
5	The turbine doesn't run full and air has a free access to the bucket.	Water completely fills at the passages between the blades and while flowing between inlet and outlet sections does work on the blades.
6	The turbine is always installed above the tail race and there is no draft tube used.	Reaction turbine are generally connected to the tail race through a draft tube which is a gradually expanding passage. It may be installed below or above the tail race.
7	Flow regulation is done by means of a needle valve fitted into the nozzle.	The flow regulation in reaction turbine is carried out by means of a guide-vane assembly. Other component parts are scroll casing, stay ring runner and the draft tub.
8	The blades are symmetrical	The blades are unsymmetrical
9	Lower efficiency due to high losses	Higher efficiency due to less

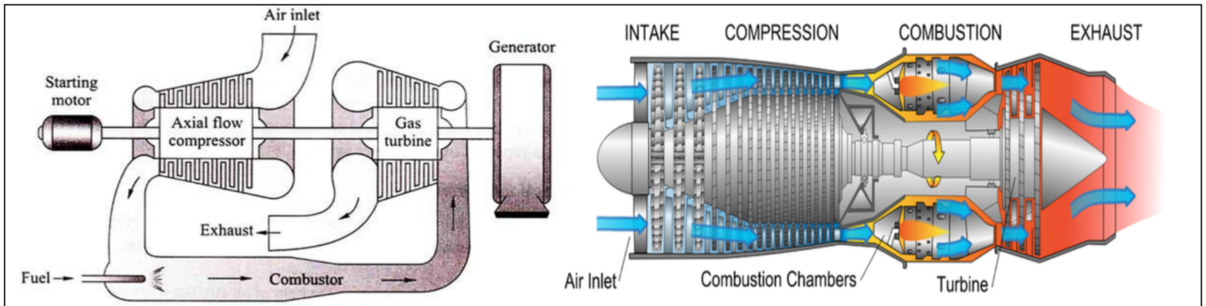
Difference between Francis and Kaplan turbine:

Sl no	Francis turbine	Kaplan turbine
1	It is a mixed flow turbine	It is an axial flow turbine
2	Medium head turbine, requires medium quantity of water	Low head turbine, requires large quantity of water
3	Number of guide vanes are around 16 to 24	Number of guide vanes are around 3 to 8
4	The runner is supported by a driving shaft	The runner is the extension of the vertical shaft
5	Guide vanes are assembled with the help of links and levers to act as valves	Guide vanes are made adjustable for smooth flow of water. They are so designed and fixed around

		the hub
6	Requires large space	Requires less space due to sloped vanes
7	Cavitation do not occurs	Cavitation is likely to occur
8	Draft tube is of simple elbow type	Draft tube is of circular to rectangular type

GAS TURBINES

A gas turbine is a thermal prime mover (also called a combustion turbine /rotary type of IC engine) that converts the heat energy of the hot air or burnt gases into mechanical work in the form of rotation of shaft. This energy then drives a generator that produces electrical energy and drives the aircraft.



38 Actual gas turbine cycle

Based on the flow of the working substance during the cycle of operation, gas turbines are classified into two types:

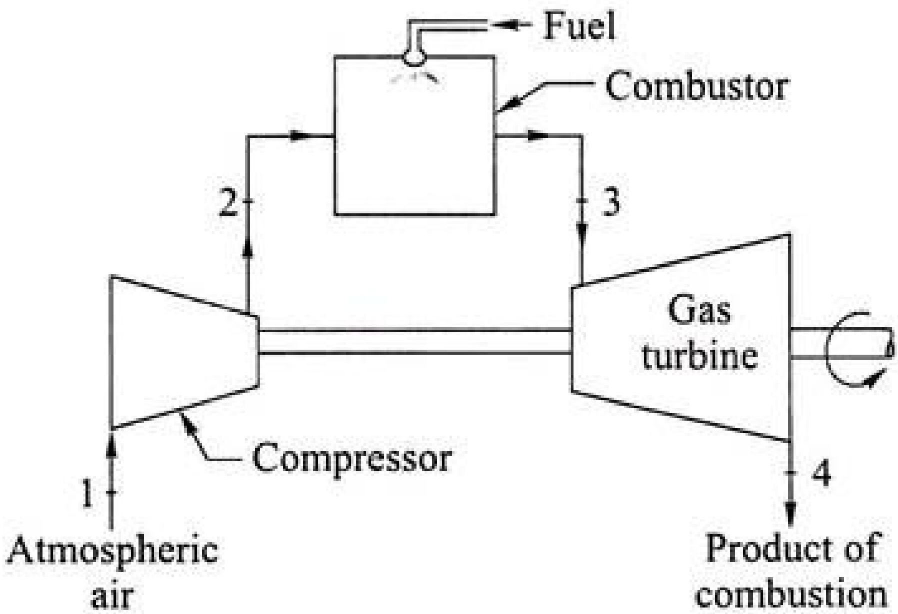
Open cycle gas turbine: In the open cycle gas turbine, the working fluid is the atmospheric air and the heat rejection process occurs in the atmosphere as the turbine exhaust is discharged into the atmosphere.

Closed cycle gas turbine: In the closed cycle gas turbine the heat rejection process is accomplished in a heat exchanger and the same working fluid is cycled continuously. The working fluid does not come in contact with the product of combustion.

1) Working of an OPEN CYCLE GAS TURBINE

Figure shows the line diagram of an open cycle gas turbine. It consists of a rotary compressor, combustion chamber, and a turbine (reaction type). Both the turbine and the compressor are mounted on a common shaft. This is because, a part of the power developed by the turbine is required to drive the compressor. In an operation, the compressor draws air from the atmosphere and compresses it to a high pressure. The compressed air then flows into the combustion chamber where the fuel is burnt at constant pressure. The hot gases produced by combustion process mixes with the compressed air. Due to this, the air gets heated up and also its mass increases.

The high-pressure and high-temperature hot gases are then made to flow through the turbine blades, where in the heat energy is converted into mechanical work, in much the same way as in the case of steam turbines. The shaft of the turbine may be connected to a generator for producing electricity. The gases coming out from the turbine are discharged to the atmosphere as they cannot be used any more. Since, the working substance is discharged to the atmosphere, this type of turbine is called as open cycle gas turbine. The working substance (air and fuel) must be replaced continuously for every cycle of operation.



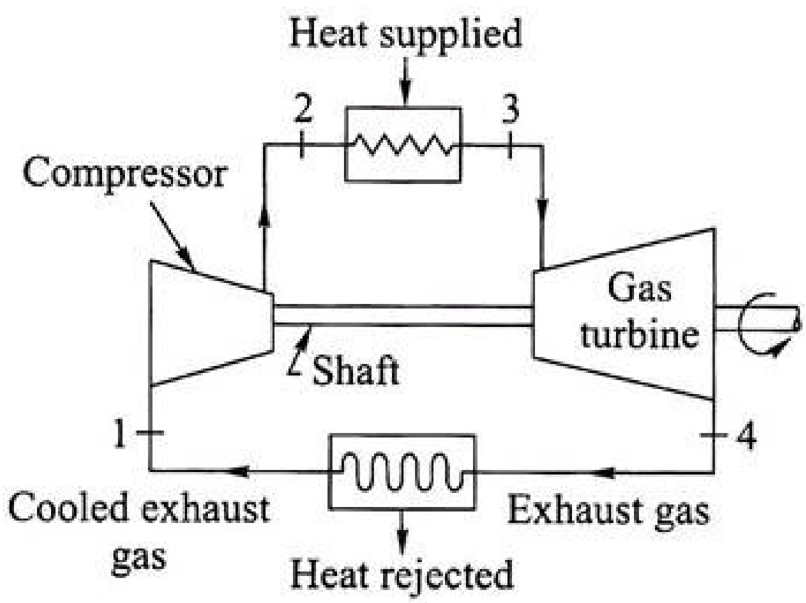
2) Working of a CLOSED CYCLE GAS TURBINE

Figure shows the line diagram of a closed cycle gas turbine. It consists of a rotary compressor, heater, a turbine (reaction type) and a cooler. The compressor and the turbine are mounted on a common shaft. In a closed cycle gas turbine atmospheric air or some other stable gases like argon, helium, nitrogen, carbon dioxide, etc., may be used as the working fluid.

In operation, the working fluid is compressed to a high pressure in a compressor r and then passed to a heater where it is heated with the help of some external source. The working fluid will not come in contact with the products of combustion as in the case of open cycle gas turbine. Instead, heat is transferred using a heat exchanger.

The high-pressure and high-temperature fluid is then made to flow through the turbine blades, where in the heat energy is converted into mechanical work in much the same way as in the case of steam turbines. From the turbine the fluid is passed to a cooler, where it is cooled to its original temperature from external cooling source.

The low-temperature and low-pressure fluid from the cooler is then passed to the compressor for the next cycle to take place. Since the working fluid is circulated again and again, this type of turbine is called closed cycle gas turbine.



Difference between closed and open cycle gas turbines:

Comparison bet^n Close Cycle and Open Cycle Gas Turbines:

Close Cycle Gas Turbine	Open cycle Gas Turbine
1. The compressed air is heated in a heating chamber. Since the gas is heated by an external source, so the amount of gas remains the same.	The compressed air is heated in a combustion chamber. The products of combustion get mixed up in the heated air.
2. The gas from the turbine is passed into the cooling chamber.	2.The gas from the turbine is exhausted into the atmosphere.
3. The working fluid is circulated continuously.	3. The working fluid is replaced continuously.
4. Any fluid with better thermodynamic properties can be used.	4. Only air can be used as the working fluid.
5. The turbine blades do not wear away earlier, as the enclosed gas does not get contaminated while flowing through the heating chamber.	5.The turbine blades wear away earlier, as the air from the atmosphere gets contaminated while flowing through the combustion chamber.
6. It is best suited for stationary installation or marine uses.	6. It is best suited for moving vehicle.
7. Its maintenance cost is high.	7. Its maintenance cost is low.