TURBINES & their Classifications

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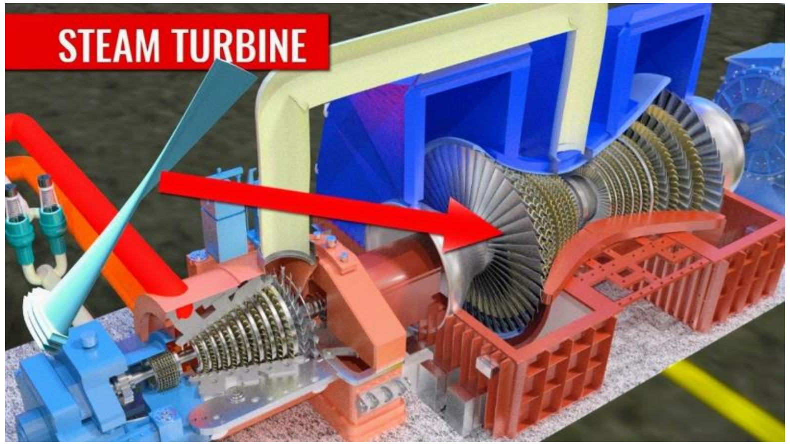
What is Turbine?

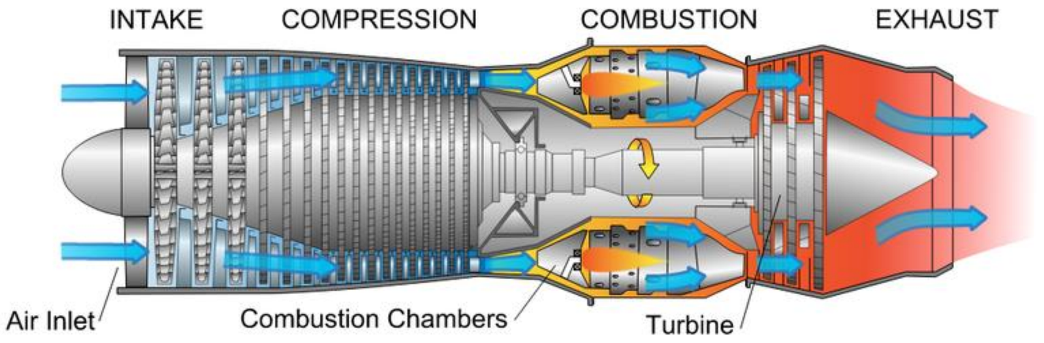
- A **turbine** is a rotary engine that extracts energy from a fluid flow and converts it into useful work.
- The simplest **turbines** have one moving part (i.e. a rotor assembly) which is a shaft with blades attached.

(Hydraulic Turbine)



(Steam Turbine)

(Wind Turbine)



(Gas Turbine)

Classifications of Turbines Based on Working Fluid

- Hydraulic turbines: When the working fluid is water, turbines are called hydraulic turbines.

- Wind turbine: When the working fluid is air, and energy is extracted from wind, the machine is called wind turbine.

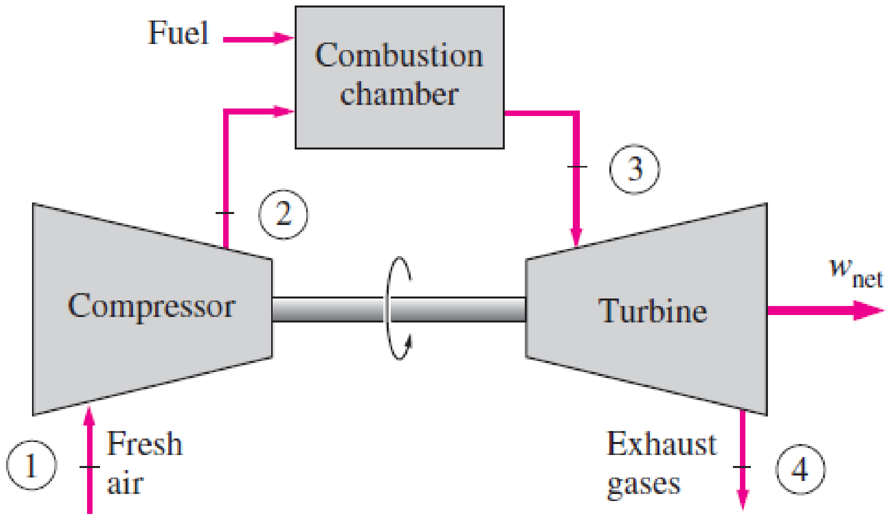
- Steam turbine: When the working fluid is steam, the turbines are called steam turbines.

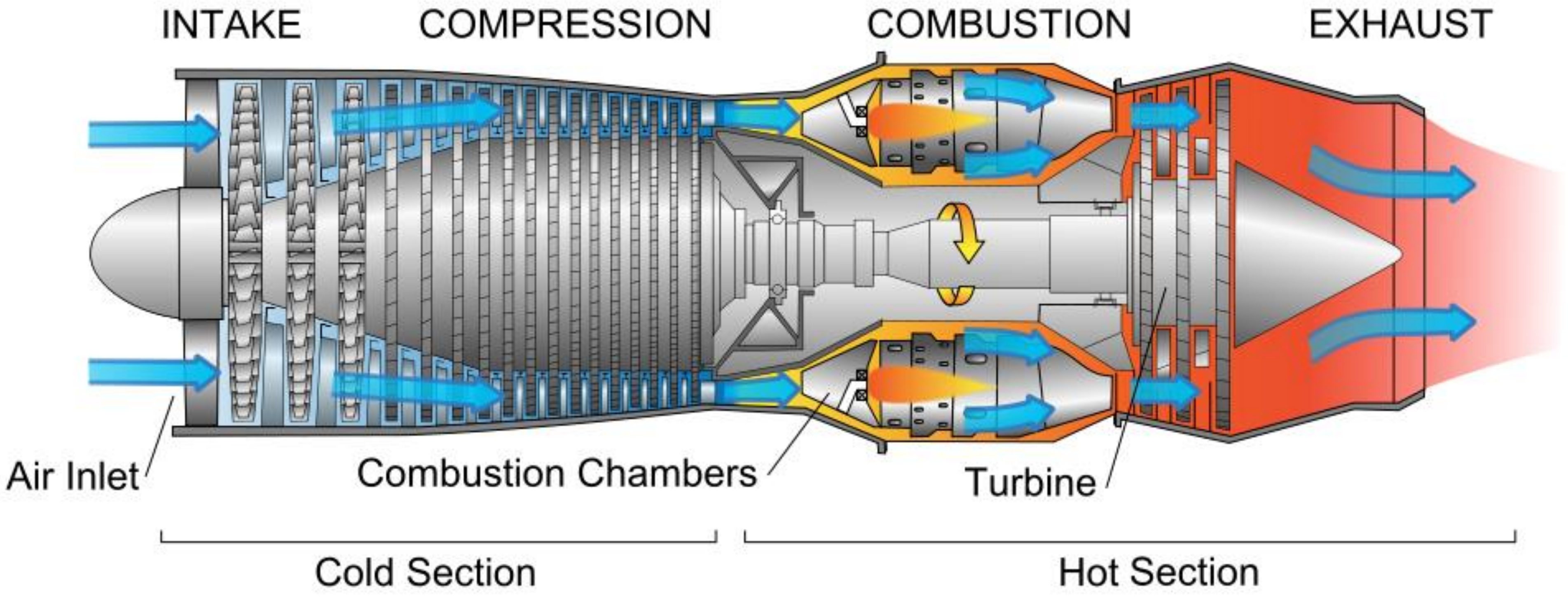
- Gas turbine: When the working fluid is a compressible gas, the turbine is called gas turbine.

Gas Turbine

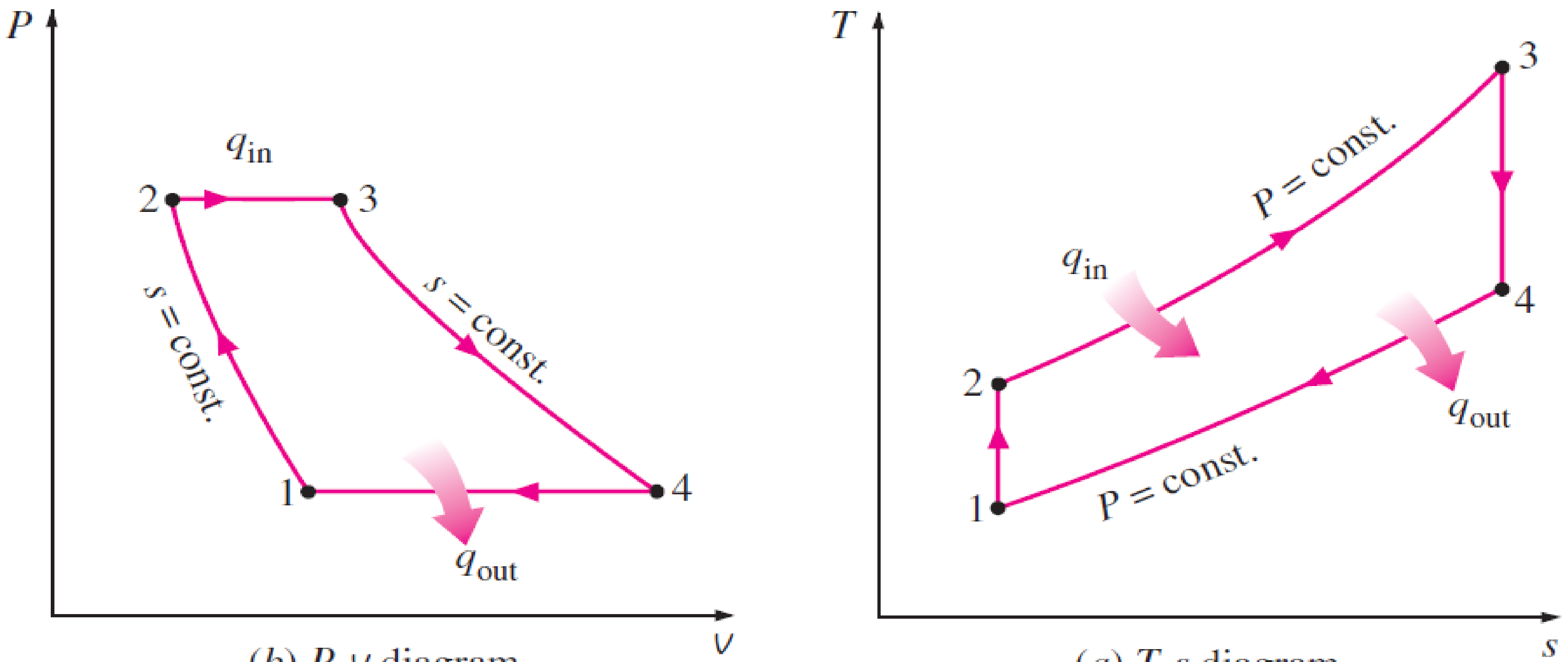
- Gas turbine is a **rotary machine** that uses gas as a working fluid. When hot gases are passed through set of blades connected to shaft, it rotates producing the mechanical work.
- **Applications:** Power Generation, Aircraft Propulsion, Marine Propulsion etc.
- Gas turbine works on **Brayton cycle** and its efficiency normally ranges from 30% to 40%.
- Although gas turbines are less efficient, but they are **cheaper**.
- Gas turbine power plants are small in **size**, **mass** and are available at short delivery times. Their **installation is easier**.
- Gas turbines have a **high power to weight ratio**.

Gas Turbine


Fuel
Combustion chamber
2
3
Compressor
Turbine
w_{net}
1
Fresh air
Exhaust gases
4


INTAKE
COMPRESSION
COMBUSTION
EXHAUST
Air Inlet
Combustion Chambers
Turbine
Cold Section
Hot Section

Ideal Brayton Cycle



(*b*) *P*-v diagram (*a*) *T*-*s* diagram

1 – 2: Isentropic compression.	2 – 3: Constant pressure heat addition.
3 – 4: Isentropic expansion.	4 – 1: Constant pressure heat rejection.

Processes in Brayton Cycle

i. Isentropic compression

(COMPRESSOR)

- Temperature increases from T_1 to T_2
- Pressure increases from P_1 to P_2
- Volume decreases from V_1 to V_2
- Heat transfer is zero, entropy remains constant

ii. Constant pressure heat addition

(COMBUSTION CHAMBER)

- Temperature increases from T_2 to T_3
- Pressure remains constant ($P_2 = P_3$)
- Volume increases from V_2 to V_3

iii. Isentropic expansion

(GAS TURBINE)

- Temperature decreases from T_3 to T_4
- Pressure decreases from $P_3 = P_2$ to $P_4 = P_1$
- Volume increases from V_3 to V_4
- Heat transfer is zero, entropy remains constant

iv. Constant pressure heat rejection

(HEAT EXCHANGER)

- Temperature decreases from T_4 to T_1
- Pressure remains constant at $P_1 = P_4$
- Volume decreases from V_4 to V_1

Facts
(2nd Law of Thermodynamics)

- No heat device can generate work without net rejection of heat to a low temperature reservoir.

- It is impossible for any device that operates in a cycle to receive heat from a single high temperature reservoir and produce a net amount of work and no other effects.

- (This is 2nd law of thermodynamics)

(Some Terminologies)

Net work done:

- It is the difference of turbine work and compressor work.

Net work done = Turbine work – Compressor work

Work Ratio:

- It is the ratio of the net work done to the turbine work.

Work Ratio = Net work done / Turbine work

Thermal Efficiency:

- It is the ratio of net work done to the heat supplied.

Thermal Efficiency = Net work done / Heat added

Advantages of Gas Turbine Powerplant

- Gas turbines are capable of reaching full load **operation in a matter of minutes**. These engines are very popular for using as peak power plants, this due to their ability of be taken into service during peak power demand when and as required.

- Furthermore, they have a **very attractive initial cost** as compared with steam turbines.

- **High power-to-weight ratio** as compared to steam turbine powerplants.

- Require **much less water** than steam turbines power plants.

- **Smaller size and weight** compared to steam turbines.

- **Less space** is needed for installation.

Disadvantages of Gas Turbine Powerplant

- One of the disadvantages of gas turbines is their limited ability to use different fuels in comparison with steam turbines. In fact, just a little variation in the fuel specs used in a gas turbine can lead to efficiency drop, increase maintenance factor, early inspection etc.

- Low part load efficiency.

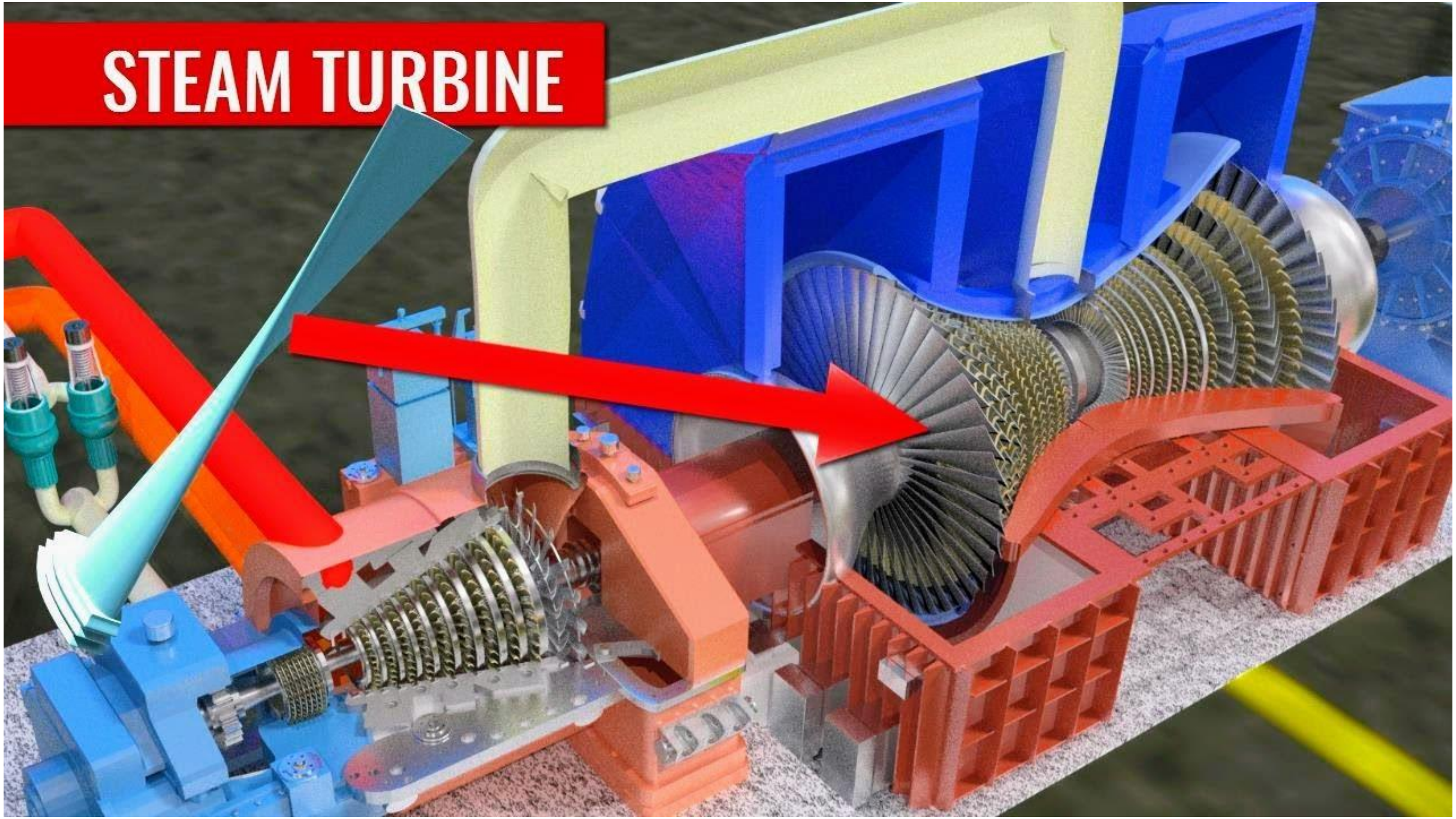
- Due to high operating temperatures, special and expensive materials are needed.

- About two thirds of the power produces is used to drive the compressor.

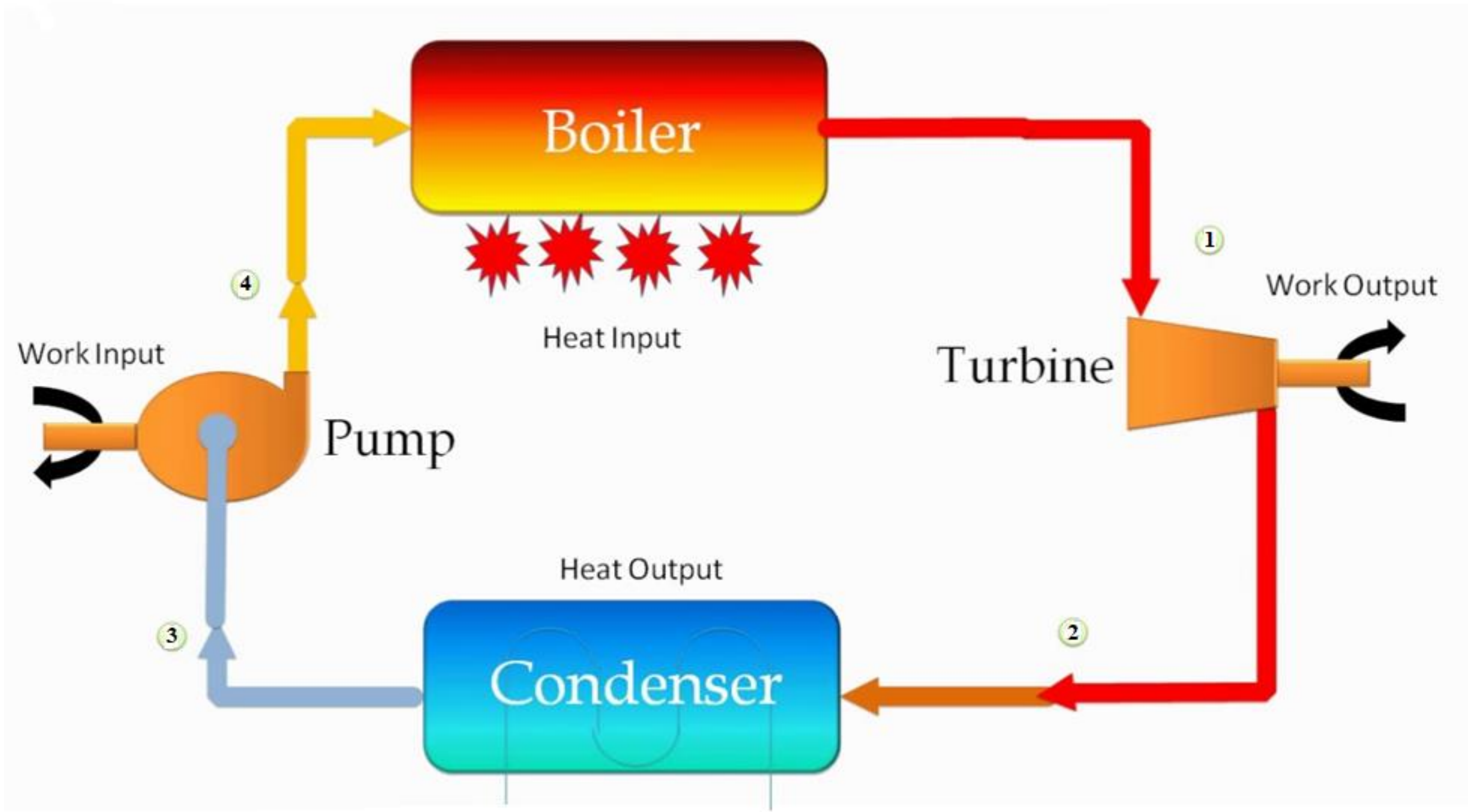
- External source of power needed to start self-sustained operation.

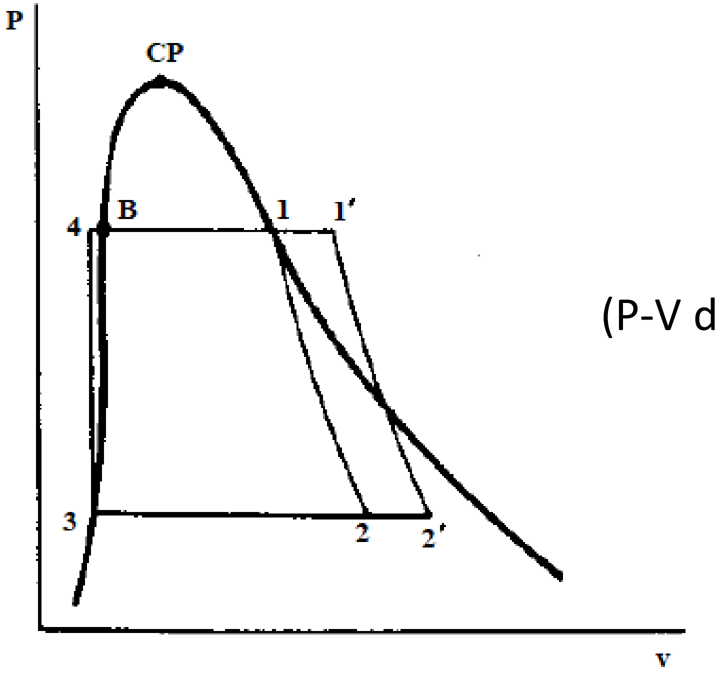
Steam Turbine

- Steam turbine is a **rotary machine** that uses steam as a working fluid. When steam is passed through set of blades connected to shaft, it rotates producing the mechanical work.
- <u>Applications:</u> Power Generation
- Steam turbine works on **Rankine cycle** and its efficiency normally ranges up to 60%.
- The basic Rankine cycle operates between working temperature of 40^oC and 560^oC.
- Although steam turbines are **more efficient**, but they are **expensive** as compared to gas turbines.
- Steam turbine power plants are large in **size**, **mass** and need a lot of time to for their installation as well as startup.
- Steam turbines have a **less power to weight ratio** but they have high power producing capacities.

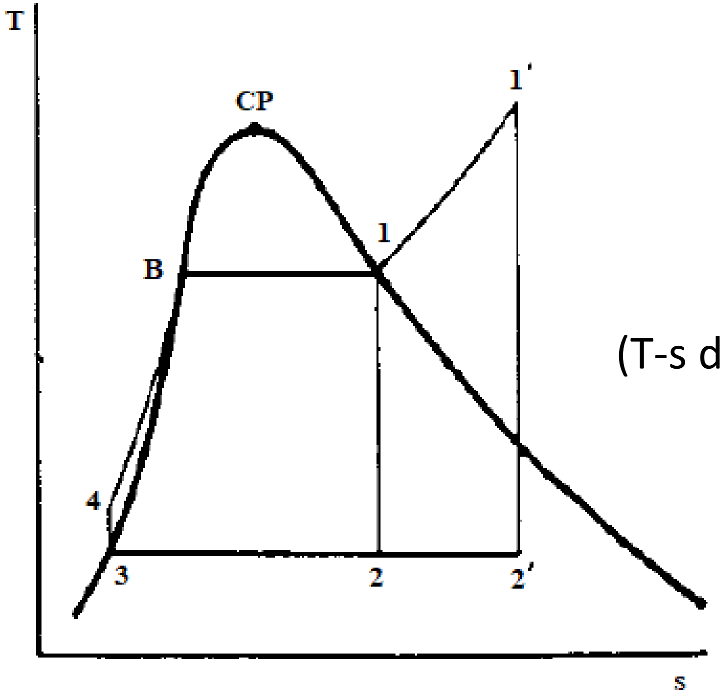

STEAM TURBINE

Rankine Cycle





(P-V diagram)



(T-s diagram)

(Processes in Rankine Cycle)

i. Isentropic Expansion in Turbine
ii. Constant pressure heat rejection in Condensor
iii. Isentropic Compression in Pump
iv. Constant pressure heat addition in Boiler

Advantages of Steam Turbine Powerplant

- One of the main advantages of steam turbines is the boiler ability to burn **multiple types of fuels**. The boiler is capable of burning different fuels at each stage of the start-up process. For instance, it can use LPG for ignition, light diesel oil for start-up and then heavy oil for continuous operation as an example.

- Steam turbines have a **high power-to-weight ratio** which makes them more practical **than reciprocating engines**. Also, for a given power output, their size is smaller and produce less vibrations than their reciprocating counterparts.

- Power generation is **not affected by atmospheric conditions** as it operates on a closed cycle.

- Another advantages of steam turbine power plants compared to gas turbines are the **high operating efficiency and higher reliability**.

Disadvantages of Steam Turbine Powerplant

- Long start-up time. Start-up of a steam turbine takes a considerable amount of time specially during cold start-ups and requires a long list of steps before it can operate at base load. Therefore, steam turbines cannot be used as peak power plants.

- The operation of a steam turbine power plant requires more components than that of a simple cycle gas turbine. Among this components are huge boiler, cooling towers, feedwater systems and so forth.

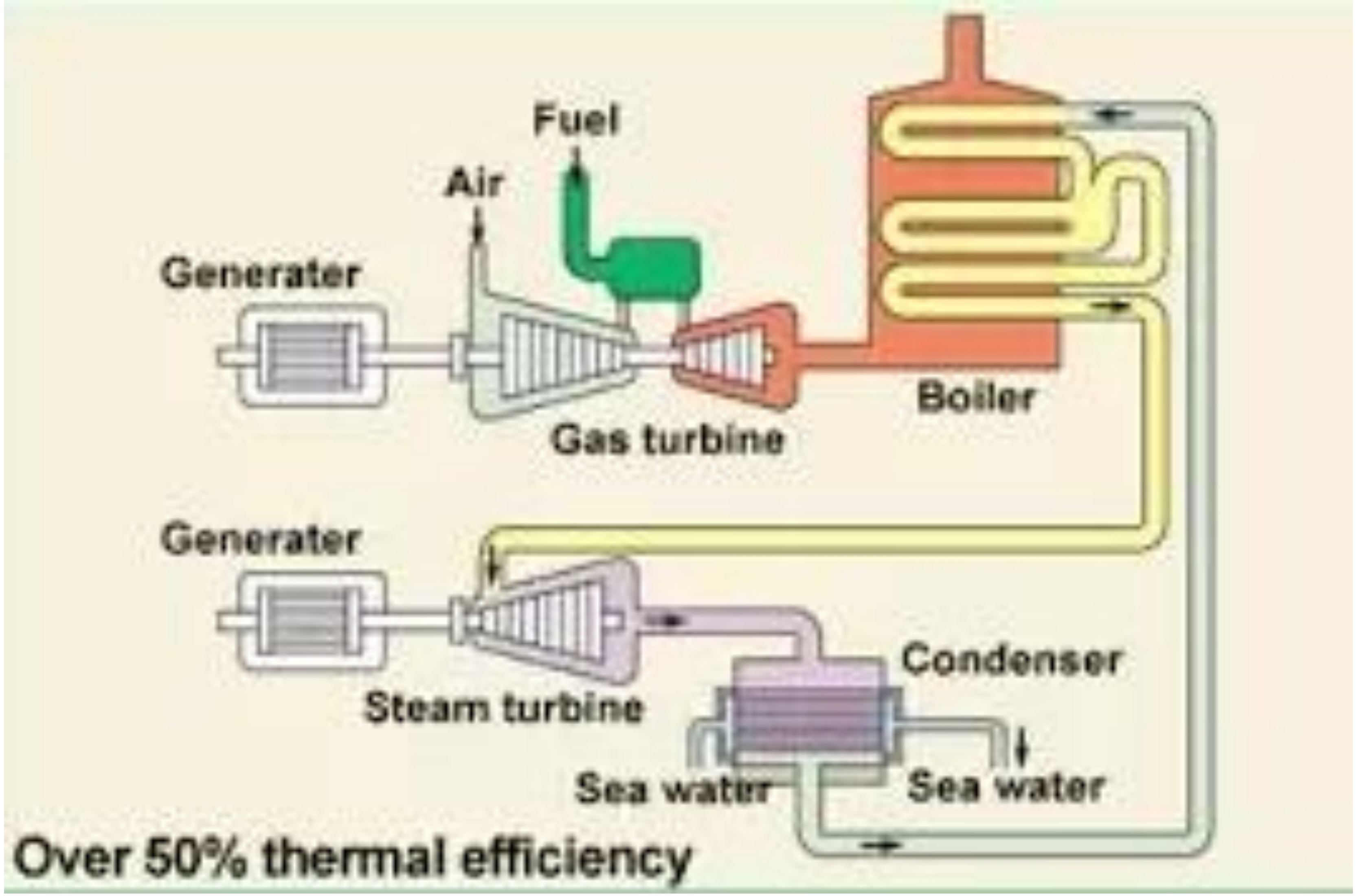
- Require to be installed near large water reservoirs.

Combined Cycle Powerplant

A combined-cycle power plant uses both a gas and a steam turbine together to produce up to 50 percent more electricity from the same fuel than a traditional simple-cycle plant. The waste heat from the gas turbine is routed to the nearby steam turbine, which generates extra power.

1. Gas turbine burns fuel.
   - The gas turbine compresses air and mixes it with fuel that is heated to a very high temperature. The hot air-fuel mixture moves through the gas turbine blades, making them spin.
   - The fast-spinning turbine drives a generator that converts a portion of the spinning energy into electricity.
2. Heat recovery system captures exhaust.
   - A Heat Recovery Steam Generator (HRSG) captures exhaust heat from the gas turbine that would otherwise escape through the exhaust stack.
   - The HRSG creates steam from the gas turbine exhaust heat and delivers it to the steam turbine.
3. Steam turbine delivers additional electricity.
   - The steam turbine sends its energy to the generator drive shaft, where it is converted into additional electricity.

Combined Cycle Powerplant



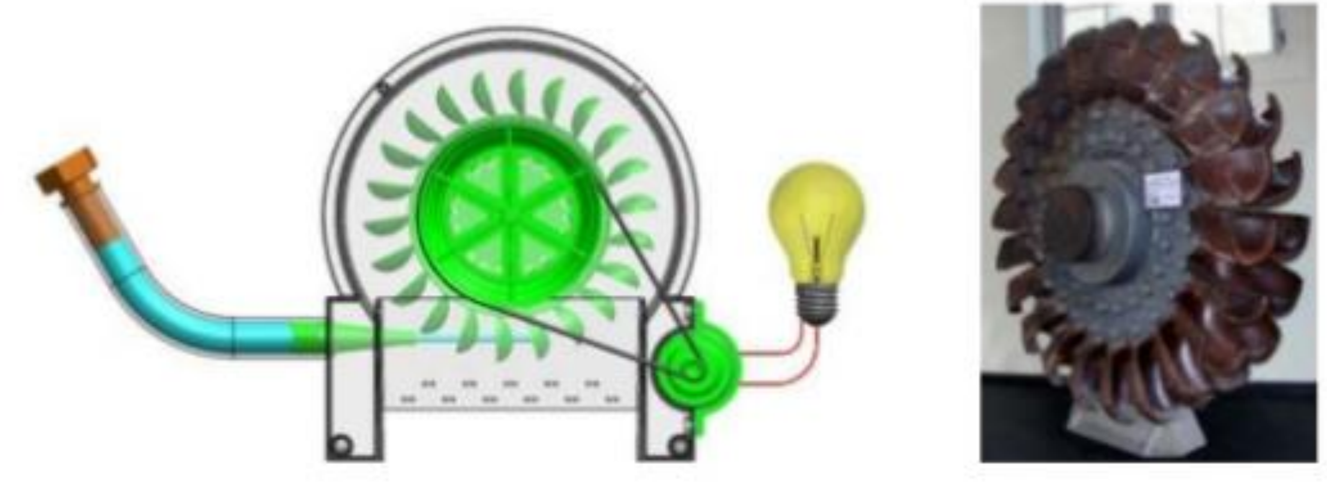
Classifications of Turbines Based on Working Mechanism

- Impulse Turbine: In an impulse turbine, the whole of the fluid available energy is converted to Kinetic energy before the fluid acts on the moving parts of the turbine.
- *Pelton wheel* is an example of such turbines.

- Reaction Turbine: In a reaction turbine, the rotation is mainly achieved by the reaction forces created by the acceleration of the fluid in the rotating blade.
- *Francis turbine and Kaplan turbines* are the examples of reaction turbine.

Impulse Turbine

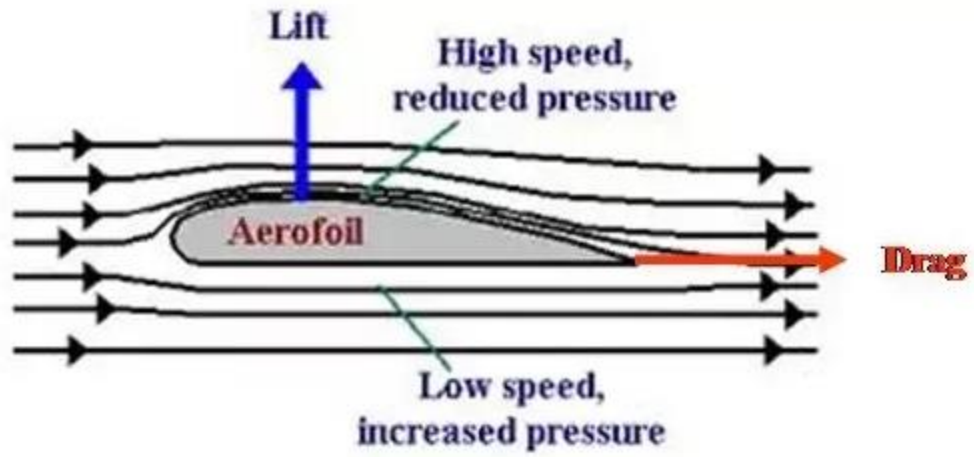
- In impulse turbine the main and only force which causes the rotation of turbine is the force or **impact** due the steam. The total pressure drop takes place in the nozzle.
- In an Impulse turbine, the working fluid is made to change its direction of flow within the gap between any two moving blades.
- This causes change in momentum and there by causes a force acting on the moving blade. This force makes the turbine to rotate.

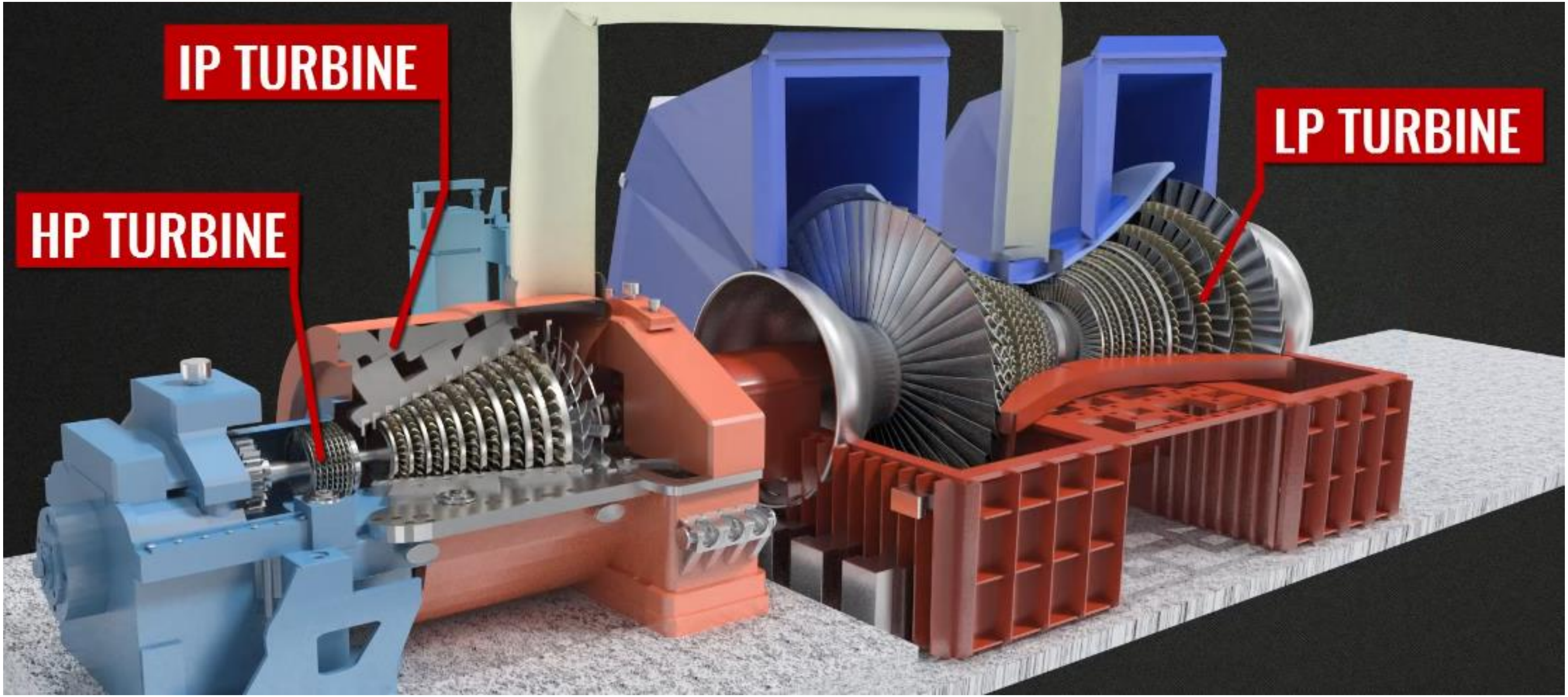


Pelton Wheel (Impulse Turbine)

Reaction Turbine

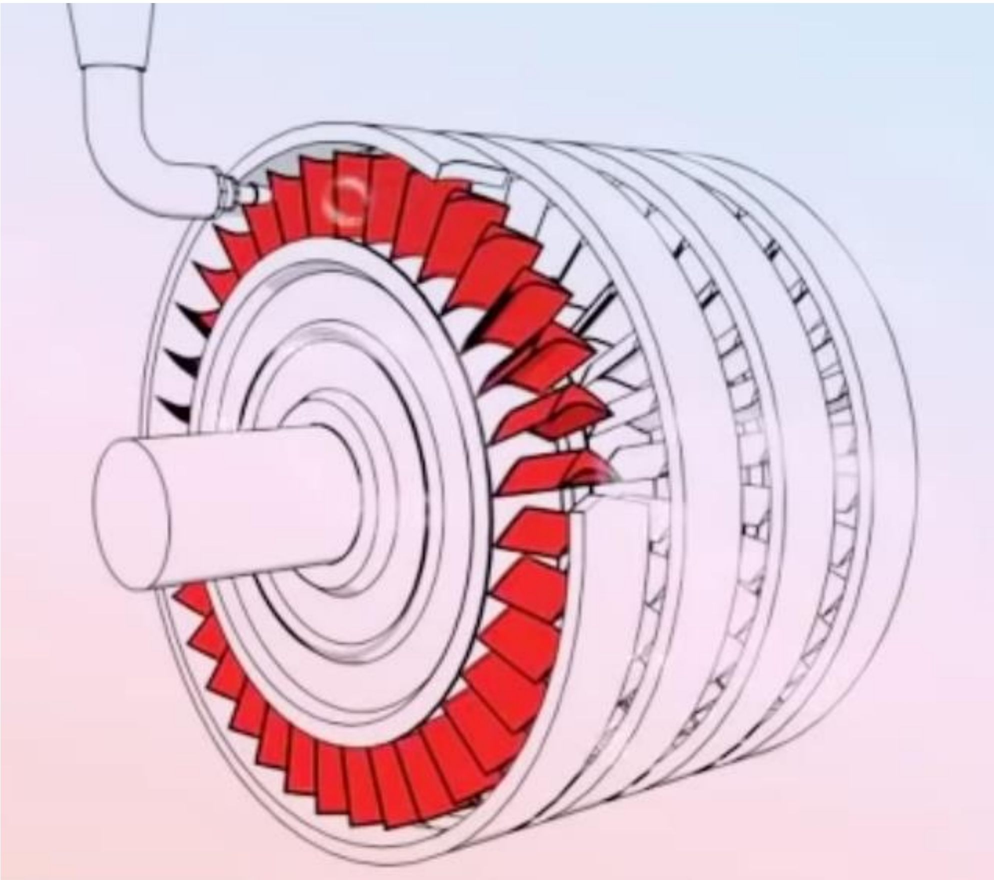
- In a Reaction turbine, the working fluid is accelerated while passing through the gap between any two moving blade. This high velocity jet of working fluid causes a **reaction force** on the moving blades which in turn causes the turbine rotor to rotate.
- In case of reaction turbine , **design (aerofoil shape)** of moving blade plays an important role. The force which causes the rotation is **partially due to impact** of steam and **partially due the aerofoil shape** which causes generation of high pressure and low pressure formation around the body. The difference in pressure across the **airfoil produces** the **lift / reaction force due to which shaft rotates.**
- In reality there are **no pure** Impulse type or Reaction type of turbines. They are always of combination type. However, the proportion of degree of reaction varies in these turbines.



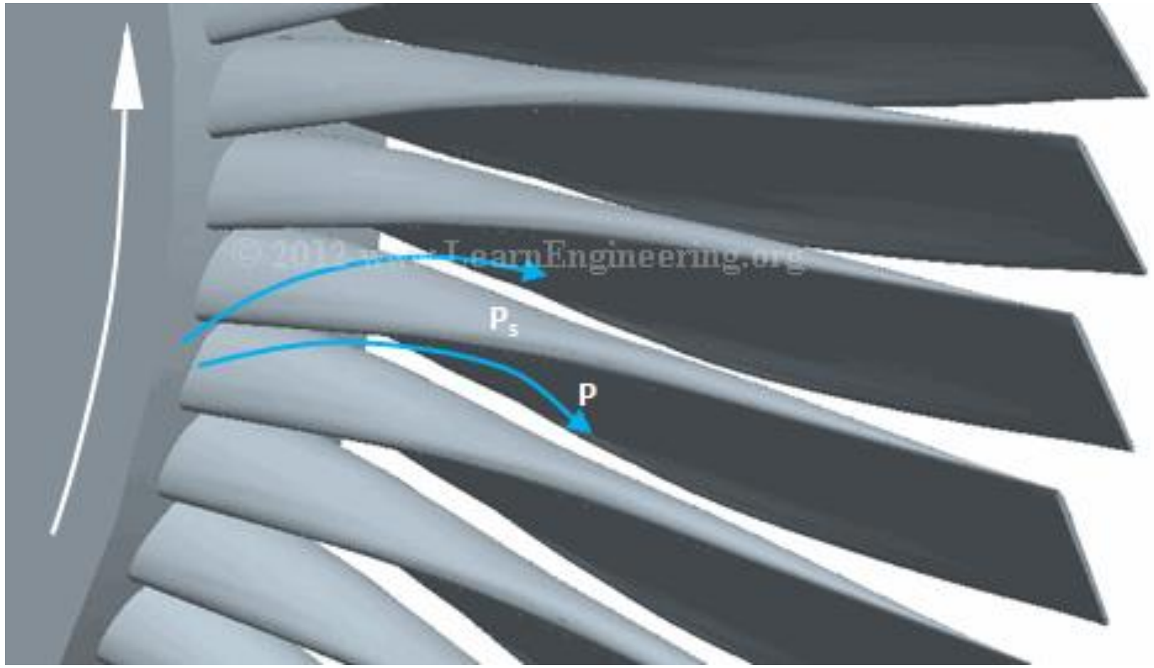

IP TURBINE
HP TURBINE
LP TURBINE

	Impulse Turbine	***Reaction Turbine***
1	Steam strikes on the moving blade with kinetic energy.	Steam strikes on moving blades with kinetic energy & pressure energy.
2	Steam flows through the nozzle and strikes on moving blade.	Steam first flows through fixed blade and then flows through moving blade.
3	Steam pressure remains constant during its flow through moving blade.	Steam pressure is reduced during its flow through moving blade.
4	The velocity of steam remains constant while striking over the moving blade.	The velocity of steam increases while striking over the moving blades.
5	Blades are small in size and symmetrical in shape.	Blades are not symmetrical in shape and large.
6	Blades are in the shape of profile.	Blades are of aerofoil shape.
7	Occupies less space per unit power.	Occupies more space per unit power.
8	Less number of stages are required.	More number of stages are required.
9	Less maintenance is required.	More maintenance is required.
10	**Example:** Pelton wheel turbine	**Examples:** Francis turbine, Kaplan turbine

Blades Design



Impulse turbine blades



Reaction turbine blades