

AL-MAMON UNIVERSITY COLLAGE
DEPARTMENT OF ELECTRICAL POWER
ENGINEERING TECHNIQUES



Part 3

Lecture notes 3 & 4

FLUID MECHANICS

Prepared by

Eng. Ammar T. Ahmed

Eng. Hayder Baqer Mahdi

Prospective students: Second year

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Basic Concepts of Thermodynamic

This lecture notes consist the following topics:

- Introduction.
- Types of Fluid Flow.
- Continuity Equation.
- Turbines.
- Pumps

FLUID MECHANICS

Fluid Flow,

1.1 Introduction

Fluid flows play a crucial role in a vast variety of natural phenomena and manmade systems. The life-cycles of stars, the creation of atmospheres, the sounds we hear, the vehicles we ride, the systems we build for flight, energy generation and propulsion all depend in an important way on the mechanics and thermodynamics of fluid flow.

1.2 Types of Fluid Flow:

There are Six different types of fluid flow:

1.2.1 Steady and Unsteady flows:

The steady flow is defined as that type of flow in which the fluid properties like velocity, density, pressure, ... etc, at a point do not change with the time. However, the fluid property at a point can also vary with time which means the flow is **unsteady**/transient.

التدفق المستقر هو جريان المائع من دون اي تغيير في خاصية منة خواص المائع(الضغط، درجة الحرارة، اللزوجة، الكثافة، السرعة غيرها) في نقطة معينة مع مرور الوقت ، فاذا تغير قيمة اي خاصية مع مور الوقت يعني أن التدفق غير مستقر.

1.2.2 Uniform and Non-uniform fluid flow:

This **uniform fluid flow** is defined as the type of flow in which the velocity at any given time does not change with respect to space (i.e. length of direction of the flow).

Whereas the **Non-uniform flow** is defined as the type of flow in which the velocity at any given time changes with respect to space (i.e., length of the direction of the flow).

التدفق المنتظم للموائع هو نوع التدفق الذي لا تتغير فيه السرعة في أي وقت فيما يتعلق بالمكان (أي طول اتجاه التدفق). في حين يتم تعريف التدفق غير المنتظم على أنه نوع التدفق الذي تتغير فيه السرعة في أي وقت معين فيما يتعلق بالمكان (أي طول اتجاه التدفق).

1.2.3 Laminar, and Turbulent fluid flow:

This laminar fluid flow is defined as the type of flow in which the fluid particles move along well-defined paths or streamline and all the streamlines are straight and parallel. laminar fluid flow is also called as streamline flow or viscous flow.

This Turbulent fluid flow is defined as the type of flow in which the fluid particles move in a zig-zag way, the eddies formation takes place which is responsible for high energy loss.

التدفق الطبقي هذا بأنه نوع التدفق الذي تتحرك فيه جزيئات المائع على طول مسارات محددة جيداً أو انسيابية وتكون جميع خطوط الانسياب مستقيمة ومتوازية. يسمى تدفق السوائل الطبقي أيضاً باسم التدفق الانسيابي أو التدفق اللزج.

يتم تعريف تدفق المائع المضطرب هذا على أنه نوع التدفق الذي تتحرك فيه جزيئات المائع بطريقة متعرجة ، يحدث تكوين الدوامات وهو المسؤول عن فقدان الطاقة العالي.

بالنسبة لجريان الموائع في الأنابيب ، يتم تحديد نوع الجريان بواسطة رقم رينولد Re .

For pipe flow, the type of flow is determined by a non-dimensional number called the Reynolds number.

$$R_e = \frac{\rho V D}{\mu} = \frac{V D}{\nu}$$

R_e = Reynolds number

ρ = density of the fluid

V = flow speed

D = pipe diameter

μ = dynamic viscosity of the fluid

ν = Kinematic viscosity

If the **Reynold Number** is less than 2000, the flow is called **Laminar flow**.

If the **Reynold Number** is more than 4000, the flow is called **Turbulent flow**.

If the **Reynold Number** is lies between 2000-4000, the flow transitional

1.2.4 Compressible and Incompressible fluid flow

Compressible fluid flow is defined as the flow in which the density is not constant which means the density of the fluid changes from point to point.

Incompressible fluid flow is defined as the flow in which the density is constant which means the density of the fluid does not change from point to point.

Gases are compressible fluid flow but whereas the liquid is incompressible fluid flow.

تدفق الموائع القابلة للضغط بأنه التدفق الذي تكون فيه الكثافة غير ثابتة مما يعني أن كثافة المائع تتغير من نقطة إلى أخرى. أما التدفق للموائع الغير القابلة للضغط على أنه التدفق الذي تكون فيه الكثافة ثابتة مما يعني أن كثافة السائل لا تتغير من نقطة إلى أخرى.

الغازات هي تدفق مائع قابل للضغط ولكن في حين أن السائل هو تدفق مائع غير قابل للضغط.

1.2.5 Rotational and irrotational Fluid flow:

The **rotational fluid flow** is defined as the type of fluid flow in which the fluid particles while flowing along streamline and also rotate about their own axis. Whereas, The **Ir-rotational fluid flow** is defined as the type of fluid flow in which the fluid particles while flowing along streamline and do not rotate about their own axis.

تدفق المائع الدوراني هو تدفق جزيئات المائع بشكل انسيابي وأيضاً تدور حول محورها الخاص. حيث أن تدفق المائع الغير دوراني هو تدفق جزيئات المائع بشكل انسيابي ولا تدور حول محورها الخاص.

1.2.6 One, Two and Three-dimensional fluid Flow

One dimensional flow is that type of flow in which the flow parameter such as velocity is a function of time and one space co-ordinate only, say x .

$$\mathbf{u} = \mathbf{f}(x), \mathbf{v} = \mathbf{0} \text{ and } \mathbf{w} = \mathbf{0}$$

Two-dimensional fluid flow is the type of flow in which velocity is a function of time and two rectangular space co-ordinate say x, y .

$$\mathbf{u} = \mathbf{f}_1(x, y, t), \mathbf{v} = \mathbf{f}_2(x, y, t) \text{ and } \mathbf{w} = \mathbf{0}$$

Three-dimensional fluid flow is the type of flow in which velocity is a function of time and three mutually perpendicular directions. The function of 3 space coordinates (x, y, z) .

$$\mathbf{u} = \mathbf{f}_1(x, y, z, t), \mathbf{v} = \mathbf{f}_2(x, y, z, t) \text{ and } \mathbf{w} = \mathbf{f}_3(x, y, z, t)$$

التدفق ذو البعد الواحد هو ذلك النوع من التدفق الذي تكون فيه عامل التدفق مثل السرعة دالة للزمن. تدفق المائع ثنائي الأبعاد هو نوع التدفق الذي تكون فيه السرعة دالة للوقت واثنين من الاتجاهات المتعامدة (x, y) . أما تدفق السوائل ثلاثي الأبعاد هو نوع التدفق الذي تكون فيه السرعة دالة للوقت وثلاثة اتجاهات متعامدة بشكل متبادل (x, y, z) .

1.3 Continuity Equation

When a fluid is in motion, it must move in such a way that mass is conserved. To see how mass conservation places restrictions on the velocity field, consider the steady flow of fluid through a duct (that is, the inlet and outlet flows do not vary with time).

The inflow and outflow are one-dimensional, so that the velocity V and density are constant over the area A (figure 1-1).

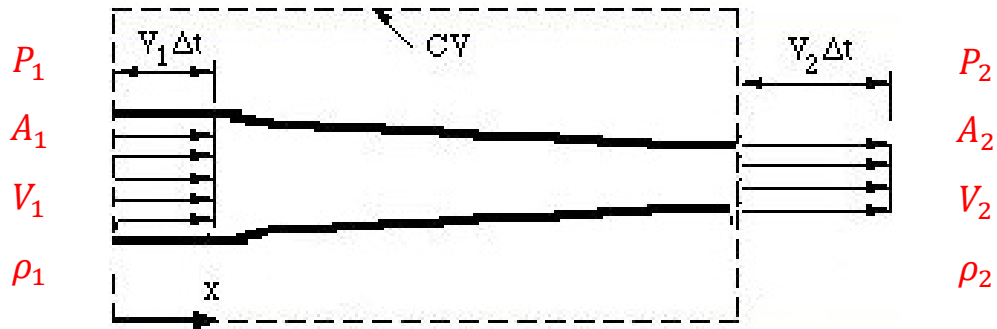


Figure 1-1 the flow in pipe

Now we apply the principle of mass conservation. Since there is no flow through the side walls of the duct, what mass comes in over A_1 goes out of A_2 , (the flow is steady so that there is no mass accumulation). Over a short time, interval Δt ,

$$\text{volume flow in over } A_1 = A_1 V_1 \Delta t$$

$$\text{volume flow out over } A_2 = A_2 V_2 \Delta t$$

Therefore

$$\text{mass in over } A = \rho A_1 V_1 \Delta t$$

$$\text{mass out over } A = \rho A_2 V_2 \Delta t$$

$$\text{So: } \boxed{\rho A_1 V_1 = \rho A_2 V_2}$$

The continuity equation in on side of pipe

$$Q = V A$$

v = is the velocity (m/s)

A = the area available for flow (m² e.g. cross sectional area of a pipe)

Q = is the flowrate (m³/s)

Example 1: A liquid flows through a pipe with a diameter of **10 cm** at a velocity of **9 cm/s**. If the diameter of the pipe, then decreases to **6 cm**, what is the new velocity of the liquid?

Solution:

$$D_1 = 10 \text{ cm}$$

$$D_2 = 6 \text{ cm}$$

$$v_1 = 9 \text{ cm/s}$$

$$v_2 = \text{????? cm/s}$$

$$A_1 = \left(\frac{D_1}{2}\right)^2 \cdot \pi$$

$$A_1 = 79 \text{ cm}^2$$

$$A_2 = \left(\frac{D_2}{2}\right)^2 \cdot \pi$$

$$A_2 = 28 \text{ cm}^2$$

$$\rho A_1 V_1 = \rho A_2 V_2$$

بما انه نفس السائل فتحذف الكثافة ρ من الطرفين

$$A_1 V_1 = A_2 V_2$$

$$V_2 = \frac{A_1 V_1}{A_2}$$

$$V_2 = 25 \text{ cm/s}$$

Example 2: If a pipe with flowing water has a cross-sectional area nine times greater at point **2** than at point **1**, what would be the velocity at point 2 if the velocity at point **1** (**2 m/s**)?

Solution:

$$A_1 V_1 = A_2 V_2$$

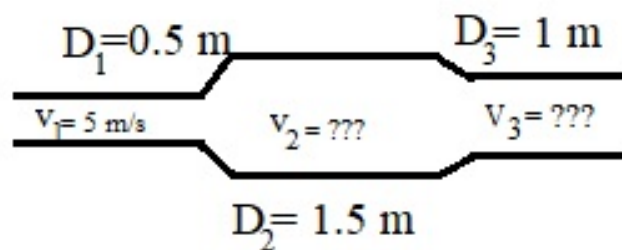
$$A_2 = 9 A_1$$

~~$$A_1 2 = 9 A_1 V_2$$~~

$$V_2 = 0.222 \text{ m/s}$$

Example 3: As water is traveling from a water tower, to someone's home, the pipes it travels in frequently change size. Water is traveling at 5 m/s in a tube with a diameter of 0.5m. The tube gradually increases in size to a diameter of 1.5m, and then gradually decreases to a diameter of 1m. Neglecting any energy losses due to friction and pressure changes, what is the speed of the water when it reaches the tube diameter of 1m?

Solution:



$$A_1 = \left(\frac{D_1}{2}\right)^2 \cdot \pi$$

$$A_1 = 0.2 \text{ m}^2$$

$$A_2 = \left(\frac{D_2}{2}\right)^2 \cdot \pi$$

$$A_2 = 1.8 \text{ m}^2$$

$$A_3 = \left(\frac{D_3}{2}\right)^2 \cdot \pi$$

$$A_3 = 0.8 \text{ m}^2$$

$$A_1 V_1 = A_2 V_2$$

$$V_2 = \frac{A_1 V_1}{A_2}$$

$$V_2 = 0.6 \text{ m/s}$$

$$A_2 V_2 = A_3 V_3$$

$$V_3 = \frac{A_2 V_2}{A_3}$$

$$V_3 = 1.4 \text{ m/s}$$

Example 4: A pipe with a radius of **7.5 mm** is attached to a garden hose with a nozzle. If the velocity of flow in the pipe is 2 m/s, what is the velocity of the flow at the nozzle when it is adjusted to have a diameter of **8 millimeters**, and what is the flow rate?

Solution:

$$r_1 = 7.5 \text{ mm}$$

$$D_2 = 8 \text{ mm}$$

$$v_1 = 2 \text{ m/s}$$

$$v_2 = \text{????? cm/s}$$

$$A_1 = (r)^2 \cdot \pi$$

$$A_1 = 0.00018 \text{ m}^2$$

$$A_2 = \left(\frac{D_2}{2}\right)^2 \cdot \pi$$

$$A_2 = 0.00005 \text{ m}^2$$

$$A_1 V_1 = A_2 V_2$$

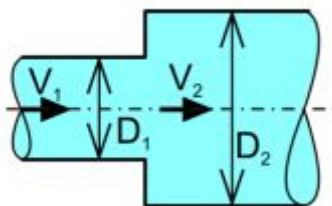
$$V_2 = \frac{A_1 V_1}{A_2}$$

$$V_2 = 7.2 \text{ m/s}$$

$$Q = V_2 A_2$$

$$Q = 0.00036 \text{ m}^3/\text{s}$$

Example 5: The pipe has a different diameter: diameter (**D₁ = 2 m**) changes into (**D₂ = 3 m**). The water velocity in the entrance profile was measured (**v₁ = 3 m/s**). Calculate the **discharge** and leave velocity (see figure). Determine also type of flow in input pipe (whether the flow is laminar or turbulent).



Solution:

$$D_1 = 2 \text{ m}$$

$$D_2 = 3 \text{ m}$$

$$v_1 = 3 \text{ m/s}$$

$$v_2 = \text{????? cm/s}$$

$$A_1 = \left(\frac{D_1}{2}\right)^2 \cdot \pi$$

$$A_1 = 3.14 \text{ m}^2$$

$$A_2 = \left(\frac{D_2}{2}\right)^2 \cdot \pi$$

$$A_2 = 7.06 \text{ m}^2$$

$$A_1 V_1 = A_2 V_2$$

$$V_2 = \frac{A_1 V_1}{A_2}$$

$$V_2 = 1.333 \text{ m/s}$$

$$Q = V_2 A_2$$

$$Q = 9.41 \text{ m}^3/\text{s}$$

To determine type of flow in conduit, the Reynolds number $R_e = \frac{\rho V D}{\mu} = \frac{V D}{\nu}$

will be used. Kinematic viscosity of water of 12°C

$$\nu = 1.24 \times 10^{-6} \text{ m}^2 \cdot \text{s}^{-1}$$

For laminar flow:

$$Re < 2000$$

For turbulent flow

$$Re > 4000$$

$$R_e = \frac{V_1 D_1}{\nu}$$

$$R_e = \therefore 4838.7 \cdot 10^3 > 4000$$

\therefore The flow in entrance of pipe is turbulent flow.

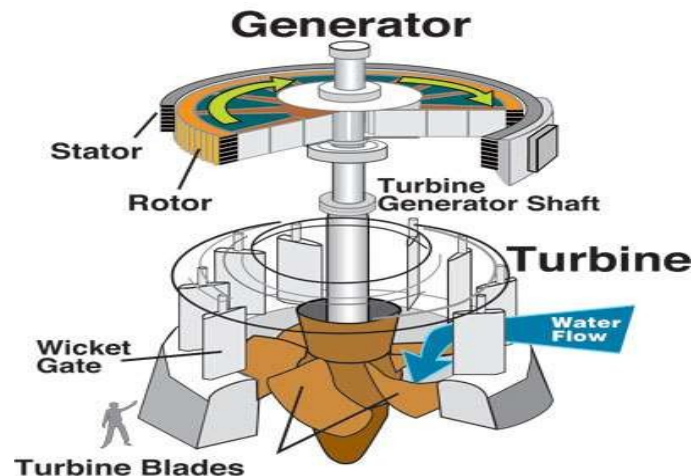
1.4 TURBINES

A turbine is a rotary mechanical device that extracts energy from a fast-moving flow of water, steam, gas, air, or other fluid and converts it into useful work. A turbine is a turbo-machine with at least one moving part called a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades so that they move and impart rotational energy to the rotor. We can generate electricity by coupling to electric generator.

التوربين عبارة عن جهاز ميكانيكي دوار يستخرج الطاقة من تدفق سريع الحركة للماء أو البخار أو الغاز أو الهواء أو أي مائع آخر ويحولها إلى شغل مفيد. التوربين به جزء متحرك واحد على الأقل يسمى الدوار، والدوار عبارة عن عمود أو أسطوانة متصلة بشفرات. يدفع المائع المتحرك الشفرات بحيث تتحرك وتنقل طاقة الدوران إلى الدوار. و يمكننا توليد الكهرباء من التوربين عن طريق الاقتران بالمولد الكهربائي.

The working principle of turbine is very much simple. When the fluid strikes the blades of the turbine, the blades are displaced, which produces rotational energy. The turbine shaft is directly coupled to an electric generator mechanical energy is converted into electrical energy.

مبدأ عمل التوربين بسيط للغاية. عندما يضرب السائل ريش التوربين ، يتم إزاحة الشفرات ، مما ينتج طاقة دورانية. يقترن عمود التوربين مباشرة بمولد كهربائي يتم تحويل الطاقة الميكانيكية إلى طاقة كهربائية.



1.5 Advantages of Turbines

- Large power achieved by relatively small size
- High efficiency
- Simple design
- High revolution

1.6 Classification Turbines: Based on working fluid

Turbines can be classified by many ways such as based on fluid, in the basis of principle operation and direction of flow. For example, when the working fluid is water, the turbomachines are called hydraulic turbines or hydro turbines.

- Water turbine
 - Impulse turbine
 - Reaction turbine
- Steam Turbine
- Gas Turbine
- Wind Turbine

1.6.1 Water Turbine

A water turbine is a rotary machine that converts kinetic energy and potential energy of water into mechanical work. Water turbines were developed in the 19th century and were widely used for industrial power prior to electrical grids. Now they are mostly used for electric power generation. The water turbine also classify into two type based on working principles.

التوربينات المائية عبارة عن آلة دوارة تقوم بتحويل الطاقة الحركية والطاقة الكامنة للمياه إلى شغل ميكانيكي. تم تطوير توربينات المياه في القرن التاسع عشر وكانت تستخدم على نطاق واسع للطاقة الصناعية قبل الشبكات الكهربائية، الآن يتم استخدامها في الغالب لتوليد الطاقة الكهربائية. يتم تصنيف التوربينات المائية أيضاً إلى نوعين بناءً على مبادئ العمل.

1- Impulse Turbine.

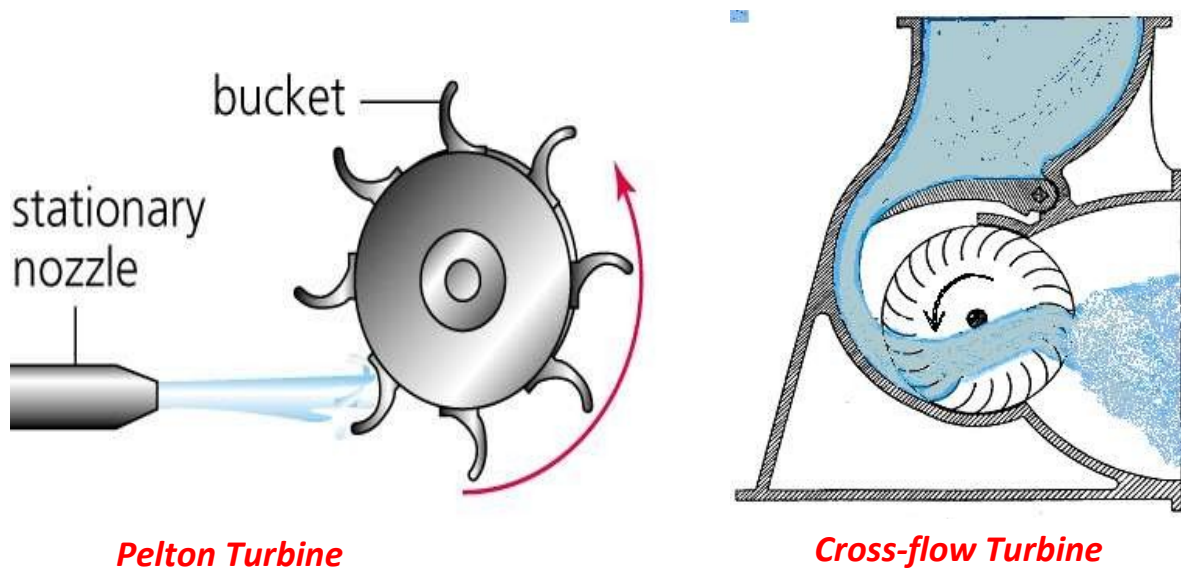
The pressure of liquid does not change while flowing through the rotor of the machine. Pressure change occur only in the nozzles of the machine. The energy to rotate an impulse turbine is derived from the kinetic energy of the fluid flowing through the nozzles. The typed of impulse turbine:

➤ Pelton Turbine

A Pelton wheel is an impulse-type water turbine. The Pelton wheel extracts energy from the impulse of moving water.

➤ Cross-flow Turbine

As with a water wheel, the water is admitted at the turbine's edge after passing the runner, it leaves on the opposite side and going through the runner twice provides additional efficiency. The cross-flow turbine is a low-speed machine that is well suited for locations with a low head but high flow.



2- Reaction Turbine

In a reaction turbine, forces driving the rotor are achieved by the reaction of an accelerating water flow in the runner while the pressure drops. In reaction turbines torque developed by reacting to the fluid's pressure. The pressure of the fluid changes as it passes through the turbine rotor blades. There are three types of reaction turbine:

➤ **Kaplan Turbine**

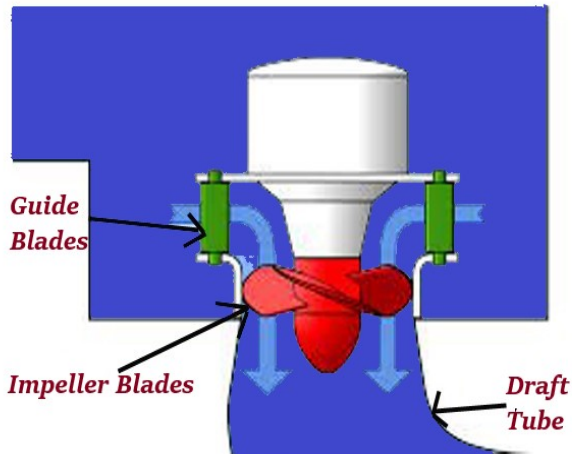
The Kaplan turbine is a water turbine which has adjustable blades and is used for low heads and high discharges. The Kaplan turbine is an inward flow reaction turbine, which means that the working fluid changes pressure as it moves through the turbine and gives up its energy.

➤ **Francis turbine**

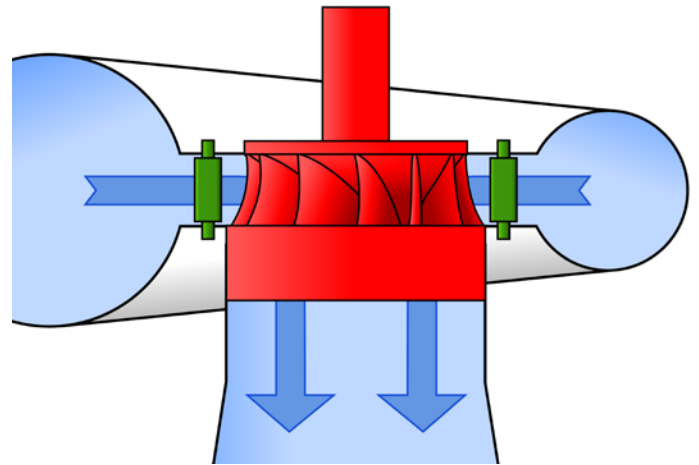
The Francis turbine is a type of water turbine and are used for medium head (45-400 m) and medium discharge. (10-700 m³/s)
The Francis turbine is a type of reaction turbine, a category of turbine in which the working fluid comes to the turbine under immense pressure and the energy is extracted by the turbine blades from the working fluid.

➤ **Kinetic turbines**

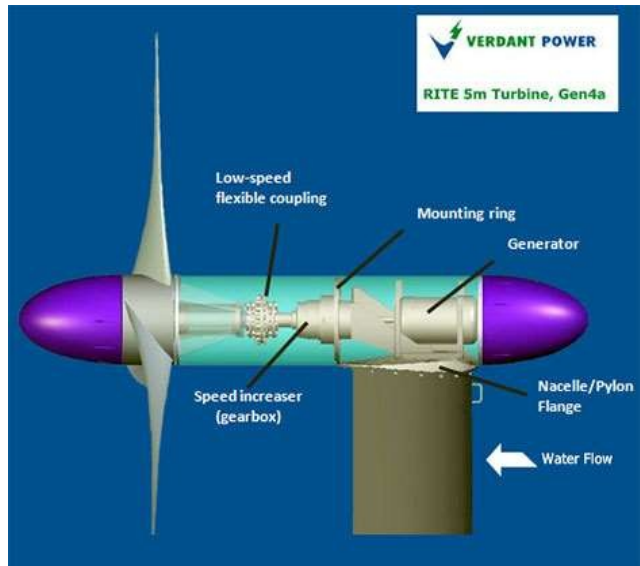
Kinetic energy turbines, also called free-flow turbines generate electricity from the kinetic energy present in flowing water. The systems may operate in rivers, man-made channels, tidal waters, or ocean currents. Kinetic systems utilize the water stream's natural pathway.



Kaplan Turbine



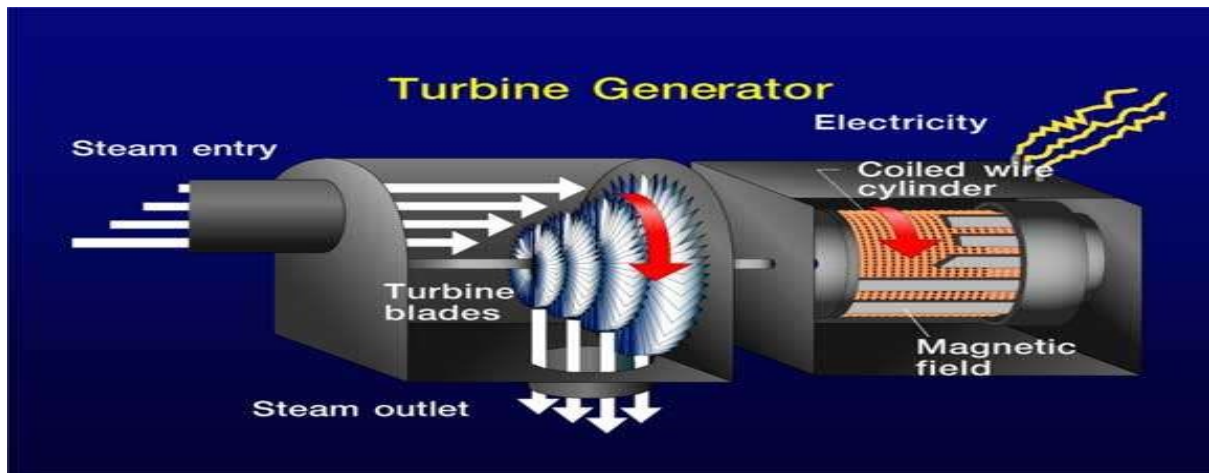
Kaplan Turbine



Kinetic turbine

1.6.2 Steam Turbine

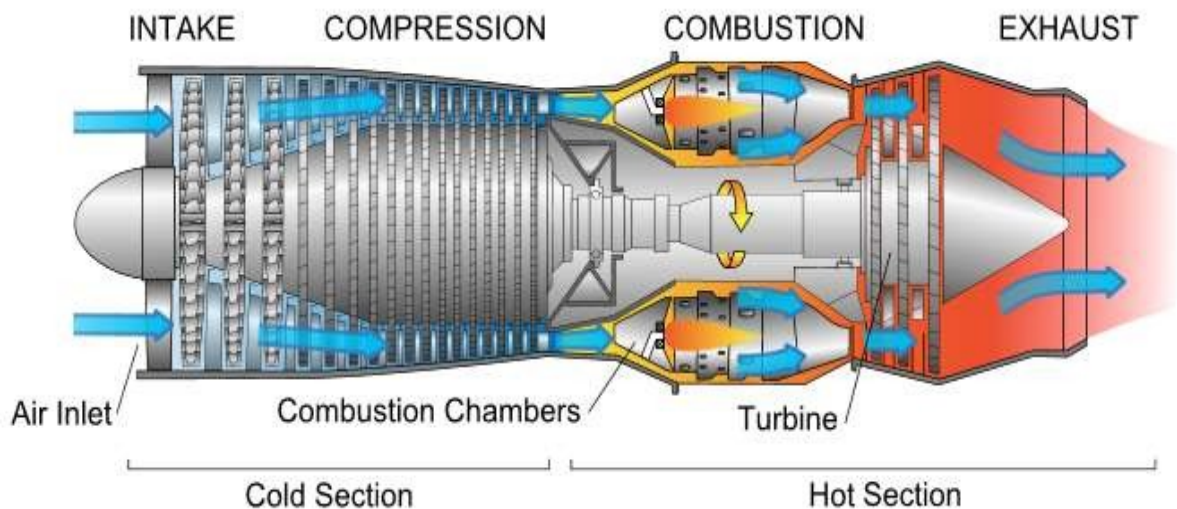
a steam turbine is a device that extracts thermal energy from pressurized steam and uses it to do mechanical work on a rotating output shaft. Steam turbines are used for the generation of electricity in thermal power plants, such as plants using coal fuel oil or nuclear fuel.



Steam turbine

1.6.3 Gas Turbine

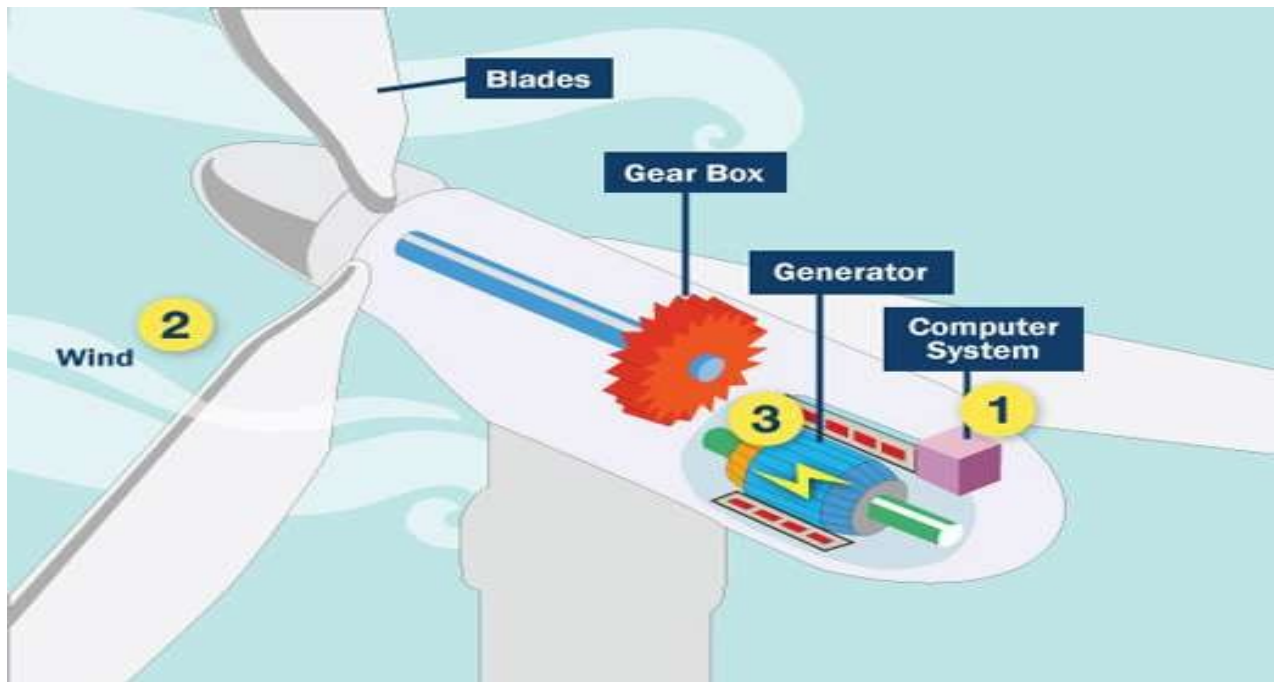
A gas turbine, also called a combustion turbine, is a type of internal combustion engine. Gas turbines are used to power aircraft, trains, ships, electrical generators or even tanks.



Gas turbine

1.6.4 Wind Turbine

A wind turbine is a device that converts kinetic energy from the wind into electrical power. Wind turbine used for charging batteries may be referred to as a wind charger.



Wind turbine

1.5 PUMPS

A pump is a device used to transfer fluids from lower elevation to higher elevation. The hydraulic machines which convert the mechanical energy into hydraulic energy are called pumps. The hydraulic energy is in the form of pressure energy. This pressure energy is converted into potential energy, as the liquid is lifted from a lower level to a higher level.

1.5.1 Pumps uses

- Used for irrigation purposes and in chemical industries, petroleum industries, etc.
- Used to feed the water into the boiler (called Feed Water Pump) in power plants.
- Used to circulate water in the condenser (called Condensate Pump)
- Used to remove the condensed steam from the condenser (called Condensate extraction Pump)

- Used to transfer the oil from the reservoir to its proper place in I.C. Engines.
- Used to force the lubricating oil into the moving or rotating parts of internal combustion engines.

1.5.2 Classification of Pumps

Pumps are broadly classified into

- **Positive- displacement pumps**

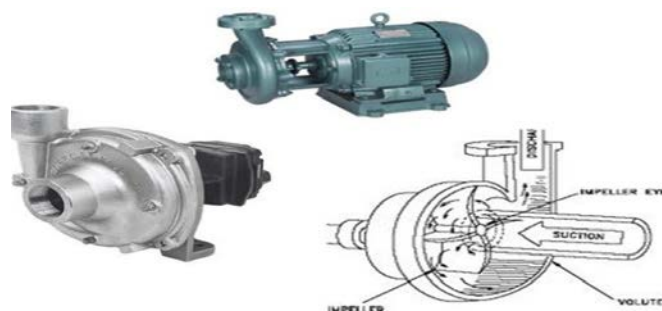
Positive- displacement pumps They make a fluid move by trapping a fixed amount and displacing the trapped volume into the discharge pipe. Discharge is directly proportional to speed, like Reciprocating pump, Vane pump, Gear pump

- **Rotodynamic pumps**

It is a machine in which energy is continuously imparted to the pumped fluid by means of a rotor and thus fluid is raised to higher elevation. Like Centrifugal pump.

1.6 Centrifugal pumps

A centrifugal pump is a rotodynamic pump that converts mechanical energy to hydraulic pressure energy. It uses a rotating impeller to increase the pressure of a fluid. The fluid enters the pump impeller along or near to the rotating axis and is accelerated by the impeller, flowing radially outward.



1.6.1 COMPONENTS

Impeller: it is a wheel or rotor which is provided with a series of backward curved blades or vanes. It is mounted on a shaft which is coupled to an electric motor.

Volute casing: it is an air tight chamber which surrounds the impeller.

Suction pipe: it is a pipe which connected to the inlet of pump. The other end is dips into water in a sump or well. Foot valve and strainer are connected to it.

Delivery pipe: it is a pipe which connected to the outlet of pump and it delivers the water into the required height.

Delivery valve: controls the flow from pump to delivery pipe.