

2. Fluid Flow

2.1 KINEMATICS OF FLOW

Kinematics is defined as that branch of science which deals with motion of particles without considering the forces causing the motion. The velocity at any point in a flow field at any time is studied in this branch of fluid mechanics. Once the velocity is known then the pressure distribution and hence forces acting on the fluid can be determine.

2.2 Types of fluid flow-

The fluid flow is classified as

- a. Steady and unsteady flows
- b. Uniform and non-uniform flows
- c. Laminar and turbulent flow
- d. compressible and incompressible flows
- e. Rotational and irrotational flow
- f. one, two and three dimensional flow

1. *Steady and Unsteady flow* – Steady flow is defined as that type of flow in which the fluid characteristic like velocity, pressure, density etc. at a point do not change with time.

Thus for steady flow,
mathematically

$$[\partial V / \partial t]_{x_0, y_0, z_0} = 0 \quad [\partial p / \partial t]_{x_0, y_0, z_0} = 0 \quad [\partial \rho / \partial t]_{x_0, y_0, z_0} = 0$$

Where x_0, y_0, z_0 is a fixed point in fluid flow

2. *Uniform and non-uniform flows*- Uniform flow is defined as that type of flow in which the velocity at any given time does not changes with respect to space (i.e. length of direction of the flow) mathematically for uniform flow

$$[\partial V / \partial s]_{t=\text{constant}} = 0$$

Where ∂V = Change of velocity

∂s = Length of flow in the direction of s.

3. *Laminar and Turbulent flow -*

Laminar flow is defined as that type of flow in which the fluid particles move along well defined paths or stream line and all the stream lines are straight and parallel. Thus the particles move in laminas or layers gliding smoothly over the adjacent layer. This type of flow is called stream line flow or viscous flow.

Turbulent flow is that type of flow in which the fluid particles move in a zigzag way the eddies formation takes place which are responsible for high energy loss. For pipe flow the type of flow is determined by a non-dimensional number called as the Reynolds number (VD/v)

Where D = Diameter of pipe

V = Mean velocity of flow in pipe

v = Kinematics viscosity of fluid.

If the Reynolds number is less than 2000, the flow is called laminar. If the Reynold number is more that 4000 it is called turbulent flow. If the Reynold number lies between 2000 and 4000 the flow may be laminar or turbulent.

4. *Compressible and Incompressible flows-*

Compressible flow is that type of flow in which the density of the fluid changes from point to point or in other words the density is not constant for the fluid. Thus mathematically for compressible flow

$$\rho \neq \text{constant}$$

Incompressible flow is that type of flow in which the density is constant for the fluid flow liquids are generally incompressible while gases are compressible. Mathematically for incompressible flow

$$\rho = \text{Constant}$$

5. *Rotational and Irrotational Flows-*

Rotational flow is that type of flow in which fluid particles while flowing along stream line also rotate about their own axis. And if the fluid particles while flowing along stream lines do not rotate about their own axis that type of flow is called as Irrotational flow.

6. *One , two and three dimensional 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 coordinator only, say x for a steady

one dimensional flow, the velocity is a function of one space coordinator only. The variation of velocities in other two mutually perpendicular directions is assumed negligible.

Hence mathematically for one dimensional flow,

$$u = f(x), v=0, w=0$$

Where u, v, w are velocity component in x, y and z direction.

Two dimensional flow is that type of flow in which the velocity is a function of time and two rectangular space coordinates say x and y. For steady two dimensional flow the velocity is a function of two space coordinates only. The variation of velocity in the third direction is negligible.

Thus mathematically,

$$u = f_1(x, y) \quad v = f_2(x, y) \quad \text{and } w = 0$$

Three dimensional flow is that type of flow in which the velocity is a function of time and three mutually perpendicular direction. But for a steady three dimensional flow the fluid parameters are functions of three space coordinates.

Thus mathematically,

$$u = f_1(x, y, z) \quad v = f_2(x, y, z) \quad w = f_3(x, y, z)$$

3. Continuity equation and momentum equation

3.1 Discharge or Rate of Flow-

It is defined as the quantity of fluid flowing per second through a section of a pipe or a channel. For an incompressible fluid (or liquid) the rate of flow or discharge is expressed as the volume of fluid flowing across the section per second. For compressible fluids, the rate of flow is usually expressed as the weight of fluid flowing across the section.

Thus,

- i. For liquids the units of Q are m^3/s or liters/s
- ii. For gases the units of Q is kgf/s or Newton/s

Consider a liquid flowing through pipe in which

A = cross sectional area of pipe

V = average velocity of fluid across the section

Then discharge $Q = A \times V$

1.2 Continuity equation

The equation based on the principle of conservation of mass is called continuity equation. Thus for a fluid flowing through the pipe at all the cross section the quantity of fluid per second is constant.

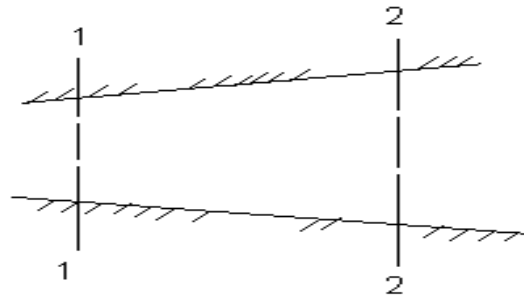
Consider two cross sections of a pipe as shown in fig

Let V_1 = Average velocity at cross section 1-1

ρ_1 = Density at cross section 1-1

A_1 = Area of pipe at section 1-1

And V_2, ρ_2, A_2 are corresponding values at section 2-2



Fluid flowing through a pipe

Then rate of flow at section 1-1 = $\rho_1 A_1 V_1$

Rate of flow at section 2-2 = $\rho_2 A_2 V_2$

According to law of conservation of mass

Rate of flow at section 1-1 = Rate of conservation at section 2-2

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$$

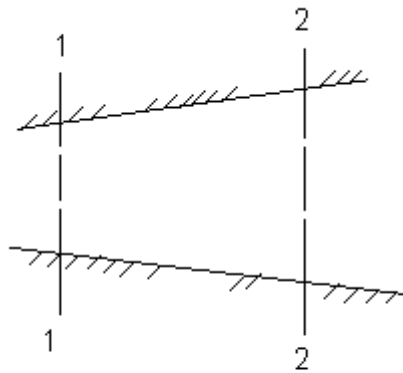
Equation is applicable to the compressible as well as incompressible fluid and is called continuity equation. If the fluid is incompressible, then $\rho_1 = \rho_2$ and continuity equation reduce to $A_1 V_1 = A_2 V_2$

FORMULAE

1. $Q = a v$
2. $A_1 V_1 = A_2 V_2$
3. for compressible fluid $\rho \neq \text{constant}$
4. For incompressible fluid $\rho = \text{Constant}$

Problems-

1. The diameters of a pipe at the sections 1 and 2 are 10 cm and 15 cm respectively. Find the discharged through the pipe if the velocity of water flowing through the pipe at section 1 is 5 m/s. Determine also the velocity at section 2.



Fluid flowing through a pipe

Solution-

$$D_1 = 10 \text{ cm} = 0.1 \text{ m}$$

$$A_1 = \frac{\pi}{4} D_1^2 = \frac{\pi}{4} (0.1)^2 = 0.007854 \text{ m}^2$$

$$V_1 = 5 \text{ m/s}$$

$$D_2 = 15 \text{ cm} = 0.15 \text{ m}$$

$$A_2 = \frac{\pi}{4} D_2^2 = \frac{\pi}{4} (0.15)^2 = 0.01767 \text{ m}^2$$

Discharge through pipe is given by equation

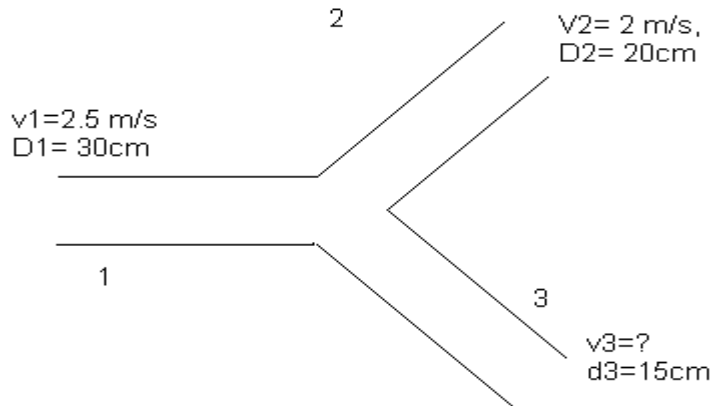
$$Q = A_1 \times V_1$$

$$= 0.007854 \times 5 = 0.03927 \text{ m}^3/\text{s}$$

We have $A_1 V_1 = A_2 V_2$

$$V_2 = \frac{0.007854 \times 5}{0.01767} = \mathbf{2.22 \text{ m/s} \dots \dots \dots \text{ans}}$$

2. A 30 cm diameter pipe conveying water, branches into two pipes of diameters 20 cm and 15 cm respectively. If the average velocity in the 30 cm diameter pipe is 2.5 m/s, find the discharge in this pipe. Also determine the velocity in 15 cm pipe if the average velocity in 20 cm diameter pipe is 2 m/s.



$$D_1 = 30 \text{ cm} = 0.3 \text{ m}$$

$$A_1 = \frac{\pi}{4} D_1^2 = \frac{\pi}{4} (0.3)^2 = 0.07068 \text{ m}^2$$

$$V_1 = 2.5 \text{ m/s}$$

$$D_2 = 20 \text{ cm} = 0.20 \text{ m}$$

$$\therefore A_2 = \frac{\pi}{4} (0.2)^2 = \frac{\pi}{4} (0.4)^2 = 0.0314 \text{ m}^2$$

$$\therefore V_2 = 2 \text{ m/s}$$

$$D_3 = 15 \text{ cm} = 0.15 \text{ m}$$

$$A_3 = \frac{\pi}{4} (0.15)^2$$

$$= 0.01767 \text{ m}^2$$

Find

- i) discharge in pipe 1 or Q
- ii) Velocity in pipe of dia. 15 cm or V_3

Let Q_1 , Q_2 and Q_3 are discharges in pipe 1, 2 and 3 respectively

Then according to continuity equation

$$Q_1 = Q_2 + Q_3$$

The discharge Q_1 in pipe 1 is given by

$$Q = A_1 \times V_1 = 0.07068 \times 2.5 \text{ m}^3/\text{s} = 0.1767 \text{ m}^3/\text{s}$$

Value of V_3

$$Q_2 = A_2 \times V_2 = 0.0314 \times 2.0 = 0.0628 \text{ m}^3/\text{s}$$

Substituting the values of Q_1 , Q_2 in equation

$$0.1767 - 0.0628 = 0.1139 \text{ m}^3/\text{s}$$

$$Q_3 = A_3 \times V_3$$

$$= 0.01767 \times V_3$$

$$\therefore V_3 = 0.1139 / 0.01767 = 6.44 \text{ m/s} \dots\dots\text{ans}$$

General Energy Equation

The conservation of energy principle states that energy can be neither created nor destroyed. This is equivalent to the First Law of Thermodynamics, which was used to

develop the general energy equation in the module on thermodynamics. Equation 3-8 is a statement of the general energy equation for an open system.

$$Q + (U + PE + KE + PV)_{in} = W + (U + PE + KE + PV)_{out} + (U + PE + KE + PV)_{stored}$$

Where:

- Q = heat
- U = internal energy
- PE = potential energy
- KE = kinetic energy
- P = pressure
- V = volume
- W = work

Simplified Bernoulli Equation

Bernoulli's equation results from the application of the general energy equation and the first law of thermodynamics to a steady flow system in which no work is done on or by the fluid, no heat is transferred to or from the fluid, and no change occurs in the internal energy (i.e., no temperature change) of the fluid. Under these conditions, the general energy equation is simplified to Equation.

$$(PE + KE + PV)_1 = (PE + KE + PV)_2$$

Substituting appropriate expressions for the potential energy and kinetic energy.

$$\frac{mgz_1}{g_c} + \frac{mv_1^2}{2g_c} + p_1v_1 = \frac{mgz_2}{g_c} + \frac{mv_2^2}{2g_c} + p_2v_2$$

Where:

- m = mass
- z = height above reference
- v = average velocity
- g = acceleration due to gravity
- g_c = gravitational constant,

Note: The factor g_c is only required when the English System of measurement is used and mass is measured in pound mass. It is essentially a conversion factor needed to allow the units to come out directly. No factor is necessary if mass is measured in slugs or if the metric system of measurement is used. Each term in Equation represents a form of energy possessed by a moving fluid (potential, kinetic, and pressure related energies). In essence, the equation physically represents a balance of the KE, PE, PV energies so that if one form of energy increases, one or more of the others will decrease to compensate and vice versa.

Head

Since the units for all the different forms of energy in Equation are measured in units of distance, these terms are sometimes referred to as "heads" (pressure head,

velocity head, and elevation head). The term *head* is used by engineers in reference to pressure. It is a reference to the height, typically in meter, of a column of water that a given pressure will support. Each of the energies possessed by a fluid can be expressed in terms of head. The elevation head represents the potential energy of a fluid due to its elevation above a reference level. The velocity head represents the kinetic energy of the fluid. It is the height in meter that a flowing fluid would rise in a column if all of its kinetic energy were converted to potential energy. The pressure head represents the flow energy of a column of fluid whose weight is equivalent to the pressure of the fluid. The sum of the elevation head, velocity head, and pressure head of a fluid is called the total head. Thus, Bernoulli's equation states that the total head of the fluid is constant.

Energy Conversions in Fluid Systems

Bernoulli's equation makes it easy to examine how energy transfers take place among elevation head, velocity head, and pressure head. It is possible to examine individual components of piping systems and determine what fluid properties are varying and how the energy balance is affected. If a pipe containing an ideal fluid undergoes a gradual expansion in diameter, the continuity equation tells us that as the diameter and flow area get bigger, the flow velocity must decrease to maintain the same mass flow rate. Since the outlet velocity is less than the inlet velocity, the velocity head of the flow must decrease from the inlet to the outlet. If the pipe lies horizontal, there is no change in elevation head; therefore, the decrease in velocity head must be compensated for by an increase in pressure head. Since we are considering an ideal fluid that is incompressible, the specific volume of the fluid will not change. The only way that the pressure head for an incompressible fluid can increase is for the pressure to increase. So the Bernoulli equation indicates that a decrease in flow velocity in a horizontal pipe will result in an increase in pressure. If a constant diameter pipe containing an ideal fluid undergoes a decrease in elevation, the same net effect results, but for different reasons. In this case the flow velocity and the velocity head must be constant to satisfy the mass continuity equation.

So the decrease in elevation head can only be compensated for by an increase in pressure head. Again, the fluid is incompressible so the increase in pressure head must result in an increase in pressure.

Although the Bernoulli equation has several restrictions placed upon it, there are many physical fluid problems to which it is applied. As in the case of the conservation of mass, the Bernoulli equation may be applied to problems in which more than one flow may enter or leave the system at the same time. Of particular note is the fact that series and parallel piping system problems are solved using the Bernoulli equation.

Restrictions on the Simplified Bernoulli Equation

A practical application of the simplified Bernoulli Equation to real piping systems is not possible due to two restrictions. One serious restriction of the Bernoulli equation in its present form is that no fluid friction is allowed in solving piping problems. Therefore,

Equation 3-10 only applies to ideal fluids. However, in reality, the total head possessed by the fluid cannot be transferred completely from one point to another because of friction. Taking these losses of head into account would provide a much more accurate description of what takes place physically.

This is especially true because one purpose of a pump in a fluid system is to overcome the losses in pressure due to pipe friction. The second restriction on Bernoulli's equation is that no work is allowed to be done on or by the fluid. This restriction prevents two points in a fluid stream from being analyzed if a pump exists between the two points. Since most flow systems include pumps, this is a significant limitation. Fortunately, the simplified Bernoulli equation can be modified in a manner that satisfactorily deals with both head losses and pump work.

Extended Bernoulli

The Bernoulli equation can be modified to take into account gains and losses of head. The resulting equation, referred to as the Extended Bernoulli equation, is very useful in solving most fluid flow problems. In fact, the Extended Bernoulli equation is probably used more than any other fluid flow equation. Equation is one form of the Extended Bernoulli equation.

$$\frac{p_1 v_1 g_c}{g} + \frac{v_1^2}{2g} + z_1 + H_p = \frac{p_2 v_2 g_c}{g} + \frac{v_2^2}{2g} + z_2 + H_f$$

Where:

z = height above reference level

v = average velocity of fluid

P = pressure of fluid

v = specific volume of fluid

H_p = head added by pump

H_f = head loss due to fluid friction

g = acceleration due to gravity

The head loss due to fluid friction (H_f) represents the energy used in overcoming friction caused by the walls of the pipe. Although it represents a loss of energy from the standpoint of fluid flow, it does not normally represent a significant loss of total energy of the fluid. It also does not violate the law of conservation of energy since the head loss due to friction results in an equivalent increase in the internal energy (u) of the fluid. These losses are greatest as the fluid flows through entrances, exits, pumps, valves, fittings, and any other piping with rough inner surfaces.

Most techniques for evaluating head loss due to friction are empirical (based almost exclusively on experimental evidence) and are based on a proportionality constant called the friction factor

(f).

Summary

The main points of this chapter are summarized below.

Bernoulli's Equation Summary

Bernoulli's equation is an application of the First Law of Thermodynamics.

Bernoulli's equation is an application of the general energy equation to a steady flow system in which no work is done on or by the fluid, no heat is transferred to or from the fluid, and no change occurs in the internal energy of the fluid.

Head is the term used to describe pressure exerted on or by a fluid.

As fluid flows in a piping system, changes in elevation, velocity, and pressure heads must be consistent so that Bernoulli's equation is satisfied.

Bernoulli's equation can be modified to take into account friction losses and pump work.

A venturi can be used to determine mass flow rates due to changes in pressure and fluid velocity.

The volumetric flow rate through a venturi is directly proportional to the square root of the differential pressure between the venturi's inlet and its throat.

MOMENTUM EQUATION-

It is based on the law of conservation of momentum or on the momentum principle, which states that the net force acting on a fluid mass is equal to the change in momentum of flow per unit time in that direction. The force acting on a fluid mass 'm' is given by the Newton's second law of motion.

$$F = m \times a$$

Where a is the acceleration acting in the same direction of force F.

$$\text{But } a = \frac{dv}{dt}$$

$$\therefore F = m \frac{dv}{dt}$$

$$F = \frac{d(mv)}{dt} \quad m \text{ is constant and can be taken inside the differential}$$

This is known as the *momentum equation*.

$F \cdot dt = d(mv)$ Which is known as *the impulse momentum equation* and states that the impulse of the force F acting on a fluid of mass m in a short interval of time dt is equal to the change of momentum d(mv) in the direction of force.

4. Flow through pipes

Loss of energy in pipes

When a fluid is flowing through a pipe, the fluid experiences some resistance due to which some of the energy of fluid is lost. This loss of energy is classified as

1. Major Energy Losses
 2. Minor Energy Losses
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1. Major energy losses – this is due to friction and it is calculated with the help of Darcy Weisbach formula and Chezy's formula.
 2. Minor energy losses – this is due to
 - a) Sudden expansion of pipe
 - b) Sudden contraction of pipe
 - c) Bend in pipe
 - d) Pipe fittings etc.
 - e) An obstruction in pipe

In case of long pipe the above losses are small as compared with the loss of head due to friction and hence they are called minor losses and even may be neglected without serious error. But in case of a short pipe, these losses are comparable with the loss of head due to friction.

Hydraulic gradient line- It is defined as the line which gives the sum of pressure head (p/w) and datum head (z) of a flowing fluid in a pipe with respect to some reference line or it is of a flowing fluid in a pipe from the centre of the pipe. It is briefly written as H.G.L.(hydraulic gradient line)

Total Energy Line-

It is defined as the line which gives the sum of pressure head, datum head and kinetic head of a flowing fluid in a pipe with respect to some reference line. It is also defined as the line which is obtained by joining the tops of all vertical ordinates showing the sum of pressure head and kinetic head from the centre of the pipe. It is briefly written as T.E.L. (Total Energy Line).

Head Loss

Head loss is a measure of the reduction in the total head (sum of elevation head, velocity head and pressure head) of the fluid as it moves through a fluid system. Head loss is unavoidable in real fluids. It is present because of: the friction between the fluid and the walls of the pipe; the friction between adjacent fluid particles as they move relative to one another; and the turbulence caused whenever the flow is redirected or affected in any way by such components as piping entrances and exits, pumps, valves, flow reducers, and fittings.

Frictional loss is that part of the total head loss that occurs as the fluid flows through straight pipes. The head loss for fluid flow is directly proportional to the length

of pipe, the square of the fluid velocity, and a term accounting for fluid friction called the friction factor. The head loss is inversely proportional to the diameter of the pipe.

$$\text{Head Loss} \propto \frac{fLv^2}{D}$$

Friction Factor

The friction factor has been determined to depend on the Reynolds number for the flow and the degree of roughness of the pipe's inner surface.

The quantity used to measure the roughness of the pipe is called the relative roughness, which equals the average height of surface irregularities (ϵ) divided by the pipe diameter (D).

$$\text{Relative Roughness} = \frac{\epsilon}{D}$$

The value of the friction factor is usually obtained from the Moody. The Moody Chart can be used to determine the friction factor based on the Reynolds number and the relative roughness.

Example:

Determine the friction factor (f) for fluid flow in a pipe that has a Reynolds number of 40,000 and a relative roughness of 0.01.

Solution:

Using the Moody Chart, a Reynolds number of 40,000 intersects the curve corresponding to a relative roughness of 0.01 at a friction factor of 0.04.

Darcy's Equation

The frictional head loss can be calculated using a mathematical relationship that is known as Darcy's equation for head loss. The equation takes two distinct forms. The first form of Darcy's equation determines the losses in the system associated with the length of the pipe.

$$H_f = \frac{fLv^2}{D 2g}$$

Where:

f = friction factor (unit less)

L = length of pipe

D = diameter of pipe

v = fluid velocity

g = gravitational acceleration

Minor Losses

The losses that occur in pipelines due to bends, elbows, joints, valves, etc. are sometimes called *minor losses*. This is a misnomer because in many cases these losses are more important than the losses due to pipe friction, considered in the preceding section. For all minor losses in turbulent flow, the head loss varies as the square of the velocity. Thus a convenient method of expressing the minor losses in flow is by means of a loss coefficient (k). A value of the loss coefficient (k) for typical situations and fittings is found in standard handbooks. The form of Darcy's equation used to calculate minor losses of individual fluid system components is expressed by Equation.

$$H_f = \frac{k v^2}{2g}$$

Equivalent Piping Length

Minor losses may be expressed in terms of the equivalent length (L_{eq}) of pipe that would have the same head loss for the same discharge flow rate. This relationship can be found by setting the two forms of Darcy's equation equal to each other.

$$\frac{f L v^2}{D 2g} = \frac{k v^2}{2g}$$

This yields two relationships that are useful.

$$L_{eq} = k \frac{D}{f}$$

The equivalent length of piping that will cause the same head loss as a particular component can be determined by multiplying the value of L_{eq}/D for that component by the diameter of the pipe.

The higher the value of L_{eq}/D , the longer the equivalent length of pipe.

Summary

The main points of this chapter are summarized below.

Head Loss Summary

- Head loss is the reduction in the total head (sum of potential head, velocity head, and pressure head) of a fluid caused by the friction present in the fluid's motion.
- Frictional loss is that part of the total head loss that occurs as the fluid flows through straight pipes.
- Minor losses are the head losses that occur due to bends, elbows, joints, valves, and other components. Any time the flow experiences a change in direction or a change in cross-sectional area, it will experience a head loss.

- The friction factor for fluid flow can be determined using a Moody Chart if the relative roughness of the pipe and the Reynolds number of the flow can be determined.
- Darcy's equation can be used to calculate frictional losses.
- A special form of Darcy's equation can be used to calculate minor losses.
- The length of pipe that would cause the same head loss as a valve or fitting can be determined by multiplying the value of L/D for the component found in handbooks or vendor manuals by the diameter of the pipe.

5. Pumps and Fans

INTRODUCTION TO CENTRIFUGAL PUMPS

Hydraulic machines which convert the mechanical energy into hydraulic energy are called as pumps. The hydraulic energy is in the form of pressure energy. If the mechanical energy is converted into pressure energy by means of centrifugal force acting on the fluid, the hydraulic machine is called centrifugal pump.

The centrifugal pump acts as a reversed of an inward radial flow reaction turbine. This means that the flow in centrifugal pumps is in the radial outward directions. The centrifugal pump works on the principle of forced vortex flow which means that when a certain mass of liquid is rotated by an external torque, the rise in pressure head of the rotating liquid takes place. The rise in pressure head at any point of the rotating liquid is proportional to the square of tangential velocity of the liquid at that point. Thus at the outlet of the impeller where radius is more the rise in pressure head will be more and the liquid will be discharged at the outlet with a high pressure head. Due to this high pressure head, the liquid can be lifted to high level.

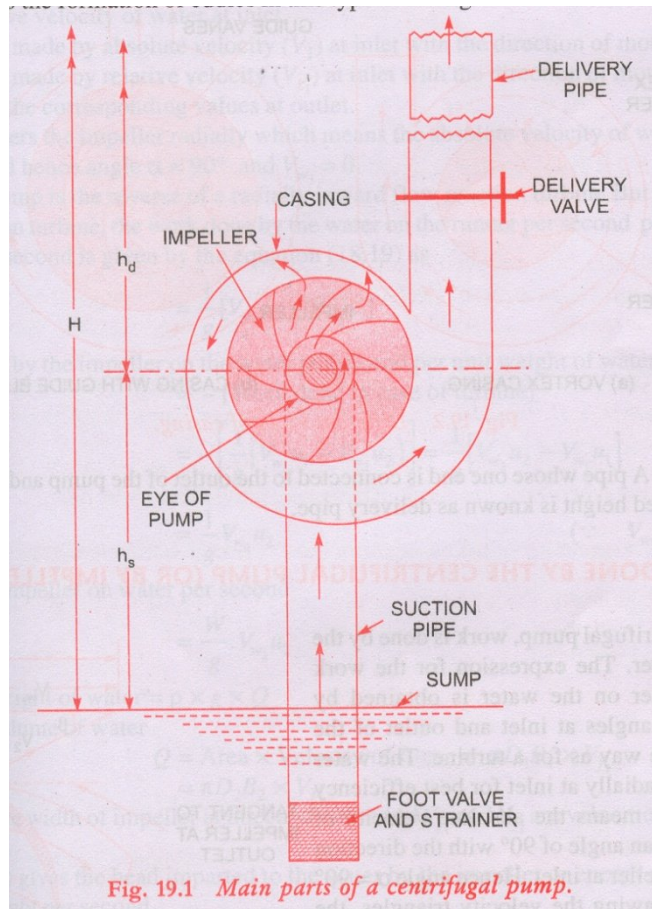
Main parts of Centrifugal Pump-

The following are the main parts of a centrifugal pump:

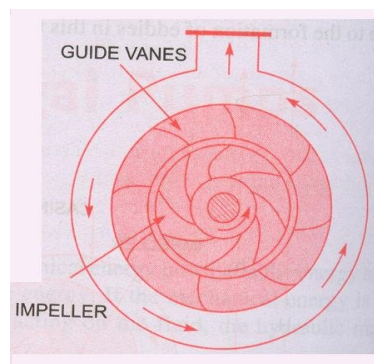
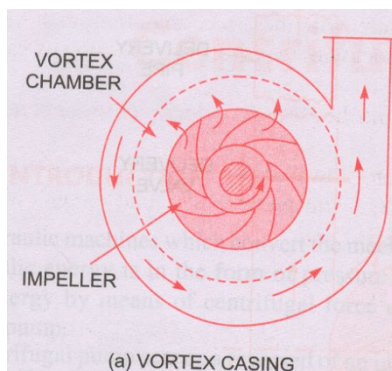
1. Impeller
2. Casing
3. Suction pipe with a foot valve and a strainer
4. Delivery pipe

All the main parts of the centrifugal pump are shown in fig

- 1. Impeller-** The rotating part of a centrifugal pump is called Impeller. It consists of a series of backward curved vanes. The impeller is mounted on a shaft which is connected to the shaft of an electric motor.
- 2. Casing-** The casing of a centrifugal pump is similar to the casing of a reaction turbine. It is an airtight passage surrounding the impeller and is designed in such a way that the kinetic energy of the water discharged at the outlet of the impeller is converted into pressure energy before the water leaves the casing and enters the delivery pipe. The following three types of casings are adopted.
- 3. Volute Casing-** It surrounds the impeller. It is of spiral type in which area of flow increases gradually. The increase in area of flow decreases the velocity of flow. The decrease in velocity increases the pressure of the water flowing through the casing. It has been observed that in case of volute casing, the efficiency of the pump increases slightly as a large amount of energy is lost due to the formation of eddies in this type of casing.
- 4. Vortex Casing-** If the circular chamber is introduced between the casing and the impeller. The casing is known as Vortex Casing. By introducing the circular chamber, the loss of energy due to the formation of eddies is reduced to a considerable extent. Thus the efficiency of the pump is more than the efficiency when only volute casing is provided.



5. Casing with Guide Blades- In this casing the impeller is surrounded by a series of guide blades mounted on a ring which is known as diffuser. The guide vanes are designed in such a way that the water from the impeller enters the guide vanes without shock. Also the area of vanes increases, thus reducing the velocity of flow through guide vanes and consequently increasing the pressure of water. The water from the guide vanes then passes through the surrounding casing which is in most of the cases concentric with the impeller as shown in fig.



Casing with guide blades

- 3. Suction pipe with a Foot – valve and a Strainer-** A pipe whose one end is connected to the inlet of the pump and other end dips into water in a sump is known as suction pipe. A foot valve which is a non-return valve or one way type of valve is fitted at the lower end of the suction pipe. The foot valve opens only in the upward direction. A strainer is also fitted at the lower end of the suction pipe.
- 4. Delivery Pipe-** A pipe whose one end is connected to the outlet of the pump and other end delivers the water at a required height is known as delivery pipe.

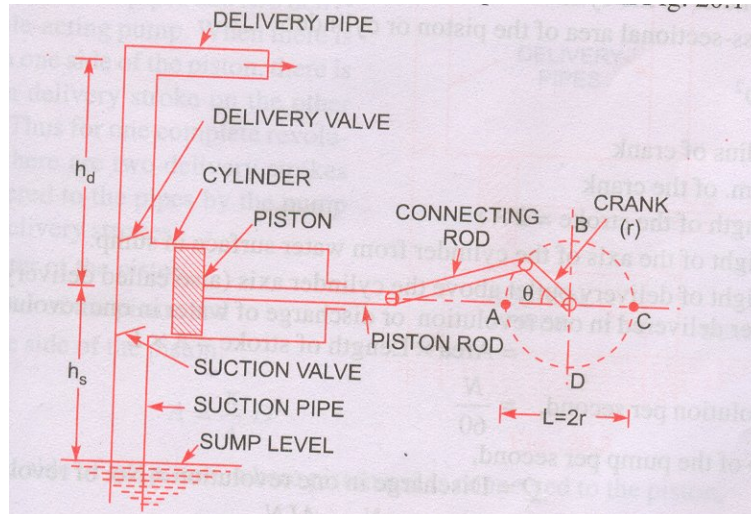
Priming of a Centrifugal Pump-

Priming of a centrifugal pump is defined as the operation in which the suction pipe casing of the pump and a portion of the delivery pipe up to the delivery valve is completely filled up from outside source with the liquid to be raised by the pump before starting the pump. Thus the air from these parts of the pump is removed and these parts are filled with the liquid to be pumped.

The work done by the impeller per unit weight of liquid per sec is known as the head generated by the pump. Head generated by the pump as $= v_w^2 u_2^2 / g$ meter. This equation is independent of the density of the liquid. This means that when pump is running in air, the head generated is in terms of meter of air. If the pump is primed with water, the head generated is same meter of water. But as the density of air is very low, the generated head of air in terms of equivalent meter of water head is negligible and hence the water may not be sucked from the pump. To avoid this difficulty priming is necessary.

INTRODUCTION TO RECIPROCATING PUMPS-

If the mechanical energy is converted into hydraulic energy (or pressure energy) by sucking the liquid into a cylinder in which a piston is reciprocating (moving backwards and forwards) which exerts thrust on the liquid and increases its hydraulic energy (pressure energy) the pump is known as reciprocating pump.



Main parts of Reciprocating Pump-

1. A cylinder with a piston, piston rod, connecting rod and crank.
2. Suction Pipe
3. Delivery pipe
4. Suction Valve
5. Delivery valve

Working Principle of a Reciprocating Pump-

Single acting reciprocating pump which consists of a piston moves forwards and backwards in a close fitting cylinder. The movement of the piston is obtained by connecting the piston rod to crank by means of a connecting rod. The crank is rotated by means of an electric motor. Suction and delivery pipes with suction valve and delivery valve are connected to the cylinder. The suction and delivery valves are one way valves or not return valves which allow the water to flow in one direction only. Suction valve allows water from suction pipe to the cylinder which delivers valve allows water from cylinder to delivery pipe only.

When crank starts rotating the piston moves to and fro in the cylinder. When crank is at A, the piston is at the extreme left position in the cylinder. As the crank is rotating from A to C (i.e. from $\theta = 0$ to $\theta = 180^\circ$) the piston is moving towards right in the cylinder. The movement of the piston towards right creates a partial vacuum in the cylinder. But on the surface of the liquid in the sump atmospheric pressure is acting which is more than the pressure inside the cylinder. Thus the liquid is forced in the suction pipe from the sump. This liquid opens the suction valve and enters the cylinder.

When crank is rotating from C to A (i.e. from $\theta = 180^\circ$ to $\theta = 360^\circ$) the piston from its extreme right position starts moving towards left in the cylinder. The movement of the piston towards left increases the pressure of the liquid inside the cylinder more than

atmospheric pressure. Hence suction valve closes and delivery valve opens. The liquid is forced into the delivery pipe and is raised to a required height.

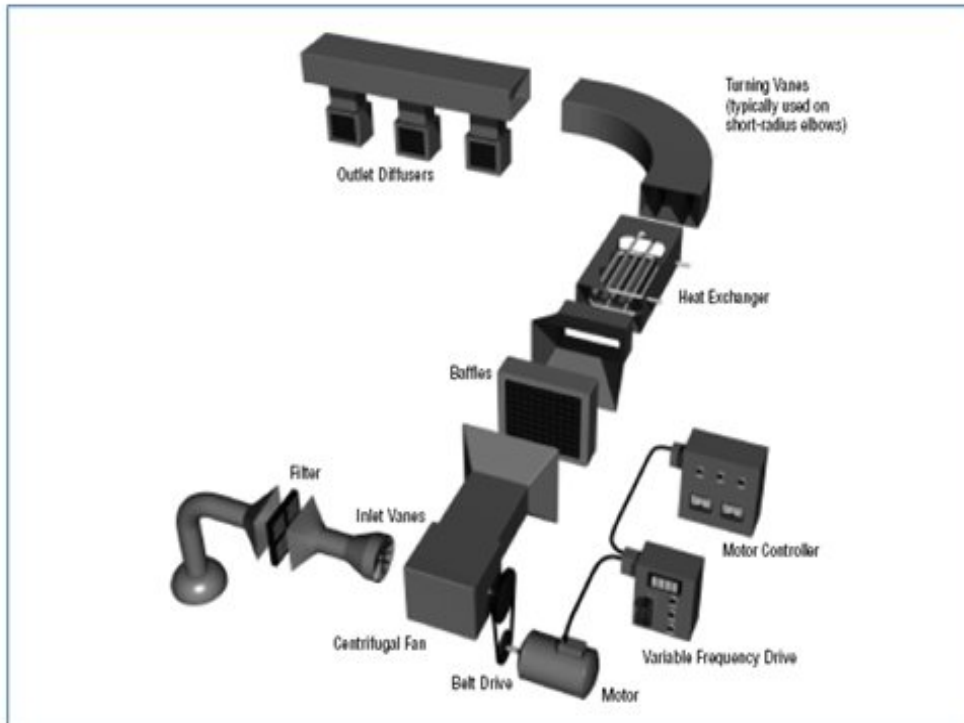
Fans-

Most manufacturing plants use fans and blowers for ventilation and for industrial processes that need an air flow. Fan systems are essential to keep manufacturing processes working, and consist of a fan, an electric motor, a drive system, ducts or piping, flow control devices, and air conditioning equipment (filters, cooling coils, heat exchangers, etc.). An example system is illustrated in Figure 1. The US Department of Energy estimates that 15 percent of electricity in the US manufacturing industry is used by motors. Similarly, in the commercial sector, electricity needed to operate fan motors composes a large portion of the energy costs for space conditioning (US DOE, 1989).

Fans, blowers and compressors are differentiated by the method used to move the air, and by the system pressure they must operate against. The American Society of Mechanical Engineers (ASME) uses the specific ratio, which is the ratio of the discharge pressure over the suction pressure, to define fans, blowers and compressors (see Table 1).

Table 1: Difference between Fans, Blowers and Compressors

Equipment	Specific Ratio	Pressure rise
Fans	up to 1.11	1136
Blowers	1.11 to 1.20	1136 -2066
Compressors	more than 1.20	-



Important terms and definitions

Before types of fans and blowers are described it is important to first understand terms and definitions.¹

System characteristics

The term “system resistance” is used when referring to the static pressure. The system resistance is the sum of static pressure losses in the system. The system resistance is a function of the configuration of ducts, pickups, elbows and the pressure drops across equipment, for example bag filter or cyclone. The system resistance varies with the square of the volume of air flowing through the system. For a given volume of air, the fan in a system with narrow ducts and multiple short radius elbows is going to have to work harder to overcome a greater system resistance than it would in a system with larger ducts and a minimum number of long radius turns. Long narrow ducts with many bends and twists will require more energy to pull the air through them. Consequently, for a given fan speed, the fan will be able to pull less air through this system than through a short system with no

elbows.

Thus, the system resistance increases substantially as the volume of air flowing through the system increases; square of air flow.

Conversely, resistance decreases as flow decreases. To determine what volume the fan will produce, it is therefore necessary to know the system resistance characteristics. In existing systems, the system resistance can be measured. In systems that have been designed, but not built, the system resistance must be calculated. Typically a system resistance curve (see

Figure 2) is generated with for various flow rates on the x-axis and the associated resistance on the y-axis.

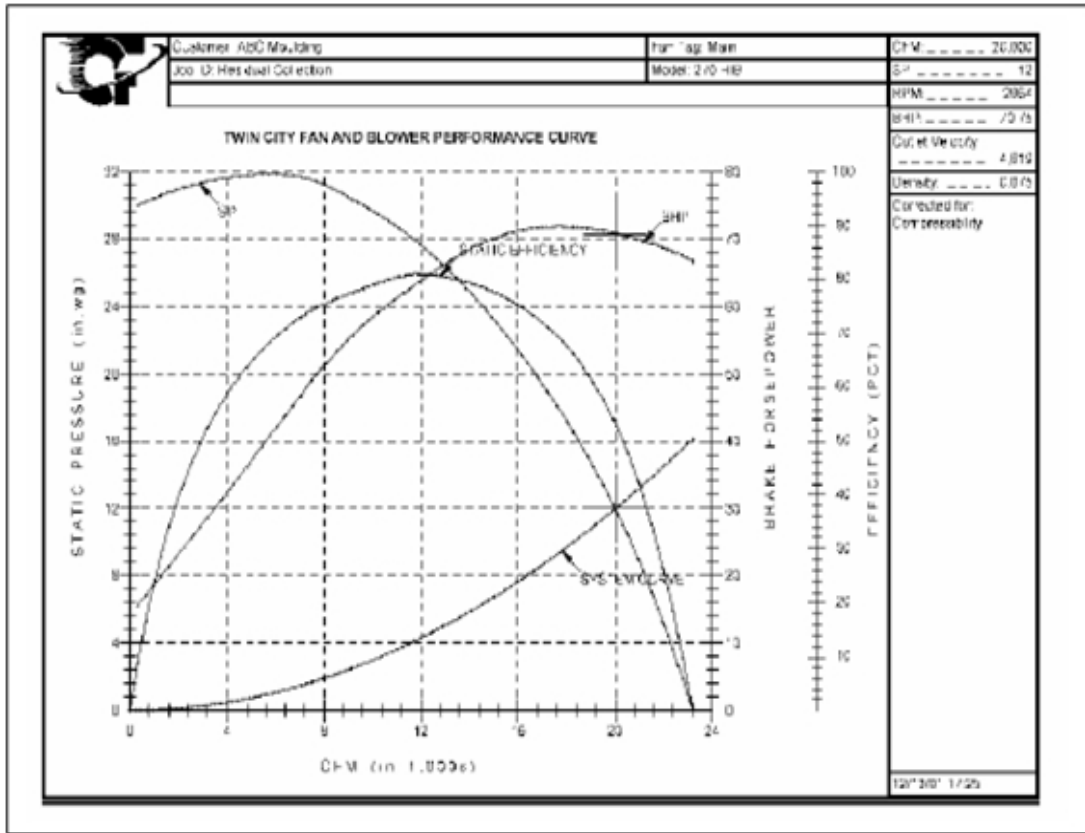


Figure 2. System Curve of a Fan and Effect of System Resistance

Fan characteristics

Fan characteristics can be represented in form of fan curve(s). The fan curve is a performance curve for the particular fan under a specific set of conditions. The fan curve is a graphical representation of a number of inter-related parameters. Typically a curve will be developed for a given set of conditions usually including: fan volume, system static pressure, fan speed, and brake horsepower required to drive the fan under the stated conditions. Some fan curves will also include an efficiency curve so that a system designer will know where on that curve the fan will be operating under the chosen conditions (see Figure 3). Of the many curves shown in the figure, the curve static pressure (SP) versus flow is especially important.

The intersection of the system curve and the static pressure curve defines the operating point. When the system resistance changes, the operating point also changes. Once the operating point is fixed, the power required can be determined by following a vertical line that passes through the operating point to an intersection with the power (BHP) curve. A horizontal line drawn through the intersection with the power curve will lead to the required power on the right vertical axis. In the depicted curves, the fan efficiency curve is also presented.

Type of fans and blowers

This section briefly describes different types of fans and blowers.

Types of fans

There exist two main fan types. Centrifugal fans used a rotating impeller to move the air stream. Axial fans move the air stream along the axis of the fan.

Centrifugal fans

Centrifugal fans increase the speed of an air stream with a rotating impeller. The speed increases as the reaches the ends of the blades and is then converted to pressure. These fans are able to produce high pressures, which makes them suitable for harsh operating conditions, such as systems with high temperatures, moist or dirty air streams, and material handling. Centrifugal fans are categorized by their blade shapes.

Axial fans

Axial fans move an air stream along the axis of the fan. The way these fans work can be compared to a propeller on an airplane: the fan blades generate an aerodynamic lift that pressurizes the air. They are popular with industry because they are inexpensive, compact and light. The main types of axial flow fans (propeller, tube-axial and vane-axial).

Types of blowers

Blowers can achieve much higher pressures than fans, as high as 1.20 kg/cm^2 . They are also used to produce negative pressures for industrial vacuum systems. The centrifugal blower and the positive displacement blower are two main types of blowers, which are described below.²

Centrifugal blowers



Centrifugal blowers look more like centrifugal pumps than fans. The impeller is typically gear-driven and rotates as fast as 15,000 rpm. In multi-stage blowers, air is accelerated as it passes through each impeller. In single-stage blower, air does not take many turns, and hence it is more efficient.

Centrifugal blowers typically operate against pressures of 0.35 to 0.70 kg/cm^2 , but can achieve higher pressures. One characteristic is that airflow tends to drop drastically as system pressure increases, which can be a disadvantage in material conveying systems that depend on a steady air volume. Because of this, they are most often used in applications that are

not prone to clogging.

Positive-displacement blowers

Positive displacement blowers have rotors, which "trap" air and push it through housing. These blowers provide a constant volume of air even if the system pressure varies. They are especially suitable for applications prone to clogging, since they can produce enough pressure (typically up to 1.25 kg/cm^2) to blow clogged materials free. They turn much slower than centrifugal blowers (e.g. 3,600 rpm) and are often belt driven to facilitate speed changes.