Dimensional analysis

1. In physics and all science, dimensional analysis is the practice of checking relations among physical quantities.
2. The dimension of any physical quantity is the combination of the basic physical dimensions that compose it.
3. Some fundamental physical dimensions are length, mass, time, and electric charge.

Great principle of similitude

1. The basic principle of dimensional analysis was known to Isaac Newton (1686) modern use of dimensional analysis
2. This led to the conclusion that meaningful laws must be homogeneous equations in their various units of measurement.

3. This theorem describes how every physically meaningful equation involving n variables can be equivalently rewritten as an equation of $n - m$ dimensionless parameters,
4. A dimensional equation can have the dimensions reduced or eliminated through non-dimensionalization,

Definition

- The dimension of a physical quantity can be expressed as a product of the basic physical dimensions mass, length, time, electric charge, and absolute temperature, represented by sans-serif symbols M, L, T, Q, and Θ, respectively.

- **Mathematical properties**

1. The dimensions that can be formed from a given collection of basic physical dimensions, such as M, L, and T, form a group:
2. The identity is written as 1; $L^0 = 1$, and the inverse toL is 1/L or L^{-1}. L raised to any rational power p is a member of the group, having an inverse of L^{-p} or $1/L^p$.
3. The operation of the group is multiplication, having the usual rules for handling exponents ($L^n \times L^m = L^{n+m}$).
4. This group can be described as a vector space over the rational numbers, with for example dimensional symbol $M^iL^jT^k$ corresponding to the vector (i, j, k).
5. When physical measured quantities (be they like-dimensioned or unlike-dimensioned) are multiplied or divided by one other,

Centrifugal Pumps

1. The hydraulic machines which convert the mechanical energy into hydraulic energy are called pumps.

2. 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.

3. The centrifugal pump acts as reversed of an inward radial flow reaction turbine, This means that flow in centrifugal pumps is in radial outward direction.

4. The centrifugal pumps works on the principle of forced vertex 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.

5. Due to this high pressure head the liquid can be lifted to high level.

Figure of Centrifugal Pump

Main Parts of a Centrifugal Pump

The following are the main parts of the centrifugal pump:

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

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 the centrifugal pump is similar to the casing of a reaction turbine.

It is an air tight passage surrounding the impeller and is designed in such a way that the kinetic energy of the water is discharged at the outlet of the impeller is converted into pressure energy before the water leaves the casing and enters the delivery pipe.

- Three types of casing are commonly adopted.:-

1. Volute casing
2. Vortex casing
3. Casing with guide blades

Volute Casing:-It is of spiral type in which area of flow increases gradually.

1. The increase in area of flow decreases the velocity of flow.
2. The decrease in velocity increases the pressure of the water flowing through the casing.
3. In case of the volute casing, the efficiency of the pump increases slightly as a large amount of the energy is lost due to the formation of eddies.

Vortex casing:-If a circular chamber is introduced between the casing and the impeller, then the casing is known as vortex casing.

1. By introducing the chamber the loss of energy due to the formation of eddies is reduced to a considerable extent.
2. Thus the efficiency of pump is more than the efficiency when the volute casing is provided.

Casing with guide blades:-In this the impeller is surrounded by a series of guide vanes mounted on a ring which is known as diffuser.

1. The guide vanes are designed in such a way that the water from the impeller enters the guide vanes without shock.

2. The water from the guide vanes then passes through the surrounding casing which is in most of the cases concentric with impeller.

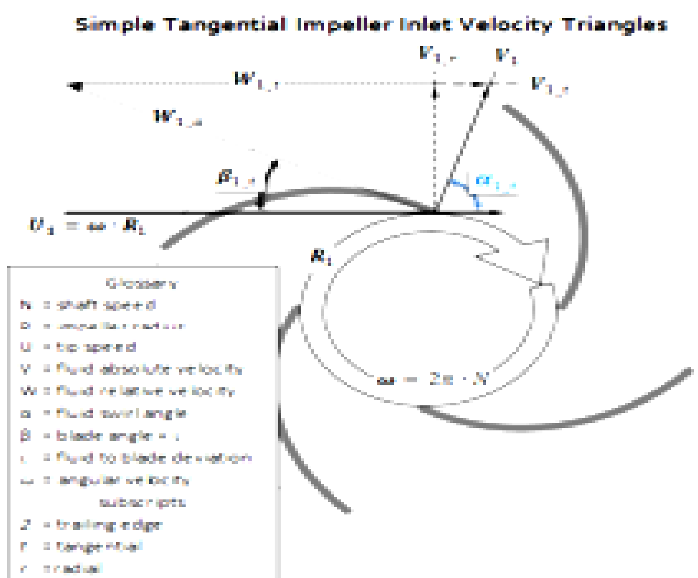
3. Suction pipe with a foot-valve and a strainer:-

A pipe whose one end is connected to the inlet of the pump and the other end dips into water in a sump is known as suction pipe.

a) 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.

How it works

- Like most pumps, a centrifugal pump converts mechanical energy from a motor to energy of a moving fluid.
- A portion of the energy goes into kinetic energy of the fluid motion, and some into potential energy, represented by fluid pressure.



Work done by the Centrifugal pump (or by impeller) on water

In case of the centrifugal pump, work is done by the impeller on the water.

The expression for the work done by the impeller on the water is obtained by drawing velocity triangles at inlet and outlet of the impeller in the same way as for a turbine.

The water enters the impeller radially at inlet for best efficiency of the pump, which means the absolute velocity of water at inlet makes an angle of 90º with the direction of motion of the impeller at inlet.

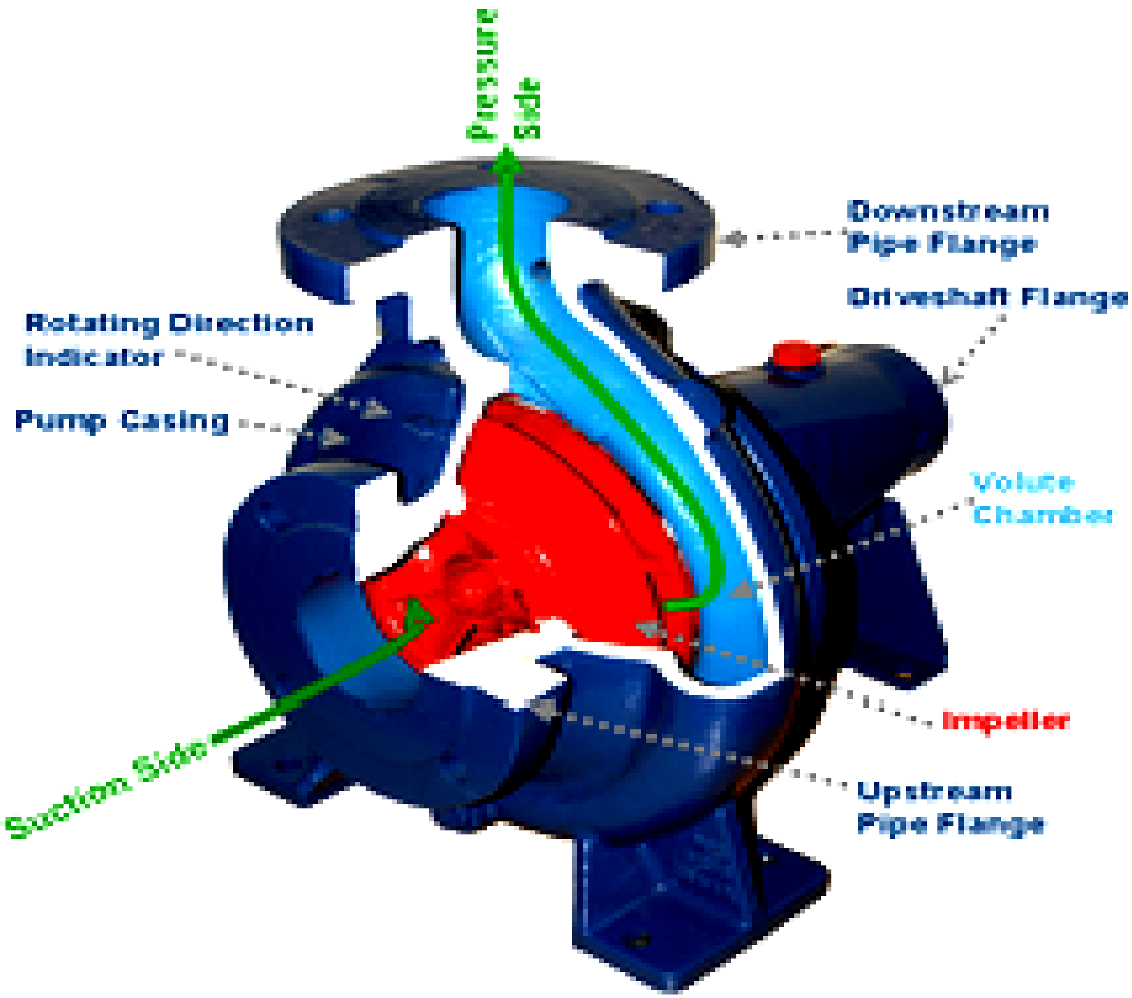
- Hence, angle $\alpha = 90^\circ$ and $V_{w1} = 0$.

Let,

N = speed of the impeller in rpm

D_1 = Diameter of the impeller at inlet

U_1 = Tangential velocity of impeller at inlet = $\frac{\pi D_1 N}{60}$



Cutaway view of centrifugal pump

U_2 = Tangential velocity of impeller at outlet $= \frac{\pi D_2 N}{60}$

V_1 = absolute velocity of water at inlet

V_{r1} = relative velocity of water at inlet

α = angle made by absolute velocity at inlet with the direction of motion of vanes

θ = angle made by the relative velocity at inlet with the direction of motion of vane and V_2

β, φ, V_{r1} are the values at outlet.

As the water enters the impeller radially which means the absolute velocity of water at inlet is in the radial direction and hence angle $\alpha = 90^\circ$ and $V_{w1} = 0$.

As the centrifugal pump is the reverse of the radially inward flow reaction turbine . In case of a radially inward flow reaction turbine, the work done by the water on the runner /s /unit weight of the water striking /second is given by

$$= \frac{V_{w1}U_1 - V_{w2}U_2}{g}$$

Workdone by the impeller on the water /sec/unit weight of water striking /sec =

- [Work done in case of turbines]

$$= -\frac{V_{w1}U_1 - V_{w2}U_2}{g}$$

$$= \frac{V_{w2}U_2 - V_{w1}U_1}{g}$$

$$= \frac{V_{w2}U_2}{g}$$

Work done by impeller on water/sec $= \frac{W}{g} V_{w2}U_2$

W = Weight of water = ρ x g x Q

Q = volume of water , Q = area x velocity of flow $= \pi D_1 B_1 \times V_{f1}$

$$= \pi D_2 B_2 \times V_{f2}$$

B_1 and B_2 are the width of impeller at inlet and outlet and V_{f1} and V_{f2} are the velocities of flow at inlet and outlet.

Minimum speed for starting a centrifugal pump

If the pressure rise in the impeller is more than or equal to manometric head the centrifugal pump will start delivering water.

In the forced vortex , the centrifugal head or head due to pressure rise in the impeller is equal to

$$= \frac{\omega^2 r_2^2}{2g} - \frac{\omega^2 r_1^2}{2g}$$

Where, ωr_2 = Tangential velocity of impeller at outlet= U_2 and ωr_1 = Tangential velocity of impeller at inlet= U_1

Head due to pressure rise in impeller

$$= \frac{u_2^2}{2g} - \frac{u_1^2}{2g}$$

The flow of water will commence only if,

Head due to pressure rise in impeller $\geq H_m$ or $\frac{u_2^2}{2g} - \frac{u_1^2}{2g} \geq H_m$

For maximum speed , we have $\frac{u_2^2}{2g} - \frac{u_1^2}{2g} = H_m$ .... (A)

Therefore, $\eta_{man} = \frac{gH_m}{V_{w2}u_2}$

$$H_m = \eta_{man} \times \frac{V_{w2}u_2}{g}$$

Put the value of H_m in equation (A) $\frac{u_2^2}{2g} - \frac{u_1^2}{2g} = \eta_{man} \times \frac{V_{w2}u_2}{g}$ .... (B)

Put the values of U_1 and U_2 in equation (B)

$$\frac{1}{2g}\left(\frac{\pi D_2 N}{60}\right)^2 - \frac{1}{2g}\left(\frac{\pi D_1 N}{60}\right)^2 = \eta_{man} \times \frac{V_{w2} \times \pi D_2 N}{g \times 60}$$

Dividing by $\frac{\pi N}{g \times 60}$ we get,

$$\frac{\pi N D_2^2}{120} - \frac{\pi N D_1^2}{120} = \eta_{man} \times V_{w2} \times D_2$$

$$\frac{\pi N}{120}\left[D_2^2 - D_1^2\right] = \eta_{man} \times V_{w2} \times D_2$$

$$N = \frac{120 \times \eta_{man} \times V_{w2} \times D_2}{\pi\left[D_2^2 - D_1^2\right]}$$

Equation gives the minimum starting speed of the centrifugal pump

Multistage Centrifugal Pumps

1. To produce a high head
2. To discharge a large quantity of liquid
3. If a high head is to be developed, the impeller are connected in series (or on the same shaft)
4. while for discharging large quantity of liquid, the impellers (pumps) are connected in parallel.

A) Multistage Centrifugal Pump for High Heads

1. The water from the suction pipe enters the 1st impeller at inlet and is discharged at outlet with increased pressure.

2. The water with increased pressure from the outlet of the 1st impeller is taken to the inlet of the 2nd impeller with the help of a connecting pipe.

At the outlet of the 2nd impeller the pressure of the water will be more than the pressure of water at the outlet of the 1st impeller.

Let, n = number of identical impellers mounted on the same shaft

H_m = head developed by each impeller

Then the total head developed. = $n \times H_m$

The discharge passing through each impeller is same.

B) Multistage Centrifugal Pump for High discharge

Each of pump is working against the same head.

Let, n = number of identical pumps arranged in parallel

Q = discharge from one pump

Then the total discharge. = $n \times Q$