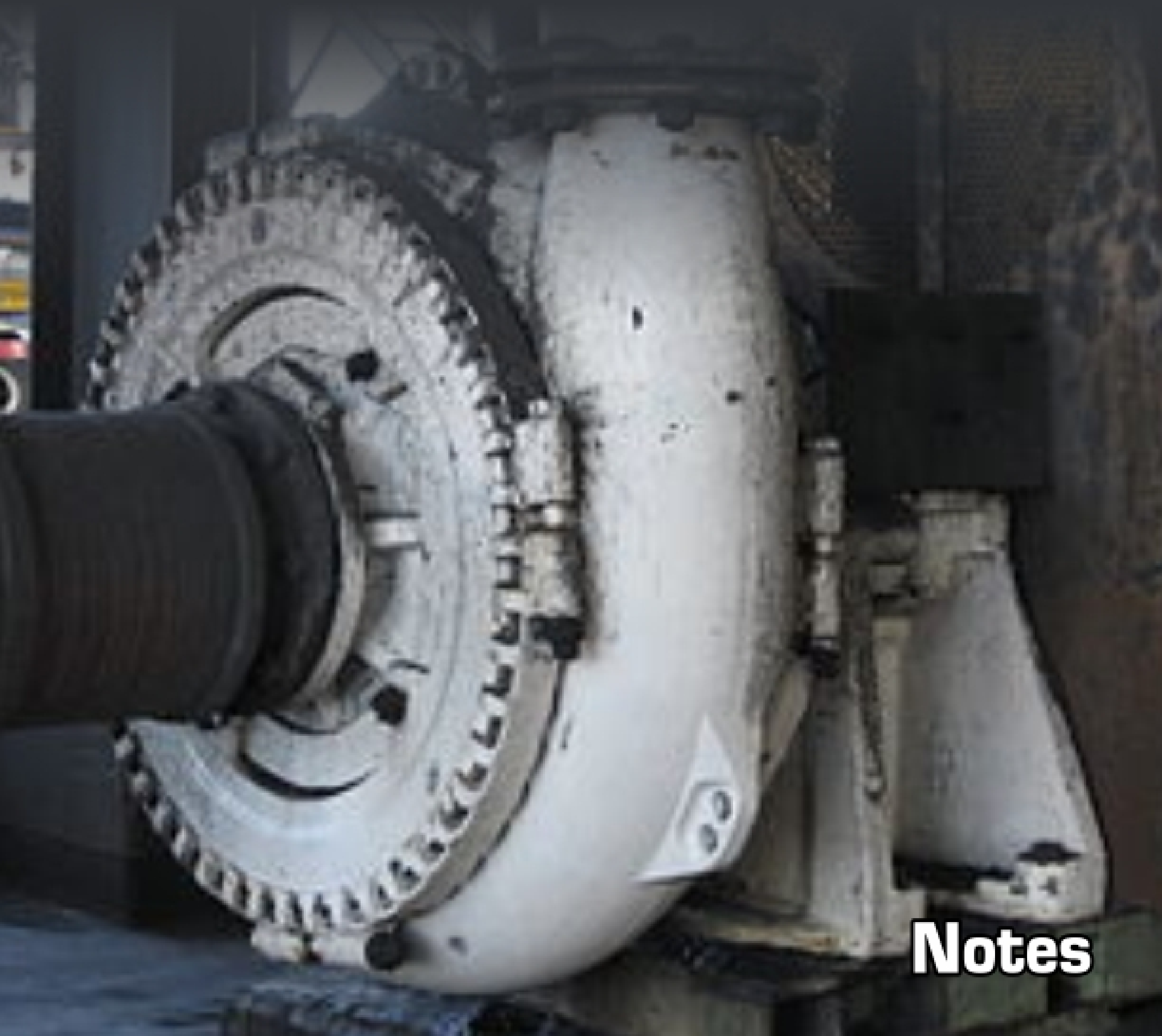
Hydraulics and Hydraulic Machines



Notes

CENTRIFUGAL PUMPS

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A pump is a hydraulic machine which converts mechanical energy into hydraulic energy or pressure energy.
A centrifugal pump is also known as a Rotodynamic pump or dynamic pressure pump. It works on the principle of centrifugal force. In this type of pump the liquid is subjected to whirling motion by the rotating impeller which is made of a number of backward curved vanes. The liquid enters this impeller at its center or the eye and gets discharged into the casing enclosing the outer edge of the impeller. The rise in the pressure head at any point/outlet of the impeller is Proportional to the square of the tangential velocity of the liquid at that point $(i.e, \alpha \frac{u^2}{2g})$. Hence at the outlet of the impeller where the 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 a higher level. Generally centrifugal pumps are made of the radial flow type only. But there are also axial flow or propeller pumps which are particularly adopted for low heads.

Advantages of centrifugal pumps:-

1. Its initial cost is low
2. Efficiency is high.
3. Discharge is uniform and continuous
4. Installation and maintenance is easy.
5. It can run at high speeds,without the risk of separation of flow

Classification of centrifugal pumps

Centrifugal pumps may be classified
Into the following types

1.According to casing design
   a) Volute pump b) diffuser or turbine pump
2. According to number of impellers
   a) Single stage pump b) multistage or multi impeller pump
3. According to number of entrances to the impeller:
   a) Single suction pump **(FOR FIGURES DOWNLOAD PRESENTATION)**
   b) Double suction pump
4. According to disposition of shaft
   a) Vertical shaft pump
   b) Horizontal shaft pump
5. According to liquid handled
   a) Semi open impeller
   b) Open impeller pump

6.According to specific speed

a) Low specific speed or radial flow impeller pump
b) Shrouded impeller
c) Medium specific speed or mixed flow impeller pump

c) High specific speed or axial flow type or propeller pump.

7. According to head (H)

- Low head if $H<15m$
- Medium head if $15<H<40m$
- High head if $H>40m$

In the case of a volute pump a spiral casing is provided around the impeller. The water which leaves the vanes is directed to flow in the volute chamber circumferentially. The area of the volute chamber gradually increases in the direction flow. Thereby the velocity reduces and hence the pressure increases. As the water reaches the delivery pipe a considerable part of kinetic energy is converted into pressure energy. However, the eddies are not completely avoided , therefore some loss of energy takes place due to the continually increasing quantity of water through the volute chamber.
In the case of a diffuser pump the guide wheel containing a series of guide vanes or diffuser is the additional component. The diffuser blades which provides gradually enlarging passages surround the impeller periphery. They serve to augment the process of pressure built up that is normally achieved in the volute casing. Diffuser pumps are also called turbine pumps in view of their resemblance to a reaction turbine.
Multistage pumps and vertical shaft deep-well pumps fall under this category.
Centrifugal pumps can normally develop pressures upto 1000kpa (100m). If higher pressures are required there are three options.a) Increase of impeller diameter. b)Increase of Rpm. c)Use of two or more impellers in series.
The pump looks clumsy in option (a). The impeller material is heavily stressed in option (b) The third choice is the best and is generally adopted, the impellers which are usually of the same size are mounted on the same shaft. The unit is called a multistage pump. It discharges the same quantity of fluid as a single stage pump but the head developed is high. There are centrifugal pumps upto 54 stages. However, generally not more than 10 stages are required. In the case of the double suction impeller, two impellers are set back to back. The two suction eyes together reduce the intake. The two suction eyes together reduce the intake velocity reduce the risk of cavitations. Mixed flow type double suction axial flow pumps besides are capable of developing higher heads. For convenience of operation and maintenance, horizontal shaft settings are the preferred setups for centrifugal pumps. The exceptions are deep-well turbine pumps and axial flow pumps, these have vertical shafts. Restricted space conditions usually require a vertical shaft setting. Centrifugal impellers usually have vanes fitted between the shroudes or plate.

The crown plate has the suction eye and the base plate is mounted on a sleeve which is keyed to the shaft. An impeller without the crown plate is called the non-clog or semi-open impeller. In an open impeller both crown plate and the base plate are absent.
Only clear liquids, can be safely pumped by a shrouded impeller pump. The semi-open impeller is useful for pumping liquids containing suspended solids, such as sewage, molasses or paper pulp. The open-vane impeller pump is employed for dredging operations in harbours and rivers. Shrouded and semi open impellers may be made of cast

iron Or cast steel. Open vane impellers are usually made of forged steel. If the liquid pumped are corrosive, brass, bronze or gun metal are the best materials for making the impellers.

A radial flow impeller has small specific speeds (300 to 1000) & is suitable for discharging relatively small quantities of flow against high heads. The direction of flow at exit of the impeller is radial. The mixed flow type of impellers has a high specific speed (2500 to 5000), has large inlet diameter D and impeller width B to handle relatively large discharges against medium heads. The axial flow type or propeller impellers have the highest speed range (5000 to 10,000). They are capable of pumping large discharges against small heads. The specific speed of radial pump will be $10 < N_s < 80$, Axial pump $100 < N_s < 450$, Mixed flow pump $80 < N_s < 160$.

Components of a centrifugal pump

The main components of a centrifugal pump are:

i) Impeller ii) Casing iii) Suction pipe iv) Foot valve with strainer, v) Delivery pipe vi) Delivery valve.

Impeller is the rotating component of the pump. It is made up of a series of curved vanes. The impeller is mounted on the shaft connecting an electric motor.

Casing is an air tight chamber surrounding the impeller. The shape of the casing is designed in such a way that the kinetic energy of the impeller is gradually changed to potential energy. This is achieved by gradually increasing the area of cross section in the direction of flow.

Suction pipe It is the pipe connecting the pump to the sump, from where the liquid has to be lifted up.

Foot valve with strainer the foot valve is a non-return valve which permits the flow of the liquid from the sump towards the pump. In other words the foot valve opens only in the upward direction.

The strainer is a mesh surrounding the valve, it prevents the entry of debris and silt into the pump.

Delivery pipe is a pipe connected to the pump to the overhead tank.

Delivery valve is a valve which can regulate the flow of liquid from the pump.

Priming of a centrifugal pump

Priming is the process of filling the suction pipe, casing of the pump and the delivery pipe upto the delivery valve with the liquid to be pumped.

If priming is not done the pump cannot deliver the liquid due to the fact that the head generated by the Impeller will be in terms of meters of air which will be very small (because specific weight of air is very much smaller than that of water).

Priming of a centrifugal pump can be done by any one of the following methods:

i) Priming with suction/vacuum pump.
ii) Priming with a jet pump.
iii) Priming with separator.
iv) Automatic or self priming.

Heads on a centrifugal pump:

Suction head (hs): it is the vertical distance between the liquid level
in the sump and the centre line of the pump. It is expressed as meters.

Delivery head (hd): It is the vertical distance between the centre line of the pump and the liquid level in the overhead tank or the supply point. It is expressed in meters.

Static head (Hs): It is the vertical difference between the liquid levels
In the overhead tank and the sump, when the pump is not working. It is expressed as meters.
Therefore, **HS= (hs+ hd)**
Friction head (hf): It is the sum of the head loss due to the friction in the suction and delivery pipes. The friction loss in both the pipes is calculated using the Darcy's equation, **hf=(fLV2/2gD)**.
Total head (H): It is the sum of the static head Hs, friction head (hf) and the velocity head in the delivery pipe (Vd 2/2g). Where, Vd=velocity in the delivery pipe.

$$\therefore H_m = \left(h_s + h_d + h_f + \frac{Vd^2}{2g} \right) --- (1)$$

Manometric head(Hm): It is the total head developed by the pump. This head is slightly less than the head generated by the impeller due to some losses in the pump

$$\therefore H_m = H + \frac{Vs^2}{2g} - \frac{Vd^2}{2g}$$

Working of a centrifugal pump:

A centrifugal pump works on the principal that when a certain mass of fluid is rotated by an external source, it is thrown away from the central axis of rotation and a centrifugal head is impressed which enables it to rise to a higher level.
Working operation of a centrifugal pump is explained in the following steps.

1) Close the delivery valve and prime the pump.
2) Start the motor connected to the pump shaft, this causes an increase in the impeller pressure.
3) Open the delivery valve gradually, so that the liquid starts flowing into the deliver pipe.
4) A partial vacuum is created at the eye of the centrifugal action, the liquid rushed from the sump to the pump due to pressure difference at the two ends fo the suction pipe.
5) As the impeller continues to run, move & more liquid is made available to the pump at its eye. Therefore impeller increases the energy of the liquid and delivers it to the reservoir.
6) While stopping the pump, the delivery valve should be closed first, otherwise there may be back flow from the reservoir.

It may be noted that a uniform velocity of flow is maintained in the delivery pipe. This is due to the special design of the casing. As the flow proceeds from the tongue of the casing to the delivery pipe, the area of the casing increases. There is a corresponding change in the quantity of the liquid from the impeller. Thus a uniform flow occurs in the delivery pipe.
Operation difficulties in centrifugal pumps

a) Pump fails to pump the fluid.

Cause	Remedial Measures
1) Improper priming due to leakage of foot valve or incomplete filling.	Repair or replace the foot valve, prime completely.
2) Head more than design head	Reduce the head or change the pump
3) Clogging of impeller, suction pipe or strainer	Clean the suspected part
4) Suction lift may be excessive	Reduce the height of pump above the sump
5) Speed more than design speed	Connect another prime mover of higher speed
6) Direction of rotation of impeller is wrong	Change the direction.

B) Pump does not give the required capacity

a) Leakage of air through the suction pipe or through the gland packing	Stop the leakage
b) Damage to some parts of the pump by wear & tear	Replace the damaged parts
c) Clogging of impeller passages	Clean the impeller

C) Pump has poor efficiency

a) Higher than design speed	**Reduce the speed**

b) Low head & higher discharge	**Reduce the discharge**
c) Impeller touching, the casing or improper alignment of shaft	**Carryout the necessary repair.**

D) Pump stops working

a) Air entry into suction pipe	Stop the pump, plug the leakage, reprime and start
b) Suction lift is high	Reduce the suction lift.

Efficiencies of centrifugal pump

Manometric efficiency (η): it is the ratio of the manometric head to the head actually generated by the impeller $n_{mano} = \left\{ \frac{Hm}{Vw_2u2/g} \right\} = \left\{ \frac{gHm}{Vw_2u_2} \right\}$

Mechanical efficiency(η **mech**): It is the ratio of the impeller power to the power of the motor or the prime mover. $\therefore n\,mech = \left\{ \frac{impeller\ power}{motor\ power} \right\}$

Overall efficiency(ηo): It is the ratio of the work done by the pump in lifting water against gravity and friction in the pipes to the energy supplied by the motor.

$$\therefore n_o = \left\{ \frac{work\ done\ against\ gravity\ friction}{power\ of\ the\ prime\ mover\ or\ motor} \right\}$$

Velocity Triangles of a Centrifugal Pump

Figure shows the inlet and outlet velocity triangles for a centrifugal pump.It may be noted that the inlet velocity triangle is radial,(velocity of whirl is zero at inlet or VW1 =0

Depending on the geometry of the blade at outlet it can be:

Forward:if the blade angle**$<90^0$,**Radial if $\Phi=90^0$, c) Backward if ¤ $> 90^0$

Work done by the impeller of a centrifugal pump:

Figure shows the velocity triangles at the inlet and outlet tips of a vane fixed to the impeller.

Let N=speed of the impeller in RPM

D= Diameter of the impeller at inlet

D=Diameter of the impeller at outlet

U_1 = Tangential velocity of the impeller at inlet $\pi D_1 N/60$

U_2= tangential velocity of the impeller at outlet $\pi D_2 N/60$

V_1=absolute velocity of the liquid at inlet

V_2= absolute velocity of the liquid at outlet.

Vf_1 & Vf_2 are the velocities of flow at inlet and outlet.

Vr_1 & Vr_2 Relative velocities at inlet and outlet

Vw_2 whirl velocity at outlet

~ angle made by V_1 with respect to the motion of the vane

– blade angle at inlet

¤ = blade angle at outlet

For a series of curved vanes the force exerted can be determined using the impulse momentum equation Work=force x distance.

similarly the work done/sec/unit weight of the liquid striking the vane= $\frac{1}{g}(Vw_2u_2 - Vw_1u_1)$

But for a centrifugal pump $V\omega_1 = 0$

Work done/sec/unit weight $\frac{Vw_2u_2}{g}$

And the work done/sec ¥ $\frac{Q}{g} Vw_2u_2 - (4)$

Where Q=volume of liquid flowing per second = Area x velocity of flow $Q = \pi D_2 B_2 Vf_2 - (5)$

In eq (5), B_2 is the width of the impeller at the outlet.

Design factors of centrifugal pumps:

a) Rim diameter D_2

Rim velocity or impeller velocity $u_2 = \frac{\pi D_2 N}{60} = K_u\sqrt{2gHm}$

Rim diameter $D_2 = \frac{60}{\pi N}\sqrt{2gKu}\sqrt{Hm} = \frac{85}{N}K_u\sqrt{Hm}$

Where N= speed in RPM Hm= manometric head, m

$K_u = U_2/\sqrt{2gHm} = \text{speed ratio}$

Value of varies from 0.95 to 1.8 depending on the specific speed.

b) Pipeline diameter:

The diameter of section and delivery pipes are designed to give velocities not exceeding 1.5 to 3 m/s on section and delivery sides.

c) Discharge (Q): the discharge or capacity of a centrifugal pump is given by

Where k =factor which accounts the reduction in flow area due to

To thickness of impeller vanes,

D2 =Rim diameter,B2 =Rim width,

Vf2=Constant velocity of flow through the impeller. Generally k=1 is considered.

PROBLEMS

1.A centrifugal pump running at 800 Rpm is working against a total head of 20.2 m. the external diameter of the impeller is 480mm and outlet width 60mm. If the valve angle at outlet is 40 and manometric efficiency is 70% determine

a)Absolute velocity of water leaving

b) Flow velocity at outlet The valve.

c) Angle made by the absolute velocity at outlet with the direction of motion at outlet.

d) Rate of flow through the pump.

Soln: velocity of valve at outlet $u_2 = \frac{®D_2N}{60} = \frac{®x0.48x800}{60} = 20.1m/s$

$manometric\ efficiency\ n_{mano} = \frac{gHm}{Vw_2u_2} \quad ,0.70 = \frac{9.81x20.2}{Vw_2x20.1}, \quad Vw_2 = 14.08m/s$

From the outlet velocity triangle $\tan ¤ = \frac{Vf_2}{u_2 - Vw_2}$

$\therefore Vf_2 = \tan 40^0 x(20.1 - 14.08) = 5.05m/s$

Absolute velocity of water leaving the valve V_2 is given by

$V_2 = \sqrt{Vf_2^2 + Vw_2^2} = \sqrt{5.05^2 + 14.08^2} = 14.96m/s$

Angle made by the absolute velocity at outlet with the direction of motion is given by

$\tan \quad = \frac{Vf_2}{Vw_2} = \frac{5.05}{14.08} = 0.3586 \qquad \therefore \quad = 19.7^0$

Rate of flow through the pump $Q = ®D_2B_2Vf_2 = ®x0.48x0.06x5.05 = 0.457m3/s$

2. A centrifugal pump impeller having external and internal diameter 480mm and 240mm respectively is running at 100 Rpm. The rate of flow through the pump is 0.0576 m3/s and velocity of flow is constant and equal to 2.4m/s. the diameter of the section and delivery pipes are 180mm and 120mm respectively and section and delivery heads are 6.2m(abs) and 30.2m(abs) of water respectively. If the power required to drive the pump is 23.3KW and the outlet vane angle is 45 determine. a) inlet vane angle b) Overall efficiency c) manometric efficiency of the pump

Soln: tangential velocity or impeller velocity at inlet

$u_1 = \frac{®D_1N}{60} = \frac{®x0.24x1000}{60} = 12.56m/s$

From the inlet velocity triangle $\tan ¤ = \frac{Vf_1}{u_1} = \frac{2.41}{12.56} = 0.191$

$\therefore ¯ = 10.8^0$ $(inlet\ vane\ angle)$

Overall efficiency $n_0 = \frac{rQHm}{P} = \frac{9.81x0.05xHm}{23.3}$ $\therefore n_0 = 0.02387Hm$ (1)

$$but, Hm = \left\{ \left(Z_2 + \frac{p_2}{r} + \frac{V_2^2}{2g} \right) - \left(Z_1 + \frac{p_1}{r} + \frac{V_1^2}{2g} \right) \right\}$$

$$where, V_2 = V_d = \frac{4Q}{®d_d^2} = \frac{4x0.0567}{®x0.12^2} = 5.01m/s$$

$$where, V_2 = V_s = \frac{4Q}{®d_s^2} = \frac{4x0.0567}{®x0.18^2} = 2.23m/s$$

$let\ Z_1 = Z_2$ i.e pump inlet and outlet are at same level.

$$\frac{p_1}{r} = h_s = 6.2m(abs) \quad \frac{p_2}{r} = h_d = 30.2m(abs)$$

$$\therefore Hm = \left\{ \left(30.2 + \frac{5.01^2}{2x9.81} \right) - \left(6.2 + \frac{2.23^2}{2x9.81} \right) \right\} = 25.03m$$

n_0, overall efficiency of pump

=0.02387x25.03=0.597=59.7%

Velocity of the impeller at outlet $u_2 = \frac{®D_2N}{60} = \frac{®x0.48x1000}{60} = 25.13m/s$

From the outlet velocity triangle $\tan ¤ = \frac{Vf_2}{u_2 - Vw_2}$, $\tan 45^0 = \frac{2.4}{25.13 - Vw_2}$,

$Vw_2 = 22.73m/s$

Manometric efficiency $n_{mano} = \frac{gHm}{Vw_2u_2} = \frac{9.81x25.03}{22.73x25.13} = 0.43 = 43\%$

3. It is required to deliver 0.048m3/s of water to a height of 24m through a 150mm diameter and 120m long pipe by a centrifugal pump. If the overall Efficiency of the pump is 75% and co efficient of friction f=0.01 for the pipe line. Find the power required to drive the pump.

Soln: velocity of water pipe $V_s = V_d = V = \frac{4Q}{®d^2} = \frac{4x0.048}{®x0.15^2} = 2.7m/s$

Overall efficiency $n_0 = \frac{rQHm}{P}$ $0.75 = \frac{9.81x0.048x27.37}{P}$, $P = 17.2KW$

4. The impeller of a centrifugal pump is of 300mm diameter and 50mm width at the periphery and has blades whose tip angle incline backwards 60 from the radius. The pump deliveries 17m3/min of water and the impeller rotates at 1000 Rpm. Assuming that the pump is design to admit radically. calculate

a)Speed and direction of water as it leaves the impeller,
b)Torque exerted by the impeller on water c) Shaft power required

d) Lift of the pump. Take mechanical=95% and hydraulic efficiency=75%

Soln: tangential velocity of the impeller at the outlet

$$u_2 = \frac{®D_2N}{60} = \frac{®x0.3x1000}{60} = 15.71m/s$$

From continuity equation $Q = ®D_2B_2Vf_2$, $Vf_2 = \frac{0.2833}{®x0.3x0.05} = 6m/s$

From the outlet velocity triangle $\tan ¤ = \frac{Vf_2}{u_2 - Vw_2}$

$$Vw_2 = \left(u_2 - \frac{Vf_2}{\tan ¤}\right) = \left(15.71 - \frac{6}{\tan 60^0}\right) = 12.24m/s$$

Absolute velocity of water at the outlet tip of the impeller

$$V_2 = \sqrt{Vf_2^2 + Vw_2^2} = \sqrt{6^2 + 12.24^2} \qquad V_2 = 13.63\, m/s\ (magnitude)$$

$$= \tan^{-1}\left(\frac{Vf_2}{Vw_2}\right) = \tan^{-1}\left(\frac{6}{12.24}\right) = 26.5^0$$

Torque exerted by the impeller on water

$$T = \frac{rQ}{g}(Vw_2R_2) = \frac{9.81x0.2833}{9.81}x(12.24x\frac{0.3}{2}) = 0.52KN\ m$$

Shaft power (P) impeller or rotor power $\frac{2®NT}{60} = \frac{2®x1000x0.52}{60} = 54.45KW$

But, mechanical efficiency $n_{mech} = \frac{impeller\ power}{shaft\ power}$ $i.e,\ 0.95 = \frac{54.45}{P}$ $P = 57.31KW$

<u>Lift of the pump</u>

Impeller power=r(Q+q)H

Where r=sp wt of water=9.81 KN/m3

H =ideal head=(theoretical head-hyd losses)

Q=leakage of water m3/s

Neglecting leakages q we have

54.45=9.81x0.2833xH

Or h =19.59m

We know, hydraulic efficiency $n_h = \frac{Actual\ head\ or\ lift}{ideal\ head}$

$$Actual\ hft = n_h xideal\ head(H_i) \quad 0.70x19.59 = 13.71m\ of\ water$$

5. The following data relate to a centrifugal pump. Diameter of the impeller at inlet & outlet =180mm and 360mm respectively. width of impeller at inlet and outlet=144mm & 72mm respectively. rate of flow through the pump=17.28lps. Speed of the impeller = 1500 Rpm. Vane angle at outlet=45 water enters the impeller radially at inlet neglecting losses through the impeller. Find the pressure rise in the impeller.

Soln: velocity of flow at inlet $Vf_1 = \frac{Q}{®D_1B_1} = \frac{0.01728}{®x0.18x0.0144}$

Velocity of flow at outlet $Vf_2 = \frac{Q}{®D_2B_2} = \frac{0.01728}{®x0.36x0.0072} = 2.12m/s$

Tangential velocity of impeller at outlet $u_2 = \frac{®D_2N}{60} = \frac{®x0.36x1500}{60} = 28.27m/s$

Pressure rise in the impeller is given by the equation $= \frac{1}{2g}\left\{Vf_1^2 + u_2^2 - Vf_2^2 \cos ec^2¤\right\}$

$$= \frac{1}{2x9.81}\left\{2.12^2 + 28.27^2 - 2.12^2 x \cos ec^2 45^0\right\}$$

6. A centrifugal pump delivers water at the rate of 1800 lpm,to a height of 20m, Through a 0.1m, dia, 80m. long pipe. Find the power required to drive the pump, if the overall efficiency is 65%, and Darcy's friction factor=0.02.

Soln. Discharge Q=1800 lpm=0.03 cumecs.
Delivery head hd =20m
Dia of delivery pipe dd=0.1m
Length of delivery pipe $l_d = 80m$
Overall efficiency $n_0 = 0.65 \quad f = 0.02$

Total head $\mathbf{H = h_s + h_d + h_{fs} + h_{fd} + \frac{Vd^2}{2g}}$

So this prob $h_s = 0 \; h_{fs} = 0$ (details are not given)

$$\therefore \mathbf{H = h_d + h_{fd} + \frac{Vd^2}{2g}}$$

$$= \left\{\mathbf{20 + \frac{8x0.02x80x0.03^2}{9.81x\pi^2x0.1^5} + \left(\frac{4x0.03}{\pi x0.1^2}\right)^2 x \frac{1}{9.81x2}}\right\} \qquad H=32.65m$$

Output of the pump=$¥QH = 9.81x0.03x32.65 = 9.6kw$

But overall efficieny $¦_0 = \frac{Output\ of\ the\ pump}{power\ require\ to\ drive\ the\ pump}$

Power required to drive the pump = 9.6/0.65=14.8kw

7. A centrifugal pump is required to deliver 280 ltrs of water per second against a head of 16m, when running at 800rpm. If the blades of the impeller are radial at inlet and velocity of flow is constant and equal to 2m/sec, find the proportions of the pump. Assume overall efficiency as 80% and ratio of breadth to diameter at outlet as 0.1

Soln: the inlet and outlet velocity triangles will be as shown
From continuity equation $Q = ®D_2B_2Vf_2 \quad 0.28 = ®x0.1xD_2x2$

$\therefore D_2 = 0.67m(\textit{diameter of the impeller at outlet})$

$B_2 = 0.1x0.67 = 0.067m = 6.7cm$ (Width of the impeller at outlet).

$n_{mano} = \frac{gHm}{Vw_2 u_2} \quad 0.8 = \frac{9.81x16}{Vw_2 u_2}$

$Vw_2 u_2 = 196.2 \quad (i) \quad but \;\; u_2 = \frac{®D_2 N}{60} = \frac{®x0.67x800}{60} = 28.1m/s$

From eq (i) $Vw_2 x2.81 = 196.2 \;\; or \;\; Vw_2 = 6.99m/s$

From the outlet velocity triangle $\tan ¤ = \frac{Vf_2}{u_2 - Vw_2} = \left\{\frac{2}{28.1 - 6.99}\right\} = 0.0947$

$\therefore ¤ = 5.41^0$ (Blade angle at outlet) $\tan \quad = \frac{Vf_2}{Vw_2} = \frac{2}{6.99} = 0.286 \quad \therefore \quad = 16^0$

8. The following data refer to a centrifugal pump static head = 40m, suction height 5m, dia of suction and delivery pipes = 0.1m, loss of head in suction pipe = 2m, loss of head in delivery pipe = 8m, impeller dia at outlet =0.4m, impeller breadth at outlet 25mm.blades occupy 10% of the outlet area, speed 1200rpm. Exit angle of blade = 1500 with the tangent, Manometric efficiency = 80%, overall efficiency = 70%. Find the power required to drive the pump and what pressures will be indicated by the gauges mounted on the suction and delivery sides.

Soln: Outlet vane angle $\therefore ¤ = 180 - 150 = 30^0$

Delivery head $h_d = (H_s - h_s) = (40 - 5) = 35m$

Head on the pump H=40+2+8=50m

From the outlet velocity triangle $\tan ¤ = \left\{\frac{Vf_2}{u_2 - Vw_2}\right\}$

$where, u_2 = \frac{®D_2 N}{60} = \frac{®x0.4x1200}{60} = 25.13m/s$

Also from the equation $n_{mano} = \frac{gHm}{Vw_2 u_2} \qquad Vw_2 = \frac{9.81x50}{25.13x0.8} = 24.4m/s$

$Vf_2 = (u_2 - Vw_2)\tan ¤ = (25.13 - 24.4)\tan 30^0 \;\; Vf_2 = 0.422m/s$

$disch\arg e, Q = K®D_2 B_2 Vf_2 = 0.9x®x0.4x0.025x0.422 = 0.0119m3/s$

Power given to the liquid P=rQH $= 9.81x0.0119x50 = 5.85KW$

Power required to drive the pump $= \frac{P}{¦_0} = \frac{5.85}{0.7} = 8.36kw$

Pressure gauge reading on the suction side = hs+hfs $= 5 + 2 = 7m \textit{ of water}$

Pressure gauge reading on the delivery side = $h_d + h_{fd} = 35 + 8 = 43m$

9. Following data were obtained from a centrifugal pump in a laboratory. Pressure gauge reading on the suction side 15cm of mercury, pressure gauge reading on the delivery side 170kN/m2. quantity of water raised by the pump =7.5kN/min. vertical height difference

between the gauges =500mm. Total input to the pump = 6.5kw.Find the efficiency of the pump.

Soln: Suction head hs=0.15x13.5=2.04m of water
Delivery head hd=170/9.81=17.34m of water. Head on the pump = (hs+hd+x+Vd2/2g)
Since the dia of the delivery pipe is not given, velocity in the delivery pipe is ignored.
$\therefore H = \left(2.04 + 17.34 + 5)\right) = 19.88m$

Discharge from the pump $= \frac{7.5}{60} x \frac{1}{9.81} = 0.0127 m^3 / \sec$

Output of the pump ¥$QH = 9.81x0.127x19.88 = 2.48kw$
Efficiency of the pump =2.48/6.5=0.382.=38.2%

10. The internal and external diameters of the impeller of a centrifugal pump are 40cms and 80cms respectively. The pump is running at 1200rpm. The vane angles at inlet and outlet are 200 and 300 respectively. Water enters the impeller radially and velocity of flow is constant. Determine the workdone by the impeller per kN of water.

$$so\ln : u_1 = \frac{®D_1 N}{60} = \frac{®x0.4x1200}{60} = 25.13 m/s$$

$$u_2 = \frac{®D_1 N}{60} = \frac{®x0.8x1200}{60} = 50.26 m/s$$

From the inlet velocity triangle $\tan^{-} = \frac{Vf_1}{u_1}$

$\therefore Vf_1 = Vf_2 = 25.13 \tan 20^0 = 9.15 m/s$
From the outlet velocity triangle
tanΦ=Vf2/(u2-vw2)=9.15/(50.26-vw2)
or , Vw2=34.41m/s
Work done/sec=1/g(vw2 u2) =34.41*50.26/9.81=176.3kn-m/s/kn

11. The impeller of a centrifugal pump runs at 90 Rpm and has vaves inclined at 120 to the direction of motion at exit. If the manometric head is 20m and manometric efficiency is 75% Vane angles at inlet. Take the velocity of flow as 2.5m/s, throughout and the diameter of the impeller at exit as twice that at inlet.

a) Diameter of the impeller at exit.

Soln: From the definition of manometric efficiency $¦_{mano} = gHm / Vw_2 u_2$

$$Vw_2 u_2 = \frac{9.81x20}{0.75} = 261.6 \quad (i)$$

From the outlet velocity triangle $(u_2 - Vw_2) = \frac{Vf_2}{\tan 60^0} = \frac{2.5}{\tan 60^0} = 1.44 \quad Vw_2 = (u_2 - 1.44)$

Substituting the value $Vw_2, (u_2 - 1.44) u_2 = 261.6 = 16.9 m/s \quad but\ u_2 = \frac{®D_2 N}{60}$

$D_2 = \frac{60x16.9}{®x90} = 3.59m/s$

further $u_1 = \frac{u_2}{2} = \frac{16.9}{2} = 8.45m/s$

From the inlet velocity triangle $\tan^{-} = \frac{Vf_1}{u_1} = \frac{2.5}{8.45} = 0.2959$

$\therefore^{-} = 16.48^0 (Inlet\,Vane\;Angle)$

12. A centrifugal pump delivers 250lps against a head of 20m. When the impeller rotates at 1500rpm. If the mano metric efficiency is 75% and the loss of head in the pump is 0.033V22, where V2 is the absolute velocity at exit. The diameter of the impeller

a) The blade angle at exit

Take the width of the impeller at exit as 0.4D where D is the diameter of the impeller

Soln: $u_2 = \frac{®D_2N}{60} = \frac{®xDx1500}{60} = 78.5D \quad Vf_1 = \frac{Q}{®DB} = \frac{0.25}{®xDx0.4D} = \frac{0.199}{D^2}$

From the definition of manometric efficiency $n_{mano} = \frac{gHm}{Vw_2u_2}$

$\therefore \frac{Vw_2u_2}{g} = \frac{Hm}{n_{mano}} = \frac{20}{0.75} = 26.7$

But, manometric head=(workdone the impeller –losses in the pump)

$\therefore 0.033V_2^2 = 26.7 - 20 \quad V_2 = 14.25m/s$

From eq (i) and (ii)

$\therefore \frac{Vw_2x78.5D}{9.81} = 26.7 \; or \; Vw_2 = \frac{3.34}{D}$

From the outlet velocity triangle $Vf_2^2 + Vw_2^2 = V_1^2$

$\left(\frac{0.199}{D^2}\right)^2 + \left(\frac{3.34}{D}\right)^2 = 14.2^2$

Solving by trial and error D=0.242 m

$\therefore u_2 = 78.5D = 78.5x0.242 = 19m/s \quad Vf_2 = \frac{0.199}{D^2} = \frac{0.199}{0.242^2} = 3.4m/s$

$Vw_2 = \frac{3.34}{D} = \frac{3.34}{0.242} = 13.8m/s \quad \tan ¤ = \frac{Vf_2}{u_2 - Vw_2} = \left(\frac{3.4}{19 - 13.8}\right) = 0.654$

$¤ = 33.2^0 \; (outlet\; vane\; angle)$

13. A centrifugal pump lifts water against a static head of 40m. The section and delivery pipes are each 15cm in diameter. The head loss in the section and delivery pipes are respectively 2.20m and 7.5m. The impeller is 40cm in diameter and 2.5cm wide at the month. It revolves at 1200Rpm and the vane angle at exit is 30. if the manometric efficiency is 80%. Calculate the discharge.

Soln: $\frac{®}{4} x0.15^2 xV_s = Q \qquad V_s$ = velocity in the section pipe