ME 2204 - FLUID MECHANICS AND MACHINERY

CLASS: III SEM **BRANCH: MECHANICAL**

QUESTION BANK

1. INTRODUCTION ***12***

Units & Dimensions. Properties of fluids – Specific gravity, specific weight, viscosity, compressibility, vapour pressure and gas laws – capillarity and surface tension. Flow characteristics: concepts of system and control volume. Application of control volume to continuity equation, energy equation, momentum equation and moment of momentum equation.

PART - A

1. Define fluids.

Fluid may be defined as a substance which is capable of flowing. It has no definite shape of its own, but confirms to the shape of the containing vessel.

2. What are the properties of ideal fluid?

Ideal fluids have following properties

i) It is incompressible

ii) It has zero viscosity

iii) Shear force is zero

3. What are the properties of real fluid?

Real fluids have following properties

i) It is compressible

ii) They are viscous in nature

iii) Shear force exists always in such fluids.

4. Define density and specific weight.

Density is defined as mass per unit volume (kg/m3)

Specific weight is defined as weight possessed per unit volume (N/m3)

5. Define Specific volume and Specific Gravity.

Specific volume is defined as volume of fluid occupied by unit mass (m3/kg)

Specific gravity is defined as the ratio of specific weight of fluid to the specific weight of standard fluid.

6. Define Surface tension and Capillarity.

Surface tension is due to the force of cohesion between the liquid particles at the free surface.

Capillary is a phenomenon of rise or fall of liquid surface relative to the adjacent general level of liquid.

7. Define Viscosity.

It is defined as the property of a liquid due to which it offers resistance to the movement of one layer of liquid over another adjacent layer.

8. Define kinematic viscosity.

It is defined as the ratio of dynamic viscosity to mass density. (m^2/sec)

9. Define Relative or Specific viscosity.

It is the ratio of dynamic viscosity of fluid to dynamic viscosity of water at 20°C.

10. Define Compressibility.

It is the property by virtue of which fluids undergoes a change in volume under the action of external pressure.

11. Define Newton's law of Viscosity.

According to Newton's law of viscosity the shear force F acting between two layers of fluid is proportional to the difference in their velocities du and area A of the plate and inversely proportional to the distance between them.

12. What is cohesion and adhesion in fluids?

Cohesion is due to the force of attraction between the molecules of the same liquid.

Adhesion is due to the force of attraction between the molecules of two different liquids or between the molecules of the liquid and molecules of the solid boundary surface.

13. State momentum of momentum equation?

It states that the resulting torque acting on a rotating fluid is equal to the rate of change of moment of momentum

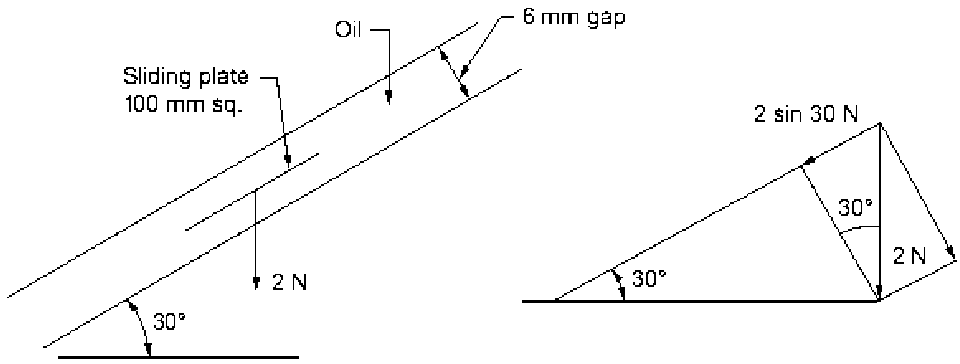
14. What is momentum equation?

It is based on the law of conservation of momentum or on the momentum principle It 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.

PART – B

1. The space between two large inclined parallel planes is 6mm and is filled with a fluid. The planes are inclined at 30° to the horizontal. A small thin square plate of 100 mm side slides freely down parallel and midway between the inclined planes with a constant velocity of 3 m/s due to its weight of 2N. Determine the viscosity of the fluid.

   The vertical force of 2 N due to the weight of the plate can be resolved along and perpendicular to the inclined plane. The force along the inclined plane is equal to the drag force on both sides of the plane due to the viscosity of the oil.
   Force due to the weight of the sliding plane along the direction of motion = 2 sin 30 = 1
   Viscous force, $F = (A \times 2) \times \mu \times (du/dy)$ (both sides of plate). Substituting the values,
   $1 = \mu \times [(0.1 \times 0.1 \times 2)] \times [(3 - 0)/6/ (2 \times 1000)\}]$
   Solving for viscosity, $\mu = 0.05$ Ns/m^2 or 0.5 Poise



2. The velocity of the fluid filling a hollow cylinder of radius 0.1 m varies as u = 10 [1 (r/0.1)2] m/s along the radius r. The viscosity of the fluid is 0.018 Ns/m2. For 2 m length of the cylinder, determine the shear stress and shear force over cylindrical layers of fluid at r = 0 (centre line), 0.02, 0.04, 0.06 0.08 and 0.1 m (wall surface.)

Shear stress = μ (du/dy) or μ (du/dr), u = 10 [1 – (r/0.1)2] m/s
∴ du/dr = 10 (– 2r/0.12) = – 2000 r
The – ve sign indicates that the force acts in a direction opposite to the direction of velocity, u.
Shear stress = 0.018 × 2000 r = 36 rN/m^2
Shear force over 2 m length = shear stress × area over 2m = 36r × 2πrL = 72 πr^2 × 2 = 144 πr^2

Radius, m	Shear stress, N/m^2	Shear force, N	Velocity, m/s
0.00	0.00	0.00	0.00
0.02	0.72	0.18	9.60
0.04	1.44	0.72	8.40
0.06	2.16	1.63	6.40
0.08	2.88	2.90	3.60
0.10	3.60	4.52	0.00

3. What is the effect of temperature on Viscosity?

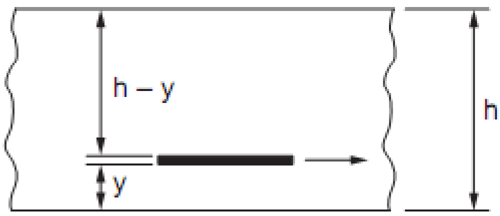
When temperature increases the distance between molecules increases and the cohesive force decreases. So, viscosity of liquids decrease when temperature increases. In the case of gases, the contribution to viscosity is more due to momentum transfer. As temperature increases, more molecules cross over with higher momentum differences. Hence, in the case of gases, viscosity increases with temperature.

4. Determine the power required to run a 300 mm dia shaft at 400 rpm in journals with uniform oil thickness of 1 mm. Two bearings of 300 mm width are used to support the shaft.

The dynamic viscosity of oil is 0.03 Pas. (Pas = (N/m^2) × s).
Shear stress on the shaft surface = τ = μ (du/dy) = μ (u/y)
u = π DN/60 = π × 0.3 × 400/60 = 6.28 m/s
τ = 0.03 {(6.28 – 0)/ 0.001} = 188.4 N/m^2
Surface area of the two bearings, A = 2 π DL
Force on shaft surface = τ × A = 188.4 × (2 × π × 0.3 × 0.3) = 106.6 N
Torque = 106.6 × 0.15 = 15.995 Nm

Power required = 2 π NT/60 = 2 × π × 400 × 15.995/60 = 670 W.

5. A small thin plane surface is pulled through the liquid filled space between two large horizontal planes in the parallel direction. Show that the force required will be minimum if the plate is located midway between the planes.



Let the velocity of the small plane be u, and the distance between the large planes be h.
Let the small plane be located at a distance of y from the bottom plane. Assume linear variation of velocity and unit area. Refer Fig.
Velocity gradient on the bottom surface = u/y
Velocity gradient on the top surface = u/(h – y),
Considering unit area,
Force on the bottom surface = μ × (u/y), Force on the top surface = μ × u/(h – y)
Total force to pull the plane = μ × u × {(1/y) + [1/(h – y)]} ...(A)
To obtain the condition for minimisation of the force the variation of force with respect to y should be zero, or dF/dy = 0, Differentiating the expression A,
dF/dy = μ × u {(–1/y2) + [1/(h – y)2]}, Equating to zero
$y^2 = (h - y)^2$ or y = h/2
or the plane should be located at the mid gap position for the force to be minimum.

6. *Calculate the dynamic viscosity of an oil, which is used for lubrication between a square plate of size 0.8 m × 0.8 m and an inclined plane with angle of inclination 30° as shown in Fig. 1.4. The weight of the square plate is 300 N and it slides down the inclined plane with a uniform velocity of 0.3 m/s. The thickness of oil film is 1.5 mm.*

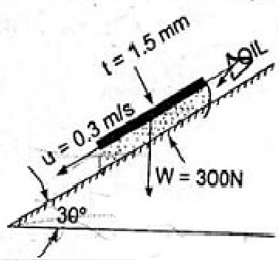
Solution. Given :

Area of plate, $A = 0.8 \times 0.8 = 0.64\ m^2$

Angle of plane, $\theta = 30°$

Weight of plate, $W = 300$ N

Velocity of plate, $u = 0.3$ m/s



Thickness of oil film, $t = dy = 1.5\ mm = 1.5 \times 10^{-3}$ m

Let the viscosity of fluid between plate and inclined plane is μ.

Component of weight W, along the plane = $W \cos 60° = 300 \cos 60° = 150$ N

Thus the shear force, F, on the bottom surface of the plate = 150 N

and shear stress, $$\tau = \frac{F}{\text{Area}} = \frac{150}{0.64}\ N/m^2$$

Now using equation (1.2), we have

$$\tau = \mu \frac{du}{dy}$$

where du = change of velocity = $u - 0 = u = 0.3$ m/s

$$dy = t = 1.5 \times 10^{-3}\ m$$

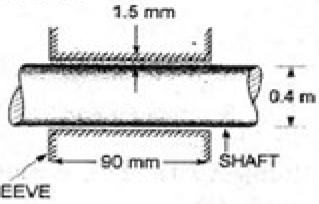
$$\therefore \quad \frac{150}{0.64} = \mu \frac{0.3}{1.5 \times 10^{-3}}$$

$$\therefore \quad \mu = \frac{150 \times 1.5 \times 10^{-3}}{0.64 \times 0.3} = 1.17\ N\ s/m^2 = 1.17 \times 10 = \mathbf{11.7\ poise.}$$

7.

The dynamic viscosity of an oil, used for lubrication between a shaft and sleeve is 6 poise. The shaft is of diameter 0.4 m and rotates at 190 r.p.m. Calculate the power lost in the bearing for a sleeve length of 90 mm. The thickness of the oil film is 1.5 mm.

Solution. Given :



Viscosity $\mu = 6$ poise

$= \frac{6}{10}\frac{Ns}{m^2} = 0.6\ \frac{Ns}{m^2}$

Dia. of shaft, $D = 0.4$ m

Speed of shaft, $N = 190$ r.p.m

Sleeve length, $L = 90\text{ mm} = 90 \times 10^{-3}$ m

Thickness of oil film, $t = 1.5\text{ mm} = 1.5 \times 10^{-3}$ m

Tangential velocity of shaft, $u = \frac{\pi DN}{60} = \frac{\pi \times 0.4 \times 190}{60} = 3.98$ m/s

Using the relation $\tau = \mu \frac{du}{dy}$

where du = Change of velocity $= u - 0 = u = 3.98$ m/s

dy = Change of distance $= t = 1.5 \times 10^{-3}$ m

$$\tau = \frac{6}{10} \times \frac{3.98}{1.5 \times 10^{-3}} = 1592\ \text{N/m}^2$$

This is shear stress on shaft

∴ Shear force on the shaft, F = Shear stress × Area

$= 1592 \times \pi D \times L = 1592 \times \pi \times .4 \times 90 \times 10^{-3} = 180.05$ N

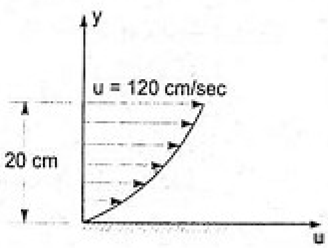
Torque on the shaft, $T = \text{Force} \times \frac{D}{2} = 180.05 \times \frac{0.4}{2} = 36.01$ Nm

∴ *Power lost $= \frac{2\pi NT}{60} = \frac{2\pi \times 190 \times 36.01}{60} =$ **716.48 W. Ans.**

8.

If the velocity profile of a fluid over a plate is a parabolic with the vertex 20 cm from the plate, where the velocity is 120 cm/sec. Calculate the velocity gradients and shear stresses at a distance of 0, 10 and 20 cm from the plate, if the viscosity of the fluid is 8.5 poise.

Solution. Given :



Distance of vertex from plate = 20 cm

Velocity at vertex, $u = 120$ cm/sec

Viscosity, $\mu = 8.5\text{ poise} = \frac{8.5}{10}\frac{Ns}{m^2} = 0.85.$

The velocity profile is given parabolic and equation of velocity profile is

$$u = ay^2 + by + c \quad \text{...}(i)$$

where a, b and c are constants. Their values are determined from boundary conditions as :

(a) at $y = 0$, $u = 0$

(b) at $y = 20$ cm, $u = 120$ cm/sec

(c) at $y = 20$ cm, $\frac{du}{dy} = 0$.

Substituting boundary condition (a) in equation (i), we get

$$c = 0.$$

Boundary condition (b) on substitution in (i) gives

$$120 = a(20)^2 + b(20) = 400a + 20b \quad \text{...}(ii)$$

Boundary condition (c) on substitution in equation (i) gives

$$\frac{du}{dy} = 2ay + b \quad \text{...}(iii)$$

or $$0 = 2 \times a \times 20 + b = 40a + b$$

Solving equations (ii) and (iii) for a and b

From equation (iii), $b = -40a$

Substituting this value in equation (ii), we get

$$120 = 400a + 20 \times (-40a) = 400a - 800a = -400a$$

$$\therefore \quad a = \frac{120}{-400} = \frac{3}{10} = 0.3$$

$$\therefore \quad b = -40 \times (-0.3) = 12.0$$

Substituting the values of a, b and c in equation (i),

$$u = -0.3y^2 + 12y.$$

Velocity Gradient

$$\frac{du}{dy} = -0.3 \times 2y + 12 = -0.6y + 12$$

at $y = 0$, Velocity gradient, $\left(\frac{du}{dy}\right)_{y=0} = -0.6 \times 0 + 12 =$ **12/s. Ans.**

at $y = 10$ cm, $\left(\frac{du}{dy}\right)_{y=10} = -0.6 \times 10 + 12 = -6 + 12 = 6$/s. **Ans.**

at $y = 20$ cm, $\left(\frac{du}{dy}\right)_{y=20} = -0.6 \times 20 + 12 = -12 + 12 =$ **0. Ans.**

Shear Stresses

Shear stress is given by, $\tau = \mu \frac{du}{dy}$

(i) Shear stress at $y = 0$, $\tau = \mu \left(\frac{du}{dy}\right)_{y=0} = 0.85 \times 12.0 = 10.2$ N/m².

(ii) Shear stress at $y = 10$, $\tau = \mu \left(\frac{du}{dy}\right)_{y=10} = 0.85 \times 6.0 = 5.1$ N/m².

(iii) Shear stress at $y = 20$, $\tau = \mu \left(\frac{du}{dy}\right)_{y=20} = 0.85 \times 0 = 0$. Ans.

9.

A 15 cm diameter vertical cylinder rotates concentrically inside another cylinder of diameter 15.10 cm. Both cylinders are 25 cm high. The space between the cylinders is filled with a liquid whose viscosity is unknown. If a torque of 12.0 Nm is required to rotate the inner cylinder at 100 r.p.m., determine the viscosity of the fluid. (A.M.I.E., Winter 1979)

Solution. Given :

Diameter of cylinder = 15 cm = 0.15 m

Dia. of outer cylinder = 15.10 cm = 0.151 m

Length of cylinders, L = 25 cm = 0.25 m

Torque, T = 12.0 Nm

Speed, $N = 100$ r.p.m.

Let the viscosity $= \mu$

Tangential velocity of cylinder, $u = \frac{\pi DN}{60} = \frac{\pi \times 0.15 \times 100}{60} = 0.7854$ m/s

Surface area of cylinder, $A = \pi D \times L = \pi \times 0.15 \times 0.25 = .1178$ m^2

Now using relation $\tau = \mu \frac{du}{dy}$

where $du = u - 0 = u = .7854$ m/s

$$dy = \frac{0.151 - 0.150}{2} \text{ m} = .0005 \text{ m}$$

$$\tau = \frac{\mu \times .7854}{.0005}$$

$\therefore$ Shear force, $F = \text{Shear stress} \times \text{Area} = \frac{\mu \times .7854}{.0005} \times .1178$

Torque, $T = F \times \frac{D}{2}$

$$12.0 = \frac{\mu \times .7854}{.0005} \times .1178 \times \frac{.15}{2}$$

$$\therefore \mu = \frac{12.0 \times .0005 \times 2}{.7854 \times .1178 \times .15} = 0.864 \text{ N s/m}^2$$

$= 0.864 \times 10 = 8.64$ **poise. Ans.**

10.

A vertical gap 2.2 cm wide of infinite extent contains a fluid of viscosity 2.0 N s/m^2 and specific gravity 0.9. A metallic plate 1.2 m × 1.2 m × 0.2 cm is to be lifted up with a constant velocity of 0.15 m/sec, through the gap. If the plate is in the middle of the gap, find the force required. The weight of the plate is 40 N.

Solution. Given :

Width of gap $= 2.2$ cm, viscosity, $\mu = 2.0$ N s/m^2

Sq. gr. of fluid $= 0.9$

∴ Weight density of fluid

$= 0.9 \times 1000 = 900\ \text{kgf/m}^3 = 900 \times 9.81\ \text{N/m}^3$

($\because$ 1 kgf = 9.81 N)

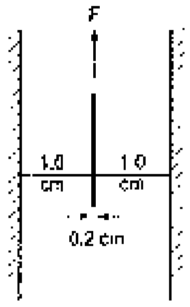


Fig. 1.8

Volume of plate $= 1.2\ \text{m} \times 1.2\ \text{m} \times 0.2\ \text{cm}$

$= 1.2 \times 1.2 \times .002\ \text{m}^3 = .00288\ \text{m}^3$

Thickness of plate = 0.2 cm

Velocity of plate = 0.15 m/sec

Weight of plate = 40 N.

When plate is in the middle of the gap, the distance of the plate of plate from vertical surface, of the gap

$$= \left(\frac{\text{Width of gap} - \text{Thickness of plate}}{2}\right)$$

$$= \frac{(2.2 - 0.2)}{2} = 1\ \text{cm} = .01\ \text{m}.$$

Now the shear force on the left side of the metallic plate,

$$F_1 = \text{Shear stress} \times \text{Area}$$

$$= \mu \left(\frac{du}{dy}\right)_1 \times \text{Area} = 2.0 \times \left(\frac{0.15}{.01}\right) \times 1.2 \times 1.2\ \text{N}$$

($\because$ Area $= 1.2 \times 1.2\ \text{m}^2$)

$$= 43.2\ \text{N}.$$

Similarly, the shear force on the right side of the metallic plate,

$$F_2 = \text{Shear stress} \times \text{Area} = 2.0 \times \left(\frac{0.15}{.01}\right) \times 1.2 \times 1.2 = 43.2\ \text{N}$$

∴ Total shear force $= F_1 + F_2 = 43.2 + 43.2 = 86.4$ N.

In this case the weight of plate (which is acting vertically downward) and upward thrust is also to be taken into account.

The upward thrust = Weight of fluid displaced

= (Weight density of fluid) × Volume of fluid displaced

$= 9.81 \times 900 \times .00288$ N

($\because$ Volume of fluid displaced = Volume of plate = .00288)

= 25.43 N.

The net force acting in the downward direction due to weight of the plate and upward thrust

= Weight of plate − Upward thrust = 40 − 25.43 = 14.57 N

∴ Total force required to lift the plate up

= Total shear force + 14.57 = 86.4 + 14.57 = **100.97 N. Ans.**

11.

A square plate of size 1 m × 1 m and weighing 350 N slides down an inclined plane with a uniform velocity of 1.5 m/s. The inclined plane is laid on a slope of 5 vertical to 12 horizontal and has an oil film of 1 mm thickness. Calculate the dynamic viscosity of oil. *[J.N.T.U., Hyderabad, S 2002]*

[**Hint.** $A = 1 \times 1 = 1\ \text{m}^2$, $W = 350$ N, $u = 1.5$ m/s, $\tan\theta = \frac{5}{12} = \frac{BC}{AB}$

Component of weight along the plane $= W \times \sin\theta$

where $\sin\theta = \frac{BC}{AC} = \frac{5}{13}$ $\left(\because AC = \sqrt{AB^2 + BC^2} = \sqrt{12^2 + 5^2} = 13\right)$

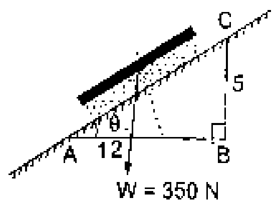


Fig. 1.15

∴ $F = W \sin\theta = 350 \times \frac{5}{13} = 134.615$

Now $\tau = \mu \frac{du}{dy}$, where $du = u - 0 = u = 1.5$ m/s and

$dy = 1\ \text{mm} = 1 \times 10^{-3}$ m

or $\frac{F}{A} = \mu \frac{du}{dy}$, $\therefore \mu = \frac{F}{A} \times \frac{dy}{du} = \frac{134.615}{1} \times \frac{1 \times 10^{-3}}{1.5} = 0.0897\ \frac{\text{Ns}}{\text{m}^2} = 0.897$ poise Ans.]

12. *An oil of sp. gr. 0.8 is flowing through a venturimeter having inlet diameter 20 cm and throat diameter 10 cm. The oil-mercury differential manometer shows a reading of 25 cm. Calculate the discharge of oil through the horizontal venturimeter. Take $C_d = 0.98$.*

Solution. Given :

Sp. gr. of oil, $S_o = 0.8$

Sp. gr. of mercury, $S_h = 13.6$

Reading of differential manometer, $x = 25$ cm

∴ Difference of pressure head, $h = x\left[\frac{S_h}{S_o} - 1\right]$

$$= 25\left[\frac{13.6}{0.8} - 1\right] \text{ cm of oil} = 25\,[17 - 1] = 400 \text{ cm of oil.}$$

Dia. at inlet, $d_1 = 20$ cm

∴ $a_1 = \frac{\pi}{4} d_1^2 = \frac{\pi}{4} \times 20^2 = 314.16 \text{ cm}^2$

$d_2 = 10$ cm

∴ $a_2 = \frac{\pi}{4} \times 10^2 = 78.54 \text{ cm}^2$

$C_d = 0.98$

∴ The discharge Q is given by equation (6.8)

or
$$Q = C_d \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh}$$

$$= 0.98 \times \frac{314.16 \times 78.54}{\sqrt{(314.16)^2 - (78.54)^2}} \times \sqrt{2 \times 981 \times 400}$$

$$= \frac{21421375.68}{\sqrt{98696 - 6168}} = \frac{21421375.68}{304} \text{ cm}^3/\text{s}$$

$= 70465 \text{ cm}^3/\text{s} = 70.465$ **litres/s. Ans.**

UNIT II FLOW THROUG CIRCULAR CONDUITS 12

Laminar flow though circular conduits and circular annuli. Boundary layer concepts. Boundary layer thickness. Hydraulic and energy gradient. Darcy – Weisbach equaition. Friction factor and Moody diagram. Commercial pipes. Minor losses. Flow though pipes in series and in parallel.

PART – A

1. Mention the general characteristics of laminar flow.

- There is a shear stress between fluid layers
- 'No slip' at the boundary
- The flow is rotational
- There is a continuous dissipation of energy due to viscous shear

2. What is Hagen poiseuille's formula?

P1-P2 / pg = h f = 32 μUL / _gD2

The expression is known as Hagen poiseuille formula.

Where P1-P2 / _g = Loss of pressure head

U = Average velocity

μ = Coefficient of viscosity

D = Diameter of pipe

L = Length of pipe

3. What are the factors influencing the frictional loss in pipe flow?

Frictional resistance for the turbulent flow is

i. Proportional to vn where v varies from 1.5 to 2.0.

ii. Proportional to the density of fluid.

iii. Proportional to the area of surface in contact.

iv. Independent of pressure.

v. Depend on the nature of the surface in contact.

4. What is the expression for head loss due to friction in Darcy formula?

$hf = 4fLV^2 / 2gD$

Where

f = Coefficient of friction in pipe

L = Length of the pipe

D = Diameter of pipe

V = velocity of the fluid

5. What do you understand by the terms a) major energy losses, b) minor energy losses

Major energy losses: -

This loss due to friction and it is calculated by Darcy weis bach formula and chezy's formula.

Minor energy losses:-

This is due to

i. Sudden expansion in pipe.

ii. Sudden contraction in pipe.

iii. Bend in pipe.

iv. Due to obstruction in pipe .

6. Give an expression for loss of head due to sudden enlargement of the pipe:

he = (V1-V2)2 /2g

Where

he = Loss of head due to sudden enlargement of pipe .

V1 = Velocity of flow at section 1-1

V2 = Velocity of flow at section 2-2

7. Give an expression for loss of head due to sudden contraction:

hc =0.5 V2/2g

here,

c = Loss of head due to sudden contraction.

V = Velocity at outlet of pipe.

8. Give an expression for loss of head at the entrance of the pipe:

hi =0.5V2/2g

Where,

hi = Loss of head at entrance of pipe.

V = Velocity of liquid at inlet and outlet of the pipe.

9. Define the terms a) Hydraulic gradient line [HGL], b) Total Energy line [TEL]

a) Hydraulic gradient line:

Hydraulic gradient line is defined as the line which gives the sum of pressure head and datum head of a flowing fluid in apipe with respect the reference line.

b) Total energy line:

Total energy line 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.

10. What is sypon ? Where it is used:

Sypon is along bend pipe which is used to transfer liquid from a reservoir at a higher elevation to another reservoir at a lower level.

Uses of sypon : -
1. To carry water from one reservoir to another reservoir separated by a hill ridge.
2. To empty a channel not provided with any outlet sluice.

11. What are the basic educations to solve the problems in flow through branched pipes?

i. Continuity equation.
ii. Bernoulli's formula.
iii. Darcy weisbach equation.

12. What is Dupuit's equation?

L1/d15+L2/d25 +L3/d35 = L / d5

Where

L1, d1 = Length and diameter of the pipe 1
L2, d2 = Length and diameter of the pipe 2
L3, d3 = Length and diameter of the pipe 3

PART - B

1.

Problem 2.6 *An open tank contains water upto a depth of 2 m and above it an oil of sp. gr. 0.9 for a depth of 1 m. Find the pressure intensity (i) at the interface of the two liquids, and (ii) at the bottom of the tank.*

Solution. Given :

Height of water, $Z_1 = 2$ m
Height of oil, $Z_2 = 1$ m
Sp. gr. of oil, $S_0 = 0.9$
Density of water, $\rho_1 = 1000$ kg/m^3
Density of oil, ρ_2 = Sp. gr. of oil × Density of water $= 0.9 \times 1000 = 900$ kg/m^3

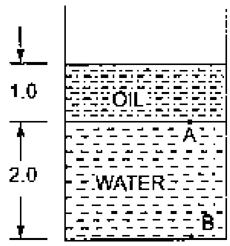


Fig. 2.4

Pressure intensity at any point is given by

$$p = \rho \times g \times Z.$$

(*i*) At interface, *i.e.*, at *A*

$$p = \rho_2 \times g \times 1.0 = 900 \times 9.81 \times 1.0 = 8829 \frac{N}{m^2} = \frac{8829}{10^4} = \mathbf{0.8829\ N/cm^2.\ Ans.}$$

(*ii*) At the bottom, *i.e.*, at *B*

$$p = \rho_2 \times gZ_2 + \rho_1 \times g \times Z_1 = 900 \times 9.81 \times 1.0 + 1000 \times 9.81 \times 2.0$$
$$= 8829 + 19620 = 28449\ N/m^2 = \frac{28449}{10^4}\ N/cm^2 = \mathbf{2.8449\ N/cm^2.\ Ans.}$$

2.

Water is flowing through a pipe having diameter 300 mm and 200 mm at the bottom and upper end respectively. The intensity of pressure at the bottom end is 24.525 N/cm² and the pressure at the upper end is 9.81 N/cm². Determine the difference in datum head if the rate of flow through pipe is 40 lit/s.

Solution. Given :

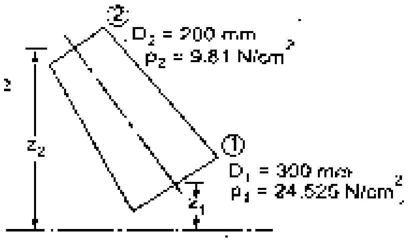


Fig. 6.4

Section 1, $D_1 = 300 \text{ mm} = 0.3 \text{ m}$

$p_1 = 24.525 \text{ N/cm}^2 = 24.525 \times 10^4 \text{ N/m}^2$

Section 2, $D_2 = 200 \text{ mm} = 0.2 \text{ m}$

$p_2 = 9.81 \text{ N/cm}^2 = 9.81 \times 10^4 \text{ N/m}^2$

Rate of flow $= 40$ lit/s

or $$Q = \frac{40}{1000} = 0.04 \text{ m}^3/\text{s}$$

Now $A_1V_1 = A_2V_2 = $ rate of flow $= 0.04$

$\therefore$ $$V_1 = \frac{.04}{A_1} = \frac{.04}{\frac{\pi}{4}D_1^2} = \frac{0.04}{\frac{\pi}{4}(0.3)^2} = 0.5658 \text{ m/s}$$

$$= 0.566 \text{ m/s}$$

$$V_2 = \frac{.04}{A_2} = \frac{.04}{\frac{\pi}{4}(D_2)^2} = \frac{0.04}{\frac{\pi}{4}(0.2)^2} = 1.274 \text{ m/s}$$

Applying Bernoulli's equation at (1) and (2), we get

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + z_2$$

or $$\frac{24.525 \times 10^4}{1000 \times 9.81} + \frac{.566 \times .566}{2 \times 9.81} + z_1 = \frac{9.81 \times 10^4}{1000 \times 9.81} + \frac{(1.274)^2}{2 \times 9.81} + z_2$$

or $$25 + .32 + z_1 = 10 + 1.623 + z_2$$

or $$25.32 + z_1 = 11.623 + z_2$$

$\therefore$ $$z_2 - z_1 = 25.32 - 11.623 = 13.697 = 13.70 \text{ m}$$

$\therefore$ Difference in datum head $= z_2 - z_1 = $ **13.70 m. Ans.**

3.

Three pipes of 400 mm, 350 mm and 300 mm diameter ***are connected in series*** *between two reservoirs with a difference in level of 12 m. The friction factors are 0.024, 0.021 and 0.019 respectively. The lengths are 200 m, 300 m and 250 m respectively. Determine the flow rate neglecting minor losses.*

This problem can be solved using

$$12 = \frac{8 f_1 L_1 Q^2}{\pi^2 g D_1^5} + \frac{8 f_2 L_2 Q^2}{\pi^2 g D_2^5} + \frac{8 f_3 L_3 Q^2}{\pi^2 g D_3^5}$$

Solving $Q^2 = 0.04$ $\therefore$ **Q = 0.2 m³/s**

Using equivalent length concept and choosing 0.4 m pipe as the base.

Refer 7.17.1 $L_{2e} = 300\ (0.021/0.024) \times (0.4/0.35)^5 = 511.79$ m

$L_{3e} = 250(0.019/0.024) \times (0.4/0.3)^5 = 834.02$ m

Total length $= 200 + 511.79 + 834.02 = 1545.81$ m

$12 = (8 \times 0.024 \times 1545.81 \times Q^2)/(9.81 \times \pi^2 \times 0.4^5)$

$Q^2 = 0.04$; **Q = 0.2 m³/s.**

4.

Two reservoirs are connected by three ***pipes in parallel*** *with the following details of pipes:*

Pipe No.	*Length, m*	*Diameter, m*	*Friction factor*
1	600	0.25	0.021
2	800	0.30	0.019
3	400	0.35	0.024

The total flow is 24,000 l/min. Determine the flow in each pipe and also the level difference between the reservoirs.

Let the flows be designated as Q_1, Q_2, Q_3

Then $Q1 + Q2 + Q3 = 24000/(60 \times 1000) = 0.4\ m^3/s$

Considering pipe 1 as base

$$\frac{Q_2}{Q_1} = \left[\frac{f_1}{f_2}\frac{L_1}{L_2}\left(\frac{D_2}{D_1}\right)^5\right]^{-0.5} = \left[\frac{0.021}{0.019}\times\frac{600}{800}\times\left(\frac{0.3}{0.25}\right)^5\right]^{0.5} = 1.4362$$

$$Q_2 = 1.4362\ Q_1$$

$$\frac{Q_3}{Q_1} = \left[\frac{f_1}{f_3}\frac{L_1}{L_3}\left(\frac{D_3}{D_1}\right)^5\right]^{-0.5} = \left[\frac{0.021}{0.024}\times\frac{600}{400}\times\left(\frac{0.35}{0.25}\right)^5\right]^{0.5} = 2.6569$$

$$Q_3 = 2.6569\ Q_1$$

Total flow $= 0.4 = Q_1 + 1.4362\ Q_1 + 2.6569\ Q_1 = 5.0931\ Q_1$

$\mathbf{Q_1 = 0.07854\ m^3/s}$

$\mathbf{Q_2 = 1.4362\ Q_1 = 0.11280\ m^3/s}$

$\mathbf{Q_3 = 2.6569\ Q_1 = 0.20867\ m^3/s}$

Total $= 0.4001\ m^3/s$

5.

*Oil of specific gravity 0.92 flows at a rate of 4.5 litres/s through a pipe of 5 cm dia, the pressure drop over 100 m horizontal length being 15 N/cm². **Determine the dynamic viscosity of the oil.***

Hagen-Poiseuille eqn. $\Delta p = 128\ \mu LQ/\pi D^4$

$\mu = \Delta p\ .\ \pi.D^4/128LQ$

$= 15 \times 10^4 \times \pi \times 0.05^4/128 \times 100 \times 0.0045 =$ **0.05113 Ns/m²** (Pa.s)

(**Note:** $N/cm^2 \to 10^4\ N/m^2$, litre $= 0.001\ m^3$)

Reynolds number $= uD\ \rho/\mu$, $u = Q \times 4/\pi D^2$

$\therefore$ $Re = (4Q/\pi D^2) \times (D\ \rho/\mu) = (0.0045 \times 920 \times 4)/(\pi \times 0.05 \times 0.05113)$

$= 2061.6$

$\therefore$ Flow is laminar but just on the verge of turning turbulent

6.

Example 6.3 *A tap discharges water evenly in a jet at a velocity of 2.6 m/s at the tap outlet, the diameter of the jet at this point being 15 mm. The jet flows down vertically in a smooth stream.* ***Determine the velocity and the diameter*** *of the jet at 0.6 m below the tap outlet.*

The pressure around the jet is atmospheric throughout. Taking the tap outlet as point 1 and also taking it as the datum using Bernoulli equation.

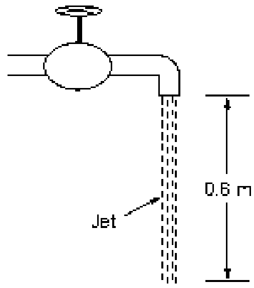


Figure Ex. 6.3 Problem model

$$\frac{P_1}{\gamma} - Z_1 - \frac{V_1^2}{2g} = \frac{P_2}{\gamma} - Z_2 - \frac{V_2^2}{2g},$$

$$P_1 = P_2,\ Z_1 = 0,$$

$$Z_2 = -\,0.6 \text{ m},\ V_1 = 2.6 \text{ m/s}$$

$$\therefore \quad \frac{2.6^2}{2 \times 9.81} = -\,0.6 - \frac{V_2^2}{2 \times 9.81}$$

$$\therefore \quad \mathbf{V_2 = 4.3\ m/s.}$$

using continuity equation (one dimensional flow) and noting that density is constant.

$$A_1V_1 = A_2V_2$$

$$\frac{\pi \times 015^2}{4} \times 2.6 = \frac{\pi \times D^2}{4} \times 4.3, \quad \therefore \quad \mathbf{D = 0.01166\ m\ or\ 11.66\ mm}$$

As the potential energy decreases, kinetic energy increases. As the velocity is higher the flow area is smaller.

Entrainment of air may increase the diameter somewhat.

7.

Lubricating Oil at a velocity of 1 m/s (average) flows through a pipe of 100 mm ID. ***Determine whether the flow is laminar or turbulent. Also determine the friction factor and*** *the pressure drop over 10 m length. What should be the velocity for the flow to turn turbulent? Density = 930 kg/m³. Dynamic viscosity μ = 0.1 Ns/m² (as N/m² is call Pascal, μ can be also expressed as Pa.s).*

$$\mathbf{Re} = \frac{uD\rho}{\mu} = \frac{1 \times 0.1 \times 930}{1 \times 0.1} = \mathbf{930}, \text{ so the flow is laminar}$$

Friction factor, f = 64/930 = **0.0688**

$$h_f = fL\,u_m^2/2gD = (64/930) \times 10 \times 1^2/(2 \times 9.81 \times 0.1)$$

$$= \mathbf{0.351} \text{ m head of oil.}$$

or $\quad \Delta P = 0.351 \times 0.93 \times 9810 = \mathbf{3200}\ \text{N/m}^2$

At transition Re = 2000 (can be taken as 2300 also)

Using (7.9.1) (Hagen-Poiseuille eqn.)

$$\mathbf{\Delta P} = \frac{32 \times \mu \times u_m \times L}{D^2} = \frac{32 \times 0.1 \times 1 \times 10}{0.1^2}$$

$$= \mathbf{3200}\ \text{N/m}^2,\ \text{(same as by the other equation)}$$

UNIT III DIMENSIONAL ANALYSIS 9

Dimension and units: Buckingham's Π theorem. Discussion on dimensionless parameters. Models and similitude. Applications of dimensionless parameters.

PART-A

1. **What are the types of fluid flow?**
   Steady & unsteady fluid flow
   Uniform & Non-uniform flow
   One dimensional, two-dimensional & three-dimensional flows
   Rotational & Irrotational flow

2. **Name the different forces present in fluid flow**
   Inertia force
   Viscous force
   Surface tension force
   Gravity force

3. **When in a fluid considered steady?**
   In steady flow, various characteristics of following fluids such as velocity, pressure, density, temperature etc at a point do not change with time. So it is called steady flow.

4. **Give the Euler's equation of motion?**
   (dp/p)+gdz+vdv=0

5. **What are the assumptions made in deriving Bernouillie's equation?**
   1.The fluid is ideal
   2.The flow is steady.
   3.The flow is incompressible.
   4.The flow is irrotational.

6. **What is bernouillie's equation for real fluid?**
   (p1/pg)+(v12/2g)+z1=(p2/pg)+(v22/2g)+z2+hl
   where hl is the loss of energy (p/pg)-Pressure energy. (v2/2g)=Kinetic energy.
   z-Datum energy.

7. **State the application of Bernouillie's equation ?**
   It has the application on the following measuring devices.
   1.Orifice meter.
   2.Venturimeter.
   3.Pitot tube.

8. **State the methods of dimensional analysis.**
   1. Rayleigh's method
   2. Buckingham's Π theorem

9. **State Buckingham's Π theorem**
   It states that if there are 'n' variables in a dimensionally homogeneous equation and if these variables contain 'm' fundamental dimensions (M,L,T), then they are grouped into (n-m), dimensionless independent Π-terms.

10. **State the limitations of dimensional analysis.**
    1. Dimensional analysis does not give any due regarding the selection of variables.
    2.The complete information is not provided by dimensional analysis.
    3.The values of coefficient and the nature of function can be obtained only by experiments or from mathematical analysis.

11. Define Similitude

Similitude is defined as the complete similarity between the model and prototype.

12. State Froude's model law

Only Gravitational force is more predominant force. The law states 'The Froude's number is same for both model and prototype'.

PART-B

1.

The pressure drop ΔP per unit length in flow through a smooth circular pipe is found to depend on (i) the flow velocity, u (ii) diameter of the pipe, D (iii) density of the fluid ρ, and (iv) the dynamic viscosity μ.

(a) Using π theorem method, evaluate the dimensionless parameters for the flow.

(b) Using Rayleigh method (power index) evaluate the dimensionless parameters.

Choosing the set mass, time and length as primary dimensions, the dimensions of the parameters are tabulated.

S.No.	Parameter	Unit used	Dimension
1	Pressure drop/m, ΔP	(N/m^2/m (N = kgm/s^2)	M/L^2T^2
2	Diameter, D	m	L
3	Velocity, u	m/s	L/T
4	Density, ρ	kg/m^3	M/L^3
5	Dynamic viscosity, μ	kg/ms	M/LT

There are five parameters and three dimensions. Hence two π terms can be obtained. As ΔP is the dependent variable D, ρ and μ are chosen as repeating variables.

Let $\pi_1 = \Delta P\, D^a \rho^b u^c$, Substituting dimensions,

$$M^0L^0T^0 = \frac{M}{L^2T^2} L^a \frac{M^b}{L^{3b}} \frac{L^c}{T^c}$$

Using the principle of dimensional homogeneity, and in turn comparing indices of mass, length and time.

$$1 + b = 0 \quad \therefore \quad b = -1, \quad -2 + a - 3b + c = 0 \quad \therefore \quad a + c = -1$$

$$-2 - c = 0 \quad \therefore \quad c = -2, \quad \text{Hence } a = 1.$$

Substituting the value of indices we obtain

∴ $\pi_1 = \Delta PD/\rho u^2$;

This represents the ratio of pressure force and inertia force.

Check the dimension :

$$\frac{M}{L^2T^2} L \frac{L^3}{M} \frac{T^2}{L^2} = M^0L^0T^0$$

Let $\pi_2 = \mu\, D^a \rho^b u^c$, substituting dimensions and considering the indices of M, L and T,

$$M^0L^0T^0 = \frac{M}{LT} L^a \frac{M^b}{L^{3b}} \frac{L^c}{T^c}$$

$$1 + b = 0 \quad \text{or} \quad b = -1, \quad -1 + a - 3b + c = 0, \quad a + c = -2, -1 - c = 0, \quad c = -1 \quad a = -1$$

Substituting the value of indices,

∴ $\pi_2 = \mu/u\rho D$

check, $$\frac{M}{LT} \frac{T}{L} \frac{L^3}{M} \frac{1}{L} = M^0L^0T^0$$

This term may be recognised as inverse of Reynolds number. So π_2 can be modified as $\pi_2 = \rho uD/\mu$ also $\pi_2 = (uD/\nu)$. The significance of this π term is that it is the ratio of inertia force to viscous force. In case D, u and μ had been choosen as the repeating, variables, $\pi_1 = \Delta PD^2/u\,\mu$ and $\pi_2 = \rho Du/\mu$. The parameter π_1/π_2 will give the dimensionless term. $\Delta P\, D/\rho u^2$. In this case π_1 represents the ratio pressure force/viscous force. This flow phenomenon is influenced by the three forces namely pressure force, viscous force and inertia force.

2.

The pressure drop ΔP in flow through pipes per unit length is found to depend on the average velocity μ, diameter D, density of the fluid ρ, and viscosity μ. Using FLT set of dimensions evaluate the dimensionless parameters correlating this phenomenon.

The dimensions of the influencing parameters are tabulated below choosing FLT set.

S.No.	Variables	Unit	Dimensions
1	Pressure drop per unit length, $\Delta P/l$	$(N/m^2)/m$	F/L^3
2	Diameter, D	m	L
3	Velocity, u	m/s	L/T
4	Density, ρ	kg/m^3	FT^2/L^4
5	Viscosity, μ	Ns/m^2	FT/L^2

As there are five variables and three dimensions, two π terms can be obtained.

Using D, u and ρ as repeating parameters,

Let $\pi_1 = \Delta P d^a u^b \rho^c$ or $F^0L^0T^0 = \frac{F}{L^3} L^a \frac{L^b}{T^b} \frac{F^c\,T^{2c}}{L^{4c}}$

Comparing the indices of M, L and T solving for a, b and c,

$$1 + c = 0, -3 + a + b - 4c = 0, -b + 2c = 0$$

∴ $c = -1, b = -2, a = 1$

Substituting the value of indices

∴ $\boldsymbol{\pi_1 = D\Delta P/\rho u^2}$

Let, $\pi_2 = \mu D^a u^b \rho^c$, or $F^0 L^0 T^0 = \frac{F}{L^2} L^a \frac{L^b}{T^b} \frac{F^c\,T^{2c}}{L^{4c}}$

Comparing the value of indices for M, L and T

∴ $1 + c = 0, -2 + a + b - 4c = 0, 1 - b + 2c = 0$

Solving, $a = -1$, $b = -1$, $c = -1$ substituting the values of a, b, c, d

∴ $\boldsymbol{\pi_2 = \mu/\rho uD}$ or $\boldsymbol{\rho uD/\mu}$

∴ $$\frac{D\Delta P}{\rho u^2} = f\left[\frac{\rho uD}{\mu}\right]$$

3.

In film lubricated journal bearings, the frictional torque is found to depend on the speed of rotation, viscosity of the oil, the load on the projected area and the diameter. Evaluate dimensionless parameters for application to such bearings in general.

The variables with dimensions are listed below, adopting *MLT* set.

S.No.	Variable	Unit	Dimensions
1	Frictional Torque, τ	Nm	ML^2/T^2
2	Speed, N	1/s	1/*L*
3	Load per unit area, P	N/m²	M/LT^2
4	Diameter, D	m	L
5	Viscosity, μ	kg/ms	M/LT

There are five parameters and three dimensions. Hence two π parameters can be found. Considering N, D and μ as repeating variables,

Let $\pi_1 = \tau N^a D^b \mu^c$ or $M^0L^0T^0 = \dfrac{ML^2}{T^2}\dfrac{1}{T^a}L^b\dfrac{M^c}{L^cT^c}$

∴ $1 + c = 0,\ 2 + b - c = 0,\ -2 - a - c = 0$ ∴ $c = -1,\ a = -1,\ b = -3$

∴ $\boldsymbol{\pi_1 = \tau/N\mu D^3}$ Also $\pi = \tau/\mu\mu D$ (τ–Torque)

Let $\pi_2 = PN^aD^b\mu^c$ or $M^0L^0T^0 = \dfrac{M}{LT^2}\dfrac{1}{T^a}L^b\dfrac{M^c}{L^cT^c}$

∴ $1 + c = 0,\ -1 + b - c = 0,\ -2, -a - c = 0$

∴ $c = -1,\ a = -1,\ b = 0$

∴ $\boldsymbol{\pi_2 = P/N\mu}$, ∴ $\dfrac{\tau}{N\mu D^3} = f\left[\dfrac{P}{N\mu}\right]$

Note : $P/N\mu$ is also Reynolds number, try to verify.

4.

The volume flow rate, Q over a V-notch depends on fluid properties namely density ρ, kinematic viscosity υ, and surface tension σ. It is also influenced by the angle of the notch, head of fluid over the vertex, and acceleration due to gravity. Determine the dimensionless parameters which can correlate the variables.

As θ, the notch angle is a dimensionless parameter, the other parameters are listed below with dimensions, adopting *MLT* set.

S.No.	Variable	Unit	Dimension
1	Density, ρ	kg/m³	M/L^3
2	kinematic viscosity, υ	m²/s	L^2/T
3	Surface tension, σ	N/m	M/T^2
4	Head of fluid, h	m	L
5	Gravitational acceleration, g	m/s²	L/T^2
6	Flow rate, Q	m³/s	L^3/T

There are six parameters and three dimensions. So three π terms can be identified. Considering ρ, *g* and *h* as repeating variables.

Let $\pi_1 = Q\,\rho^a g^b h^c$ or $M^0L^0T^0 = \dfrac{L^3}{T}\dfrac{M^a}{L^{3a}}\dfrac{L^b}{T^{2b}}L^c$

∴ $a = 0,\ 3 - 3a + b + c = 0,\ -1 - 2b = 0$

∴ $b = -0.5,\ c = 2.5$ ∴ $\boldsymbol{\pi_1 = Q/g^{1/2}h^{5/2}}$

Let $\pi_2 = \upsilon\rho^a g^b h^c$ or $M^0L^0T^0 = \dfrac{L^2}{T}\dfrac{M^a}{L^{3a}}\dfrac{L^b}{T^{2b}}L^c$

∴ $a = 0,\ 2 - 3a + b + c = 0,\ -1 - 2b = 0$

∴ $b = -0.5,\ c = (-1.5)$ ∴ $\boldsymbol{\pi_2 = v/g^{1/2}h^{3/2}}$

Let $\pi_3 = \sigma\,\rho^a g^b h^c$ or $M^0L^0T^0 = \dfrac{M}{T^2}\dfrac{M^a}{L^{3a}}\dfrac{L^b}{T^{2b}}L^c$

∴ $1 + a = 0,\ -3a + b + c = 0,\ -2 - 2b = 0$ ∴ $a = -1,\ b = -1,\ c = -2$

∴ $\boldsymbol{\pi_3 = \sigma/\rho g h^2}$ ∴ $Q = g^{1/2}h^{5/2} f\left[\dfrac{\upsilon}{g^{1/2}h^{3/2}}, \dfrac{\sigma}{\rho g h^2}, \theta\right]$

Note : In case surface tension is not considered, π_3 will not exist. π_2 can be identified as Reynolds number.

5.

The capillary rise h is found to be influenced by the tube diameter D, density ρ, gravitational acceleration g and surface tension σ. Determine the dimensionless parameters for the correlation of experimental results.

The variables are listed below adopting *MLT* set of dimensions.

S.No.	Variable	Unit	Dimension
1	Diameter, D	m	L
2	Density, ρ	kg/m³	M/L^3
3	Gravitational acceleration, g	m/s²	L/T^2
4	Surface tension, σ	N/m	M/T^2
5	Capillary rise, h	m	L

There are five parameters and three dimensions and so two π parameters can be identified. Considering D, ρ and g as repeating variables,

Let $\pi_1 = h\,D^a\,\rho^b\,g^c$ or $M^0L^0T^0 = LL^a\,\dfrac{M^b}{L^{3b}}\,\dfrac{L^c}{T^{2c}}$

$\therefore$ $b = 0,\ 1 + a - 3b + c = 0,\ -2c = 0$

$\therefore$ $a = -1,\ b = 0,\ c = 0$ $\therefore$ $\boldsymbol{\pi_1 = h/D}$

Let $\pi_2 = \sigma\,D^a\rho^b\,g^c$ or $M^0L^0T^0 = \dfrac{M}{T^2}\,L^a\,\dfrac{M^b}{L^{3b}}\,\dfrac{L^c}{T^{2c}}$

$\therefore$ $1 + b = 0,\ a - 3b + c = 0,\ -2 - 2c = 0$ $\therefore$ $b = -1,\ c = -1$, and $a = -2$

$\therefore$ $\boldsymbol{\pi_2 = \sigma/D^2\,g\rho}$, $g\rho$ can also be considered as specific weight γ

$$\frac{h}{D} = f\left[\frac{\sigma}{D^2\gamma}\right],$$

Note : π_2 can be identified as 1/Weber number.

6.

To study the pressure drop in flow of water through a pipe, a model of scale 1/10 is used. ***Determine the ratio of pressure drops*** *between model and prototype if water is used in the model. In case air is used determine the ratio of pressure drops.*

Case (i) Water flow in both model and prototype.

Reynolds number similarity is to be maintained.

$$\frac{u_m d_m \rho_m}{\mu_m}\ \frac{u_p d_p \rho_p}{\mu_p} \quad \therefore \quad \frac{u_m}{u_p} = \frac{\mu_m}{\mu_p} \times \frac{d_p}{d_m} \times \frac{\rho_p}{\rho_m}$$

As viscosity and density values are the same,

$$\frac{u_m}{u_p} = \frac{d_p}{d_m} = 10,$$

The pressure drop is obtained using pressure coefficient

$$[\Delta P/(1/2)\,\rho u^2]_m = [\Delta P/(1/2)\,\rho u^2]_p$$

$\therefore$ $\dfrac{\Delta p_m}{\Delta p_p} = \dfrac{\rho_m u_m^2}{\rho_p u_p^2}$, As $\rho_m = \rho_p$ and $u_m/u_p = 10$, $\Delta P_m/\Delta P_p = 10^2 = \mathbf{100}$.

Case (ii) If air is used in the model, then

$$\frac{u_m}{u_p} = \frac{\mu_m}{\mu_p} \times \frac{d_p}{d_m} \times \frac{\rho_p}{\rho_m},\quad \frac{\Delta p_m}{\Delta p_p} = \frac{\rho_m}{\rho_p}\left(\frac{\mu_m}{\mu_p} \times \frac{d_p}{d_m} \times \frac{\rho_p}{\rho_m}\right)^2$$

$$= 100\,\frac{\rho_p}{\rho_m}\left(\frac{\mu_m}{\mu_p}\right)^2$$

From data tables at 20°C, $\rho_{air} = 1.205$ kg/m³, $\mu_{air} = 18.14 \times 10^{-6}$ kg/ms,

$\rho_w = 1000$ kg/m³, $\mu_w = 1.006 \times 10^{-3}$ kg/ms

$$\therefore \quad \frac{\Delta P_m}{\Delta P_p} = 100 \times \frac{1000}{1.205} \times \left(\frac{18.14 \times 10^{-6}}{1.006 \times 10^{-3}}\right)^2 = \mathbf{26.98}$$

This illustrates that it may be necessary to use a different fluid in the model as compared to the prototype.

7.

To determine the pressure drop in a square pipe of 1 m side for air flow, a square pipe of 50 mm side was used with water flowing at 3.6 m/s. The pressure drop over a length of 3 m was measured as 940 mm water column. Determine the corresponding ***flow velocity*** *of air in the larger duct and also the* ***pressure drop*** *over 90 m length. Kinematic viscosity of air = 14.58 × 10^{-6} m²/s. Density = 1.23 kg/m³.* Kinematic viscosity of water = 1.18 × 10^{-6} m²/s

For pipe flow, Reynolds number analogy should be used. Also the drag coefficients will be equal.

For square section hydraulic mean diameter = 4 A/P = $4a^2/4a$ = a (side itself)

$$Re = uD/\nu = 3.6 \times 0.05/1.18 \times 10^{-6} = 152542$$

For air $152542 = \frac{1 \times u}{14.58 \times 10^{-6}}$ ∴ **u = 2.224 m/s**

Drag coefficient $F/\rho u^2$ should be the same for both pipes.

$$\frac{F_{air}}{F_w} \frac{\rho_{air} u_{air}^2}{\rho_w u_w^2}$$

The pressure drop equals the shear force over the area. For square section, area = a^2, perimeter = $4a$

$$\therefore \quad \Delta P = \frac{4FL}{a}, \Delta P_{air} = \frac{4F_{air}L_{air}}{a_{air}}, \Delta P_w = \frac{4F_w L_w}{a_w}$$

Dividing and substituting for F_{air}/F_w

$$\frac{\Delta P_{air}}{\Delta P_w} = \frac{L_{air}}{L_w} \times \frac{a_w}{a_{air}} \times \frac{F_{air}}{F_w} = \frac{L_{air}}{L_w} \times \frac{a_w}{a_{air}} \times \frac{\rho_{air}}{\rho_w}\left(\frac{u_{air}}{u_w}\right)^2$$

$$= \frac{90 \times 0.05^2 \times 123}{1 \times 3 \times 1000}\left(\frac{2.224}{3.6}\right)^2 = 3.521 \times 10^{-5}$$

$$\mathbf{\Delta P_{air} = 940 \times 3.521 \times 10^{-5} = 0.033 \text{ mm of water column}}$$

8.

The performance of an aeroplane to fly at 2400 m height at a speed of 290 kmph is to be evaluated by a 1/8 scale model tested in a pressurised wind tunnel maintaining similarity. The conditions at the flight altitude are temperature = – 1°C, pressure = 75 kN/m².

μ = 17.1 × 10^{-6} kg/ms. The test conditions are 2150 kN/m², and 15°C.

μ = 18.1 × 10^{-6} kg/ms. The drag resistance on the model measured at 18 m/s and 27 m/s. are 4.7N and 9.6N. ***Determine the drag on the prototype.***

At the given flight conditions, Velocity of sound is

$$C = \sqrt{g_0 kRT} = \sqrt{1 \times 1.4 \times 287 \times 272} = 330 \text{ m/s} = 1190 \text{ kmph}$$

Mach number = 290/1190 = 0.24 < 0.3

Hence Reynolds number similarity only need be considered.

Density at test conditions = 2150 × 10³/(287 × 288) = 26.01 kg/m³

Density at flight conditions = 75 × 10³/(287 × 272) = 0.961 kg/m³

Equating Reynolds numbers, assuming length L,

Velocity at flight condition = 290000/3600 = 80.56 m/s

$$\frac{80.56 \times L \times 0.961}{17.1 \times 10^{-6}} = u \times \frac{L}{8} \times \frac{26.01}{18.1 \times 10^{-6}} \quad \therefore \quad \mathbf{u = 25.195 \text{ m/s}}$$

This is also low subsonic. Drag can be obtained using drag coefficient $F/\rho Au^2$

$$\frac{F_m}{\rho_m A_m u_m^2} = \frac{F_p}{\rho_p A_p u_p^2} \quad \therefore \quad \frac{F_p}{F_m} = \frac{\rho_p}{\rho_m} \times \left(\frac{u_p}{u_m}\right)^2 \times \frac{A_p}{A_m}$$

$$= \frac{26.01}{0.961} \times \left(\frac{80.56}{25.195}\right)^2 \times 8^2 = 24.165$$

By interpolation using equality of F/u^2, **drag at 25.195 m/s** model speed is obtained as **8.78 N.** ∴ **Drag on prototype =** 8.78 × 24.165 = **212 N**

9.

A water tunnel operates with a velocity of 3m/s at the test section and power required was 3.75 kW. If the tunnel is to operate with air, ***determine for similitude the flow velocity and the power required.***

$\rho_a = 1.25$ kg/m^3, $\upsilon_a = 14.8 \times 10^{-6}$ m^2/s, $\upsilon_w = 1.14 \times 10^{-6}$ m^2/s

In this case Reynolds number similarity is to be maintained. The length dimension is the same.

$$\frac{u_a}{\upsilon_a} = \frac{u_w}{\upsilon_w}$$

$$\therefore \text{ Velocity of air, } \quad u_a = \frac{u_w}{\upsilon_w}\upsilon_a = \frac{3 \times 14.8 \times 10^{-6}}{1.14 \times 10^{-6}} = \mathbf{38.95\ m/s}$$

Power can be determined from drag coefficient, by multiplying and dividing by u as $F \times u$ power

$$\frac{F \times u}{\rho A u^2 u} = \frac{P}{\rho A u^3} \qquad \text{As } A \text{ is the same,}$$

$$P_{air} = P_w \frac{\rho_{air}}{\rho_w}\frac{u_{air}^3}{u_w^3} = 3.75 \times \frac{1.28}{1000} \times \left(\frac{38.95}{3}\right)^3 = \mathbf{10.5\ kW}$$

10.

The wave resistance of a ship when travelling at 12.5 m/s is estimated by test on 1/40 scale model. The resistance measured in fresh water was 16 N. ***Determine the speed of the model and the wave resistance of the prototype*** *in sea water. The density of sea water = 1025 kg/m³.*

Froude number similarity is to be maintained.

$$\therefore \qquad u_m = u_p\sqrt{\frac{L_m}{L_p}} = 12.5\sqrt{\frac{1}{40}} = \mathbf{1.976\ m/s}$$

The wave resistance is found to vary as given below.

$$\frac{F_m}{\rho_m u_m^2 L_m^2} = \frac{F_p}{\rho_p u_p^2 L_p^2}$$

$$\therefore \qquad F_p = F_m \times \frac{\rho_p}{\rho_m}\left(\frac{u_p}{u_m}\right)^2\left(\frac{L_p}{L_m}\right)^2 = 16 \times \frac{1025}{1000}\left(\frac{12.5}{1.976}\right)^2 (40)^2$$

$$= \mathbf{1049.6 \times 10^3\ N} \quad \text{or} \quad \mathbf{1050\ kN}$$

UNIT IV ROTO DYNAMIC MACHINES 16

Homologus units. Specific speed. Elementary cascade theory. Theory of turbo machines. Euler's equation. Hydraulic efficiency. Velocity components at the entry and exit of the rotor. Velocity triangle for single stage radial flow and axial flow machines. Centrifugal pumps, turbines, performance curves for pumps and turbines.

PART-A

1. **Define hydraulic machines.**
   Hydraulic machines which convert the energy of flowing water into mechanical energy.

2. **Give example for a low head, medium head and high head turbine.**
   Low head turbine – Kaplan turbine
   Medium head turbine – Modern Francis turbine
   High head turbine – Pelton wheel

3. **What is impulse turbine? Give example.**
   In impulse turbine all the energy converted into kinetic energy. From these the turbine will develop high kinetic energy power. This turbine is called impulse turbine. Example: Pelton turbine

4. **What is reaction turbine? Give example.**
   In a reaction turbine, the runner utilizes both potential and kinetic energies. Here portion of potential energy is converted into kinetic energy before entering into the turbine.
   Example: Francis and Kaplan turbine.

5. **What is axial flow turbine?**
   In axial flow turbine water flows parallel to the axis of the turbine shaft.
   Example: Kaplan turbine

6. **What is mixed flow turbine?**
   In mixed flow water enters the blades radially and comes out axially, parallel to the turbine shaft. Example: Modern Francis turbine.

7. **What is the function of spear and nozzle?**
   The nozzle is used to convert whole hydraulic energy into kinetic energy. Thus the nozzle delivers high speed jet. To regulate the water flow through the nozzle and to obtain a good jet of water spear or nozzle is arranged.

8. **Define gross head and net or effective head.**
   Gross Head: The gross head is the difference between the water level at the reservoir and the level at the tailstock.
   Effective Head: The head available at the inlet of the turbine.

9. **Define hydraulic efficiency.**
   It is defined as the ratio of power developed by the runner to the power supplied by the water jet.

10. **Define mechanical efficiency.**
    It is defined as the ratio of power available at the turbine shaft to the power developed by the turbine runner.

11. **Define volumetric efficiency.**
    It is defied as the volume of water actually striking the buckets to the total water supplied by the jet.

12. **Define over all efficiency.**
    It is defined as the ratio of power available at the turbine shaft to the power available from the water jet.

PART-B

1. At a location for a hydroelectric plant, the head available (net) was 335 m. The power availability with an overall efficiency of 86% was 15500 kW. The unit is proposed to run at 500 rpm. Assume Cv = 0.98, φ = 0.46, Blade velocity coefficient is 0.9. If the bucket outlet angle proposed is 165° check for the validity of the assumed efficiency.

First flow rate is calculated

$$Q = \frac{15500000}{0.86 \times 1000 \times 9.81 \times 335} = 5.484 \text{ m}^3\text{/s}$$

Jet velocity is next calculated

$$V_j = 0.98\sqrt{2 \times 9.81 \times 335} = 79.45 \text{ m/s}$$

Blade velocity $u = 0.46 \times 79.45 = 36.55$ m/s

Runner diameter $D = \frac{36.55 \times 60}{\pi \times 500} = 1.4$ m

Jet diameter assuming single jet,

$$d = \left(\frac{Q \times 4}{\pi V_j}\right)^{0.5} = \left(\frac{5.484 \times 4}{\pi \times 79.45}\right)^{0.5} = 0.296 \text{ m}$$

$$\frac{D}{d} = \frac{14}{0.296} = 4.72, \text{ not suitable should be at least 10.}$$

Assume 4 jets, then

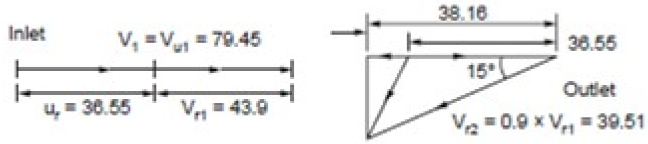
$$d = \left(\frac{5.484 \times 4}{4 \times \pi \times 79.45}\right)^{0.5} = 0.1482 \text{ m}, \frac{D}{d} = 9.5$$

may be suggested

$$\text{Per jet, } N_s = \frac{500}{60} \frac{\sqrt{15500000/4}}{335^{5/4}} = 11.44$$

Dimensionless $N_s = 0.0208$ ∴ acceptable

Such units are in operation in Himachal Pradesh.



The velocity diagrams are given above

$$V_{u1} = 79.45, V_{u2} = 38.16 - 36.55 = 1.61 \text{ m/s}$$

∴ $$W/kg = 36.55(79.45 + 1.61) = 2962.9 \text{ Nm/kg}$$

$$\eta_H = 2962.9\ (9.81 \times 335) = 0.9 \text{ or } 90\%$$

Assumed value is lower as it should be because, overall efficiency < hydraulic efficiency.

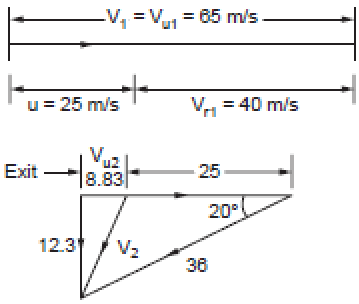
2. The jet velocity in a pelton turbine is 65 m/s. The peripheral velocity of the runner is 25 m/s. The jet is deflected by 160° by the bucket. Determine the power developed and hydraulic efficiency of the turbine for a flow rate of 0.9 m^3/s. The blade friction coefficient is 0.9.

$V_1 = V_{u1} = 65$ m/s

$u = 25$ m/s

$V_{r1} = 65 - 25 = 40$ m/s

$V_{r2} = 0.9 \times V_{r1} = 36$ m/s



As 36 cos 20 = 33.82 < 25 the shape of the exit triangle is as in figure.

$V_{u2} = 36 \cos 20 - 25$

$= 33.83 - 25 = 8.83$ m/s

In the opposite direction of V_{u1} hence addition

$P = 900 \times 25\ (65 + 8.83) = \mathbf{1.661 \times 10^6\ W}$

$$\eta_H = \frac{1661 \times 10^6 \times 2}{900 \times 65^2} = 87.37\%$$

Exit loss $$= m\frac{V_2^{\,2}}{2}$$

$$V_2^{\,2} = 36^2 + 25^2 - 2 \times 36 \times 25 \times \cos 20 = 229.55$$

$\therefore$ **Exit loss of power** $= \dfrac{900 \times 229.35}{2} = \mathbf{103.3 \times 10^3\ W}$

3. A Pelton turbine is to produce 15 MW under a head of 480 m when running at 500 rpm. If D/d = 10, determine the number of jets required.

Assume $\eta_0 = 85\%$, $C_v = 0.97$, $\phi = 0.46$

$$Q = \frac{15 \times 10^6}{0.85 \times 1000 \times 9.81 \times 480} = 3.75\ \text{m}^3/\text{s}$$

$$V_j = 0.97\sqrt{2 \times 9.81 \times 480} = 94.13\ \text{m/s}$$

$$u = 0.46 \times 94.13 = 43.3\ \text{m/s}$$

$$D = \frac{43.3 \times 60}{\pi \times 500} = 1.65\ \text{m.}$$

$\therefore$ $d = 0.165$ m

Volume flow in a jet $= \dfrac{\pi \times 0.165^2}{4} \times 94.13 = 2.01\ \text{m}^3/\text{s}$

Total required = 3.75. $\therefore$ **Two jets will be sufficient.**

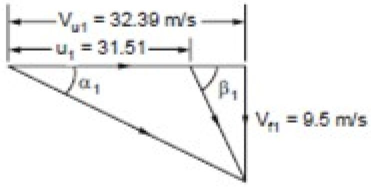
The new diameter of the jets

$$d' = \left(\frac{4 \times 3.75}{2 \times \pi \times 94.13}\right)^{0.5} = \mathbf{0.1593\ m}$$

$$N_s = \frac{500}{60} \cdot \frac{\sqrt{15 \times 10^6}}{480^{5/4}} = 14.37$$

4. The outer diameter of a Francis runner is 1.4 m. The flow velocity at inlet is 9.5 m/s. The absolute velocity at the exit is 7 m/s. The speed of operation is 430 rpm. The power developed is 12.25 MW, with a flow rate of 12 m3/s. Total head is 115 m. For shockless entry determine the angle of the inlet guide vane. Also find the absolute velocity at entrance, the runner blade angle at inlet and the loss of head in the unit. Assume zero whirl at exit. Also fluid the specific speed.

The runner speed $u_1 = \frac{\pi D N}{60} = \frac{\pi \times 430 \times 14}{60} = 31.52$ m/s



As $V_{u2} = 0$,

Power developed $= \dot{m}\, V_{u1}\, u_1$

$12.25 \times 10^6 = 12 \times 10^3 \times V_{u1} \times 31.52$

Solving $V_{u1} = 32.39$ m/s

$V_{u1} > u_1$

∴ The shape of the inlet

Velocity triangle is as given. Guide blade angle α_r

$$\tan \alpha_1 = \frac{9.5}{32.39} \quad \therefore \quad \alpha_1 = 16.35°$$

$$V_1 = (V_{f1}^2 + V_{u1}^2)^{0.5} = [9.5^2 + 32.39^2]^{0.5} = 33.75 \text{ m/s}$$

Blade inlet angle β_1

$$\tan \beta_1 = 9.5 / (32.39 - 31.52)$$

$$\therefore \quad \beta_1 = 84.77°$$

Total head = 115 m. **head equal for Euler work** $= \dot{m}\; V_{u1} u_1 / g$

$$= \frac{32.39 \times 31.52}{9.81} = 104.07 \text{ m}$$

Head loss in the absolute velocity at exit

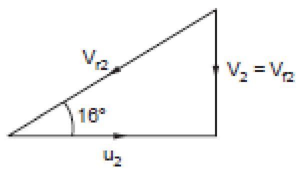
$$= \frac{7^2}{2 \times 9.81} = 2.5 \text{ m}$$

∴ Loss of head = 115 – 104.07 – 2.5 = 8.43 m

$$N_s = \frac{430}{60} \cdot \frac{\sqrt{12.25 \times 10^6}}{115^{1.25}} = 223.12$$

5. A Francis turbine works under a head of 120 m. The outer diameter and width are 2 m and 0.16 m. The inner diameter and width are 1.2 m and 0.27 m. The flow velocity at inlet is 8.1 m/s. The whirl velocity at outlet is zero. The outlet blade angle is 16°. Assume η_H = 90%. Determine, power, speed and blade angle at inlet and guide blade angle.

The outlet velocity diagram is a right angled triangle as shown



$$V_{f2} = V_{f1} \times D_1 b_1 / D_2 b_2$$

$$= 8.1 \times 2 \times 0.16 / 1.2 \times 0.27 = 8 \text{ m/s}$$

$$\therefore \quad u_2 = 8/\tan 16 = 27.9 \text{ m/s}$$

$$\frac{\pi D_2 N}{60} = u_2, \quad \frac{\pi \times 1.2 \times N}{60} = 27.9.$$

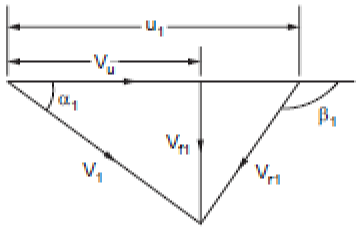
Solving $N = 444$ rpm

$$u_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 2 \times 266.4}{60} = 46.5 \text{ m/s}$$

$$\eta_H = \frac{u_1 V_{u1}}{g H}, V_{u1} = \frac{0.9 \times 9.81 \times 120}{46.5} = 22.8 \text{ m/s}$$

$u_1 > V_{u1}$.

The shape of the inlet triangle is shown.



$$\tan \alpha_1 = \frac{V_{f1}}{V_{u1}} = \frac{8.1}{22.8}$$

$$\therefore \quad \alpha_1 = 19.55°$$

$$\tan (180 - \beta_1) = \frac{V_{f1}}{u_1 - V_{u1}} = \frac{8.1}{46.5 - 22.8}$$

$$\therefore \quad \beta_1 = 161°$$

Flow rate = $\pi D_1 b_1 V_{f1} = \pi \times 2 \times 0.16 \times 8.1 = 8.143 \text{ m}^3/\text{s}$

Power = $0.9 \times 120 \times 9.81 \times 8.143 \times 10^3 / 10^3 = 8627$ **kW**

$$N_s = \frac{444}{60} \frac{\sqrt{8627 \times 10^2}}{120^{5/4}} = 54.72$$

6. In an inward flow reaction turbine the working head is 10 m. The guide vane outlet angle is 20°. The blade inlet angle is 120°. Determine the hydraulic efficiency assuming zero whirl at exit and constant flow velocity. Assume no losses other than at exit.

The velocity diagram is as shown in figure. As no velocity value

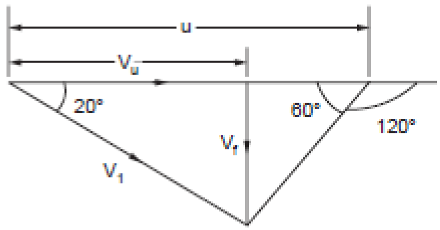
$$V_u = V_1 \cos 20 = 0.9397 V_1 \quad (1)$$

$$V_f = V_1 \sin 20 = 0.3420 V_1 \quad (2)$$

is avaivable, the method adoped is as below.

$$u = V_u + \frac{V_f}{\tan 60} = 0.9397 V_1 + \frac{0.342 V_1}{1.732} = 1.1372 V_1 \quad (3)$$

Work done = headlosses (all expressed as head)



$$\frac{u \cdot V_u}{g} = H - \frac{V_f^2}{2g}$$

$$\frac{1.1372 \times 0.9397}{9.81} \cdot V_1^2 = 10 - \frac{0.342^2 V_1^2}{2 \times 9.81}$$

$$0.10893 V_1^2 + 0.00596 V_1^2 = 10$$

$$\therefore \quad V_1 = \left[\frac{10}{0.1093 + 0.00596}\right]^{0.5} = 9.33 \text{ m/s}$$

$$\therefore \quad u = 1.1372 \times 9.33 = 10.61 \text{ m/s}$$

$$V_{u1} = 0.9397 \times 9.33 = 8.767 \text{ m/s}$$

$$\eta_H = \frac{10.61 \times 8.767}{9.81 \times 10} = 0.9482 \text{ or } 94.82\%$$

7. A Kaplan turbine plant develops 3000 kW under a head of 10 m. While running at 62.5 rpm. The discharge is 350 m3/s. The tip diameter of the runner is 7.5 m

and the hub to tip ratio is 0.43. Calculate the specific speed, turbine efficiency, the speed ratio and flow ratio.

Speed ratio is based on tip speed.

Hub diameter = 0.43 × 7.5 = 3.225 m

Turbine efficiency = $P / \rho Q H g$

$$= \frac{30000 \times 10^3}{1000 \times 350 \times 10 \times 9.81} = 0.8737 \quad \text{or } 87.37\%$$

$$\textbf{Specific speed} = \frac{60}{60} \cdot \frac{\sqrt{30{,}000 \times 10^3}}{10^{1.25}} = 308$$

$$\text{Runner tip speed} = \frac{\pi \times 7.5 \times 60}{60} = 23.56 \text{ m/s}$$

$$\therefore \quad \textbf{Speed ratio} = 23.56/\sqrt{2 \times 9.81 \times 10} = \mathbf{1.68}$$

$$\text{Flow velocity} = \frac{350 \times 4}{\pi (7.5^2 - 3.225^2)} = 9.72 \text{ m/s}$$

$$\therefore \quad \textbf{Flow ratio} = 9.72 / \sqrt{2 \times 9.81 \times 10} = \mathbf{0.69.}$$

8. A Kaplan turbine delivers 30 MW and runs at 175 rpm. Overall efficiency is 85% and hydraulic efficiency is 91%. The tip diameter 5 m and the hub diameter is 2 m. determine the head and the blade angles at the mid radius. The flow rate is 140 m^3/s.

$\rho Q g H \eta_o$ = power delivered

$$\therefore \quad H = 30 \times 10^6 / 1000 \times 9.81 \times 140 \times 0.85 = \mathbf{25.7 \text{ m}}$$

Power developed = Power available from fluid × η_H

$$\text{At midradius} \quad = \frac{30}{0.85} \times 10^6 \times 0.93 = \mathbf{32.82 \text{ kW}}$$

$$u = \pi \times \frac{D \times N}{60} = \frac{\pi \times 3.5 \times 175}{60} = \mathbf{32.07 \text{ m/s}}$$

$$\dot{m} u_1 V_{u1} = 32.82 \times 10^6 = 140 \times 10^3 \times 32.07 \times V_{u1}$$

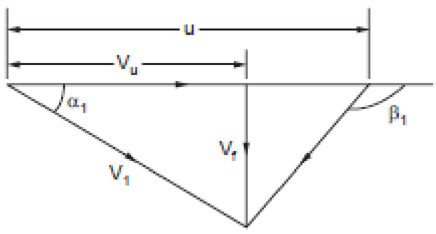
$$\therefore \quad \mathbf{V_{u1} = 7.14 \text{ m/s}}$$

(note $u_1 V_1$ = constant at all radii)

$$\mathbf{V_f = 4 \times 140 / \pi (5^2 - 2^2) = 8.5 \text{ m/s}}$$

$V_u < u$,

∴ The velocity diagram is as given



$$\tan (180 - \beta_1) = \frac{V_f}{u - V_u} = \frac{8.5}{32.07 - 7.14}$$

$\therefore \quad 180 - \beta = 18.82°,$

18.82° with – ve u direction and 161.18° with + ve u direction

Outlet triangle is right angled as $V_{u2} = 0,$

$$\tan(180 - \beta_2) = \frac{8.5}{32.07}, \ \boldsymbol{\beta_2 = 14.8°}$$

with –ve u direction 165.2° with + ve u direction

$$\tan \alpha_1 = \frac{8.5}{7.14} \quad \therefore \quad \boldsymbol{\alpha_1 = 50°}$$

9. A Kaplan turbine delivers 10 MW under a head of 25 m. The hub and tip diameters are 1.2 m and 3 m. Hydraulic and overall efficiencies are 0.90 and 0.85. If both velocity triangles are right angled triangles, determine the speed, guide blade outlet angle and blade outlet angle.

The inlet velocity diagram is shown in the figure.

Flow rate is calculated from power, head and overall efficiency

$$Q = \frac{10 \times 10^6}{10^3 \times 25 \times 9.81 \times 0.85} = \mathbf{47.97\ m^3/s}$$

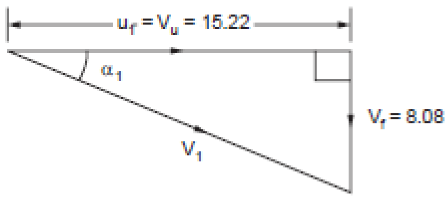
$$V_f = \frac{47.97 \times 4}{\pi(3^2 - 1.2^2)} = \mathbf{8.08\ m/s}$$

Power developed

$$u\, V_{u1}\, \dot{m} = 10 \times 10^6 / 0.90$$

$$\dot{m} = 47.97 \times 10^3 \text{ kg/s and } u = V_{u1}$$

$$\therefore \quad 47.97 \times 10^3 \times u_1^2 = \frac{10 \times 10^6}{0.9}$$



Solving $\quad u_1 = \mathbf{15.22\ m/s}$

$$\therefore \quad \tan \alpha_1 = V_{f1} / u_1 = \frac{8.08}{15.22}$$

$$\therefore \quad \boldsymbol{\alpha_1} = 28°$$

At the outlet $\quad u_2 = u_1,\ V_{f2} = V_{f1}$

$$\therefore \quad \tan \beta = \frac{8.08}{15.22}$$

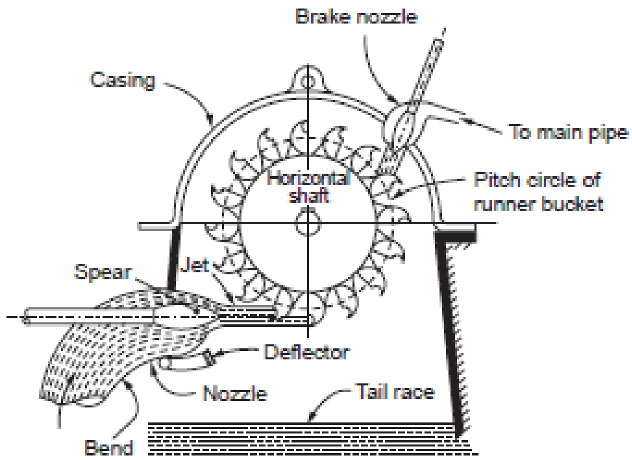
$$\therefore \quad \beta = 28°$$

$$\frac{\pi D N}{60} = 15.22$$

$$\therefore \quad N = \frac{15.22 \times 60}{\pi \times 3} = \mathbf{96.9\ rpm}$$

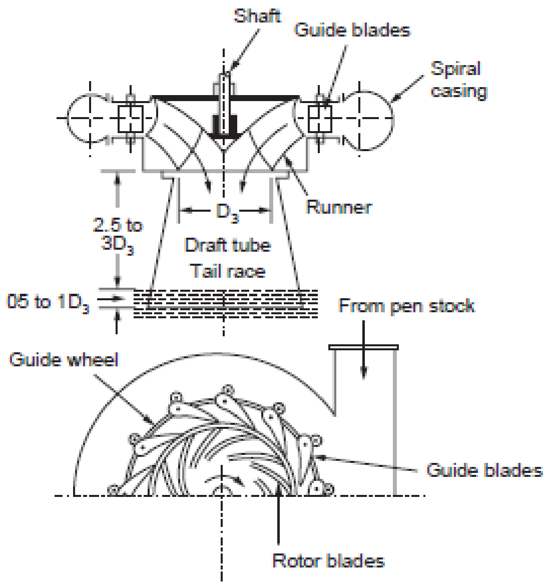
10. Explain about pelton wheel, Francis and Kaplan turbines

<u>PELTON TURBINE</u>



The rotor or runner consists of a circular disc, fixed on suitable shaft, made of cast or forged steel. Buckets are fixed on the periphery of the disc. The spacing of the buckets is decided by the runner diameter and jet diameter and is generally more than 15 in number. These buckets in small sizes may be cast integral with the runner. In larger sizes it is bolted to the runner disc. The buckets are also made of special materials and the surfaces are well polished. A view of a bucket is shown in fig. with relative dimensions indicated in the figure. Originally spherical buckets were used and pelton modified the buckets to the present shape. It is formed in the shape of two half ellipsoids with a splilter connecting the two. A cut is made in the lip to facilitate all the water in the jet to usefully impinge on the buckets. This avoids interference of the incoming bucket on the jet impinging on the previous bucket.

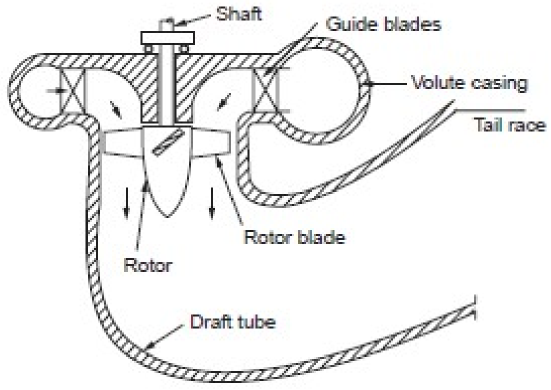
Francis Turbines



The main components are (*i*) The spiral casing (*ii*) Guide vanes (*iii*) Runner (*iv*) Draft tube and (*v*) Governor mechanism. Most of the machines are of vertical shaft arrangement while some smaller units are of horizontal shaft type.

The spiral casing surrounds the runner completely. Its area of cross section decreases gradually around the circumference. This leads to uniform distribution of water all along the circumference of the runner. Water from the penstock pipes enters the spiral casing and is distributed uniformly to the guide blades placed on the periphery of a circle. The casing should be strong enough to withstand the high pressure.

kaplan Turbine

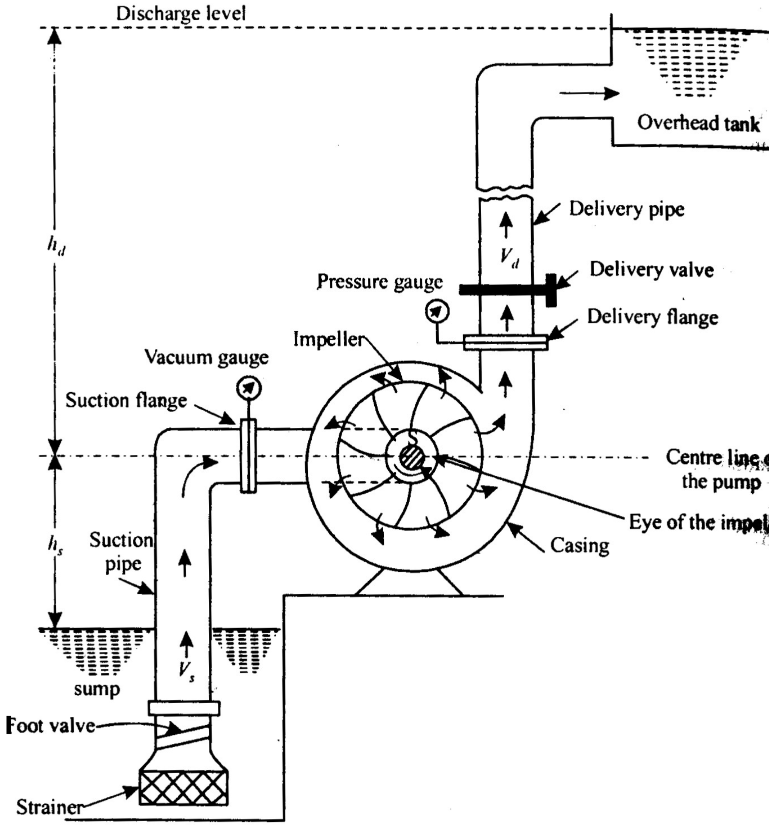


The popular axial flow turbines are the Kaplan turbine and propeller turbine. In propeller turbine the blades are fixed. In the Kaplan turbines the blades are mounted in the boss in bearings and the blades are rotated according to the flow conditions by a servomechanism maintaining constant speed. In this way a constant efficiency is achieved in these turbines. The system is costly and where constant load conditions prevail, the simpler propeller turbines are installed.

There are many locations where large flows are available at low head. In such a case the specific speed increases to a higher value. In such situations axial flow turbines are gainfully employed. A sectional view of a kaplan turbines in shown in fig. These turbines are suited for head in the range 5 – 80 m and specific speeds in the range 350 to 900. The water from supply pipes enters the spiral casing as in the case of Francis turbine. Guide blades direct the water into the chamber above the blades at the proper direction. The speed governor in this case acts on the guide blades and rotates them as per load requirements. The flow rate is changed without any change in head. The water directed by the guide blades enters the runner which has much fewer blades (3 to 10) than the Francis turbine. The blades are also rotated by the governor to change the inlet blade angle as per the flow direction from the guide blades, so that entry is without shock. As the head is low, many times the draft tube may have to be elbow type. The important dimensions are the diameter and the boss diameter which will vary with the chosen speed. At lower specific speeds the boss diameter may be higher.

11. Explain the working of centrifugal pump with neat sketch.

    Principle: 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.

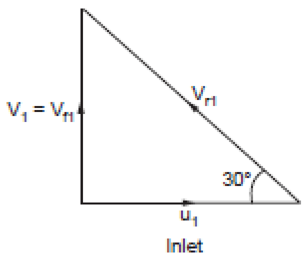


centrifugal pump

12. The following details refer to a centrifugal pump. Outer diameter : 30 cm. Eye diameter : 15 cm. Blade angle at inlet : 30°. Blade angle at outlet : 25°. Speed 1450 rpm. The flow velocity remains constant. The whirl at inlet is zero. **Determine the work done per kg**. If the manometric efficiency is 82%, **determine the working head**. If width at outlet is 2 cm, **determine the power** η_o = 76%.

$$u_1 = \frac{\pi \times 0.3 \times 1450}{60} = 22.78 \text{ m/s}$$

$$u_2 = 11.39 \text{ m/s.}$$



From inlet velocity diagram.

$$V_{f1} = u_1 \tan \beta_1$$

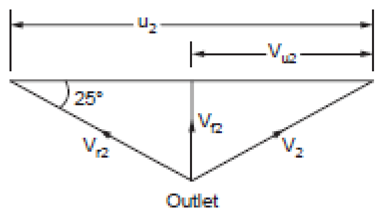
$$= 11.39 \times \tan 30 = 6.58 \text{ m/s}$$

From the outlet velocity diagram,

$$V_{u2} = u_1 - \frac{V_{f2}}{\tan \beta_2} = 22.78 - \frac{6.58}{\tan 25} = 8.69 \text{ m/s}$$

Work done per kg $= u_2 V_{u2} = 22.78 \times 8.69$

$= \mathbf{197.7\ Nm/kg/s}$



$$\eta_m = 0.82 = \frac{g H}{197.7}$$

$\therefore$ $\mathbf{H = 16.52\ m}$

Flow rate = $\pi \times 0.3 \times 0.02 \times 6.58 = 0.124 \text{ m}^3/\text{s}$

$$\textbf{Power} = \frac{0.124 \times 10^3 \times 9.81 \times 16.52}{0.76 \times 10^3} = \mathbf{26.45\ kW.}$$

13. The dimensionless specific speed of a centrifugal pump is 0.06. Static head is 30 m. Flow rate is 50 l/s. The suction and delivery pipes are each of 15 cm diameter. The friction factor is 0.02. Total length is 55 m other losses equal 4 times the velocity head in the pipe. The vanes are forward curved at 120°. The width is one tenth of the diameter. There is a 6% reduction in flow area due to the blade thickness. The manometric efficiency is 80%. Determine the impeller diameter.

Frictional head is calculated first. Velocity in the pipe

$$= \frac{0.05 \times 4}{\pi \times 0.15^2} = 2.83 \text{ m/s}$$

Total loss of head $= \frac{flV^2}{2gD} + \frac{4V^2}{2g}$

$$= \frac{0.02 \times 55 \times 2.83^2}{2 \times 9.81 \times 0.15} + \frac{4 \times 2.83^2}{2 \times 9.81} = 4.63 \text{ m}$$

Total head against which pump operates = 34.63 m

Speed is calculated from specific speed $N_s = N\sqrt{Q}/(gH)^{3/4}$

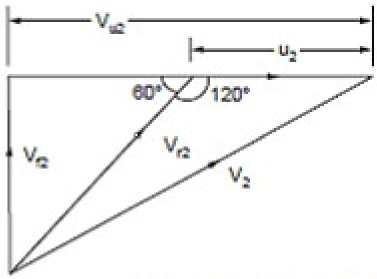
$$N = \frac{0.06 \times (9.81 \times 34.63)^{3/4}}{0.05^{1/2}} = 21.23 \text{ rps}$$

Flow velocity is determined :

Flow area $= \pi \times D \times \frac{D}{10} \times 0.94 = 0.2953\ D^2$

$$V_{f2} = \frac{0.05}{0.2953\ D^2} = 0.1693/D^2 \quad ...(1)$$

$$u_2 = \pi DN = 21.23 \times \pi \times D = 66.7\ D \quad ...(2)$$



Outlet velocity diagram
(forwerd curved)

$$\eta_m = 0.8 = \frac{9.81 \times 34.63}{66.7\ D \times V_{u2}}$$

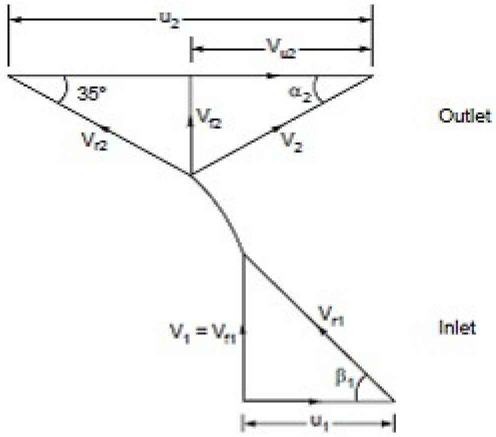
$$\therefore \quad V_{u2} = \frac{6.367}{D} \quad ...(3)$$

From velocity diagram,

$$\tan 60 = \frac{V_{f2}}{V_{u2} - u_2} = \frac{0.1693}{D^2} \cdot \frac{1}{\left(\frac{6.367}{D} - 66.7\ D\right)}$$

14. A centrifugal pump running at 900 rpm has an impeller diameter of 500 mm and eye diameter of 200 mm. The blade angle at outlet is 35° with the tangent. Determine assuming zero whirl at inlet, the inlet blade angle. Also calculate the absolute velocity at outlet and its angle with the tangent. The flow velocity is constant at 3 m/s. Also calculate the manometric head.

The velocity diagrams are as shown.



Consider inlet

$$u_1 = \frac{\pi \times 0.2 \times 900}{60} = 9.42 \text{ m/s}$$

$$V_{f1} = 3 \text{ m/s}$$

Blade angle at inlet

$$\tan \beta_1 = \frac{V_{f1}}{u_1} = \frac{3}{9.42}$$

$$\therefore \quad \beta_1 = 17.66°$$

Considering outlet

$$u_2 = \frac{\pi \times 0.5 \times 900}{60} = 23.56 \text{ m/s}$$

$$V_{u2} = u_2 - \frac{V_{f2}}{\tan 35} = 23.56 - \frac{3}{\tan 35} = 19.28 \text{ m/s}$$

$$\tan \alpha_2 = \frac{3}{19.28}$$

$$\therefore \quad \alpha_2 = 8.85°$$

$$V_2 = \sqrt{3^2 + 19.28^2} = 19.51 \text{ m/s}$$

The outlet velocity is 19.51 m/s at an angle of 8.85° to the tangent. (taken in the opposite direction of u).

Manometric head $= \frac{23.56 \times 19.28}{9.81} = 46.3$ m

UNIT V POSITIVE DISPLACEMENT MACHINES 11

Recriprocating pumps, Indicator diagrams, Work saved by air vessels. Rotory pumps. Classification. Working and performance curves.

PART-A

1. What is meant by Pump?

It is defined as the hydraulic machine in which converts the mechanical energy into hydraulic energy, which is mainly in the form of pressure energy.

2. Mention main components of Centrifugal pump.

- ✓ Casing
- ✓ Impeller
- ✓ Suction pipe, strainer & Foot valve
- ✓ Delivery pipe & Delivery valve

3. What is the slip in reciprocating pump?

Slip is the difference between the theoretical discharge and actual discharge of the pump.

Slip= Qth-Qact.

4. What is meant by Priming?

The delivery valve is closed and the suction pipe, casing and portion of the delivery pipe up to delivery valve are completely filled with the liquid so that no air pocket is left. This is called as priming.

5. What is the main parts of reciprocating pump?

- ✓ A cylinder with a piston, Piston rod, connecting rod and a crank.
- ✓ Suction pipe, Delivery pipe.
- ✓ Suction valve and

- ✓ Delivery valve.

6. How will you classify the reciprocating pump?

The reciprocating pump may be classified as,

1. According to the water in contact with one side or both sides of the piston.
2. According to the number of cylinders provided.

Classification according to the contact of water is

(1) Single acting (2) Double acting.

According to the number of cylinders provided they are classified as,

1. Single Cylinder pump.
2. Double cylinder pump.
3. Triple cylinder pump.

7. Define Mechanical efficiency.

It is defined as the ratio of the power actually delivered by the impeller to the power supplied to the shaft.

8. Define overall efficiency.

It is the ratio of power output of the pump to the power input to the pump.

9. Define speed ratio, flow ratio.

Speed ratio: It is the ratio of peripheral speed at outlet to the theoretical velocity of jet corresponding to manometric head.

Flow ratio: It is the ratio of the velocity of flow at exit to the theoretical velocity of jet corresponding to manometric head.

10. Mention main components of Reciprocating pump.

- ✓ Piton or Plunger
- ✓ Suction and delivery pipe
- ✓ Crank and Connecting rod

11. Define Slip of reciprocating pump. When the negative slip does occur?

The difference between the theoretical discharge and actual discharge is called slip of the pump.

But in sometimes actual discharge may be higher then theoretical discharge, in such a case coefficient of discharge is greater then unity and the slip will be negative called as negative slip.

12. Why negative slip occurs in reciprocating pump?

If actual discharge is more than the theoretical discharge the slip of the pump will be negative. Negative slip occurs only when delivery pipe is short, Suction pipe is long and pump is running at high speed.

13. What is indicator diagram?

Indicator diagram is nothing but a graph plotted between the pressure head in the cylinder and the distance traveled by the piston from inner dead center for one complete revolution of the crank.

14. What is meant by Cavitations?

It is defined phenomenon of formation of vapor bubbles of a flowing liquid in a region where the pressure of the liquid falls below its vapor pressure and the sudden collapsing of theses vapor bubbles in a region of high pressure.

15. What are rotary pumps?

Rotary pumps resemble like a centrifugal pumps in appearance. But the working method differs. Uniform discharge and positive displacement can be obtained by using these rotary pumps; It has the combined advantages of both centrifugal and reciprocating pumps.

16. What is an air vessel?

An air vessel is a closed chamber containing compressed air in the top portion and liquid at the bottom of the chamber. At the base of the chamber there is an opening through which the liquid may flow into the vessel or out of the vessel.

17. What is the purpose of an air vessel fitted in the pump?

1. To obtain a continuous supply of liquid at a uniform rate.
2. To save a considerable amount of work in overcoming the frictional resistance in the suction and delivery pipes, and
3. To run the pump at a high speed without separation.

18. What is the relation between Work done of a Pump and Area of Indicator Diagram?

Work done by the pump is Proportional to the area of the Indicator diagram.

19. What is the work saved by fitting a air vessel in a single acting, double acting pump?

Work saved by fitting air vessels in a single acting pump is 84.87%,
In a double acting pump the work saved is 39.2%.

PART-B

1. A single acting reciprocating pump has a bore of 200 mm and a stroke of 350 mm and runs at 45 rpm. The suction head is 8 m and the delivery head is 20 m. Determine the theoretical discharge of water and power required. If slip is 10%, what is the actual flow rate?

Theoretical flow volume $Q = \frac{L\,A\,N}{60} = \frac{0.35 \times \pi \times 0.2^2}{4} \times \frac{45}{60}$

$= 8.247 \times 10^{-3}$ m³/s or 8.247 l/s or 8.247 kg/s

Theoretical power = (mass flow/s) × head in $m \times g$ Nm/s or W

$= 0.9 \times 8.247 \times (20 + 8) \times 9.81$

= 2039 W or 2.039 kW

$$\text{Slip} = \frac{Q_{th} - Q_{ac}}{Q_{th}},\ 0.1 = \frac{8.247 - Q_{ac}}{8.247}$$

∴ $\mathbf{Q_{actual} = 7.422}$ **l/s**

The actual power will be higher than this value due to both solid and fluid friction.

2. A double acting reciprocating pump has a bore of 150 mm and stroke of 250 mm and runs at 35 rpm. The piston rod diameter is 20 mm. The suction head is 6.5 m and the delivery head is 14.5 m. The discharge of water was 4.7 l/s. Determine the slip and the power required.

$$Q = \frac{L\,A_1\,N}{60} + \frac{L\,A_2\,N}{60} = \frac{L\,N}{60}[A_1 + A_2]$$

$$= \frac{0.25 \times 35}{60}\left[\frac{\pi \times 0.15^2}{4} + \frac{\pi}{4}(0.15^2 - 0.02^2)\right]$$

$$= \frac{0.25 \times 35 \times \pi}{60 \times 4}[2 \times 0.15^2 - 0.02^2]$$

$$= \mathbf{5.108 \times 10^{-3}\ m^3/s\ or\ 5.108\ l/s\ or\ 5.108\ kg/s}$$

It piston rod area is not taken into account

$$Q = 5.154 \text{ l/s.}$$

An error of 0.9% rather negligible.

$$\textbf{Slip} = \frac{5.108 - 4.7}{5.108} \times 100 = \mathbf{7.99\%}$$

Theoretical power $= m\,g\,h = 4.7 \times 9.81 \times (14.5 + 6.5)$ W = **968 W**

The actual power will be higher than this value due to mechanical and fluid friction.

3. In a single acting reciprocating pump with plunger diameter of 120 mm and stroke of 180 mm running at 60 rpm, an air vessel is fixed at the same level as the pump at a distance of 3 m. The diameter of the delivery pipe is 90 mm and the length is 25 m. Friction factor is 0.02. Determine the reduction in accelerating head and the friction head due to the fitting of air vessel.

Without air vessel :

$$h_{ad} = \frac{l}{g} . \frac{A}{a} . \omega^2 r = \frac{25}{9.81} . \frac{0.12^2}{0.09^2} . \left(\frac{2\pi \times 60}{60}\right)^2 \times 0.09$$

$$= \mathbf{16.097\ m}$$

With air vessel :

$$h'_{ad} = \frac{3}{9.81} . \frac{0.12^2}{0.09^2} . \left(\frac{2\pi \times 60}{60}\right)^2 \times 0.09 = \mathbf{1.932\ m}$$

$$\textbf{Reduction} = 16.097 - 1.932 = \mathbf{14.165\ m}$$

Fitting air vessel reduces the acceleration head.

Without air vessel :

$$\text{Friction head} \quad h_f = \frac{4\,f\,l.V^2}{2gd} = \frac{4f\,l}{2gd}\left[\frac{A}{a} . \omega r \sin\theta\right]^2$$

At $\theta = 90°$

$$h_{f\,max} = \frac{4 \times 0.02 \times 25}{2 \times 9.81 \times 0.09}\left[\frac{0.12^2}{0.09^2} . \frac{2\pi \times 60}{60} \times 0.09 \times 1\right]^2 = \mathbf{1.145\ m}$$

With air vessel, the velocity is constant in the pipe.

$$\text{Velocity} = \frac{A\,L\,N}{60} \times \frac{4}{\pi . d^2} = \frac{\pi \times 0.12^2}{4} \times \frac{0.18 \times 60 \times 4}{60 \times \pi \times 0.09^2}$$

$$= 0.102 \text{ m/s}$$

$$\text{Friction head} = \frac{4 \times 0.02 \times 25}{2 \times 9.81 \times 0.09} \times 0.102^2 = \mathbf{0.012\ m}$$

Percentage saving over maximum

$$= \frac{1.145 - 0.012}{1.145} \times 100 = 99\%$$

Air vessel reduces the frictional loss.

4. In a reciprocating pump delivering water the bore is 14 cm and the stroke is 21 cm. The suction lift is 4 m and delivery head is 12 m. The suction and delivery pipe are both 10 cm diameter, length of pipes are 9 m suction and 24 m delivery. Friction factor is 0.015. Determine the theoretical power required. Slip is 8 percent. The pump speed is 36 rpm.

Volume delivered assuming single acting,

$$= A\,L\,N/60 = \frac{\pi \times 0.14^2}{4} \times 0.21 \times \frac{36}{60}$$

$= 1.9396 \times 10^{-3}$ m^3/s or 1.9396 kg/s

Slip is 8%

∴ Actual mass delivered = 1.9396 × 0.92 = 1.784 kg/s

Total static head = 4 + 12 = 16 m head

Friction head in the delivery pipe:

Maximum velocity, $$v = \frac{A}{a}\omega r = \frac{0.14^2}{0.1^2} \times \frac{2\pi \times 36}{60} \times 0.105 = 0.7758 \text{ m/s}$$

$$h_{fd} = \frac{flv^2}{2gd} = \frac{0.015 \times 24}{2 \times 9.81 \times 0.1} \,.\, [0.7758]^2 = 0.11 \text{ m}$$

Average is, $2/3\ \mathbf{h_{fd}} = \mathbf{0.07363\ m}$

Friction head in the suction pipe ;

Velocity is the same as diameters are equal

$$h_{fs} = \frac{0.015 \times 9}{2 \times 9.81 \times 0.1} \times [0.7758]^2 = 0.0414 \text{ m}$$

Average = $2/3\ h_{fs}$ = 0.0414 × 2/3 = 0.02761 m

Total head = 16 + 0.07363 + 0.02761 = 16.10124 m

Theoretical Power = 1.784 × 9.81 × 16.1024 = **282 W.**

5. The bore and stroke of a single acting reciprocating water pump are 20 cm and 30 cm. The suction pipe is of 15 cm diameter and 10 m long. The delivery pipe is 12 cm diameter and 28 m long. The pump is driven at 32 rpm. Determine the acceleration heads and the friction head, f = 0.02. Sketch the indicator diagram. The suction and delivery heads from atmosphere are 4 m and 16 m respectively.

$$h_{as\ max} = \frac{l_s}{g} \cdot \frac{A}{a_s} \cdot \omega^2 r = \frac{10}{9.81} \times \frac{0.2^2}{0.15^2} \left(\frac{2\pi \times 32}{60}\right)^2 \times 0.15 = 3.05 \text{ m}$$

$$h_{ad\ max} = \frac{l_d}{g} \cdot \frac{A}{a_d} \cdot \omega^2 r = \frac{28}{9.81} \times \frac{0.2^2}{0.12^2} \left(\frac{2\pi \times 32}{60}\right)^2 \times 0.15 = 13.35 \text{ m}$$

$$V_{s\ max} = \frac{A}{a} \omega r = \frac{0.2^2}{0.15^2} \times \frac{2\pi \times 32}{60} \times 0.15 = 0.8936$$

$$h_{fs} = \frac{fl_s}{2gd_s} \cdot v_s^2 = \frac{0.2 \times 10 \times 0.8436^2}{2 \times 9.81 \times 0.15} = 0.5427 \text{ m}$$

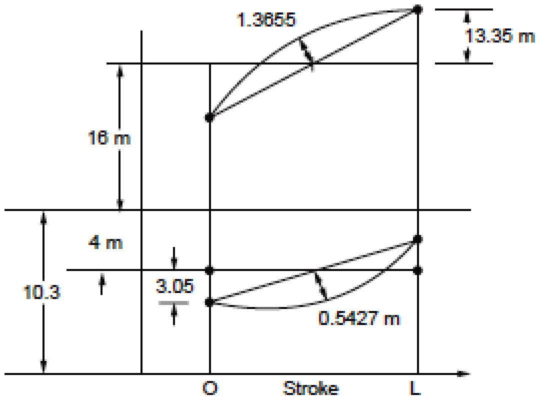


Figure P.16.9 Problem model

$$h_{fd} = \frac{fl_d}{2gd_d} \cdot V_d^2,\ V_{d\ max} = \frac{A}{a} \cdot \omega r = \frac{0.2^2}{0.12^2} \times \frac{2\pi \times 32}{60} \times 0.15$$

$$= 1.396 \text{ m/s}$$

$$h_{fd\ max} = \frac{0.02 \times 28}{2 \times 9.81 \times 0.12} \times 2.396^2 = 1.3655 \text{ m.}$$

6. A single acting reciprocating of pump handles water. The bore and stroke of the unit are 20 cm and 30 cm. The suction pipe diameter is 12 cm and length is 8 m. The delivery pipe diameter is 12 cm and length is 24 m. f = 0.02. The speed of operation is 32 rpm. Determine the friction power with and without air vessels.

Without air vessels $V = \frac{A}{a}\omega r = \frac{0.2^2}{0.12^2} \times \frac{2\pi \times 32}{60} \times 0.15$

$= 1.3963$ m/s

$$h_{fs\,max} = \frac{fl_s}{2gd_s} \times v^2 = \frac{0.02 \times 8}{2 \times 9.81 \times 0.12} \times (1.3963)^2 = \mathbf{0.1325\ m}$$

$$h_{fd\,max} = \frac{0.02 \times 24}{2 \times 9.81 \times 0.12} \times \left(\frac{0.2^2}{0.12^2} \cdot \frac{2\pi \times 32}{60} \times 0.15\right)^2 = \mathbf{0.3975\ m}$$

Total average friction head

$$= \frac{2}{3}[0.3975 + 0.1325] = 0.3533 \text{ m}$$

Flow rate $= \frac{A\,L\,N}{60} = \frac{\pi \times 0.2^2}{4} \times 0.3 \times \frac{32}{60} = 5.0265 \times 10^{-3}\ \text{m}^3/\text{s}$

or $= 5.0265$ kg/s

Friction power $= 5.0265 \times 9.81 \times 0.3533 = \mathbf{17.42\ W}$

When air vessels are installed,

Average velocity in suction pipe

$$= \frac{A}{a}\frac{L\,N}{60} = \frac{0.02^2}{0.12^2} \times 0.3 \times \frac{32}{60} = 0.4444 \text{ m/s}$$

$$h_{fs} = \frac{fl_s\,v^2}{2g\,d_s} = \frac{0.02 \times 8 \times 0.4444^2}{2 \times 9.81 \times 0.12} = 0.013424 \text{ m}$$

As diameters are equal velocity are equal

$$h_{fd} = \frac{0.02 \times 24 \times 0.4444^2}{2 \times 9.81 \times 0.12} = 0.040271 \text{ m}$$

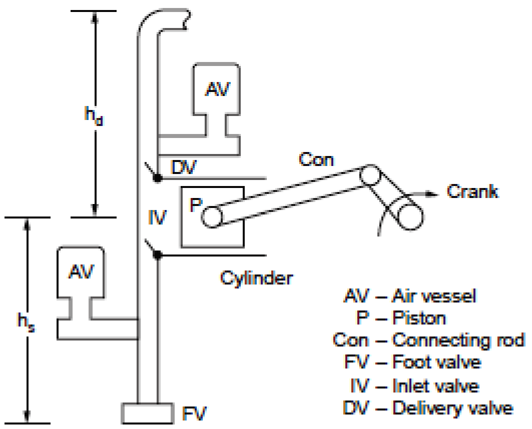
Friction power $= 5.0265 \times 9.81 \times (0.013424 + 0.040271) = \mathbf{2.65\ W}$

The percentage reduction is $\frac{17.42 - 2.65}{17.42} \times 100 = \mathbf{84.8\%}$

By use of air vessels there is a saving of 84.8% in friction power.

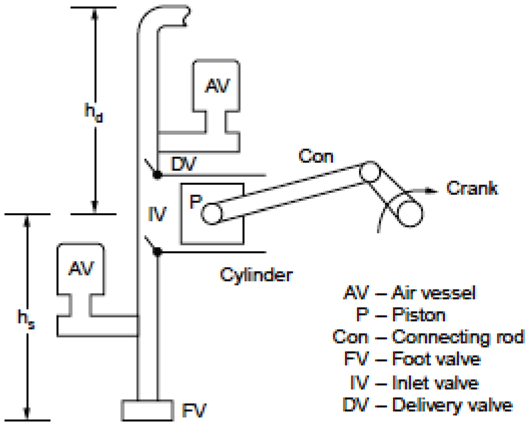
7. Explain about Reciprocating pumps

Diagramatic view of single acting reciprocating pump



The action is similar to that of reciprocating engines. As the crank moves outwards, the piston moves out creating suction in the cylinder. Due to the suction water/fluid is drawn into the cylinder through the inlet valve. The delivery valve will be closed during this outward stroke. During the return stroke as the fluid is incompressible pressure will developed immediately which opens the delivery valve and closes the inlet valve. During the return stroke fluid will be pushed out of the cylinder against the delivery side pressure. The functions of the air vessels will be discussed in a later section. The volume delivered per stroke will be the product of the piston area and the stroke length. In a single acting type of pump there will be only one delivery stroke per revolution. Suction takes place during half revolution and delivery takes place during the other half. As the piston speed is not uniform (crank speed is uniform) the discharge will vary with the position of the crank.

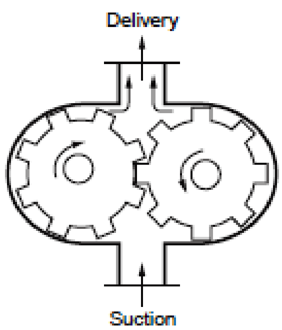
Diagramatic view of a double action pump



In this case the piston cannot be connected directly with the connecting rod. A gland and packing and piston rod and cross-head and guide are additional components. There will be nearly double the discharge per revolution as compared to single acting pump. When one side of the piston is under suction the other side will be delivering the fluid under pressure. As can be noted, the construction is more complex.

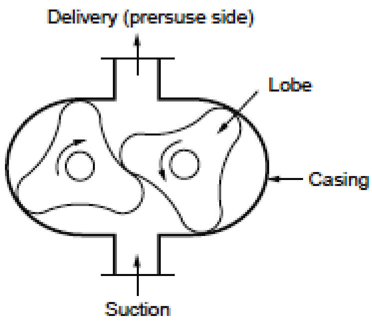
8. Explain about rotary positive displacement pumps

Gear Pump



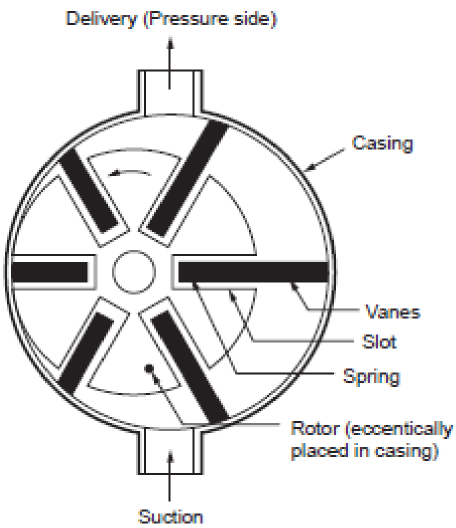
These are used more often for oil pumping. Gear pumps consist of two identical mating gears in a casing as shown in fig. The gears rotate as indicated in the sketch. Oil is trapped in the space between the gear teeth and the casing. The oil is then carried from the lower pressure or atmospheric pressure and is delivered at the pressure side. The two sides are sealed by the meshing teeth in the middle. The maximum pressure that can be developed depends on the clearance and viscosity of the oil. The operation is fairly simple. One of the gear is the driving gear directly coupled to an electric motor or other type of drives. These pumps should be filled with oil before starting. The sketch shows an external gear pump. There is also another type of gear pump called internal gear pump. This is a little more compact but the construction is more complex and involved and hence used in special cases where space is a premium.

Lobe Pump



This type is also popularly used with oil. The diagramatic sketch of a lobe pump is shown in fig.. This is a three lobed pump. Two lobe pumps is also possible. The gear teeth are replaced by lobes. Two lobes are arranged in a casing. As the rotor rotates, oil is trapped in the space between the lobe and the casing and is carried to the pressure side. Helical lobes along the axis are used for smooth operation. Oil has to be filled before starting the pump. Lobe types of compressors are also in use. The constant contact between the lobes makes a leak tight joint preventing oil leakage from the pressure side. The maximum pressure of operation is controlled by the back leakage through the clearance. This type of pump has a higher capacity compared to the gear pump.

Vane Pump



This is another popular type not only for oil but also for gases. A rotor is eccentrically placed in the casing as shown in fig. The rotor carries sliding vanes in slots along the length. Springs control the movement of the vanes and keep them pressed on the casing. Oil is trapped between the vanes and the casing. As the rotor rotates the trapped oil is carried to the pressure side. The maximum operating pressure is controlled by the back leakage.

ME 2204 FLUID MECHANICS AND MACHINERY 3 1 0 4

(Common to Aeronautical, Mechanical, Automobile & Production)

OBJECTIVES

a. The student is introduced to the mechanics of fluids through a thorough understanding of the properties of the fluids. The dynamics of fluids is introduced through the control volume approach which gives an integrated under standing of the transport of mass, momentum and energy.

b. The applications of the conservation laws to flow though pipes and hydraulics machines are studied

UNIT I INTRODUCTION 12

Units & Dimensions. Properties of fluids – Specific gravity, specific weight, viscosity, compressibility, vapour pressure and gas laws – capillarity and surface tension. Flow characteristics: concepts of system and control volume. Application of control volume to continuity equiation, energy equation, momentum equation and moment of momentum equation.

UNIT II FLOW THROUG CIRCULAR CONDUITS 12

Laminar flow though circular conduits and circular annuli. Boundary layer concepts. Boundary layer thickness. Hydraulic and energy gradient. Darcy – Weisbach equaition. Friction factor and Moody diagram. Commercial pipes. Minor losses. Flow though pipes in series and in parallel.

UNIT III DIMENSIONAL ANALYSIS 9

Dimension and units: Buckingham's Π theorem. Discussion on dimensionless parameters. Models and similitude. Applications of dimensionless parameters.

UNIT IV ROTO DYNAMIC MACHINES 16

Homologus units. Specific speed. Elementary cascade theory. Theory of turbo machines. Euler's equation. Hydraulic efficiency. Velocity components at the entry and exit of the rotor. Velocity triangle for single stage radial flow and axial flow machines. Centrifugal pumps, turbines, performance curves for pumps and turbines.

UNIT V POSITIVE DISPLACEMENT MACHINES 11

Recriprocating pumps, Indicator diagrams, Work saved by air vessels. Rotory pumps. Classification. Working and performance curves.

TOTAL :60 PERIODS

TEXT BOOKS:

1. Streeter. V. L., and Wylie, E.B., Fluid Mechanics, McGraw Hill, 1983.
2. Rathakrishnan. E, Fluid Mechanics, Prentice Hall of India (II Ed.), 2007.

REFERENCES:

1. Ramamritham. S, Fluid Mechanics, Hydraulics and Fluid Machines, Dhanpat Rai & Sons, Delhi, 1988.
2. Kumar. K.L., Engineering Fluid Mechanics (VII Ed.) Eurasia Publishing House (P) Ltd., New Delhi, 1995.
3. Bansal, R.K., Fluid Mechanics and Hydraulics Machines, Laxmi Publications (P) Ltd., New Delhi.