## BRANCH:

## Mechanical

## Question Bank

1. INTRODUCTION

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 ( $\mathrm{kg} / \mathrm{m} 3$ )
Specific weight is defined as weight possessed per unit volume ( $\mathrm{N} / \mathrm{m} 3$ )
5. Define Specific volume and Specific Gravity.

Specific volume is defined as volume of fluid occupied by unit mass ( $\mathrm{m} 3 / \mathrm{kg}$ )
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. $\left(\mathrm{m}^{2} / \mathrm{sec}\right)$
9. Define Relative or Specific viscosity.

It is the ratio of dynamic viscosity of fluid to dynamic viscosity of water at $20^{\circ} \mathrm{C}$.
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 6 mm and is filled with a fluid. The planes are inclined at $30^{\circ}$ 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 $3 \mathrm{~m} / \mathrm{s}$ due to its weight of 2 N . 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, $\mathrm{F}=(\mathrm{A} \times 2) \times \mu \times(\mathrm{du} / \mathrm{dy})$ (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, $\mu=0.05 \mathrm{Ns} / \mathrm{m}^{2}$ or 0.5 Poise

2. The velocity of the fluid filling a hollow cylinder of radius 0.1 m varies as $\mathrm{u}=10\left[\begin{array}{ll}1 & (\mathrm{r} / 0.1) 2\end{array}\right]$ $\mathrm{m} / \mathrm{s}$ along the radius r . The viscosity of the fluid is $0.018 \mathrm{Ns} / \mathrm{m} 2$. For 2 m length of the cylinder, determine the shear stress and shear force over cylindrical layers of fluid at $\mathrm{r}=0$ (centre line), $0.02,0.04,0.060 .08$ and 0.1 m (wall surface.)

Shear stress $=\mu(d u / d y)$ or $\mu(d u / d r), u=10[1-(r / 0.1) 2] m / s$
$\therefore \mathrm{du} / \mathrm{dr}=10(-2 \mathrm{r} / 0.12)=-2000 \mathrm{r}$
The - ve sign indicates that the force acts in a direction opposite to the direction of velocity, $u$.
Shear stress $=0.018 \times 2000 \mathrm{r}=36 \mathrm{rN} / \mathrm{m}^{2}$
Shear force over 2 m length $=$ shear stress $\times$ area over $2 \mathrm{~m}=36 \mathrm{r} \times 2 \pi \mathrm{rL}=72 \pi \mathrm{r}^{2} \times 2=144 \pi r^{2}$

| Radius, $\mathbf{m}$ | Shear stress, $\mathbf{N} / \mathbf{m}^{2}$ | Shear force, $\mathbf{N}$ | Velocity, $\mathbf{m} / \mathbf{s}$ |
| :---: | :---: | :---: | :---: |
| 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. $\left(\mathrm{Pas}=\left(\mathrm{N} / \mathrm{m}^{2}\right) \times \mathrm{s}\right)$.
Shear stress on the shaft surface $=\tau=\mu(\mathrm{du} / \mathrm{dy})=\mu(\mathrm{u} / \mathrm{y})$
$\mathrm{u}=\pi \mathrm{DN} / 60=\pi \times 0.3 \times 400 / 60=6.28 \mathrm{~m} / \mathrm{s}$
$\tau=0.03\{(6.28-0) / 0.001\}=188.4 \mathrm{~N} / \mathrm{m}^{2}$
Surface area of the two bearings, $\mathrm{A}=2 \pi \mathrm{DL}$
Force on shaft surface $=\tau \times \mathrm{A}=188.4 \times(2 \times \pi \times 0.3 \times 0.3)=106.6 \mathrm{~N}$
Torque $=106.6 \times 0.15=15.995 \mathrm{Nm}$

Power required $=2 \pi \mathrm{NT} / 60=2 \times \pi \times 400 \times 15.995 / 60=670 \mathrm{~W}$.
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 $=\mu \times(u / y)$, Force on the top surface $=\mu \times u /(h-y)$
Total force to pull the plane $=\mu \times u \times\{(1 / \mathrm{y})+[1 /(\mathrm{h}-\mathrm{y})]\} \ldots(\mathrm{A})$
To obtain the condition for minimisation of the force the variation of force with respect to y should be zero, or $\mathrm{dF} / \mathrm{dy}=0$, Differentiating the expression A ,
$\mathrm{dF} / \mathrm{dy}=\mu \times \mathrm{u}\{(-1 / \mathrm{y} 2)+[1 /(\mathrm{h}-\mathrm{y}) 2]\}$, 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 $0.8 \mathrm{~m} \times 0.8 \mathrm{~m}$ and an inclined plane with angle of inclination $30^{\circ}$ 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 $0.3 \mathrm{~m} / \mathrm{s}$. The thickness of oil film is 1.5 mm .

## Solution. Given :

Area of plate,

$$
\begin{aligned}
A & =0.8 \times 0.8=0.64 \mathrm{~m}^{2} \\
\theta & =30^{\circ} \\
W & =300 \mathrm{~N} \\
u & =0.3 \mathrm{~m} / \mathrm{s}
\end{aligned}
$$

Angle of plane,
Weight of plate,
Velocity of plate,


Thickness of oil film, $\quad t=d y=1.5 \mathrm{~mm}=1.5 \times 10^{-3} \mathrm{~m}$
Let the viscosity of fluid between plate and inclined plane is $\mu$.
Component of weight $W$, along the plane $=W \cos 60^{\circ}=300 \cos 60^{\circ}=150 \mathrm{~N}$
Thus the shear force, $F$, on the bottom surface of the plate $=150 \mathrm{~N}$
and shear stress, $\quad \tau=\frac{F}{\text { Area }}=\frac{150}{0.64} \mathrm{~N} / \mathrm{m}^{2}$
Now using equation (1.2), we have

$$
\begin{aligned}
& \tau=\mu \frac{d u}{d y} \\
& \text { where } d u=\text { change of velocity }=u-0=u=0.3 \mathrm{~m} / \mathrm{s} \\
& d y=t=1.5 \times 10^{-3} \mathrm{~m} \\
& \therefore \quad \frac{150}{0.64}=\mu \frac{0.3}{1.5 \times 10^{-3}} \\
& \therefore \quad \mu=\frac{150 \times 1.5 \times 10^{-3}}{0.64 \times 0.3}=1.17 \mathrm{~N} \mathrm{~s} / \mathrm{m}^{2}=1.17 \times 10=11.7 \text { poise. }
\end{aligned}
$$

7. 

The dynamic viscosity of an oil, used for labrication between a shaft and sleeve i: 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

$$
\begin{aligned}
\mu & =6 \text { poise } \\
& =\frac{6}{10} \frac{\mathrm{Ns}}{\mathrm{~m}^{2}}=0.6 \frac{\mathrm{Ns}}{\mathrm{~m}^{2}} \\
D & =0.4 \mathrm{~m} \\
N & =190 \text { r.p.m } \\
L & =90 \mathrm{~mm}=90 \times 10^{-3} \mathrm{~m} \\
t & =1.5 \mathrm{~mm}=1.5 \times 10^{-3} \mathrm{~m}
\end{aligned}
$$

Dia. of shaft,
Speed of shaft,
LEEVE

Thickness of oil film,
$\mathrm{t}, \vec{u}=\frac{\pi D N}{60}=\frac{\pi \times 0.4 \times 190}{60}=3.98 \mathrm{~m} / \mathrm{s}$
Using the relation $\quad \tau=\mu \frac{d u}{d y}$
where $\quad d u=$ Change of velocity $=u-0=u=3.98 \mathrm{~m} / \mathrm{s}$
$d y=$ Change of distance $=t=1.5 \times 10^{-3} \mathrm{~m}$

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

This is shear stress on shaft
$\therefore \quad$ Shear force on the shaft, $F=$ Shear stress $\times$ Area

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

Torque on the shaft.

$$
T=\text { Force } \times \frac{D}{2}=180.05 \times \frac{0.4}{2}=36.01 \mathrm{Nm}
$$

$\therefore \quad$ *Power lost

$$
=\frac{2 \pi N T}{60}=\frac{2 \pi \times 190 \times 36.01}{60}=716.48 \mathrm{~W} . \text { Ans. }
$$

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 $120 \mathrm{~cm} / \mathrm{sec}$. 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 $=20 \mathrm{~cm}$
Velocity at vertex, $\quad u=120 \mathrm{~cm} / \mathrm{sec}$
Viscosity,
$\mu=8.5$ poise $=\frac{8.5}{10} \frac{\mathrm{Ns}}{\mathrm{m}^{2}}=0.85$.


The velocily profile is given paraborlic and equation of welocity profide is

$$
\begin{equation*}
a=a y^{2}+b y+c \tag{i}
\end{equation*}
$$

uthere $a$, b and $c$ are constants. Their values are determined from boundary cunditions as:
(a) at $y=0,[t=0$
(b) al $y=20 \mathrm{~cm}$, r $=120 \mathrm{~cm} / \mathrm{sec}$
(c) at $y=20 \mathrm{~cm} . \frac{d t}{d y}=0$.

Substituting boundiary candition (a) jin equation (i), we get

$$
c=0
$$

Boundary condition (b) on substicution in (i) eitres

$$
\begin{equation*}
120=a(20)^{2}+b(20)=400 a+20 b \tag{i}
\end{equation*}
$$

Boundary conctiaion ( r ) on suhstiution in equation ( f ) gives

$$
\begin{align*}
\frac{d t}{d y} & =2 d y+b \\
0 & =2 \times a \times 20+b=40 a+b
\end{align*}
$$

115
Solving cquations (ii) and (iif) for $a$ and $b$
From equation (iia). $\quad b=-4(\mathrm{k})$
Stbstituting this value in equation (ii), we get

$$
120=40 L a+20 \times i-4(1 a)=40)_{a r}-800 a=-400 a
$$

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

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

Suhstitutinut the values of $a$, bande in stofution (i),

$$
u=-0.3 y^{2}+12 y
$$

## Velocity Gradient

$$
\frac{d \mid s}{d y}=-0.3 \times 2 y+12=-0.6 y+12
$$


at $y=10 \mathrm{~cm} . \quad\left(\begin{array}{c}d / 4 \\ d \\ d\end{array}\right)_{,-10}=0.6 \times 10+12=-6-12+6 / \mathrm{sen} \times 5$.
A1 $v=2\left[\mathrm{~cm}_{7} \quad\left(\frac{d f t}{d y}\right)_{,-2}=-6.6 \times 26+12=-12+12=0\right.$. Ans.
Sisear Sitresses

(i) Sheatsonss at $y=0, \quad \tau-\mu\left(\frac{d a t}{d y}\right)_{y=13}=0.85 \times 12.0=10.2 \mathrm{Nim}^{2}$.
(ii) Shëtr sucss ai $y=10, \quad \tau=\mu\left(\frac{d r}{d y}\right)_{y=10}=0.85 \times 6.0-5.1 \mathrm{Nim}^{3}$.
(iii) Shear stress att $y=20 . \quad \tau=\mu\left(\frac{d u}{d y}\right)_{y-20}=0.85 \times 0=0, \frac{1}{2}+5$,
9.




(A.M.3.E., Winter 1979)

Solution. Given :
jianester of cyliruler
1)it. of outer ey jinder
lunglh or cylinglers

$$
\begin{aligned}
& =15 \mathrm{ctu}=0.1 .15 \mathrm{~m} \\
& =15.10 \mathrm{~cm}=0.1 .91 \mathrm{~m} \\
& \text { L }-25 \mathrm{ctu}=0.25 \mathrm{~m} \\
& 7=12.0 \mathrm{~N}
\end{aligned}
$$

Speed,
Let the viscosity
Tangential velocity ar cyjinder. is $=\frac{\pi / O N}{60}=\frac{\pi \times(0.15 \times 100}{60}=0.7854 \mathrm{~m} / \mathrm{s}$
Surtice atea of cylinuler. $\quad A=\pi D \times L=\pi \times 0.15 \times 0.25=.1178 \mathrm{~m}^{2}$
Now using relation

Where $\mathrm{L}_{\mathrm{t}}=\mathrm{tf}-0=\mathrm{n}=.7854 \mathrm{~m} / \mathrm{s}$

$$
\begin{aligned}
d y & =-\frac{0.51-0.150}{2} \cdot m=.01655 \\
\tau & =\frac{\mu \times .7854}{.1000 .5}
\end{aligned}
$$

10. 



 Thie ureight of the retate is to N.

Solution, Gient :


$$
\begin{aligned}
& \text { Trimue. } \quad T=F \times \frac{D}{2} \\
& 12.0=\frac{\mu \times .7854}{.0105} \times .1178 \times{ }_{2}^{.15} \\
& \therefore \quad \mu=-\frac{12.05 \times .0005 \times 2}{.7854 \times .178 \times .15}=12.864 \mathrm{~N} \mathrm{s/m} \mathrm{~m}^{2} \\
& =0.364 \times 10=8.64 \text { proise. Ans. }
\end{aligned}
$$

$\therefore$ Weight deasity of fturd

|  | $\begin{gathered} \overline{=0.9} \times 1000=900 \mathrm{kgtt} \mathrm{~m}^{3}=900 \times 9.81 \mathrm{~N}^{3} \mathrm{~m}^{3} \\ (\because 1 \mathrm{~kg}=9.81 \mathrm{~N}) \end{gathered}$ |
| :---: | :---: |
| Volume of plate | $=1.2 \mathrm{~m} \times 1.2 \mathrm{~m} \times 4.2 \mathrm{~cm}$ |
|  | $=1.2 \times 1.2 \times .0 \mathrm{x} 2 \mathrm{~m}^{3}=.00288 \mathrm{~m}^{3}$ |
| Tljekness of plate | $=0.2 \mathrm{~cm}$ |
| Velocity of plate | $=0.15 \mathrm{~m} / \mathrm{scs}$ |
| Weight of plate | $=40 \mathrm{~N}$. |

When plate is in the middle of the eap, the distance of the glate of plate from vertical surfice, of the gap


Fig. 1.6

$$
\begin{aligned}
& =\binom{\text { Widlth of gap-Thickness of plase }}{-} \\
& =\frac{(2.2-0.2)}{2}=1 \mathrm{~cm}=.01 \mathrm{~m} .
\end{aligned}
$$

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

$$
\begin{aligned}
F_{\mathrm{L}} & =\text { Shear stress } \times \text { Arch } \\
& \left.=\mu\left(\frac{d \mathrm{du}}{d y}\right)_{1} \times A \text { ren }=2.0 \times \frac{(0.15}{.11}\right) \times 1.2 \times 1.2 \mathrm{~N} \\
& =43.2 \mathrm{~N} .
\end{aligned}
$$

Simitarly, the shear force on the righe side of the meterlic plate,

$$
F_{2}=\text { Shear stress } \times \text { Afct }=2.0 \times\left(\frac{0.15}{.01}\right) \times 1.2 \times 1.2=43.2 \mathrm{~N}
$$

$\therefore$ Toral sthear force

$$
=F_{1}+F_{z}=43.2+43.2=86.4 \mathrm{~N} .
$$

In this case the weight of plate (which is acting vertically downuard) and upward thrust is also to be aiken ipto account.

The upward thtust $=$ Weight of Inaid displaced

$$
\begin{aligned}
& =(\text { Weip }) \text { density of fluid }) \times \text { Volume of fluid displaced } \\
& =9.81 \times 900 \times .00288 \mathrm{~N} \\
& \quad(\because \text { Volume of חuid displaced }=\text { Voluane of plate }=.09288) \\
& =25.43 \approx .
\end{aligned}
$$

The net force acting in the downward dieection due to weight of the plate and uphard thrust

$$
=\text { Weight of plate }- \text { Upward thrust }=40-25.43=14.57 \mathrm{~N}
$$

$\therefore$ Total force required to lift the plate up

11.

A square plate of size $1 \mathrm{~m} \times 1 \mathrm{~m}$ and weighing 350 N slides down an inclined plane with a uniform velocity of $1.5 \mathrm{~m} / \mathrm{s}$. The inclined plane is laid on a slope of 5 vertical to 12 horizontat and has an oil film of 1 mm thickness. Calculate the dynamic viscosity of oil.
[J.N.T.U. Hyderabad, S 2002]
[ Hint. $\mathrm{A}=1 \times 1=1 \mathrm{~m}^{2}, W=350 \mathrm{~N}, \mu=1.5 \mathrm{~m} / \mathrm{s}, \tan \theta=\frac{5}{12}=\frac{\mathrm{BC}}{\mathrm{AB}}$
Component of weight along the plane $=W \times \sin \theta$
where $\sin \theta=\frac{B C}{A C}=\frac{5}{13}$

$$
\left(\begin{array}{rl}
\because \quad A C & =\sqrt{A B^{2}+B C^{2}} \\
& =\sqrt{12^{2}+5^{2}=13}
\end{array}\right)
$$

$\therefore \quad F=W \sin \theta=350 \times \frac{5}{1.3}=134.615$


Fig. 1.15

Now
$t=\mu \frac{d u}{d y}$, where $d u=u-0=u=1.5 \mathrm{~m} / \mathrm{s}$ and

$$
d y=1 \mathrm{~mm}=1 \times 10^{-3} \mathrm{~m}
$$

or

$$
\frac{\mathrm{F}}{\mathrm{~A}}=\mu \frac{d u}{d y}, \therefore \mu=\frac{\mathrm{F}}{\mathrm{~A}} \times \frac{d y}{d u}=\frac{134.615}{\mathrm{I}} \times \frac{1 \times 10^{-3}}{1.5}=0.0897 \frac{\mathrm{Ns}}{\mathrm{~m}^{2}}=0.897 \text { poise Ans.] }
$$

12. 

$$
\begin{aligned}
& \text { and ithront dianle } \\
& \text { late che discharge of ois thrnugh the horizortad venturimeter. Take } C_{n}=0.98 \text {. } \\
& \text { Solution. Given: } \\
& S_{\text {p. gr of oil. }} \\
& s_{n}=0.8 \\
& \text { \$p. gr. of mercury. } \\
& S_{\text {tit }}=13.6 \\
& \text { Readinger al differential nanometer, } x=25 \mathrm{~cm} \\
& \therefore \text { Difference ol pressure berad, } t=x\left[\frac{3_{k}}{5_{11}}-1\right]
\end{aligned}
$$

$$
\begin{aligned}
& \text { Dia. at inter. } \\
& d_{1}=20 \mathrm{~cm} \\
& \therefore \quad \pi_{1}=\frac{\pi}{4} d_{1}{ }^{2}=\frac{\pi}{4} \times 20^{2}=314.16 \mathrm{~cm}^{2} \\
& d_{2}=10 \mathrm{~cm} \\
& \therefore \quad a_{2}=\frac{\pi}{4} \times 10^{2}=78.54 \mathrm{~cm}^{2} \\
& c_{d}=0.98
\end{aligned}
$$

$\therefore$ The discharge $Q$ is given by equation (6.8)
or

$$
\begin{aligned}
Q & =C_{d} \frac{a_{1} a_{2}}{\sqrt{a_{1}^{2}-7 a_{2}^{2}}} \times \sqrt{2 g h} \\
& =0.98 \times \frac{314.16 \times 78.54}{\sqrt{(314.16)^{2}-(78.54)^{2}}} \times \sqrt{2 \times 981 \times 400} \\
& =\frac{2142.1375 .68}{\sqrt{98696}-6163}=\frac{21421375.68}{304} \mathrm{~cm}^{3} / \mathrm{s} \\
& =70465 \mathrm{~cm}^{3 / 5}=70.465 \text { titres/s. Ans. }
\end{aligned}
$$

## UNIT II

FLOW THROUG CIRCULAR CONDUITS
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 = $32 \mu \mathrm{LL} / \mathrm{gD} 2$
The expression is known as Hagen poiseuille formula.
Where P1-P2 / _g = Loss of pressure head
$\mathrm{U}=$ Average velocity
$\mu=$ 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?
$h f=4 f L V^{2} / 2 g D$
Where
$\mathrm{f}=$ Coefficient of friction in pipe $\quad \mathrm{L}=$ Length of the pipe
$D=$ Diameter of pipe $\quad V=$ 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 $=(\mathrm{V} 1-\mathrm{V} 2) 2 / 2 \mathrm{~g}$
Where
he = Loss of head due to sudden enlargement of pipe .
$\mathrm{V} 1=$ Velocity of flow at section 1-1
$\mathrm{V} 2=$ Velocity of flow at section 2-2
7. Give an expression for loss of head due to sudden contraction:
$\mathrm{hc}=0.5 \mathrm{~V} 2 / 2 \mathrm{~g}$
here,
$\mathrm{c}=$ Loss of head due to sudden contraction.
$\mathrm{V}=$ Velocity at outlet of pipe.
8. Give an expression for loss of head at the entrance of the pipe:
hi $=0.5 \mathrm{~V} 2 / 2 \mathrm{~g}$
Where,
$\mathrm{hi}=$ Loss of head at entrance of pipe.
$\mathrm{V}=$ 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.
3. 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
$\mathrm{L} 1, \mathrm{~d} 1=$ 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 mand above it an oil of $\mathrm{sp}, \mathrm{gr} .0 .9$ for a depth of 1 m . Find the pressure intensity (i) at the interface of the two liquids. and fit) at the bottom of the tank.

Solution. Given:
Height of water,
Height of oil.

$$
Z_{1}=2 \mathrm{~m}
$$

Sp. gr. of oil.
Density of water,
$Z_{2}=1 \mathrm{~m}$
$S_{0}=0.9$
$\rho_{1}=1000 \mathrm{~kg} / \mathrm{m}^{3}$
$\rho_{2}=\mathrm{Sp}$. gr. of oil $\times$ Density of water $=0.9 \times 1000=900 \mathrm{~kg} / \mathrm{m}^{3}$
Pressure intensity at any point is given by


Fig. 2.4
(i) At interface, i.e., at $A$

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

$$
\begin{aligned}
p & =\rho_{2} \times g \times 1.0 \\
& =900 \times 9.81 \times 1.0 \\
& =8829 \frac{\mathrm{~N}}{\mathrm{~m}^{2}}=\frac{8829}{10^{4}}=0.8829 \mathrm{~N} / \mathrm{cm}^{2} . \text { Ans. }
\end{aligned}
$$

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

$$
\begin{aligned}
p & =\rho_{2} \times g Z_{2}+\rho_{1} \times g \times Z_{1}=900 \times 9.81 \times 1.0+1000 \times 9.81 \times 2.0 \\
& =8829+19620=28449 \mathrm{~N} / \mathrm{m}^{2}=\frac{28449}{10^{4}} \mathrm{~N} / \mathrm{cm}^{2}=2.8449 \mathrm{~N} / \mathrm{cm}^{2} . \mathrm{Ans}
\end{aligned}
$$

2. 

Water in fowing sfroutgl a pipe having dianveter 300 min and 200 man as the bonom and mpper ena' respectively. Trie intensitr of presstere at the botton end is $24.525 \mathrm{~N} / \mathrm{cm}^{2}$ ond sthe pressure at she apper end is $9.81 \mathrm{~N} / \mathrm{mow}^{-}$. Domemine the differetice in dalum head if the rate of flow strrough pipe is $70 \mathrm{fit} / \mathrm{s}$.
Solution. Given:
Section I,

$$
D_{1}=300 \mathrm{mma}=0.3 \mathrm{~m}
$$

$$
p_{1}=24.525 \mathrm{~N}^{2} \mathrm{~cm}^{2}-24.525 \times 10^{4} \mathrm{~N} / \mathrm{m}^{2}
$$

Section 2,

$$
\begin{aligned}
D_{2} & =2000 \mathrm{~mm}=0.2 \mathrm{~m} \\
P_{2} & =9.81 \mathrm{~N} / \mathrm{crt}^{2}=9.81 \times 10^{4} \mathrm{~N} / \mathrm{m}^{2} \\
& =40 \mathrm{lit} / \mathrm{s}
\end{aligned}
$$

Rate of fow
or

$$
Q=\frac{40}{1000}=0.04 \mathrm{~cm}^{3} / \mathrm{si}
$$



Now

$$
A_{3} V_{1}=A_{2} V_{2}=\text { fale of flow }=0.04
$$

$\therefore \quad V_{1}=:_{A_{1}}^{i j 4}=\frac{.04}{\pi v_{1}^{2}}=\frac{0.04}{\pi}=0.56 .58 \mathrm{~m} / \mathrm{m}$

$$
=0.566 \mathrm{~m} / \mathrm{s}
$$

$$
v_{2}=\frac{0.4}{A_{2}}=\frac{04}{\pi_{4}^{\left(D_{2}\right)^{2}}}=\frac{0.04}{\pi_{4}(0.2)^{2}}=1.27+\mathrm{ms}
$$

Applying Hemoulli's cejuation at (1) and (2), we get

$$
\frac{p_{1}}{p g} \div \frac{r_{1}^{\prime}}{2 g} \cdot 1=z_{1}=\frac{p_{7}}{\rho g}+\frac{v_{2}^{\prime}}{2 g}+n_{2}
$$

or
3.

Three pipes of $400 \mathrm{~mm}, 350 \mathrm{~mm}$ 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 $200 \mathrm{~m}, 300 \mathrm{~m}$ 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

$$
Q^{2}=0.04 \quad \therefore \quad Q=0.2 \mathrm{~m}^{3 / \mathrm{g}}
$$

Using equivalent length concept and choosing 0.4 mp pipe as the base.
Refer 7.17.1

$$
\begin{aligned}
L_{2 k} & =300(0.021 / 0.024) \times(0.4 / 0.35)^{5}=511.79 \mathrm{~m} \\
L_{3 k} & =250(0.019 / 0.024) \times(0.4 / 0.3)^{5}=834.02 \mathrm{~m} \\
& =200+511.79+834.02=1545.81 \mathrm{~m} \\
12 & =\left(8 \times 0.024 \times 1545.81 \times Q^{2}\right)\left(9.81 \times \pi^{2} \times 0.4^{5}\right) \\
Q^{2} & =0.04 ; Q=0.2 \mathrm{~m}^{2} / \mathrm{Q} .
\end{aligned}
$$

4. 

$$
\begin{aligned}
& \frac{24.535 \times 10^{1}}{11100 \times 9.81}+\frac{.566 \times .561}{2 \times 9.81}+=\frac{9.81 \times 10^{4}}{10081 \times 9.81}+\frac{(1.274)^{2}}{2 \times 1.81}+2 \\
& \text { or } \quad 25+.32+z_{1}=10 \div 1.62 .3+z_{2} \\
& \text { or } \quad 25.32+z_{1}=11.62 .3+z_{2} \\
& \therefore \quad z_{i}-z_{1}=25.32-11.623=13.697=13.76 \mathrm{~m} \\
& \therefore \text { Sifference in datum head }=z,-z_{i}=13.70 \mathrm{~m}, \text { Ans. }
\end{aligned}
$$

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 $24,000 \mathrm{l} / \mathrm{min}$. Determine the flow in each pipe and also the level difference between the reservoirs.
Let the flows be designated as $\mathrm{Q}_{1}, \mathrm{Q}_{2}, \mathrm{Q}_{3}$
Then $\mathrm{Q} 1+\mathrm{Q} 2+\mathrm{Q} 3=24000 /(60 \times 1000)=0.4 \mathrm{~m}^{3} / \mathrm{s}$
Considering pipe 1 as base

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 $15 \mathrm{~N} / \mathrm{cm}^{2}$. Determine the dynamic viscosity of the oil.

$$
\begin{aligned}
& \text { Hagen-Poiseuille eqn. } \Delta p=128 \mu L Q / \pi D^{4} \\
\mu= & \Delta p \cdot \pi \cdot D^{4} / 128 L Q \\
= & 15 \times 10^{4} \times \pi \times 0.05^{4} / 128 \times 100 \times 0.0045=0.05113 \mathrm{Ns} / \mathrm{m}^{2}(\mathrm{~Pa} . \mathrm{s})
\end{aligned}
$$

(Note: $\mathrm{N} / \mathrm{cm}^{2} \rightarrow 10^{4} \mathrm{~N} / \mathrm{m}^{2}$, litre $=0.001 \mathrm{~m}^{8}$ )
Reynolds number $\quad=u D \rho / \mu, u=Q \times 4 / \pi D^{2}$

$$
\operatorname{Re}=\left(4 Q / \pi D^{2}\right) \times(D \rho / \mu)=(0.0045 \times 920 \times 4) /(\pi \times 0.05 \times 0.05113)
$$

$$
=2061.6
$$

$\therefore$ Flow is laminar but just on the verge of turning turbulent
6.

$$
\begin{aligned}
& \left.\left.\frac{Q_{2}}{Q_{1}}=\cdot \frac{f_{1}}{f_{2}} \frac{L_{1}}{L_{2}}!\frac{D_{2}}{D_{1}}\right]^{-5}\right]^{-0.5}=\left[\frac{0.021}{0.019} \times \frac{600}{800} \times\left(\frac{0.3}{0.2 \overline{5}}\right)^{5}\right]^{0.5}=1.4362 \\
& Q_{2}=1.4362 Q \text {. } \\
& \frac{Q_{3}}{Q_{1}}=\left.\left[\frac{f_{1}}{f_{3}} \frac{L_{1}}{L_{3}}: \frac{D_{3}}{D_{1}}\right)^{3^{-0.5}}\right|_{i} ^{0}=\left[\frac{0.021}{0.024} \times \frac{600}{400} \times\left(\frac{0.3 \overline{0}}{0.2 \overline{0}}\right)^{5}\right]^{0.5}=2.6569 \\
& Q_{S}=2.6669 Q . \\
& \text { Total flow }=0.4=Q_{:}-1.4362 Q_{:}-2.6669 Q_{:}=5.0931 Q \text {. } \\
& Q_{1}=0.07854 \mathrm{~m}^{3} / \mathrm{s} \\
& \mathrm{Q}_{2}=1.4362 \mathrm{Q}_{1}=0.11280 \mathrm{~m}^{3} / \mathrm{s} \\
& \mathrm{Q}_{3}=2.6569 \mathrm{Q}_{1}=0.20867 \mathrm{~m}^{3} / \mathrm{s} \\
& \text { lotal }=0.4001 \mathrm{~m}^{\mathrm{s}} / \mathrm{s}
\end{aligned}
$$

Example 6.3 A tap discharges water evenly in a jet at a velocity of $2.6 \mathrm{~m} / \mathrm{s}$ at the tap outlet, the diameter of the jet at this point being 15 mm . The jet fous doun tertically 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.

$$
\begin{aligned}
\frac{P_{1}}{i}-Z_{1}-\frac{V_{1}^{2}}{2 g} & =\frac{P_{2}}{i}-Z_{2}-\frac{V_{2}^{2}}{2 g}, \\
P_{:} & =P_{2}, Z_{2}=0, \\
Z_{2} & =-0.6 \mathrm{~m}, V_{:}=2.6 \mathrm{~m} / \mathrm{s} \\
\frac{2.6^{2}}{2 \times 9.81} & =-0.6-\frac{V_{2}^{2}}{2 \times 9.81}
\end{aligned}
$$



Figure Ex. 6.3 Problem model

$$
\therefore \quad \mathrm{V}_{2}=4.3 \mathrm{~m} / \mathrm{s}
$$

using continuity equation ione dimensional flow and noting that density is constant.

$$
\begin{aligned}
& A . V_{:}=A_{2} V_{2} \\
& \frac{\pi \times 015^{2}}{4} \times 2.6=\frac{\pi \times D^{2}}{4} \times 4.3, \quad \therefore \quad \mathbf{D}=0.01166 \mathrm{~m} \text { or } 11.66 \mathrm{~mm}
\end{aligned}
$$

As the potential energy decreases, kinetic energy incteases. As the velocity is higher the flow area is smaller.
Entrainment of air may inctease the diameter somewhat.
7.



 a d'c.s.





$$
\begin{aligned}
& \text { - 介thth mhead pf pil. }
\end{aligned}
$$

Dimension and units: Buckingham's $\Pi$ 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) $+\mathrm{gdz}+\mathrm{vdv}=0$
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?
( $\mathrm{p} 1 / \mathrm{pg}$ ) $+(\mathrm{v} 12 / 2 \mathrm{~g})+\mathrm{z} 1=(\mathrm{p} 2 / \mathrm{pg})+(\mathrm{v} 22 / 2 \mathrm{~g})+\mathrm{z} 2+\mathrm{hl}$ where hl is the loss of energy ( $\mathrm{p} / \mathrm{pg}$ )-Pressure energy. $(\mathrm{v} 2 / 2 \mathrm{~g})=$ 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 $\Pi$ theorem
3. State Buckingham's $\Pi$ 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 $\Pi$-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.
2. 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 $\Delta P$ per unit length in flow through a smooth circular pipe is found to depend on (i) the flow velocity, $u$ (iii) diameter of the pipe, $D$ (iii) density of the fluid $\rho$, and (iiv) the dynamic uiscossity $\mu$.
(a) Using $\pi$ theorem method, evaluate the dimensionless parameters for the flow.
(b) Uieng Rayleigh method (pouer index) eualuate 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 $/ \mathrm{m}, \Delta P$ | $\left(\mathrm{~N} / \mathrm{m}^{2} / \mathrm{m} / \mathrm{N}=\mathrm{kgm} / \mathrm{s}^{2}\right)$ | $M / L^{2} T^{2}$ |
| 2 | Diameter, $D$ | m | $L$ |
| 3 | Velosity, $u$ | $\mathrm{~m} / \mathrm{s}$ | $L / T$ |
| 4 | Density, $\rho$ | $\mathrm{kg} / \mathrm{m}^{3}$ | $M / L^{3}$ |
| 5 | Dynamic viscosity, $\mu$ | $\mathrm{kg} / \mathrm{ms}$ | $M / L T$ |

There are five parameters and three dimensions. Hence two $n$ terms can be obtained. As $\Delta P$ is the dependent variable $D, \rho$ and $\mu$ are chosen as repeating variables.
Let $\pi_{1}=\Delta P D{ }^{\rho} b^{b} b^{c}$, Substituting dimensions,

$$
M^{a} L^{a} T^{\square}=\frac{M}{L^{2} T^{2}} L^{a} \frac{M^{b}}{L^{3 B}} \frac{L^{e}}{T^{\varepsilon}}
$$

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

$$
\begin{aligned}
& 1+b=0 \quad \therefore b=-1,-2+a=3 b+c=0 \quad \therefore \quad a+c=-1 \\
& -2-c=0 \quad \therefore c=-2, \text { Hence } a=1 .
\end{aligned}
$$

Substituting the value of indices we obtain
$\therefore \quad \pi_{1}=\Delta P D / p u^{2} ;$
This represents the ratio of pressure forse and inertia force.
Check the dimension :

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

Let $\pi_{2}=\mu D^{a} \rho^{b} \mu^{\varepsilon}$, substituting dimensions and considering the indices of $M, L$ and $T$,

$$
\begin{gathered}
M^{0} L^{0} T^{\mathrm{a}}=\frac{M}{L T} L^{a} \frac{M^{b}}{L^{3}} \frac{L^{\varepsilon}}{T^{\varepsilon}} \\
1+b=0 \text { or } b=-1,-1+a=3 b+c=0, \quad a+c=-2,-1=c=0, \quad c=-1 \quad a=-1
\end{gathered}
$$

Substituting the value of indices,
$\begin{array}{lc}\therefore & \Gamma_{2}=\mu / u \rho D \\ \text { check, } & \frac{M}{L T} \frac{T}{L} \frac{L^{3}}{M} \frac{1}{L}=M^{0} L^{0} T^{0}\end{array}$
This term may be recognised as inverse of Reynolds number. So $\pi_{2}$ can be modified as $\pi_{2}=\rho u D / \mu$ also $\pi_{2}=(\mu D / v)$. The significance of this $\pi$ term is that it is the ratio of inertia force to viscous force. In case $D, u$ and $\mu$ had been choosen as the repeating, variables, $\pi_{1}=\Delta P D D^{2} / u \mu$ and $r_{2}=\rho D u / \mu$. The prameter $\pi_{1} / \pi_{2}$ will give the dimensionless term. $\Delta P D / \rho u^{2}$. In this case $\pi_{1}$ represents the ratio pressure forcelviscous force. This flow phenomenon isinfluenced by the three forces namely pressure force, viscous force and inertia force.

The preasure drop $\Delta P$ in flow through pipes per unit length is found to deperd on the a verage velocity $\mu$, diameter $D$, denaity of the fluid $\rho$, and viscosity $\mu$. Uaing FLT aet of dimenaiona evaluate the dimenaionleas pamameters cormelating 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, $\Delta P I$ | $\left(\mathrm{~N} / \mathrm{m}^{2} \mathrm{Vm}\right.$ | $F / L^{3}$ |
| 2 | Diameter, $D$ | m | $L$ |
| 3 | Velocity, $\mu$ | $\mathrm{m} / \mathrm{s}$ | $L / T$ |
| 4 | Density, $\rho$ | $\mathrm{kg} / \mathrm{m}^{3}$ | $F T 2 / \mathrm{L}^{4}$ |
| 5 | Viscosity, $\mu$ | $\mathrm{Ns} / \mathrm{m}^{2}$ | $F T / L^{2}$ |

As there are five variables and three dimensions, two $\pi$ terms can be obtained.
Using $D, u$ and $\rho$ as repeating parameters,
Let

$$
\pi_{1}=\Delta P d^{a} u^{b} \rho F \quad \text { or } \quad F^{\circ} L^{\circ} T^{\circ}=\frac{F}{L^{3}} L^{a} \frac{L^{b}}{T^{b}} \frac{F^{c} T^{2 e}}{L^{4 \varepsilon}}
$$

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

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

$\therefore \quad c=-1, b=-2, a=1$
Substituting the value of indices
$\therefore \quad \boldsymbol{\pi}_{1}=\mathrm{DAP} / \mathrm{pu}^{2}$
Let, $\quad \pi_{2}=\mu D^{a} u^{b} \rho^{f}, \quad$ or $\quad F^{\circ} L^{\circ} T^{\circ}=\frac{F}{L^{2}} L^{a} \frac{L^{b}}{T^{b}} \frac{F^{e} T^{2 e}}{L^{4 e}}$
Comparing the value of indices for $M, L$ and $T$
$\therefore \quad 1+c=0,-2+a+b-4 c=0,1-b+2 c=0$
Solving, $\alpha=-1, b=-1, c=-1$ substituting the values of $a, b, c, d$
$\therefore \quad \pi_{2}=\boldsymbol{\mu} / \rho u \mathrm{D}$ or $\mathrm{puD} / \mu$
$\therefore \quad \frac{D \Delta P}{\rho u^{2}}=f\left[\frac{\rho u D}{\mu}\right]$
3.

In film lub ricated journal bearings, the frictional torque is found to depend on the speed of rotation, viscosity of the oil, the load on the projected anea 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 | Fristional Tarque, t | Nm | $M L^{2} / T^{2}$ |
| 2 | Spesi, $N$ | $1 / \mathrm{s}$ | $1 / L$ |
| 3 | Load per unit area, $P$ | $\mathrm{~N} / \mathrm{m}^{2}$ | $M / L T^{2}$ |
| 4 | Diameter, $D$ | m | $L$ |
| 5 | Viscosity, $\mu$ | $\mathrm{kg} / \mathrm{ms}$ | $M L T$ |

There are five parameters and three dimensions. Hence two $\pi$ parameters can be found. Considering N, D and $\mu$ as repeating variables,

$$
\begin{aligned}
& \text { Let } \\
& \pi_{4}=\tau N^{a} D^{\dot{b}} \mu^{\varepsilon} \text { or } M^{0} L^{0} T^{0}=\frac{M L^{2}}{T^{2}} \frac{1}{T^{a}} L^{b} \frac{M^{\varepsilon}}{L^{c} T^{\varepsilon}} \\
& \therefore \quad 1+c=0,2+b=c=0,-2=a=c=0 \quad \therefore c=-1, a=-1, b=-3 \\
& \therefore \quad \boldsymbol{\pi}_{1}=\boldsymbol{N} \boldsymbol{N} \mu \mathrm{D}^{3} \quad \text { Also } \pi=\tau / \mu \nu D \quad \text { ( } \tau \text {-Torque) } \\
& \text { Let } \\
& \pi_{2}=P N^{a} D^{b} \mu^{\varepsilon} \text { or } M^{0} L^{0} T^{0}=\frac{M}{L T^{2}} \frac{1}{T^{a}} L^{b} \frac{M^{\varepsilon}}{L^{c} T^{\varepsilon}} \\
& \therefore \quad 1+c=0,-1+b-c=0,-2,-a-c=0 \\
& \therefore \quad c=-1, a=-1, b=0 \\
& \therefore \quad \boldsymbol{\pi}_{2}=\mathbf{P} / \mathbf{N} \boldsymbol{\mu}, \quad \therefore \quad \frac{\tau}{N \mu D^{3}}=f\left[\frac{P}{N \mu}\right]
\end{aligned}
$$

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

The volumie fow rate, Qover a V-notch deperde on fuid properties na mely denaity $\rho$, kinematic viacoaity $v$, and alurface tenaton $\sigma$. It is alao influenced by the angle of the notch, head of fluid over the vertex, and accelenation due to gravity. Determine the dimensionleas parameters which can cornelate the variablea.

As $\theta$, 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, $\rho$ | $\mathrm{kg} / \mathrm{m}^{3}$ | $M / L^{3}$ |
| 2 | kinematic vicosity, $v$ | $\mathrm{~m}^{2} / \mathrm{s}$ | $L^{2} / T$ |
| 3 | Surface tension, $\sigma$ | $\mathrm{N} / \mathrm{m}$ | $M / T^{2}$ |
| 4 | Head of fluid, $h$ | m | $L$ |
| 5 | Gravitational asceleration, $g$ | $\mathrm{~m}^{2} / \mathrm{s}^{2}$ | $L / T^{2}$ |
| 6 | Flow rate, $Q$ | $\mathrm{~m}^{3} / \mathrm{s}$ | $L{ }^{3} / T$ |

There are six parameters and three dimensions. So three $\pi$ terms can be identified. Considering $\rho, g$ and $h$ as repeating variables.

$$
\begin{aligned}
& \text { Let } \\
& \pi_{1}=Q \rho^{a} g^{b} h^{c} \quad \text { or } \quad M^{c} L^{c} T^{0}=\frac{L^{a}}{T} \frac{M^{a}}{L^{s a}} \frac{L^{d}}{T^{2 a}} L^{c} \\
& a=0,3-3 a+b+c=0,-1-2 b=0 \\
& b=-0.5, c=2.5 \quad \therefore \quad \pi_{1}=\mathrm{Q} / \mathrm{g}^{1 / 2} \mathrm{~h}^{5 / 2} \\
& \pi_{2}=v \rho^{a} g^{h} h^{c} \text { or } M^{0} L^{0} T^{\circ}=\frac{L^{2}}{T} \frac{M^{a}}{L^{3 a}} \frac{L^{b}}{T^{2 h}} L^{c} \\
& a=0,2-3 a+b+c=0,-1-2 b=0 \\
& b=-0.5, c=(-1.5) \quad \therefore \quad \pi_{2}=\mathbf{v} / \mathrm{g}^{\mathrm{d}} / \mathrm{h}^{3 / 2} \\
& \pi_{a}=\sigma \rho^{a} g^{b} h^{c} \text { or } M^{0} L^{0} T^{0}=\frac{M}{T^{2}} \frac{M^{a}}{L^{3 a}} \frac{L^{b}}{T^{2 \alpha}} L^{c} \\
& \therefore \quad 1+a=0,-3 a+b+c=0,-2-2 b=0 \quad \therefore \quad a=-1, b=-1, c=-2 \\
& \pi_{3}=\omega^{\sigma} \rho g^{2} \quad \therefore \quad Q=g^{3 / 2} h^{52} f\left[\frac{v}{g^{3 / 2} h^{3 / 2}}, \frac{\sigma}{\rho g^{h^{2}}}, \theta\right]
\end{aligned}
$$

Note 1 In case surface tension is not considered, $r_{3}$ will not exist. $r_{2}$ can be identified as Fieynolds number.

The capillary rise $h$ is found to be influenced by the tube diameter $D$, denaity $\rho$, gravitational acceleration g and aurface tenaton a. Determine the dimaenaionlesa parameters for the cornelation of experimental mesults.

The variables are listed below adopting MLT set of dimensions.

| S.No. | Variable | Unit | Dimension |
| :---: | :--- | :---: | :---: |
| 1 | Diameter, $D$ | m | $L$ |
| 2 | Density, $\rho$ | $\mathrm{kg} / \mathrm{m}^{3}$ | $M / L^{3}$ |
| 3 | Gravitational asceleration, $g$ | $\mathrm{~m} / \mathrm{s}^{2}$ | $L / T^{2}$ |
| 4 | Surface tension, $\sigma$ | $\mathrm{N} / \mathrm{m}$ | $M / T^{2}$ |
| 5 | Capillary rise, $h$ | m | $L$ |

There are five parameters and three dimensions and so two $\pi$ parameters can be identified. Considering $D, \rho$ and $g$ as repeating variables,

Note $\mathrm{I}_{\mathrm{r}}$, can be identified as $1 /$ Weher 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

$$
\left[\Delta P /(1 / 2) \rho u^{2}\right]_{m}=\left[\Delta P /(1 / 2) \rho u^{2}\right]_{p}
$$

$$
\therefore \quad \frac{\Delta \mathbf{p}_{m}}{\Delta \mathbf{p}_{\mathrm{p}}}=\frac{\rho_{\mathrm{m}} \mathbf{u}_{\mathrm{m}}{ }^{2}}{\rho_{\mathrm{p}} \mathbf{u}_{\mathrm{p}}{ }^{2}}, \text { As } \rho_{m}=\rho_{p} \text { and } u_{m} / u_{p}=10, \Delta P_{m} / \Delta P_{p}=10^{2}=100 .
$$

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

$$
\begin{aligned}
\frac{u_{m}}{u_{p}} & =\frac{\mu_{m}}{\mu_{p}} \times \frac{d_{p}}{d_{m}} \times \frac{\rho_{p}}{\rho_{m}}, \frac{\Delta p_{m}}{\Delta p_{p}}=\frac{\rho_{m}}{\rho_{p}}\left(\frac{\mu_{m}}{\mu_{p}} \times \frac{d_{p}}{d_{m}} \times \frac{\rho_{p}}{\rho_{m}}\right)^{2} \\
& =100 \frac{\rho_{p}}{\rho_{m}}\left(\frac{\mu_{m}}{\mu_{p}}\right)^{2}
\end{aligned}
$$

From data tables at $20^{\circ} \mathrm{C}, \rho_{\text {air }}=1.205 \mathrm{~kg} / \mathrm{m}^{3}, \mu_{\text {air }}=18.14 \times 10^{-6} \mathrm{~kg} / \mathrm{ms}$,

$$
\rho_{w}=1000 \mathrm{~kg} / \mathrm{m}^{3}, \mu_{\nu}=1.006 \times 10^{-3} \mathrm{~kg} / \mathrm{ms}
$$

$$
\therefore \quad \frac{\Delta \mathrm{P}_{\mathrm{m}}}{\Delta \mathrm{P}_{\mathrm{p}}}=100 \times \frac{1000}{1.205} \times\left(\frac{18.14 \times 10^{-6}}{1.006 \times 10^{-4}}\right)^{2}=26.98
$$

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

$$
\begin{aligned}
& \text { Let } \quad \pi_{1}=h D^{a} \rho^{\phi} g^{e} \text { or } M^{\circ} L^{\circ} T^{v}=L L^{a} \frac{M^{\dot{\alpha}}}{L^{3 a}} \frac{L^{\varepsilon}}{T^{2 \varepsilon}} \\
& \therefore \quad b=0,1+a-3 b+c=0,-2 c=0 \\
& \therefore \quad a=-1, b=0, c=0 \quad \therefore \boldsymbol{\pi}_{1}=\mathbf{h} / \mathbf{D} \\
& \text { Let } \quad \pi_{2}=\sigma D^{p} \rho^{\phi} g^{e} \quad \text { or } \quad M^{0} L^{\circ} T^{0}=\frac{M}{T^{2}} L^{a} \frac{M^{d}}{L^{3 a}} \frac{L^{e}}{T^{2 \varepsilon}} \\
& \therefore \quad 1+b=0, a-3 b+c=0,-2-2 c=0 \quad \therefore b=-1, c=-1 \text {, and } a=-2 \\
& \therefore \quad \boldsymbol{\pi}_{2}=\boldsymbol{\sigma} / \mathrm{D}^{2} \mathrm{~g} \boldsymbol{\rho}, \mathrm{~g} \rho \text { can also be considered as specific weight } \gamma \\
& \frac{h}{D}=f\left[\frac{\sigma}{D^{2} \gamma}\right],
\end{aligned}
$$

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 $3.6 \mathrm{~m} / \mathrm{s}$. The pressure drop over a length of 3 m was measured as 940 mm water column. Determine the corresponding flow veloclty of air in the larger duct and also the pressure drop over 90 m length Kinematic viscosity of air $=14.58 \times 10^{-8} \mathrm{~m}^{2} / \mathrm{s}$. Density $=1.23 \mathrm{~kg} / \mathrm{m}^{8}$. Kinematic viscosity of water $=1.18 \times$ $10^{-4} \mathrm{~m}^{2 / \mathrm{s}}$

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

For square section hydraulic mean diameter $=4 \mathrm{~A} / P=4 a^{2} / 4 a=a$ (side itself)

$$
R e=u D / v=3.6 \times 0.05 / 1.18 \times 10^{-6}=152542
$$

For air

$$
152542=\frac{1 \times u}{14.58 \times 10^{-\varepsilon}} \quad \therefore \quad u=2.224 \mathrm{~m} / \mathrm{s}
$$

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

$$
\frac{F_{a i r}}{F_{w}} \frac{\rho_{a i r} u_{a i r}}{\rho_{w} u_{w}^{2}}
$$

The pressure drop equals the shear force over the area. For square section, area $=a^{2}$, perimeter $=4 a$ $k m p h$ is to be evaluated by a $1 / 8$ scale model tested in a pressurised wind tunnel maintaining similarity. The conditions at the flight al titude are temperature $=-1^{\circ} \mathrm{C}$, pressure $=75 \mathrm{kN} / \mathrm{m}^{2}$.

$$
\mu=17.1 \times 10^{-8} \mathrm{~kg} / \mathrm{ms} \text {. The test conditions are } 2150 \mathrm{kN} / \mathrm{m}^{2} \text {, and } 15^{\circ} \mathrm{C} \text {. }
$$

$\mu=18.1 \times 10^{-8} \mathrm{~kg} / \mathrm{ms}$. The drag resistance an the model measured at $18 \mathrm{~m} / \mathrm{s}$ and $27 \mathrm{~m} / \mathrm{s}$. are 4.7 N and 9.6 N . Determine the drag on the prototype.

At the given flight conditions, Velocity of sound is

$$
C=\sqrt{g_{0}^{k R T}}=\sqrt{1 \times 1.4 \times 287 \times 272}=380 \mathrm{~m} / \mathrm{s}=1190 \mathrm{kmph}
$$

$$
\text { Mach number } \quad=290 / 1190=0.24<0.3
$$

Hence Reynolds number similarity only need be considered.
Density at test conditions $=2150 \times 10^{9} /(287 \times 288)=26.01 \mathrm{~kg} / \mathrm{m}^{3}$
Density at flight conditions $=75 \times 10^{3} /(287 \times 272)=0.961 \mathrm{~kg} / \mathrm{m}^{3}$
Equating Reynolds numbers, assuming length $L$,
Velocity at flight condition $=290000 / 3600=80.56 \mathrm{~m} / \mathrm{s}$

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

This is also low subsonic. Drag can be obtained using drag coefficient $F \gamma_{\rho} A u^{2}$

$$
\begin{aligned}
\frac{F_{m}}{\rho_{m} A_{m} u_{m}^{2}} & =\frac{F_{F}}{\rho_{p} A_{p} u_{F}^{2}} \quad \therefore \frac{F_{F}}{F_{m}}=\frac{\rho_{p}}{\rho_{m}} \times\left(\frac{u_{p}}{u_{m}}\right)^{2} \times \frac{A_{p}}{A_{m}} \\
& =\frac{26.01}{0.961} \times\left(\frac{80.56}{25.185}\right)^{2} \times 8^{2}=24.165
\end{aligned}
$$

By interpolation using equality of $F / u^{2}$, drag at $25.195 \mathrm{~m} / \mathrm{s}$ model speed is obtained as 8.78 N. $\quad \therefore$ Drag on prototype $=8.78 \times 24.165=212 \mathrm{~N}$

$$
\begin{aligned}
& \Delta P=\frac{4 F L}{a}, \Delta P_{\text {air }}=\frac{4 F_{\text {air }} L_{\text {air }}}{a_{\text {air }}}, \Delta P_{w n} \frac{4 F_{w} L_{w}}{a_{w}} \\
& \text { Dividing and substituting for } F_{\text {air }} / F_{w} \\
& \frac{\Delta P_{\text {air }}}{\Delta P_{w}}=\frac{L_{\text {air }}}{L_{w}} \times \frac{a_{w}}{a_{\text {air }}} \times \frac{F_{\text {air }}}{F_{w}}=\frac{L_{\text {air }}}{L_{w}} \times \frac{a_{w}}{a_{\text {air }}} \times \frac{\rho_{\text {air }}}{\rho_{w}}\left(\frac{u_{\text {air }}}{u_{w}}\right)^{2} \\
& =\frac{90 \times 0.05^{2} \times 123}{1 \times 3 \times 1000}\left(\frac{2.224}{3.6}\right)^{2}=3.521 \times 10^{-5} \\
& \Delta \mathrm{P}_{\text {sir }}=940 \times 3.521 \times 10^{-6}=0.033 \mathrm{~mm} \text { of water column }
\end{aligned}
$$

A water tunnel operates with a velocity of $3 \mathrm{~m} / \mathrm{s}$ at the test section and power requined was 3.75 kW . If the tunnel is to operate with air, determine for similltude the flow velocity and the power required.

$$
\rho_{a}=1.25 \mathrm{~kg} / \mathrm{m}^{3}, v_{a}=14.8 \times 10^{-6} \mathrm{~m}^{2} / \mathrm{s}, \quad v_{w}=1.14 \times 10^{-6} \mathrm{~m}^{2} / \mathrm{s}
$$

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

$$
\begin{aligned}
\frac{u_{a}}{v_{a}} & =\frac{u_{w}}{v_{w}} \\
\therefore \text { Velocity of air, } \quad u_{a} & =\frac{u_{w}}{v_{w}} v_{a}=\frac{3 \times 14.8 \times 10^{-4}}{1.14 \times 10^{-6}}=38.95 \mathrm{~m} / \mathrm{s}
\end{aligned}
$$

Power can be determined from drag coefficient, by multiplying and dividing by $u$ as

$$
\begin{aligned}
& F \times u \text { power } \quad \frac{F \times u}{\rho A u^{2} u}=\frac{P}{\rho A u^{3}} \quad \text { As } A \text { is the same, } \\
& P_{\text {air }}=P_{w} \frac{\rho_{\text {air }}}{\rho_{w}} \frac{u_{\text {air }}{ }^{3}}{u_{w}{ }^{3}}=3.75 \times \frac{1.28}{1000} \times\left(\frac{38.95}{3}\right)^{3}=10.5 \mathrm{~kW}
\end{aligned}
$$

10. 

The wave resistance of a ship when travelling at $12.5 \mathrm{~m} / \mathrm{s}$ 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 $=1025 \mathrm{~kg} / \mathrm{m}^{8}$.

Froude number similarity is to be maintained.

$$
\mathrm{u}_{\mathrm{m}}=u_{p} \sqrt{\frac{L_{m}}{L_{p}}}=12.5 \sqrt{\frac{1}{40}}=1.976 \mathrm{~m} / \mathrm{s}
$$

The wave resistance is found to vary as given below.

$$
\begin{aligned}
\frac{F_{m}}{\rho_{m} u_{m}{ }^{2} L_{m}{ }^{2}} & =\frac{F_{F}}{\rho_{F}{ }^{u_{F}{ }^{2} L_{F}{ }^{2}}} \\
\mathrm{~F}_{\mathrm{p}} & =F_{m} \times \frac{\rho_{F}}{\rho_{m}}\left(\frac{u_{F}}{u_{m}}\right)^{2}\left(\frac{L_{p}}{L_{m}}\right)^{2}=16 \times \frac{1025}{1000}\left(\frac{12.5}{1.976}\right)^{2}(40)^{2} \\
& =1049.6 \times 10^{3} \mathrm{~N} \quad \text { or } \quad 1050 \mathrm{kN}
\end{aligned}
$$

UNIT IV ROTO DYNAMIC MACHINES
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 $\mathrm{Cv}=0.98, \varphi=0.46$, Blade velocity coefficient is 0.9 . If the bucket outlet angle proposed is $165^{\circ}$ check for the validity of the assumed efficiency.

First flow rate is calculated

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

Jet velocity is next calculated

$$
V_{j}=0.98 \sqrt{2 \times 9.81 \times 335}=79.45 \mathrm{~m} / \mathrm{s}
$$

Blade velocity $\quad u=0.46 \times 79.45=36.55 \mathrm{~m} / \mathrm{s}$
Runner diameter $\quad D=\frac{36.55 \times 60}{\pi \times 500}=1.4 \mathrm{~m}$
Jet diameter assuming single jet,

$$
\begin{aligned}
& d=\left(\frac{Q \times 4}{\pi V_{j}}\right)^{0.5}=\left(\frac{5.484 \times 4}{\pi \times 79.45}\right)^{0.5}=0.296 \mathrm{~m} \\
& \frac{D}{d}=\frac{14}{0.296}=4.72, \text { not suitable should be at least } 10 .
\end{aligned}
$$

Assume 4 jets, then

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

may be suggested

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

Dimensionless $N_{s}=0.0208 \quad \therefore$ acceptable
Such units are in operation in Himachal Pradesh.


The velocity diagrams are given above

$$
\begin{array}{lrl} 
& V_{u 1}=79.45, V_{u 2}=38.16-36.55=1.61 \mathrm{~m} / \mathrm{s} \\
\therefore \quad \mathrm{~W} / \mathrm{kg} & =36.55(79.45+1.61)=2962.9 \mathrm{Nm} / \mathrm{kg} \\
& \eta_{H} & =2962.9(9.81 \times 335)=0.9 \text { or } 90 \%
\end{array}
$$

Assumed value is lower as it should be because, overall efficiency < hydraulic efficiency.
2. The jet velocity in a pelton turbine is $65 \mathrm{~m} / \mathrm{s}$. The peripheral velocity of the runner is $25 \mathrm{~m} / \mathrm{s}$. The jet is deflected by $160^{\circ}$ by the bucket. Determine the power developed and hydraulic efficiency of the turbine for a flow rate of $0.9 \mathrm{~m}^{3} / \mathrm{s}$. The blade friction coefficient is 0.9 .

$$
\begin{aligned}
V_{1} & =V_{u 1}=65 \mathrm{~m} / \mathrm{s} \\
u & =25 \mathrm{~m} / \mathrm{s} \\
V_{r 1} & =65-25=40 \mathrm{~m} / \mathrm{s} \\
V_{r 2} & =0.9 \times V_{r 1}=36 \mathrm{~m} / \mathrm{s}
\end{aligned}
$$

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

$$
\begin{aligned}
V_{u 2} & =36 \cos 20-25 \\
& =33.83-25=8.83 \mathrm{~m} / \mathrm{s}
\end{aligned}
$$



In the opposite direction of $V_{u 1}$ hence addition

$$
\begin{aligned}
& \qquad \begin{aligned}
P & =900 \times 25(65+8.83)=1.661 \times 10^{6} \mathrm{~W} \\
\boldsymbol{\eta}_{\mathbf{H}} & =\frac{1661 \times 10^{6} \times 2}{900 \times 65^{2}}=87.37 \% \\
& =m \frac{V_{2}^{2}}{2} \\
\text { Exit loss } \quad V_{2}^{2} & =36^{2}+25^{2}-2 \times 36 \times 25 \times \cos 20=229.55
\end{aligned}
\end{aligned}
$$

$\therefore \quad$ Exit loss of power $=\frac{900 \times 229.35}{2}=103.3 \times 10^{3} \mathrm{~W}$
3. A Pelton turbine is to produce 15 MW under a head of 480 m when running at 500 rpm . If $\mathrm{D} / \mathrm{d}=10$, determine the number of jets required.

$$
\text { Assume } \begin{aligned}
\eta_{0} & =85 \%, C_{v}=0.97, \phi=0.46 \\
Q & =\frac{15 \times 10^{6}}{0.85 \times 1000 \times 9.81 \times 480}=3.75 \mathrm{~m}^{3} / \mathrm{s} \\
V_{j} & =0.97 \sqrt{2 \times 9.81 \times 480}=94.13 \mathrm{~m} / \mathrm{s} \\
u & =0.46 \times 94.13=43.3 \mathrm{~m} / \mathrm{s} \\
D & =\frac{43.3 \times 60}{\pi \times 500}=1.65 \mathrm{~m} . \\
d & =0.165 \mathrm{~m}
\end{aligned}
$$

Volume flow in a jet $=\frac{\pi \times 0.165^{2}}{4} \times 94.13=2.01 \mathrm{~m}^{3} / \mathrm{s}$ Total required $=3.75 . \quad \therefore$ Two jets will be sufficient. The new diameter of the jets

$$
\begin{aligned}
& d^{\prime}=\left(\frac{4 \times 3.75}{2 \times \pi \times 94.13}\right)^{0.5}=0.1593 \mathrm{~m} \\
& N_{s}=\frac{500}{60} \cdot \frac{\sqrt{15 \times 10^{6}}}{480^{5 / 4}}=14.37
\end{aligned}
$$

4. The outer diameter of a Francis runner is 1.4 m . The flow velocity at inlet is 9.5 $\mathrm{m} / \mathrm{s}$. The absolute velocity at the exit is $7 \mathrm{~m} / \mathrm{s}$. The speed of operation is 430 rpm. The power developed is 12.25 MW , with a flow rate of $12 \mathrm{~m} 3 / \mathrm{s}$. 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 $\quad u_{1}=\frac{\pi D N}{60}=\frac{\pi \times 430 \times 14}{60}=31.52 \mathrm{~m} / \mathrm{s}$
As $\quad V_{u 2}=0$,
Power developed $\quad=\dot{m} V_{u 1} u_{1}$

$$
12.25 \times 10^{6}=12 \times 10^{3} \times V_{u 1} \times 31.52
$$

Solving

$$
\begin{aligned}
& V_{u 1}=32.39 \mathrm{~m} / \mathrm{s} \\
& V_{u 1}>u_{1}
\end{aligned}
$$


$\therefore \quad$ The shape of the inlet
Velocity triangle is as given. Guide blade angle $\alpha_{T}$

$$
\begin{aligned}
\tan \alpha_{1} & =\frac{9.5}{32.39} \quad \therefore \alpha_{1}=16.35^{\circ} \\
V_{1} & =\left(V_{f 1}^{2}+V_{u 1^{2}}^{2}\right)^{0.5}=\left[9.5^{2}+32.39^{2}\right]^{0.5}=33.75 \mathrm{~m} / \mathrm{s}
\end{aligned}
$$

Blade inlet angle $\beta_{1}$

$$
\tan \beta_{1}=9.5 /(32.39-31.52)
$$

$$
\therefore \quad \beta_{1}=84.77^{\circ}
$$

Total head $=115 \mathrm{~m}$. head equal for Euler work $=\dot{m} V_{u 1} u_{1} / g$

$$
=\frac{32.39 \times 3152}{9.81}=104.07 \mathrm{~m}
$$

Head loss in the absolute velocity at exit

$$
\begin{aligned}
& =\frac{7^{2}}{2 \times 9.81}=2.5 \mathrm{~m} \\
\therefore \quad & \text { Loss of head }
\end{aligned}=115-104.07-2.5=8.43 \mathrm{~m}
$$

$$
\mathrm{N}_{5}=\frac{430}{60} \cdot \frac{\sqrt{12.25 \times 10^{6}}}{115^{125}}=223.12
$$

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 $8.1 \mathrm{~m} / \mathrm{s}$. The whirl velocity at outlet is zero. The outlet blade angle is $16^{\circ}$. Assume $\eta_{H}=90 \%$. Determine, power, speed and blade angle at inlet and guide blade angle.

The outlet velocity diagram is a right angled triangle as shown
$V_{f 2}=V_{f 1} \times D_{1} \mathbf{b}_{1} / D_{2} b_{2}$

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

$$
\therefore \quad u_{2}=8 / \tan 16=27.9 \mathrm{~m} / \mathrm{s}
$$

$$
\frac{\pi D_{2} N}{60}=u_{2}, \frac{\pi \times 12 \times N}{60}=27.9
$$



Solving $N=444 \mathrm{rpm}$

$$
\begin{aligned}
& \mathbf{u}_{1}=\frac{\pi D_{1} N}{60}=\frac{\pi \times 2 \times 266.4}{60}=46.5 \mathrm{~m} / \mathrm{s} \\
& \eta_{H}=\frac{u_{1} V_{u 1}}{g H}, V_{u 1}=\frac{0.9 \times 9.81 \times 120}{46.5}=22.8 \mathrm{~m} / \mathrm{s} \\
& u_{1}>V_{u 1} .
\end{aligned}
$$

The shape of the inlet triangle is shown.

$$
\begin{aligned}
\tan \alpha_{1} & =\frac{V_{f 1}}{V_{u 1}}=\frac{8.1}{22.8} \\
\therefore \quad \alpha_{1} & =19.55^{\circ} \\
\therefore \quad \tan \left(180-\beta_{1}\right) & =\frac{V_{f 1}}{u_{1}-V_{u 1}}=\frac{8.1}{46.5-22.8} \\
\boldsymbol{\beta}_{1} & =161^{\circ} \\
\text { Flow rate } & =\pi D_{1} b_{1} V_{f 1}=\pi \times 2 \times 0.16 \times 8.1=8.143 \mathrm{~m}^{3} / \mathrm{s} \\
\text { Power } & =0.9 \times 120 \times 9.81 \times 8.143 \times 10^{3} / 10^{3}=8627 \mathrm{~kW} \\
\mathrm{~N}_{5} & =\frac{444}{60} \frac{\sqrt{8627 \times 10^{2}}}{120^{5 / 4}}=54.72
\end{aligned}
$$

6. In an inward flow reaction turbine the working head is 10 m . The guide vane outlet angle is $20^{\circ}$. The blade inlet angle is $120^{\circ}$. 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

$$
\begin{align*}
& V_{u}=V_{1} \cos 20=0.9397 V_{1}  \tag{1}\\
& V_{f}=V_{1} \sin 20=0.3420 V_{1} \tag{2}
\end{align*}
$$

is avaivable, the method adoped is as below.

$$
\begin{equation*}
u=V_{u}+\frac{V_{f}}{\tan 60}=0.9397 V_{1}+\frac{0.342 V_{1}}{1732}=1.1372 V_{1} \tag{3}
\end{equation*}
$$

Work done $=$ headlosses (all expressed as head)

$$
\frac{u \cdot V_{u}}{g}=H-\frac{V_{f}^{2}}{2 g}
$$

$$
\frac{11372 \times 0.9397}{9.81} \cdot V_{1}^{2}=10-\frac{0.342^{2} V_{1}^{2}}{2 \times 9.81}
$$

$0.10893 V_{1}{ }^{2}+0.00596 V_{1}{ }^{2}=10$


$$
\begin{array}{ll}
\therefore & V_{1}=\left[\frac{10}{0.1093+0.00596}\right]^{0.5}=9.33 \mathrm{~m} / \mathrm{s} \\
\therefore & u=1.1372 \times 9.33=10.61 \mathrm{~m} / \mathrm{s} \\
& V_{u 1}=0.9397 \times 9.33=8.767 \mathrm{~m} / \mathrm{s} \\
& \eta_{\mathrm{H}}=\frac{10.61 \times 8.767}{9.81 \times 10}=0.9482 \text { or } 94.82 \%
\end{array}
$$

7. A Kaplan turbine plant develops 3000 kW under a head of 10 m . While running at 62.5 rpm . The discharge is $350 \mathrm{~m} 3 / \mathrm{s}$. 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.

$$
\begin{array}{ll}
\text { Hub diameter } & =0.43 \times 7.5=3.225 \mathrm{~m} \\
\text { Turbine efficiency } & =P / \rho Q H g
\end{array}
$$

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

$$
\begin{aligned}
& \text { Specific speed }=\frac{60}{60} \cdot \frac{\sqrt{30,000 \times 10^{3}}}{10^{1.25}}=308 \\
& \text { Runner tip speed }=\frac{\pi \times 7.5 \times 60}{60}=23.56 \mathrm{~m} / \mathrm{s} \\
\therefore & \text { Speed ratio }=23.56 / \sqrt{2 \times 9.81 \times 10}=1.68 \\
\therefore & \text { Flow velocity }=\frac{350 \times 4}{\pi\left(7.5^{2}-3.225^{2}\right)}=9.72 \mathrm{~m} / \mathrm{s} \\
\therefore & \text { Flow ratio }=9.72 / \sqrt{2 \times 9.81 \times 10}=0.69 .
\end{aligned}
$$

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 $140 \mathrm{~m}^{3} / \mathrm{s}$.
$\rho Q g H \eta_{0}=$ power delivered

$$
\begin{aligned}
& \therefore \quad H=30 \times 10^{6} / 1000 \times 9.81 \times 140 \times 0.85=25.7 \mathrm{~m} \\
& \text { Power developed }=\text { Power available from fluid } \times \eta_{H} \\
& \text { At midradius } \quad=\frac{30}{0.85} \times 10^{6} \times 0.93=32.82 \mathrm{~kW} \\
& u=\pi \times \frac{D \times N}{60}=\frac{\pi \times 3.5 \times 175}{60}=32.07 \mathrm{~m} / \mathrm{s} \\
& \dot{m} u_{1} V_{u 1}=32.82 \times 10^{6}=140 \times 10^{3} \times 32.07 \times V_{u 1} \\
& \therefore \quad V_{u 1}=7.14 \mathrm{~m} / \mathrm{s} \\
& \text { (note } u_{1} V_{1}=\text { constant at all radii) } \\
& V_{f}=4 \times 140 / \pi\left(5^{2}-2^{2}\right)=8.5 \mathrm{~m} / \mathrm{s} \\
& V_{u}<u \text {, } \\
& \therefore \text { The velocity diagram is as given } \\
& \tan \left(180-\beta_{1}\right)=\frac{V_{f}}{u-V_{u}}=\frac{8.5}{32.07-7.14}
\end{aligned}
$$

$\therefore \quad 180-\beta=18.82^{\circ}$,
$18.82^{\circ}$ with - ve $u$ direction and $161.18^{\circ}$ with + ve $u$ direction
Outlet triangle is right angled as $V_{u 2}=0$,

$$
\tan \left(180-\beta_{2}\right)=\frac{8.5}{32.07}, \boldsymbol{\beta}_{2}=14.8^{\circ}
$$

with -ve $u$ direction $165.2^{\circ}$ with + ve $u$ direction

$$
\tan \alpha_{1}=\frac{8.5}{7.14} \quad \therefore \quad \boldsymbol{\alpha}_{1}=\mathbf{5 0 ^ { \circ }}
$$

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

$$
\begin{aligned}
& Q=\frac{10 \times 10^{6}}{10^{3} \times 25 \times 9.81 \times 0.85}=47.97 \mathrm{~m}^{3} / \mathrm{s} \\
& V_{f}=\frac{47.97 \times 4}{\pi\left(3^{2}-12^{2}\right)}=8.08 \mathrm{~m} / \mathrm{s}
\end{aligned}
$$

Power developed

$$
\begin{aligned}
& u V_{u 1} \dot{m}=10 \times 10^{6} / 0.90 \\
& \dot{m}=47.97 \times 10^{2} \mathrm{~kg} / \mathrm{s} \text { and } u=V_{u 1} \\
& \therefore \quad 47.97 \times 10^{3} \times u_{1}^{2}=\frac{10 \times 10^{6}}{0.9} \\
& \text { Solving } \quad u_{1}=15.22 \mathrm{~m} / \mathrm{s} \\
& \therefore \quad \tan \alpha_{1}=V_{f 1} / u_{1}=\frac{8.08}{15.22} \\
& \therefore \quad \alpha_{1}=28^{\circ} \\
& \text { At the outlet } \quad u_{2}=u_{1}, V_{f 2}=V_{f 1} \\
& \therefore \quad \tan \beta=\frac{8.08}{15.22} \\
& \therefore \quad \beta=\mathbf{2 8}{ }^{\circ} \\
& \frac{\pi D N}{60}=15.22 \\
& \therefore \quad N=\frac{15.22 \times 60}{\pi \times 3}=96.9 \mathrm{rpm}
\end{aligned}
$$

10. Explain about pelton wheel, Francis and Kaplan turbines

## PELTON TURBINE



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 $5-80 \mathrm{~m}$ 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.

12. The following details refer to a centrifugal pump. Outer diameter: 30 cm . Eye diameter : 15 cm . Blade angle at inlet : $30^{\circ}$. Blade angle at outlet : $25^{\circ}$. Speed 1450 rpm . The flow velocity remains constant. The whirl at inlet is zero. Determine the work done per $\mathbf{k g}$. If the manometric efficiency is $82 \%$, determine the working head. If width at outlet is 2 cm , determine the power $\eta_{\mathrm{o}}=76 \%$.

$$
\begin{aligned}
& u_{1}=\frac{\pi \times 0.3 \times 1450}{60}=22.78 \mathrm{~m} / \mathrm{s} \\
& u_{2}=11.39 \mathrm{~m} / \mathrm{s}
\end{aligned}
$$

From inlet velocity diagram.

$$
\begin{aligned}
V_{f 1} & =u_{1} \tan \beta_{1} \\
& =11.39 \times \tan 30=6.58 \mathrm{~m} / \mathrm{s}
\end{aligned}
$$



From the outlet velocity diagram,

$$
V_{u 2}=u_{1}-\frac{V_{f 2}}{\tan \beta_{2}}=22.78-\frac{6.58}{\tan 25}=8.69 \mathrm{~m} / \mathrm{s}
$$

Work done per kg $\quad=u_{2} V_{u 2}=22.78 \times 8.69$

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

$$
\eta_{m}=0.82=\frac{g H}{197.7}
$$

$\therefore \quad H=16.52 \mathrm{~m}$
Flow rate $=\pi \times 0.3 \times 0.02 \times 6.58=0.124 \mathrm{~m}^{3} / \mathrm{s}$


Power $=\frac{0.124 \times 10^{3} \times 9.81 \times 16.52}{0.76 \times 10^{3}}=26.45 \mathrm{~kW}$.
13. The dimensionless specific speed of a centrifugal pump is 0.06 . Static head is 30 m . Flow rate is $50 \mathrm{l} / \mathrm{s}$. 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 $120^{\circ}$. 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

$$
\begin{aligned}
& =\frac{0.05 \times 4}{\pi \times 0.15^{2}}=2.83 \mathrm{~m} / \mathrm{s} \\
& =\frac{f l V^{2}}{2 g D}+\frac{4 V^{2}}{2 g} \\
& =\frac{0.02 \times 55 \times 2.83^{2}}{2 \times 9.81 \times 0.15}+\frac{4 \times 2.83^{2}}{2 \times 9.81}=4.63 \mathrm{~m}
\end{aligned}
$$

Total head against which pump operates $=34.63 \mathrm{~m}$
Speed is calculated from specific speed $N_{5}=N \sqrt{Q} /(\mathrm{gH})^{3 / 4}$

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

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

$$
\begin{align*}
V_{f 2} & =\frac{0.05}{0.2953 D^{2}}=0.1693 / D^{2}  \tag{1}\\
u_{2} & =\pi D N=21.23 \times \pi \times D=66.7 D  \tag{2}\\
\eta_{m} & =0.8=\frac{9.81 \times 34.63}{66.7 D \times V_{u 2}} \\
\therefore \quad V_{u 2} & =\frac{6.367}{D}
\end{align*}
$$



Outlet velocity diagram (forwerd curved)

From velocity diagram,

$$
\tan 60=\frac{V_{f 2}}{V_{u 2}-u_{2}}=\frac{0.1693}{D^{2}} \cdot \frac{1}{\left(\frac{6.367}{D}-66.7 D\right)}
$$

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 $35^{\circ}$ 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 $3 \mathrm{~m} / \mathrm{s}$. Also calculate the manometric head.

The velocity diagrams are as shown.
Consider inlet

$$
\begin{aligned}
u_{1} & =\frac{\pi \times 0.2 \times 900}{60}=9.42 \mathrm{~m} / \mathrm{s} \\
V_{f 1} & =3 \mathrm{~m} / \mathrm{s}
\end{aligned}
$$

Blade angle at inlet

$$
\begin{aligned}
& \quad \tan \beta_{1}=\frac{V_{f 1}}{u_{1}}=\frac{3}{9.42} \\
& \therefore \quad \beta_{1}=17.66^{\circ} \\
& \text { Considering outlet }
\end{aligned}
$$



$$
\begin{aligned}
& u_{2}=\frac{\pi \times 0.5 \times 900}{60}=23.56 \mathrm{~m} / \mathrm{s} \\
& V_{u 2}=u_{2}-\frac{V_{f 2}}{\tan 35}=23.56-\frac{3}{\tan 35}=19.28 \mathrm{~m} / \mathrm{s} \\
& \begin{aligned}
\tan \alpha_{2} & =\frac{3}{19.28} \\
\alpha_{2} & =8.85^{\circ} \\
V_{2} & =\sqrt{3^{2}+19.28^{2}}=19.51 \mathrm{~m} / \mathrm{s}
\end{aligned}
\end{aligned}
$$

The outlet velocity is $19.51 \mathrm{~m} / \mathrm{s}$ at an angle of $8.85^{\circ}$ to the tangent. (taken in the opposite direction of $u$ ).

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

## UNIT V POSITIVE DISPLACEMENT MACHINES

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.
$\checkmark$ Casing
$\checkmark$ Impeller
$\checkmark$ Suction pipe, strainer \& Foot valve
$\checkmark$ 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?
$\checkmark$ A cylinder with a piston, Piston rod, connecting rod and a crank.
$\checkmark$ Suction pipe, Delivery pipe.
$\checkmark$ Suction valve and

$$
\checkmark \text { Delivery valve. }
$$

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.
4. 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.
$\checkmark$ Piton or Plunger
$\checkmark$ Suction and delivery pipe
$\checkmark$ 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.
4. 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?

$$
\begin{aligned}
& \text { Theoretical flow volume } \quad \begin{aligned}
Q & =\frac{L A N}{60}=\frac{0.35 \times \pi \times 0.2^{2}}{4} \times \frac{45}{60} \\
& =8.247 \times 10^{-8} \mathrm{~m}^{3} / \mathrm{s} \text { or } 8.247 \mathrm{l} / \mathrm{s} \text { or } 8.247 \mathrm{~kg} / \mathrm{s} \\
\text { Theoretical power } \quad & =(\text { mass flow/s) } \times \text { head in } m \times g \mathrm{Nm} / \mathrm{s} \mathrm{or} \mathrm{~W} \\
& =0.9 \times 8.247 \times(20+8) \times 9.81 \\
& =2039 \mathrm{~W} \text { or } 2.039 \mathrm{~kW} \\
\text { Slip } & =\frac{Q_{t h}-Q_{a c}}{Q_{t h}}, 0.1=\frac{8.247-Q_{a c}}{8.247} \\
\therefore \quad \mathbf{Q}_{\text {actual }} & =7.422 \mathrm{l} / \mathrm{s}
\end{aligned}
\end{aligned}
$$

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 $4.7 \mathrm{l} / \mathrm{s}$. Determine the slip and the power required.

$$
\begin{aligned}
\mathbf{Q} & =\frac{L A_{1} N}{60}+\frac{L A_{2} N}{60}=\frac{L N}{60}\left[A_{1}+A_{2}\right] \\
& =\frac{0.25 \times 35}{60}\left[\frac{\pi \times 0.15^{2}}{4}+\frac{\pi}{4}\left(0.15^{2}-0.02^{2}\right)\right] \\
& =\frac{0.25 \times 35 \times \pi}{60 \times 4}\left[2 \times 0.15^{2}-0.02^{2}\right] \\
& =5.108 \times 10^{-8} \mathrm{~m}^{8} / \mathrm{s} \text { or } 5.108 \mathrm{l} / \mathrm{s} \text { or } 5.108 \mathrm{~kg} / \mathrm{s}
\end{aligned}
$$

It piston rod area is not taken into account

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

An error of $0.9 \%$ rather negligible.

$$
\begin{aligned}
\text { Slip } & =\frac{5.108-4.7}{5.108} \times 100=7.99 \% \\
& =m g h=4.7 \times 9.81 \times(14.5+6.5) \mathrm{W}=968 \mathrm{~W}
\end{aligned}
$$

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 :

$$
\begin{aligned}
\mathbf{h}_{\text {ad }} & =\frac{l}{g} \cdot \frac{A}{a} \cdot \omega^{2} r=\frac{25}{9.81} \cdot \frac{0.12^{2}}{0.09^{2}} \cdot\left(\frac{2 \pi \times 60}{60}\right)^{2} \times 0.09 \\
& =16.097 \mathrm{mt}
\end{aligned}
$$

With air vessel :

$$
h_{e d}^{\prime}=\frac{3}{9.81} \cdot \frac{0.12^{2}}{0.09^{2}} \cdot\left(\frac{2 \pi \times 60}{60}\right)^{2} \times 0.09=1.932 \mathrm{~m}
$$

Reduction $=16.097-1.932=14.165 \mathrm{~m}$
Fitting air vessel reduces the acceleration head.
Without air vessel :

$$
\text { Friction head } h_{f}=\frac{4 f l \cdot V^{2}}{2 g d}=\frac{4 f l}{2 g d}\left[\frac{A}{a} \cdot \omega r \sin \theta\right]^{2}
$$

At $\theta=90^{\circ}$

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

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

$$
\begin{aligned}
\text { Velocity } & =\frac{A L N}{60} \times \frac{4}{\pi \cdot d^{2}}=\frac{\pi \times 0.12^{2}}{4} \times \frac{0.18 \times 60 \times 4}{60 \times \pi \times 0.09^{2}} \\
& =0.102 \mathrm{~m} / \mathrm{s} \\
\text { Friction head } & =\frac{4 \times 0.02 \times 25}{2 \times 9.81 \times 0.09} \times 0.102^{2}=0.012 \mathrm{~m}
\end{aligned}
$$

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,

$$
\begin{aligned}
& =A L N / 60=\frac{\pi \times 0.14^{2}}{4} \times 0.21 \times \frac{36}{60} \\
& =1.9396 \times 10^{-3} \mathrm{~m}^{3} / \mathrm{s} \text { or } 1.9396 \mathrm{~kg} / \mathrm{s}
\end{aligned}
$$

Slip is $8 \%$
$\therefore$ Actual mass delivered $=1.9396 \times 0.92=1.784 \mathrm{~kg} / \mathrm{s}$
Total static head $=4+12=16 \mathrm{~m}$ head
Friction head in the delivery pipe:
Maximum velocity, $\quad v=\frac{A}{a} \omega r=\frac{0.14^{2}}{0.1^{2}} \times \frac{2 \pi \times 36}{60} \times 0.105=0.7758 \mathrm{~m} / \mathrm{s}$

$$
h_{f d}=\frac{f l v^{2}}{2 g d}=\frac{0.015 \times 24}{2 \times 9.81 \times 0.1} \cdot[0.7758]^{2}=0.11 \mathrm{~m}
$$

Average is, $\quad 2 / 3 \mathbf{h}_{\mathrm{fd}}=0.07363 \mathrm{~m}$
Friction head in the suction pipe;
Velocity is the same as diameters are equal

Average

$$
h_{f s}=\frac{0.015 \times 9}{2 \times 9.81 \times 0.1} \times[0.7758]^{2}=0.0414 \mathrm{~m}
$$

Total head $\quad=16+0.07363+0.02761=16.10124 \mathrm{~m}$
Theoretical Power $=1.784 \times 9.81 \times 16.1024=282 \mathrm{~W}$.
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, $\mathrm{f}=0.02$. Sketch the indicator diagram. The suction and delivery heads from atmosphere are 4 m and 16 m respectively.

$$
\begin{aligned}
& \mathbf{h}_{\text {as } \max }=\frac{l_{s}}{g} \cdot \frac{A}{a_{s}} \cdot \omega^{2} r=\frac{10}{9.81} \times \frac{0.2^{2}}{0.15^{2}}\left(\frac{2 \pi \times 32}{60}\right)^{2} \times 0.15=3.05 \mathrm{~m} \\
& \mathbf{h}_{\text {ad max }}=\frac{l_{d}}{g} \cdot \frac{A}{a_{d}} \cdot \omega^{2} r=\frac{28}{9.81} \times \frac{0.2^{2}}{0.12^{2}}\left(\frac{2 \pi \times 32}{60}\right)^{2} \times 0.15=13.35 \mathrm{~m} \\
& V_{s \max }=\frac{A}{a} \omega r=\frac{0.2^{2}}{0.15^{2}} \times \frac{2 \pi \times 32}{60} \times 0.15=0.8936 \\
& \mathbf{h}_{\mathrm{fs}}=\frac{f l_{s}}{2 g d_{s}} \cdot v_{s}^{2}=\frac{0.2 \times 10 \times 0.8436^{2}}{2 \times 9.81 \times 0.15}=0.5427 \mathrm{~m} \\
& \hline
\end{aligned}
$$

Figure P.16.9 Problem model

$$
\begin{aligned}
\mathbf{h}_{\mathrm{fd}} & =\frac{f l_{d}}{2 g d_{d}} \cdot V_{d}{ }^{2}, V_{d \max }=\frac{A}{a} \cdot \omega r=\frac{0.2^{2}}{0.12^{2}} \times \frac{2 \pi \times 32}{60} \times 0.15 \\
& =1.396 \mathrm{~m} / \mathrm{s} \\
\mathbf{h}_{\mathrm{fd} \max } & =\frac{0.02 \times 28}{2 \times 9.81 \times 0.12} \times 2.396^{2}=1.3655 \mathrm{~m} .
\end{aligned}
$$

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 $24 \mathrm{~m} . \mathrm{f}=0.02$. The speed of operation is 32 rpm . Determine the friction power with and without air vessels.

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

$$
\begin{aligned}
& =1.3963 \mathrm{~m} / \mathrm{s} \\
\mathbf{h}_{\mathrm{fs} \max } & =\frac{f l_{\mathrm{s}}}{2 g d_{\mathrm{s}}} \times v^{2}=\frac{0.02 \times 8}{2 \times 9.81 \times 0.12} \times(1.3963)^{2}=0.1325 \mathrm{~m} \\
\mathbf{h}_{\mathrm{fd} \max } & =\frac{0.02 \times 24}{2 \times 9.81 \times 0.12} \times\left(\frac{0.2^{2}}{0.12^{2}} \cdot \frac{2 \pi \times 32}{60} \times 0.15\right)^{2}=0.3975 \mathrm{~m}
\end{aligned}
$$

Total average friction head

Flow rate

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

$$
\begin{aligned}
& =\frac{A L N}{60}=\frac{\pi \times 0.2^{2}}{4} \times 0.3 \times \frac{32}{60}=5.0265 \times 10^{-3} \mathrm{~m}^{3} / \mathrm{s} \\
& =5.0265 \mathrm{~kg} / \mathrm{s}
\end{aligned}
$$

$$
\text { Friction power } \quad=5.0265 \times 9.81 \times 0.3533=\mathbf{1 7 . 4 2} \mathrm{W}
$$

When air vessels are installed,
Average velocity in suction pipe

$$
\begin{aligned}
& =\frac{A}{a} \frac{L N}{60}=\frac{0.02^{2}}{0.12^{2}} \times 0.3 \times \frac{32}{60}=0.4444 \mathrm{~m} / \mathrm{s} \\
h_{f s} & =\frac{f l_{s} v^{2}}{2 g d_{s}}=\frac{0.02 \times 8 \times 0.4444^{2}}{2 \times 9.81 \times 0.12}=0.013424 \mathrm{~m}
\end{aligned}
$$

As diameters are equal velocity are equal

$$
h_{f d}=\frac{0.02 \times 24 \times 0.4444^{2}}{2 \times 9.81 \times 0.12}=0.040271 \mathrm{~m}
$$

Friction power $\quad=5.0265 \times 9.81 \times(0.013424+0.040271)=2.65 \mathrm{~W}$
The percentage reduction is $\frac{17.42-2.65}{17.42} \times 100=84.8 \%$
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.

## 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 $\Pi$ 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.
