CE 6403 APPLIED HYDRAULIC ENGINEERING (REG -2013)

CE 6403 APPLIED HYDRAULIC ENGINEERING

SYLLABUS

1.UNIT I UNIFORM FLOW

Definition and differences between pipe flow and open channel flow - Types of Flow - Properties of open channel - Fundamental equations - Velocity distribution in open channel - Steady uniform flow: Chezy equation, Manning equation - Best hydraulic sections for uniform flow - Computation in Uniform Flow - Specific energy and specific force - Critical depth and velocity.

UNIT II GRADUALLY V ARIED FLOW

Dynamic equations of gradually varied and spatially varied flows - Water surface flow profile classifications: Hydraulic Slope, Hydraulic Curve - Profile determination by Numerical method: Direct step method and Standard step method, Graphical method - Applications.

UNIT III RAPIDLY VARIED FLOW

Application of the energy equation for RVF - Critical depth and velocity - Critical, Sub-critical and Super-critical flow - Application of the momentum equation for RVF - Hydraulic jumps - Types - Energy dissipation - Surges and surge through channel transitions.

UNIT IV TURBINES

Impact of Jet on vanes - Turbines - Classification - Reaction turbines - Francis turbine, Radial flow turbines, draft tube and cavitation - Propeller and Kaplan turbines - Impulse turbine - Performance of turbine - Specific speed - Runaway speed - Similarity laws.

UNIT V PUMPS

Centrifugal pumps - Minimum speed to start the pump - NPSH - Cavitations in pumps - Operating characteristics - Multistage pumps - Reciprocating pumps - Negative slip - Flow separation conditions - Air vessels, indicator diagrams and its variations - Savings in work done - Rotary pumps: Gear pump

1. UNIT I UNIFORM FLOW

Definition and differences between pipe flow and open channel flow - Types of Flow - Properties of open channel - Fundamental equations - Velocity distribution in open channel - Steady uniform flow: Chezy equation, Manning equation - Best hydraulic sections for uniform flow - Computation in Uniform Flow - Specific energy and specific force - Critical depth and velocity.

Introduction

Flow in rivers, irrigation canals, drainage ditches and aqueducts are some examples for open channel flow. These flows occur with a free surface and the pressure over the surface is atmospheric. The surface actually represents the hydraulic grade line. In most cases water is the fluid encountered in open channel flow. While in closed conduits the flow is sustained by pressure difference, **the driving force in open channel flow is due to gravity, and is proportional to the bed slope**. The depth of flow is not restrained and this makes the analysis more complex. As most of the flow are large in scale and as viscosity of water is lower, Reynolds number are high. Hence the flow is generally turbulent. As seen in chapter 8 and 9, Froude number is the improtant parameter in the general study of open channel flow which is free surface flow. **The balance of gravity forces and surface friction forces controls the flow.** Changes in channel cross-section and changes in the slope cause changes and readjustments in the flow depth which may or not propagate upstream.

Important Two Mark Questions with Answers

1.Define open channel.

A liquid flowing at atmospheric pressure through a passage is known as flow in open channels. The flow of water through pipes at atmospheric pressure or when the level of water in the pipe is below the top of the pipe, is also classified as open channel flow

2. What are the classifications of flow in an open channel?

- Steady and unsteady flow
- Uniform flow and non-uniform flow
- Laminar flow and turbulent flow
- Sub-critical, critical, and super critical flow

3. Define steady flow and unsteady flow.

Steady Flow

If the flow characteristics such as depth of flow, velocity of flow, rate of flow at any point in open channel flow do not change with respect to time, the flow is said to be steady flow.

$\partial v/\partial t = o$ or $\partial Q/\partial t = 0$ or $\partial y/\partial t = 0$

Unsteady Flow

If at any point in open channel flow, the velocity of flow, depth of flow or rate of flow at any point in open channel flow changes with respect to time, the flow is said to be steady flow

$\partial v/\partial t \neq o$ or $\partial Q/\partial t \neq 0$ or $\partial y/\partial t \neq 0$

4. Define Uniform flow and Non-Uniform flow.

Uniform flow

If for a given length of the channel, the velocity of flow, depth of flow, slope of the channel and cross-section remain constant, the flow is said to be uniform.

$\partial v/\partial S$, $= 0$ $\quad \partial y/\partial S = 0$

Non – uniform flow

If for a given length of the channel, the velocity of flow, depth of flow, slope of the channel and cross-section do not remain constant, the flow is said to be non - uniform flow.

$\partial v/\partial S \neq 0 \quad \partial y/\partial S \neq 0$

5. What is rapidly varied flow?

It is defined as that flow in which depth of flow changes abruptly over a small length of the channel.

6. What is gradually varied flow?

If the depth of flow in a channel changes gradually over a long length of the channel, the flow is said to be gradually varied flow.

7. What is laminar and turbulent flow?

Laminar flow

The flow in open channel is said to be laminar if the Reynolds number (Re) is than 500 or 600 Reynolds number = μ ρVR

Turbulent flow

If the Reynolds number is more than 2000, the flow is said to be turbulent in open channel flow.

8. What is TRANSITION state?

If the Re lies between **500 to 2000**, the flow is considered to be in transition state.

9. Give a brief note on frude number ,Sub-critical, Critical, Super critical flow.

Fe = V/√ (g D)
critical:

The flow in open channel is said to be critical if the Froude number is 1.

Sub-critical, :

The flow in open channel is said to be super critical if the Froude number is less than one.

Super critical flow:

The flow in open channel is said to be super critical if the Froude number is greater than

10. Give the formula relating to velocity and discharge in chezy's formula.

Velocity V = C √mi Discharge

Q = A C√ (mi)

11. Give the BAZIN, GANGUILLET-KUTTER, MANNINGS formulas for chezy's constant. a)

Bazin formula

$$C = \frac{157.6}{1.81 + \frac{K}{\sqrt{m}}}$$

b) ganguillet-kutter formula

$$C = \frac{23 + \frac{0.00155}{i} + \frac{1}{N}}{1 + (23 + \frac{0.00155}{i})\frac{N}{\sqrt{m}}}$$

c) Manning's formula

$$C = \frac{1}{N} m^{\frac{1}{6}}$$

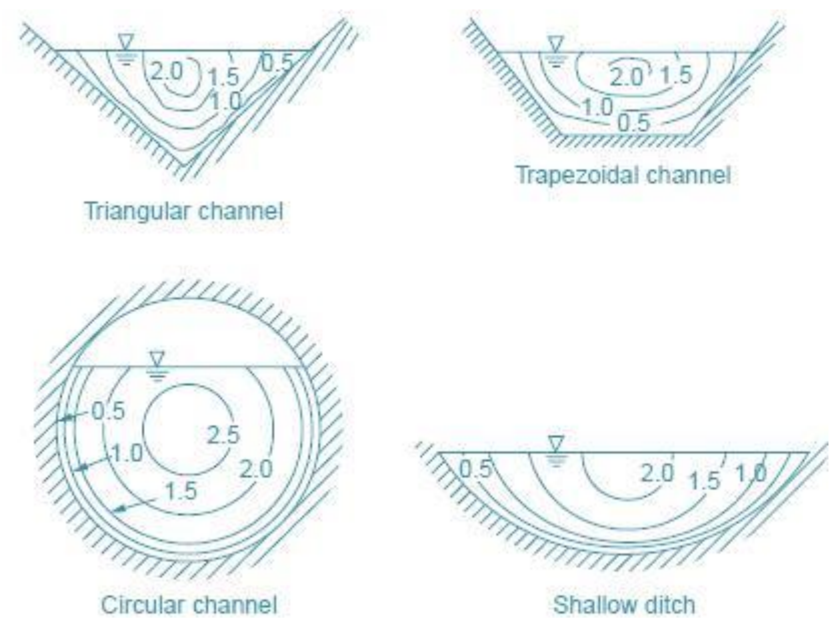
12. Give the formula for total energy

$$\text{TOTAL ENERGY} = z + h + \frac{V^2}{2g}$$

13. Define specific energy.

It is defined as energy per unit weight of the liquid with respect to the bottom of the channel.

14. Draw the Velocity distribution in open channel sections



15. Define uniform flow. Give examples.

Uniform flow is a fluid flow in which the velocity of any given instant does not change both in magnitude and direction with respect to space. Mathematically,
Example:
Flow through uniform diameter pipe.

16. What are the instruments used for measuring velocity in open channels? [May’06, May’07May’08& May’09]

Velocity of flow is measured by various instruments such as Pitot tube, Current meter, hot wire anemometer, floats and Laser Doppler velocimetry.

17. List the factors affecting Manning’s roughness coefficient. [Nov’08] The following factors affecting Manning’s roughness coefficient are:

1. Surface roughness

2. Vegetation growth

3. Channel irregularities

4. Sitting and scouring

5. Stage (water surface elevation) and discharge

6. Transport of suspended and bed material.

18. What are the condition for obtaining most economical circular channel section for maximum velocity and discharge?

a. Condition for maximum velocity of circular section

(i) Depth of flow is 0.81 times the diameter of the circular channel.

(ii) Hydraulic radius is equal to 0.3 times the diameter of channel.

(iii) Angle subtended by water surface from the centre, 20=257030'

b. Condition for maximum discharge of circular section

(iv) Depth of flow is 0.91 times the diameter of the circular channel.

(v) Hydraulic radius is equal to 0.286 times the diameter of channel.

(vi) Angle subtended by water surface from the centre, 20=3080.

19. Define non-erodible channels.

Channels which are constructed from materials, such as concrete, masonry and metal can withstand erosion under all including most extreme conditions are called as non-erodible sections.

20. Distinguish between open channel flow and conduit flow. (Nov/Dec 2010)

Open channel flow	**Conduit channel**
✓ Flow is due to gravity force only at the expense of potential energy. ✓ Cross section can be of any shape ✓ HGL free water z + h surface ✓ It exposed to atmosphere	✓ Flow takes place due to hydraulic pressure. ✓ Generally circular cross section ✓ HGL is z + ρ / ρg ✓ Water confined within conduit

21. What are wide channels? (Nov/Dec 2010)

Channels with large aspect ratio is called wide open channel.

Aspect ratio (B /y) > 10.

22. Mention the significance of Manning's formula. (Nov/Dec 2010)

$$V = (1/n)\, R^{2/3} S^{1/2}$$

Manning's roughness co-efficient n not only denotes the roughness characteristics of a channel but also the energy loss of the flow. The larger the value of n, the more the loss of energy within the flow. It depends on surface roughness, vegetation, channel irregularity, channel alignment, silting and scouring.

23. What are the essential conditions for most economical section? (Nov/Dec 2010)

The hydraulic most efficient channel section will carry maximum discharge for a given area of flow. To get maximum discharge the perimeter should be minimum.

24. How do you find the critical depth of flowing water? (April/May 2011)

It is the depth of flow of water at which the specific energy is minimum. This is denoted by h_c.

$$h_c = (q^2 / g)^{1/3}$$

25. Distinguish between uniform and non-uniform flow. (April/May 2011)

Uniform flow	Non-uniform flow
➢ If for a given length of the channel, the velocity of flow, depth of flow, slope of the channel and cross section remain constant, the flow is said to be uniform. ➢ dv/ds = 0 , dy/ds = 0	➢ If for a given length of the channel, the velocity of flow, depth of flow, slope of the channel and cross section do not remain constant, the flow is said to be Non-uniform. ➢ dv/ds = 0 , dy/ds = 0

26. Define the Froude number. What is its significance? (April/May 2011)

The Froude's number is defined as the square root of the ratio of inertia force of a flowing fluid to the gravity force.

$$F_e = \sqrt{\frac{Fi}{Fg}}$$

$F_e < 1$; Then the flow is said to be subcritical flow.

$F_e > 1$; Then the flow is said to be super critical flow.

$F_e = 1$; Then the flow is said to be critical flow.

27. What are the characteristics of open channel flow? (Nov/Dec 2011)

There is a variation in the geometrical parameters such as the cross sectional area, slope and shape. Even the surface roughness varies with depth of flow in an open channel. The flow is due to gravity force only at the expense of potential energy.

28. Define normal depth. (Nov/Dec 2011)

$Q = (1/n)\ R^2\ S^{(1/2)}\ A$

$n\ Q /\sqrt{S} = R^{(2/3)}\ A$

A R 2/3 is a function of flow depth h only. For a channel when Q, n and S is specified, it will have only one depth for uniform flow to take place. This depth is called normal depth (h_n).

29. What is the condition for maximum discharge in circular channel section? (Nov/Dec 2011)

(i) The depth of flow is equal to 0.95 times its diameter d = 0.95D.
(ii) Hydraulic radius is equal to 0.286 times the diameter of channel.
(iii) Angle subtended by water surface from the centre $2\theta = 308°$.

30. Define specific energy. (May/June 2012)

Specific energy is defined as the energy per unit weight of fluid of any cross section of a channel with respect to the channel bottom.

Total energy (E) = $Z + h + V^2/2g$

If the channel bottom is taken as the datum, then the total energy per unit / weight of liquid will be,

Total energy (E) = $h + V^2/2g$

31. Distinguish between normal depth and critical depth. (May/June 2012)

Normal Depth	Critical Depth
The depth of f low at which a given discharge flows as uniform flow in a given channel. It is designed as y_o.	The depth correspondence to the minimum specific energy is known as critical depth. It is designed by y_c.

32. What are the conditions for the most economical triangular channel section? (May/June 2012)

The conditions are:

$R = y/ (2\sqrt{2})$

$P = 2\sqrt{2}\ y$

$A = y^2$

33. Define specific energy of flowing liquid. (April/May 2011)

The specific energy of a flowing fluid per unit weight is given by:

$E = z + h + v^2/2g$

Where z – Height of the bottom of channel above datum,

h- Depth of liquid

v- Mean velocity of flow.

34. What are the different types of flow open channel? (May/June 2012)

(i) Steady flow
(ii) Unsteady flow
(iii) Uniform flow
(iv) Non – uniform flow
(v) Gradually varied flow
(vi) Rapidly varied flow
(vii) Spatially varied flow

PART B

1.Classify the various flow in open channel

Hints:

The flow in open channel is classified into the following types :

1. Steady flow and unsteady flow,
2. Uniform flow and non-uniform flow,
3. Laminar flow and turbulent flow, and
4. Sub-critical, critical and super critical flow.

2) Derive the equation for the discharge of open channel by chezys constant

Hints :

Consider uniform flow of water in a channel as shown in Fig. 16.2. As the flow is uniform means the velocity, depth of flow and area of flow will be constant for a given length of the chan Consider sections 1-1 and 2-2.

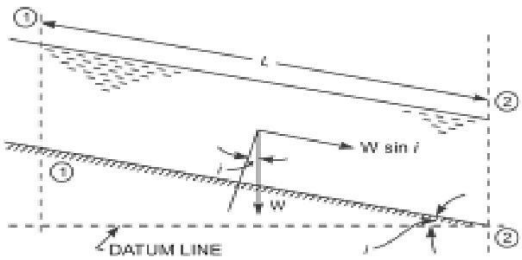


Fig. 16.2 *Uniform flow in open channel.*

Let
L = Length of channel,
A = Area of flow of water,
i = Slope of the bed,
V = Mean velocity of flow of water,
P = Wetted perimeter of the cross-section,
f = Frictional resistance per unit velocity per unit area.

The weight of water between sections 1-1 and 2-2.

$$W = \text{Specific weight of water} \times \text{volume of water}$$
$$= w \times A \times L$$

Component of W along direction of flow $= W \times \sin i = wAL \sin i$ ...(*i*)

Frictional resistance against motion of water $= f \times$ surface area $\times$ (velocity $)^n$

The value of n is found experimentally equal to 2 and surface area $= P \times L$

$\therefore$ Frictional resistance against motion $= f \times P \times L \times V^2$ ...(*ii*)

The forces acting on the water between sections 1-1 and 2-2 are:

1. Component of weight of water along the direction of flow,
2. Friction resistance against flow of water,
3. Pressure force at section 1-1,
4. Pressure force at section 2-2.

As the depths of water at the sections 1-1 and 2-2 are the same, the pressure forces on these two sections are same and acting in the opposite direction. Hence they cancel each other. In case of uniform flow, the velocity of flow is constant for the given length of the channel. Hence there is no acceleration acting on the water. Hence the resultant force acting in the direction of flow must be zero.

$\therefore$ Resolving all forces in the direction of flow, we get

$$wAL \sin i - f \times P \times L \times V^2 = 0$$

or
$$wAL \sin i = f \times P \times L \times V^2$$

$$V^2 = \frac{wAL \sin i}{f \times P \times L} = \frac{w}{f} \times \frac{A}{P} \times \sin i$$

or
$$V = \sqrt{\frac{w}{f}} \times \sqrt{\frac{A}{P} \times \sin i}$$

But
$$\frac{A}{P} = m$$
= hydraulic mean depth or hydraulic radius,

$$\sqrt{\frac{w}{f}} = C = \text{Chezy's constant}$$

Substituting the values of $\frac{A}{P}$ and $\sqrt{\frac{w}{f}}$ in equation (*iii*), $V = C\sqrt{m \sin i}$

For small values of i, $\sin i \simeq \tan i = i \quad \therefore \quad V = C\sqrt{mi}$

$\therefore$ Discharge, $Q = \text{Area} \times \text{Velocity} = A \times V$

$$= A \times C\sqrt{mi}$$

3)

Find the velocity of flow and rate of flow of water through a rectangular channel of 6 m wide and 3 m deep, when it is running full. The channel is having bed slope as 1 in 2000. Take Chezy's constant C = 55.

Hints :

$$V = C\sqrt{mi} = 55\sqrt{1.5 \times \frac{1}{2000}} = \mathbf{1.506\ m/s.\ Ans.}$$

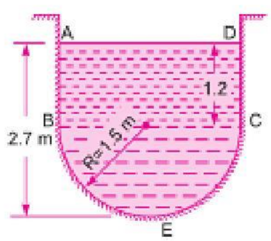
$$Q = V \times \text{Area} = V \times A = 1.506 \times 18 = \mathbf{27.108\ m^3/s.\ Ans.}$$

4)

Find the discharge

Take chezys constant 60

Bed slop 1 in 2000



Hints :

$Q = 9.585\ m^3/sec.$

5. *A trapezoidal channel has a bed slope of 1/2500. The channel is to carry2 m3/s.* ***Determine the optimum dimensions****. Side slope is 1:1. Chezy' constant = 50*

Hints : **d= 1.1907 m, b = 0.9863 m**

6) A trapezoidal channel to carry 142 cumec of water is designed to have a minimum cross-section. Find the bottom width and depth if the bed slope is 1 in 1200, the side slopes at 45° and Chezy's co-efficient = 55.

Hints :

d = 1.06m b= 0.87 m

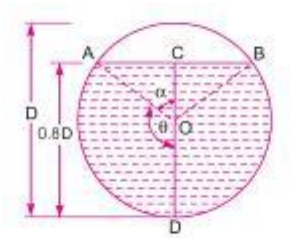
7) A power canal of trapezoidal section has to be excavated through hard clay at the least cost. Determine the dimensions of the channel given. discharge equal to 14 m3/s, bed slope 1 : 2500 and Manning's N = 0.020

Ans : d = 2.6 m b= 3.008 m

---

8) Water is flowing through a circular channel at the rate of 400 litres/s. when the channel is having a bed slope of 1 in 9000. The depth of water in the channel is 8.0 times the diameter. Find the diameter of the circular channel if the value of Manning's N = 0.015

Hints



D = 1.266 m

---

9) A sewer pipe is to be laid at a slope of 1 in 8100 to carry a maximum discharge of 600 litres/s. when the depth of water is 75% of the vertical diameter. Find the diameter of this pipe if the value of Manning's N is 0.025.

Ans : D=1.785 m

10) A concrete lined circular channel of diameter 3 m has a bed slope of l in 500. Work out the velocity and flow rate for the conditions of (I) maximum velocity and (ii) maximum discharge. Assume Chezy's C = 50.

Ans : for condition i) v= 2.13 m/s Q=13.13 m^3

11) Derive the condition for most economical trapezoidal channel
12) Derive the conditions for rectangular channel

13) How to you classify open channels? Explain in detail. Also explain the velocity distribution in open channel. (Nov/Dec 2010)

14)Write short notes on the following:
Critical flow and its computation (ii) Channel transition (Nov/Dec 2010)

15)A channel is designed to carry a discharge of 20 m3/s with Manning's n = 0.015 and bed slope of 1 in 1000 (for trapezoidal channel side slope m = 1/$\sqrt{3}$). Find the channel dimensions of the most efficient section if the channel is (i) trapezoidal (ii) rectangular. (Nov/Dec 2010)

16)Explain the computation of uniform flow using Manning's and Chezy's method. (Nov/Dec 2010)

17)A trapezoidal channel with side slopes of 2 horizontal: 3 vertical has to carry 20 m3/sec. find the slope of the channel when the bottom width of the channel is 4 m and the depth of the water is 3 m. Take Manning's n= 0.03. (April/May 2011)
Calculate the specific energy of 12 m3/sec of water flowing with a velocity of 1.5 m/s in a rectangular channel 7.5 m wide. Find the depth of water in the channel when the specific energy would be minimum. What would be the value of critical velocity as well as minimum specific energy? (April/May 2011)

18)(i) Derive the Chezy's equation for steady uniform flow.(8)
(ii) Derive the relationship for most trapezoidal channel. (8) (April/May 2011)

19)A power canal of trapezoidal section has to be excavated through hard clay at the least cost. Determine the dimensions of the channel given, discharge equal to 14 m3/sec, bed slope 1/2500. Manning's n= 0.02. (April/May 2011)

20)(i)What are the various types of flow in an open channel? (6)
(ii) Determine the critical depth for a specific energy of 1.6 m in the following channels.
(a)Rectangular channel(b) Triangular channel(c) Trapezoidal (10) (Nov/Dec 2011)

21)(i) Draw specific energy curve and explain. (6)
Determine the critical depth and specific energy for a discharge of 5 m3/s for a trapezoidal channel. The bed width of the channel is 2.10 m and the side slope is 1 (vertical) to 1.5 (Horizontal). (10) (Nov/Dec 2011)

22)(i) Derive the conditions for the most economical triangular channel section. (8)
The discharge in a trapezoidal channel is 10 m3/s. The side slope of the channel is 1 (vertical) to 1.5 (horizontal). The bed slope of the channel is 1 in 5000. The Manning's 'n' is 0.012. Determine the dimensions of the most economical section. (8) (Nov/Dec 2011)

23)(i) How are the flows classified under specific energy concepts? (6)
(ii) A 8 m wide channel conveys 15 cumecs of water at a depth of 1.2 m. Determine (1) Specific energy of the flowing water (2) Critical depth, critical velocity and minimum specific energy (3) Froude number and state whether the flow is subcritical or supercritical.
(10) (May/June 2012)

UNIT II GRADUALLY VARIED FLOW

Dynamic equations of gradually varied and spatially varied flows - Water surface flow profile classifications: Hydraulic Slope, Hydraulic Curve - Profile determination by Numerical method: Direct step method and Standard step method, Graphical method - Applications.

Important Two Mark Questions with Answers

1. Define varied flow. Explain its classification.

Flow properties, such as depth of flow area of cross section and velocity of flow vary with respect to distance is called Non-uniform flow.
It is, otherwise, called as varied flow. The varied flow is broadly classified into two types:
1) Rapidly varied flow (R.V.F)

2) Gradually varied flow (G.V.F)

2. Define gradually varied flow and rapidly varied flow in open channel. [Nov'07, May'08&Nov'08]

If the depth of flow changes quickly over a small length of the channel, the flow is said to be gradually varied flow (GVF). Example: Back water in a dam. Depth of water increases rapidly over a short length of the channel is called rapidly varied flow.
Example: hydraulic jump.

3. State the assumptions made in the derivation of dynamic equation for gradually varied flow. [Nov'08]

The following assumptions are made for analyzing the gradually varied flow:
1. The flow is steady

2. The pressure distribution over the channel section is hydrostatic, i.e., streamlines are practically straight and parallel.

3. The head loss is same as for uniform flow.

4. The channel slope is small, so that the depth measured vertically is the same as depth measured normal to the channel bottom.

5. A channel is prismatic.

6. Kinetic energy correction factor is very close to unity.

7. Roughness coefficient is constant along the channel length.

8. The formulae, such as Chezy's formula, Manning's formula which are applicable, to the uniform flow are also applicable for the gradually varied flow for determining slope of energy line.

4. Distinguish between draw down and back water curves. [Nov'07, Nov'08&May'10]

When the depth of flow decreases along the flow direction

becomes negative and the surface profile is called a drawdown curve. When the depth of flow (y) increases in the direction of flow, slope of water

surface is positive (upward slope) and the water surface is known as Backwater curve.

5. Write the expression to determine the length of the backwater curve. (Nov'09)

6. What is backwater curve in gradually varied flow profile and give practical example for getting this type of profile. (Nov'06)

When the depth of flow (y) increases in the direction of flow, slope of water surface is positive (upward slope) and the water surface is known as Backwater curve. Due to obstruction (dam), the water level raises and it has maximum depth of water near to the dam as shown in figure is an example for back water curve.

If the flow in the channel is uniform, the channel is said to have a normal slope denoted by *Sn.*

8. What are the flow profiles possible in mild sloped channels?

1. Flow behind an overflow weir.

2. Flow Over a free overall

3. Flow downstream of a sluice gate.

9. Classify surface profiles in a channel. [May'08&Nov'06]

Based on channel slopes, channels can be classified into five types as stated earlier.

1. Mild slope (M)

2. Critical slope (C)

3. Steep slope (S)

4. Horizontal slope (H)

5. Adverse slope (A)

10. What are the methods used to determine the length of surface profile?

Length of surface profile determined with the help of any one of the following methods.

1. Graphical Integration method.

2. Direct step method.

3. Standard step method.

11. Define the Afflux.

Afflux is defined as the maximum increase in water level due to obstruction in the path of flow of water.

12. What is transition in open channel?

Transition means a change of channel cross section.
(i) Provision of a hump pr depression along depth and

(ii) Contraction or expansion of channel width, in any combination.

13. Write down the applications of transition.

Transition in open channel flow is made to measure discharge of channel. Generally, discharge, = Area (*A*) x Velocity (*V*). For discharge calculation, both cross section of flow and velocity are necessary. With the help of channel transition, discharge of water obtained from measured flow cross section dimensions and / specific energy equations.

14. What is hydraulic jump in horizontal bed channel? [Nov'06 & May'07]

The rise of water level which takes place due to the transformation of the shooting to the streaming flow is known as hydraulic jump.

15. Write the expression for hydraulic jump?

16. State the uses of hydraulic jump. [Nov'06, Nov'07 & May'10]

The kinetic energy of flow after the hydraulic jump is greatly reduced, which may prevent erosion of the channel boundaries of downstream side.

17. Explain the classification of hydraulic jumps. [May'10]

Based on Froude number (F), hydraulic jump can be classified into 5 types.

a. Undulation jump: The Froude number F ranges from 1 to1.7 and the liquid surface does not rise shortly but having undulations of radically decreasing size.

b. Weak jump: The Froude number F ranges from1.7 to 2.5 and the liquid surface remains smooth.

c. Oscillating jump: The Froude number F ranges from 2.5 to 4.5 and there is an oscillating jet which enters the jump bottom and oscillating to the surface.

d. Steady jump: The Froude number F ranges from 4.5 to9 and energy loss due to steady jump in between 45 and 70%.

e. Strong jump: The Froude number greater than 9 and the downstream water surface is rough. Energy loss due to strong jump may be u

18. Define surges.

When the flow properties, such as discharge or depth varies suddenly is called surge.
Example: sudden closure of gate.

19. What are meant by positive and negative surges? [Nov'07]

1. Positive surge – a surge producing increase in depth

2. Negative surge – a surge producing decrease in depth.

20. Define the term backwater curve.

The profile of the rising water on the upstream side of the dam is called backwater curve. The distance along the bed of the channel between sections where water is having maximum height is known as length of back water curve.

21. What are the assumptions made in dynamic equation for gradually varied flow? (Nov/Dec 2010)

(i) The channel slope is small
(ii) The channel is prismatic
(iii) The stream lines are practically parallel and curvature effects are negligible
(iv) Velocity distribution co-efficient are constant and in most cases may be taken as unity.

22. What is meant by back water curve? (Nov/Dec 2010)

When the depth of flow y increases in the direction of flow, dy/dx is positive and the water surface profile is known as a back water curve.

23. How is back water curve formed? (April/May 2011)

The profile of the rising water on the upstream side of the dam is called back water curve.

If there had not been any obstruction (such as dam) in the path of flow of water in the channel the depth of water would have been constant. Due to obstruction, the water level rises and it has maximum depth from the bed at some section.

24. State any two assumptions in the dynamic equation of gradually varied flow. (Nov/Dec 2011)

(i) The pressure distribution over the channel section is hydrostatic (i.e.,) streamlines (ψ) are practically straight and parallel.
(ii) The channel slope is small, so that the depth measured vertically is the same as depth measure normal to the channel bottom.

25. Write down the dynamic equation of Gradually Varied flow. (May/June 2012)

- The bed slope of the channel is small.

- The slope is steady and discharge and discharge Q is constant.
- The energy correction factor α is unity.
- The roughness co-efficient is constant for the length of the channel and it does not depend on the depth of flow.
- The channel is prismatic.

PART B

1. Explain the flow profile by various numerical method.

2. Dynamic equation for GVF

When open channel flow encounters a change in bed slope or is approaching normal depth, flow depth changes gradually. As the change is continuous, the analysis should take into consideration a differential control volume instead of sections upstream and downstream. Water depth and channel bed height are assumed to change slowly. The velocity at any section is assumed to be uniform. Refer Fig

In this case the energy grade line and free surface are not parallel. The slope of the bed is *Sb*. The slope of the energy grade line is *S*.

In this case the energy grade line and free surface are not parallel. The slope of the bed is S_b. The slope of the energy grade line is S.

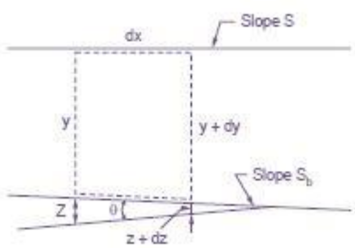


Figure 12.8.1 Flow with gradually varying depth

The specific energy flowing in at location x is $\frac{V^2}{2g} + y + z$,

The energy flow out at location $x + dx$ is

$$\frac{V^2}{2g} + d\left[\frac{V^2}{2g}\right] + y + dy + z + dz + dh_L$$

where dh_L is the head loss. The change in bed elevation can be expressed in terms of bed slope as $-S_b\,dx.dh_L = Sdx$ where S is the slope of the energy grade line. Taking the net flow and equating to the gravity drop,

$$\frac{d}{dx}\left[\frac{V^2}{2g}\right] + \frac{dy}{dx} = S_b - S \qquad (12.8.2)$$

expressing V in terms of flow q

$$\frac{d}{dx}\left[\frac{V^2}{2g}\right] = \frac{d}{dx}\left[\frac{q^2}{2gy^2}\right] = -2\frac{q^2}{2gy^3}\frac{dy}{dx} = -\frac{V^2}{gy}\frac{dy}{dx} = -Fr^2\frac{dy}{dx}$$

Substituting in 12.8.2.

$$\frac{dy}{dx} = \frac{S_b - S}{1 - Fr^2} \qquad (12.8.3)$$

The change in bed level dy along the flow direction for length dx is given by this equation. The gradient of the energy grade line can be obtained by assuming that loss is equal to the loss in steady uniform flow at normal depth. This is obtained from Manning's equation

3)

Determine the length of the back water curve caused by an afflux of 1.5 m in a rectangular channel of width 50 m and depth 2.0 m. The slope of the bed is given as 1 in 2000. Take Manning's, $N = 0.03$.

[**Ans.** 4566 m]

4)

Find the rate of change of depth of water in a rectangular channel of 12 m wide and 2 m deep, when the water is flowing with a velocity of 1.5 m/s. The flow of water through the channel of bed slope 1 in 300, is regulated in such a way that energy line is having a slope of 1 in 8000. [**Ans.** 0.000235]

5) How do you classify surface profiles? Briefly explain the various features of various profiles. Also write a note on hydraulic jump.(Nov/Dec 2010)

6) A 50 m long laboratory flame has a rectangular section with a width of 2 m and ends in a free overall. The channel is made of glass and the bed drops by 5 cm in the entire length. At a certain discharge, it was seen that the depth near the channel entrance was more or less constant at 0.5 m. Use the direct step method to obtain the length of profile. Use to equal depth increments. (Nov/Dec 2010)

7)A river of 45 m width has a normal depth of flow of 3 m and an average bed slope of 1 in 10,000. A weir is build across the river raising the water surface level at the weir site for 5 m above the bottom of the river. Assuming that the back water curve. Manning's n= 0.025. (April/May 2011)

8)(i) Derive the dynamic equation for gradually varied flow. (8)
A trapezoidal channel with bed width of 10 m and side slopes 1 (vertical) : 1.5 (horizontal) is carrying a flow of 80 m3/s. The channel bottom slope is 0.002 and Manning's 'n' is 0.015. A dam is planned in such a way that the flow depth increases to 10 m. Determine the depth of flow in the channel 250 m, 500 m and 750 m upstream of the dam. Use Standard step method. (8) (Nov/Dec 2011)

UNIT III RAPIDLY VARIED FLOW

Application of the energy equation for RVF - Critical depth and velocity - Critical, Sub-critical and Super-critical flow - Application of the momentum equation for RVF - Hydraulic jumps - Types - Energy dissipation - Surges and surge through channel transitions.

Important Two Mark Questions with Answers

1 What is rapidly varied flow?

It is defined as that flow in which depth of flow changes abruptly over a small length of the channel.

2 define Hydraulic jump

A hydraulic jump is a phenomenon in the science of hydraulics which is frequently observed in open channel flow such as rivers and spillways. When liquid at high velocity discharges into a zone of lower velocity, a rather abrupt rise occurs in the liquid surface.

3. State the uses of hydraulic jump. [Nov'06, Nov'07 & May'10]

The kinetic energy of flow after the hydraulic jump is greatly reduced, which may prevent erosion of the channel boundaries of downstream side.

4. Explain the classification of hydraulic jumps. [May'10]

Based on Froude number (F), hydraulic jump can be classified into 5 types.

a. Undulation jump: The Froude number F ranges from 1 to1.7 and the liquid surface does not rise shortly but having undulations of radically decreasing size.

b. Weak jump: The Froude number F ranges from1.7 to 2.5 and the liquid surface remains smooth.

c. Oscillating jump: The Froude number F ranges from 2.5 to 4.5 and there is an oscillating jet which enters the jump bottom and oscillating to the surface.

d. Steady jump: The Froude number F ranges from 4.5 to9 and energy loss due to steady jump in between 45 and 70%.

e. Strong jump: The Froude number greater than 9 and the downstream water surface is rough. Energy loss due to strong jump may be up to 85%.

5. Define surges.

When the flow properties, such as discharge or depth varies suddenly is called surge.
Example: sudden closure of gate.

6. What are meant by positive and negative surges? [Nov'07]

1. Positive surge – a surge producing increase in depth

2. Negative surge – a surge producing decrease in depth.

7. What is TRANSITION state?

If the Re lies between **500 to 2000**, the flow is considered to be in transition state.

8. Give a brief note on frude number ,Sub-critical, Critical, Super critical flow.

Fe = V/√ (g D)

critical:

The flow in open channel is said to be critical if the Froude number is 1.

Sub-critical, :

The flow in open channel is said to be super critical if the Froude number is less than one.

Super critical flow:

The flow in open channel is said to be super critical if the Froude number is greater than

9. Give the formula relating to velocity and discharge in chezy's formula.

Velocity V = C √mi

Discharge Q = A C√ (mi)

10. Give the BAZIN, GANGUILLET-KUTTER, MANNINGS formulas for chezy's constant.

a) Bazin formula

$$C = \frac{157.6}{1.81 + \frac{K}{\sqrt{m}}}$$

b) ganguillet-kutter formula

$$C = \frac{23 + \frac{0.00155}{i} + \frac{1}{N}}{1 + (23 + \frac{0.00155}{i})\frac{N}{\sqrt{m}}}$$

c) Manning's formula

$$C = \frac{1}{N} m^{\frac{1}{6}}$$

11. Give the formula for total energy

$$\text{TOTAL ENERGY} = z + h + \frac{V^2}{2g}$$

12. Define specific energy.

It is defined as energy per unit weight of the liquid with respect to the bottom of the channel.

13. What is the energy loss in a hydraulic jump? (April /May 2011)

When hydraulic jump takes place, a loss of energy due to eddies formation and turbulence occurs. This loss of energy is equal to the difference of specific energies at section 1-1 and 2-2

Loss of energy due to hydraulic jump

$h_L = E_1 - E_2$

14. **What are the conditions for the formation of hydraulic jump? (Nov/Dec 2011)**

(i) The flow is uniform and pressure distribution is due to hydrostatic before and after the jump.

(ii) Losses due to friction on the surface of the bed of the channel are small and hence neglected.

(iii) The slope of the bed of the channel is small, so that the component of the weight of the fluid in the direction of flow is negligible small.

15. Distinguish between positive and negative surges. (May/June 2012)

Positive surges	**Negative surges**
• A surge producing an increase in depth is called positive surge. • Positive surge moving downstream.	• A surge producing a decrease in depth is known as negative surge. • Negative surge moving of stream.

PART B

1. *In the flow through a sluice in a large reservoir, the velocity downstream is 5.33 m/s while the flow depth is 0.0563 m.* ***Determine the downstream conditions if a hydraulic jump*** *takes place downstream. Calculate the energy dissipated by eddies in the jump.*

y_2 = 0.5436 m

dissipation = 62.82 %,

2.A venture flume is formed in a horizontal channel of 2 m width by constructing the width to 1.3 m and raising floor level in the constricted section by 0.2 m above that of the channel. If the difference in level between the throat and downstream is 25 mm and both upstream and downstream depths are 0.6 m, ***determine the rate of flow****.*

Q = 0.3736 m3/s

3. *A rectangular channel of 5 m width discharges water at the rate of 1.5 m3/s into a 5 m wide apron with 1/3000 slope at a velocity of 5 m/s.* ***Determine the height of the hydraulic jump*** *and energy loss.*

Height of hydraulic jump = 0.4638 m
Energy loss =0.7937 m head of water.

4.) *A Wide channel of uniform rectangular section with a slope of 1/95 has a flow rate of 3.75 m^3/s/m. The Manning constant is 0.013. Suddenly the slope changes to 1/1420.* ***Determine the normal depths for*** *each case. Show that a hydraulic jump has to occur and calculate the downstream flow height.*

Normal Depth y2 = 1.4404 m

the downstream flow height Y_2 =1.8208 m

5) A rectangular channel of 6 m width has a flow rate of 22.5 m^3/s when the depth is 3 m. ***Determine the alternate depth and the critical depth.***

y2 = 0.5302 m, yc =1.1275 m

6) Show that for a hydraulic jump in a rectangular channel, the Froude numbers upstream and downstream are related by

$$F_{r2}^2 = \frac{8F_{r1}^2}{[(1+8F_{r1}^2)^{1/2}-1]^3}.$$

---

7)
In a trapezoidal channel of 2.4 m bottom width and 45° side slope the flow rate is 7.1 m³/s. with normal depth of flow of 1.2 m. Determine the bed slope. $N = 0.022$ (1.98/1000)

---

8) A rectangular channel of 5 m width carries water at the rate of 15 m3/s. Calculate the criticaldepth and velocity. **(hc = 0.972 m, Vc = 3.69 m/s)**

9)How do you classify surface profiles? Briefly explain the various features of various profiles. Also write a note on hydraulic jump.(Nov/Dec 2010)

10) In a rectangular channel of 0.5 m width, a hydraulic jump occurs at a point where depth of water flow is 0.15 m and Froude number is 2.5. Determine

(i) The specific energy
(ii) Loss of head
(iii) The critical and subsequent depths
(iv) Energy dissipated. (April /May 2011)

11) (i) What are the various types of surges? Explain. (6)

(ii) The depth of flow of water at a certain section of a rectangular channel 2 m wide is 0.25 m. The discharge through the channel is 1.8 m3/s. Determine whether a hydraulic jump will occur and if so, determine its height and loss of energy per kg of water. (8)
(Nov/Dec 2011)

UNIT-IV TURBINES

Impact of Jet on vanes - Turbines - Classification - Reaction turbines - Francis turbine, Radial flow turbines, draft tube and cavitations - Propeller and Kaplan turbines - Impulse turbine - Performance of turbine - Specific speed - Runaway speed - Similarity laws.

Turbines are defined as the hydraulic machines which convert hydraulic energy into mechanical energy. This mechanical energy is used in running an electric generator which is directly coupled to the shaft of the turbine. Thus the mechanical energy is converted into electrical energy. The electric power which is obtained from the hydraulic energy (energy of water) is known as Hydro-electric power. At present the generation of hydro-electric power is the cheapest as compared by the power generated by other sources such as oil, coal etc.

TWO MARK WITH ANSWERS

1. What do you mean by turbine?

The hydraulic machine which convert the hydraulic energy in to mechanical energy is called turbine

2. Define pump:

It is defined as the hydraulic machine which converts mechanical energy in to hydraulic energy

3. Explain net head

It is defined as the head available at the inlet of turbine .If Hf is the loss due to friction between water and penstock then net head

H=Hg-Hf

4. Define Hydraulic Efficiency:

It is defined as the ratio of power delivered to the runner to the power supplied at the inlet.

5. Define mechanical efficiency

It is defined as the ratio of power at the shaft of the turbine to the power delivered by the water to runner.

6. Define volumetric efficiency

It is defined as the ratio of volume of water actually striking the runner to the Volume of water supplied to the runner.

7. Define over all efficiency

It is defined as the ratio of shaft power by water power

8. Explain impulse turbine

If at the inlet of the turbine the energy available is only kinetic energy the turbine is known as impulse turbine.

9. Explain Reaction turbine

If at the inlet of the turbine the water possesses kinetic energy as well as pressure energy the turbine is known as reaction turbine.

10. Explain tangential flow turbine

If the water flows along the tangent of the runner, the turbine is known as the tangential flow turbine.

11. Explain radial flow turbine

If the water flows in the radial direction through the runner the turbine I called radial flow turbine.

12. Explain inward flow radial turbine

If the water flows from outwards to inwards radially the turbine is called inward radial flow turbine.

13. Explain outward flow radial turbine

If the water flows radially from inwards to outwards the turbine is known sa outward radial flow turbine.

14. Define axial flow turbine

If the water flows through the runner along the direction parallel to the axis of rotation of the runner the turbine is called axial flow turbine.

15. What is Pelton wheel:

Pelton wheel or Pelton turbine is a tangential flow impulse turbine. The water strikes the bucket along the tangent of the runner . The energy available at the inlet of the Turbine is only kinetic energy. This turbine is used for high heads.

16. What is breaking jet?

When the nozzle is completely closed, the amount of water striking the runner reduces to zero but the runner due to inertia goes on revolving for a long time to stop the runner in a short time a small nozzle is provided which direct the jet of water on the back of vanes .This jet of water is called breaking jet.

17. What is jet ratio?

It is the ratio of pitch diameter (D) to the diameter of jet (d).

18. What is Draft tube?

A tube or pipe of gradually increasing area is used for discharging water from the exit of the turbine to the tail race is called draft tube.

19. Define Degree of Reaction (R)

It is defined as the ratio of change of pressure energy inside the runner to the change of total energy out side the runner.

20. What is radial discharge?

This means the angle made by absolute velocity with the tangent on the wheel is and the component of whirl velocity is zero.

22. Define Francis turbine:

Inward flow reaction turbine having radial discharge at outlet is known as Francis Turbine

23. Define propeller turbine:

This is an example of axial flow reaction turbine . Here the vanes are fixed to the hub and are not adjustable.

24. Define Kaplan turbine:

This is an example of axial flow reaction turbine. Here the vanes are not fixed to the hub and are adjustable.

25. What are the uses of draft tube?

1. The net head on the turbine increases.

2. Due to increase in net head the power and efficiency of the turbine also increases.

3. The large amount of rejected kinetic energy is converted in to useful pressure energy

26. What are types of draft tube?

1. Conical draft tube

2. Simple elbow tube

3. Mood y spreading tube

3. Draft tube with circular inlet and rectangular outlet.

27. What are the types of characteristic curves?

1. Main characteristic curves

2. Operating characteristic curve

3. Muschel characteristic curves

28. What is specific speed of the turbine?

It is defined as the speed of a turbine which will develop unit power under unit head.

29. Define unit quantities;

Unit quantities are the quantities which are obtained when the head on the turbine are unity.

30. Explain about characteristic curves of a hydraulic turbine

Characteristic curves of a hydraulic turbine are the curves with the help of which the exact behavior and performance of the turbine under different working conditions can be known.

31. What are the main parts of pelton wheel turbine?

1. Nozzle and flow regulating arrangement

2. Runner with buckets

3. Casing

4. Breaking jet

32. What are the main mechanisms of Radial flow reaction turbine?

1. Casing

2. Guide mechanism

3. Runner

4. Draft tube

33. What are the classifications of hydraulic turbine according to the type of energy at inlet?

(a) Impulse turbine and
(b) Reaction turbine

34. What are the types of turbine according to direction of flow through runner?

(a) Tangential flow turbine

(b) Radial flow turbine

(c) Axial flow turbine

(d) Mixed flow turbine

35. What are the types of turbine according to the head at the inlet of the turbine?

(a) High head turbine
(b) Medium head turbine
(c) low head turbine Where on e section is taken

36. What do you know about Hub or Boss?

It is the core part of the axial flow turbine where the vanes are attached.

37. Under what head the propeller turbine take water?

About 100 m head the propeller turbine take water.

When the vanes are fixed to the hub and they are not adjustable the turbine is Called propeller turbine.

38. What are the uses of Kaplan turbine?

1. To produce more out put.
2.The efficiency of the turbine is more .

39. Distinguish between impulse and reaction turbines. (Nov/Dec 2010)

Impulse turbine	Reaction turbine
✓ The energy available is only kinetic	✓ The water possesses kinetic energy as

energy. ✓ The pressure is atmospheric from inlet to outlet of the turbine.	well as pressure energy. ✓ As the water flows through the runner the water is under pressure and the pressure energy goes on changing into kinetic energy.

40. What is the use of draft tube? (April /May 2011)

(i) The turbine may be placed above the tail race and hence turbine may be inspected properly.

(ii) Kinetic energy ($V^2/2g$) rejected at the outlet of the turbine is converted into useful pressure energy.

41. Define the specific speed of a turbine. (April /May 2011)

It is defined as the speed of the turbine which is identical in shape, geometrical dimensions blade angles, gate opening etc., with the actual turbine but of such a size that it will develop unit power when working under unit had. It is denoted by Ns.

42. What are the applications of momentum principle? (Nov/Dec 2011)

(i) To determine the resultant force acting on a pipe bend caused by the fluid flowing through it.

(ii) The force exerted by jet of fluid striking on moving (or) fixed plate surface.

(iii) Thrust on a propeller.

(iv) Reaction of a jet etc.

43. What are the advantages of draft tube? (Nov/Dec 2011)

(i) To decrease the pressure at the runner exit less than atmospheric pressure in order to increase the working head.

(ii) To recover some of kinetic energy going to tail race as waste.

44. How would you classify turbines based on the direction of flow in the runner? (May/June 2012)

- Tangential flow turbine
- Radial flow turbine
- Axial flow turbine
- Mixed flow turbine

45.What is cavitation? How do you prevent cavitation? (Nov/Dec 2010)

When a liquid flows into a region where pressure is reduced to its vapour pressure at the prevailing temperature, the liquid boils and small bubbles (or) cavities from in large numbers. This process is called cavitation.

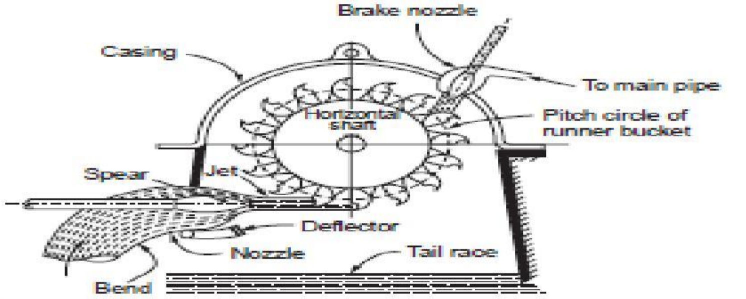
Methods to prevent Cavitation:

- Turbine may be kept under water and keeping low specific speed.
- Cavitation free runner may be designed.
- Reduced by polishing the surface.

PART B

1. Explain the general layout of the pelton turbine

Hints :



1. Nozzle and flow regulating arrangement (spear),
2. Runner and buckets,
3. Casing, and
4. Breaking jet.

---

2 .Determine the power given by the jet of water to the runner of a Pelton wheel which is having tangential velocity as 20 m/s. The net head on the turbine is 50 m and discharge through the jet water is 0.03 m3/s. The side clearance angle is 15° and rake C_v, = 0.975.

Ans : 12.432 kw

3) In inward flow reaction turbine has external and internal diameters as 0.9 m and 0.45 m respectively. The turbine is running at 200 r.p.m. and width of turbine at inlet is 200 mm. The velocity of flow through the runner is constant and is equal to 1.8 m/s. The guide blades make an angle of 10° to the tangent of the wheel and the discharge at the outlet of the turbine is radial. Draw the inlet and outlet velocity triangles and determine:

(i) The absolute velocity of water at inlet of runner,
(ii) The velocity of whirl at inlet,
(iii) The relative velocity at inlet,
(iv) The runner blade angles,
(v) Width of the runner at outlet,
(vi) Mass of water flowing through the runner per second.
(vii) Head at the inlet of the turbine,
(viii) Power developed and hydraulic efficiency of the turbine.

ANSWER :

(i) The absolute velocity of water at inlet of runner, =10.365m/s
(ii) The velocity of whirl at inlet, =10.207 m/s
(iii) The relative velocity at inlet=1.963 m/s

(iv) The runner blade angles= 66' 29'' and 20 degree 54'
(v) Width of the runner at outlet= 400 mm
(vi) Mass of water flowing through the runner per second.=1017.8kg/s
(vii) Head at the inlet of the turbine, =9.97 m
(viii) Power developed 97.9 kw
hydraulic efficiency of the turbine =98.34%

5) *Determine the specific speed for the data available at a location as given below (Both dimensionless and dimensional). Head available : 900 m. Power estimated 40000 kW, Speed required : 417.5 rpm. Also indicate the suitable type of turbine*

ANSWER :

Dimensionless specific speed : units to be used :

= **0.0163.**

Hence single jet pelton turbine is suitable.

Non dimensional specific speed.

= **8.92.**

Agrees with the former value.

Single jet impulse turbine will be suitable.

6) The following data is given for a Francis Turbine. Net head H = 60 m ; Speed N = 700 r.p.m.; shaft power = 294.3 kW ; Ro = 84% ; rib = 93%; flow ratio = 0.20 ; breadth ratio n = 0.1; Outer diameter of the runner = 2 x inner diameter of runner. The thickness of vanes occupy 5% of circumferential area of the runner, velocity of flow is constant at inlet and outlet and discharge is radial at outlet. Determine : (i) Guide blade angle, (ii) Runner vane angles at inlet

ANSWER:

Guide blade angle = 13 degree 55.7 sec

Runner vane angles at inlet =42degree 5.4sec

7) *A turbine is operating with a head of 400 m and speed of 500 rpm and flow rate of 5 m3/s producing the power of 17.66 MW. The head available changed to 350 m. It no other corrective action was taken what would be the speed, flow and power ? Assume efficiency is maintained.*

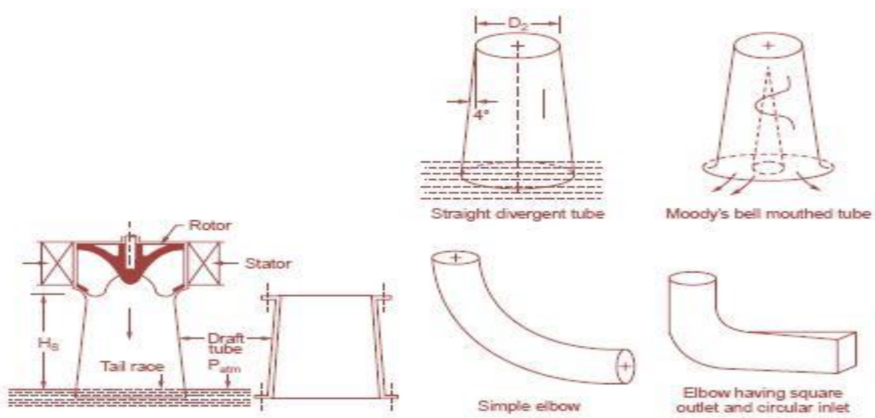
ANSWER:

N_2 = = **467.7 rpm**

P_2 = 14.45 Mw

8.Explain the type and application of draft tube

The turbines have to be installed a few meters above the flood water level to avoid innundation. In the case of impulse turbines this does not lead to significant loss of head. In the case of reaction turbines, the loss due to the installation at a higher level from the tailrace will be significant. This loss is reduced by connecting a fully flowing diverging tube from the turbine outlet to be immersed in the tailrace at the tube outlet. This reduces the pressure loss as the pressure at the turbine outlet will be below atmospheric due to the arrangement. **The loss in effective head is reduced by this arrangement. Also because of the diverging section of the tube the kinetic energy is converted to pressure energy which adds to the effective head.** The draft tube thus helps (1) to regain the lost static head due to higher
level installation of the turbine and (2) helps to recover part of the kinetic energy that otherwise may be lost at the turbine outlet



9. Explain the effect of cavitation in hydraulic machines?

If at any point in the flow the pressure in the liquid is reduced to its vapour pressure, the liquid will then will boil at that point and bubbles of vapour will form. As the fluid flows into a region of higher pressure the bubbles of vapour will suddenly condense or collapse. This action produces very high dynamic pressure upon the adjacent solid walls and since the action is continuous and has a high frequency the material in that zone will be damaged. Turbine runners and pump impellers are often severely damaged by such action. The process is called cavitation and the damage is called cavitation damage. In order to avoid cavitation, the absolute pressure at all points should be above the vapour pressure.

inlet where the pressure may be below atmospheric level. In the case of pumps such damage may occur at the suction side of the pump, where the absolute pressure is generally below atmospheric level.

In addition to the damage to the runner cavitation results in undesirable vibration noise and loss of efficiency. The flow will be disturbed from the design conditions. In reaction turbines the most likely place for cavitation damage is the back sides of the runner blades near their trailing edge. The critical factor in the installation of reaction turbines is the vertical distance from the runner to the tailrace level. For high specific speed propeller units it may be desirable to place the runner at a level lower than the tailrace level.

10 *A Pleton turbine running at 720 rmp uses 300 kg of water per second. If the head available is 425 m* ***determine the hydraulic efficiency****. The bucket deflect the jet by 165°. Also* ***find the diameter of the runner and jet.*** *Assume C_v = 0.97 and ⎞ = 0.46, Blade velocity coefficient is 0.9.*

- **Hydraulic efficiency = 92.86%**
- ***the diameter of the runner*= 1.082 m**
- ***the diameter of jet* = 0.06565 m**

---

11) *The following data refers to a Pelton turbine. It drives a 15 MW generator. The effective head is 310 m. The generator and turbine efficiencies are 95% and 86% respectively. The speed ratio is 0.46. Jet ratio is 12. Nozzle velocity coefficient is 0.98.* ***Determine the jet and runner diameters, the speed and specific speed of the runner****.*

- Jet diameter = **0.3171 m**
- ***runner diameters*=** 3.8 m
- ***the speed*= 176.71 rpm**
- ***specific speed of the runner*= 8.764**

---

12) *Determine the diameters and blade angles of a Francis turbine runningat 500 rpm under a head of 120 m and delivering 3 MW. Assume flow ratio as 0.14 and $D_2 = 0.5D_1$ and b1 = 0.1 D_1. The hydraulic efficiency is 90% and the overall efficiency is 84%.*

- **D_1 = 1.193 m, D_2 = 0.5965 m. b_1 = 0.1193 m, b_2 = 0.2386 m**
- **BLADE ANGLES = 11.32°**
  68.3°

---

13) *A Pelton wheel operates with a jet of 150 mm diameter under the head of 500 m. Its mean runner diameter is 2.25 m and it rates with a speed of 375 rpm. The angle of bucket tip at outlet as 15°, coefficient of velocity is 0.98, mechanical losses equal to 3% of power supplied and the reduction in relative velocity of water while passing through bucket is 15%. Find (i) the force of jet on the bucket, (ii) the power developed (iii) bucket efficiency (iv) overall efficiency. (Nov/Dec 2010)*

14) *Derive the equation for power and work done for the impact of jets on moving curved vanes. Explain the classification of turbines. (Nov/Dec 2010)*

15) *A pelton wheel generates 8000 kW under a net head of 130 m at a speed of 200 rpm. Assuming the co-efficient of velocity for the nozzle 0.98, hydraulic efficiency 87%, speed ratio 0.46 and jet diameter to wheel diameter ratio 1/9. Determine (April /May 2011)*

(i) Discharge required
(ii) Diameter of the wheel
(iii) Diameter and number of jets required and
(iv) Specific speed of the turbine. Take the mechanical efficiency is 75%.

16) *In an inward flow reaction turbine, the head on the turbines is 32 m. The external and internal diameters are 1.44 m and 0.72 m respectively. The velocity of flow through the runner is constant and equal to 3 m/s. The guide blade angle is 10° and the runner vanes are rigid at inlet. If the discharge at*

outlet is radial, determine

(i) The speed of the turbine.

(ii) The vane angle at outlet of the runner and

(iii) Hydraulic efficiency. *(April /May 2011)*

17) (i) What are the various types of draft tube? Explain it with neat sketches. (6)

(ii)A pelton wheel has to develop 5000 kW under a net head of 300 m at a speed of 500rpm. The co-efficient of velocity for the jet is 0.97, speed ratio is 0.46 and the jet diameter is 1/10 of wheel diameter. Determine the discharge of water supplied to the wheel, the diameter of pitch circle, diameter of jets and number of jets. (10) (Nov/Dec 2011)

18) (i) How do you classify turbines? *(6)*

(ii) An inward flow reaction turbine is supplied water at the rate of 0.60 cumecs at a velocity of flow of 6 m/s. The velocity of periphery and velocity of while at inlet is 24 m/s and 18 m/s respectively. Assuming the discharge to be radial at outlet and the velocity of flow to the constant, determine (a) the vane angle at inlet (b) head of water in the wheel. (10) (Nov/Dec 2011)

UNIT-V PUMPS

Centrifugal pumps - Minimum speed to start the pump - NPSH - Cavitations in pumps - Operating characteristics - Multistage pumps - Reciprocating pumps - Negative slip - Flow separation conditions - Air vessels, indicator diagrams and its variations - Savings in work done - Rotary pumps: Gear pump

1. How are fluid machines classified?

Fluid machines are classified into 2 categories depending upon the direction of transfer of energy:

1. Turbines

2. Pumps or compressors. .

2. What is centrifugal pump?

The hydraulic machines which convert mechanical energy in to pressure energy by means of centrifugal force is called centrifugal pump. It acts a reverse of inward radial flow turbine.

3. What are the main parts of centrifugal pump?

1. Suction pipe with foot valve and strainer

2. Impeller

3. Casing

4. Deliver y pipe

4. Write down the use of centrifugal pump?

1. Used in deep sump and basement

2. The high discharge capacity

3. It is driven by electric motors

5. Define multistage pump:

If centrifugal pump consists of two or more impellers the pump is called Multistage pump. To produce a high head impellers are connected in series .To produce high discharge impellers are connected in parallel.

6. What is Net Positive Suction Head (NPSH)?

NPSH is defined as the total head required making liquid flow through suction pipe to pipe impeller.

7. Define slip of a reciprocating pump and negative slip:

Slip is defined as the difference between theoretical discharges and actual discharge.

If actual discharge is greater than theoretical discharge negative value is found this negative value is called negative slip.

8. What do you know coefficient of discharge?

It is defined as the ratio of actual discharge b y theoretical discharge. It is denoted By Cd

9. What do you know Drop down curve?

The water surface has a convex profile upwards this curve is called drop down Curve.

10. What is separation of reciprocating pump?

If the pressure in the cylinder is below the vapour pressure , dissolved gasses will be liberated from the liquid and cavitations will takes place . The continuous flow of liquid will not ex it which means separation of liquid takes place. Th e pressure at which separation takes place is called separation pressure and head corresponding to the separation pressure is called separation pressure head.

11. What is an indicator diagram?

Indicator diagram is the graph between the pressure head and distance traveled b y the piston from inner dead center for one complete revolution.

12. What is Air vessel?

Air vessel is a closed chamber containing compressed air in the top portion and liquid at the bottom of the chamber . It is used to obtain a continuous supply of water at uniform rate to save a considerable amount of work and to run the pump at high speed with out separation.

13. 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 with out separation.

14. 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%.

15. What is Discharge through a Reciprocating Pump in per sec?

For Single acting

Discharge (Q)=ALN/60

Where,

A=Area of the Cylinder

L=Length of Stroke in m.

N=Speed of Crank in RPM

For Double acting

Q=2ALN/60

16. 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.

17 .What is the relation betweenWork done of a Pump and Area of Indicator Diagram ?

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

18.What is the Work done by the Pump per sec due to acceleration and friction in the suction and delivery Pipes ?

For single acting

W= ρgALN(hs+hd+0.67hfs+0.67hfd)/60

For Double acting

W=2ρgALN(hs+hd+0.67hfs+0.67hfd)/60

Where hfs, hfd =loss of head due to acceleration in the suction and delivery Pipe.

19.What is the Mean Velocity of Single acting reciprocating pump ?

v=Aω r/3.14a

Where

ω =Angular velocity in rad/sec r =Radius of the crank in m

A and a =Area of cylinder and Pipe in m

20. Define Priming. (Nov/Dec 2010)

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

21. What is the significance of air vessel? (Nov/Dec 2010)

(i) To obtain a continuous supply of liquid at a uniform rate.

(ii) To save a considerable amount of work in overcoming the frictional resistance in the suction and delivery pipe.

(iii) To run the pump at a high speed without separation.

22. What are the differences between jet pump and submersible pump? (April /May 2011)

Jet pump	Submersible pump
➢ It is a combination of a centrifugal pump and a nozzle converting high pressure into velocity. ➢ It is mainly used in mining and pumping oil processes.	➢ It is a centrifugal pump which is attached to an electric motor and operates while submerged in water. ➢ It is a type of pump is mainly manufactured for deep wells.

23. Define specific speed of pump. (Nov/Dec 2011) & (May/June 2012)

It is the speed of a geometrically similar turbine. (i.e) a turbine identical in shape, dimensions, blade angles and gate openings etc. which will develop unit power when working under a unit head.

24. What are the advantages of fitting air vessels in a reciprocating pump? (Nov/Dec 2011)

(i) To obtain a continuous supply of liquid at a uniform rate.

(ii) To save a considerable amount of work in overcoming the frictional resistance in the suction and delivery pipes.

(iii) To run the pump at a high speed without separation.

PART B

1) Explain the parts of **centrifugal pumps**

HINTS

The **main components** of centrifugal pumps are (1) **the impeller,** (2) **the casing** and (3) **the drive shaft with gland and packing.**

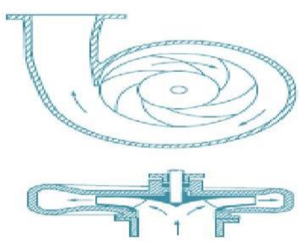


Figure 15.1.1 Volute type centrifugal pump.

Figure 15.1.2 Diffuser pump.

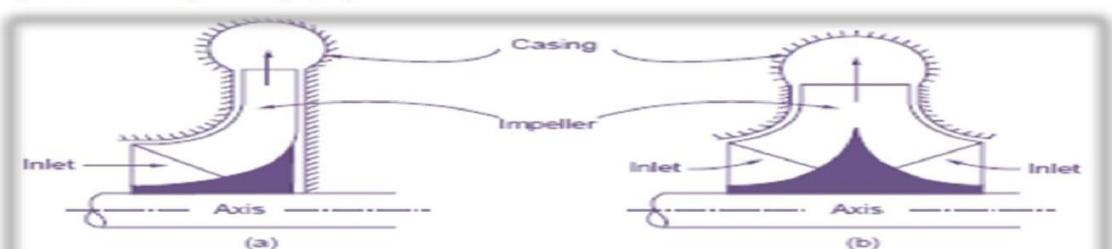


Figure 15.1.3 Single and double entry pumps

2.) Explain the Cavitations in Pump

What is cavitation and where and why it occurs has been discussed in the chapter on turbines. **In the case of pumps, the pressure is lowest at the inlet and cavitation damage occurs at the inlet.** For cavitation to occur the pressure at the location should be near the vapour pressure at the location.

Applying the energy equation between sump surface and the pump suction,

$$\frac{P_s}{\gamma} + \frac{V_s^2}{2g} + Z = \frac{P_a}{\gamma} - h_{fs} \tag{15.7.1}$$

where Z is the height from sump surface and pump suction. The other terms have their usual significance. The term h_{fs} should include all losses in the suction line.

Net Positive Suction Head (NPSH) is defined as the available total suction head at the pump inlet above the head corresponding to the vapour pressure at that temperature.

$$NPSH = \frac{P_s}{\gamma} + \frac{V_s^2}{2g} - \frac{P_v}{\gamma} \tag{15.7.2}$$

where P_v is the vapour pressure.

From 15.7.1,

$$NPSH = \frac{P_a}{\gamma} - \frac{P_v}{\gamma} - Z - h_{fs} \tag{15.7.3}$$

Thoma cavitation parameter is defined by

$$\sigma = \frac{(NPSH)}{H} = \frac{(P_A/\gamma) - (P_v/\gamma) - Z - h_{fs}}{H}$$

At cavitation conditions,

$$\sigma = \sigma_c \quad \text{and} \quad \frac{P_s}{\gamma} = \frac{P_v}{\gamma}$$

$$\therefore \quad \sigma_c = \frac{(P_a/\gamma) - (P_v/\gamma) - Z - h_{fs}}{H} \tag{15.7.4}$$

The height of suction, the frictional losses in the suction line play an important role for avoiding cavitation at a location. When pumps designed for one location is used at another location, atmospheric pressure plays a role in the onset of cavitation. Some authors use the term "suction specific speed, 'n_s'". Where H in the general equation is substituted by $NPSH$. One correlation for critical cavitation parameter for pumps is given as

$$\sigma_c = \left(\frac{n_s}{175}\right)^{4/3} \tag{15.7.5}$$

These equations depend upon the units used and should be applied with caution.

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

- **Work done per kg = 197.7 Nm/kg/s**
- **H = 16.52 m**
- **Power = 26.45 Kw**

4) A homologus model of a centrifugal pump runs at 600 rpm against a head of 8 m, the power required being 5 kW. If the prototype 5 times the model size is to develop a head of 40 m ***determine its speed, discharge and power****. The overall efficiency of the model is 0.8 while that of the prototype is 0.85.*

- **Q_p = 2.8492 m^3/s**
- **N_p = 268.32 rpm**
- **Power = 1315.3 kW.**

---

5) *The diameter and width of a contrifugal pump impeller are 50 cm and 2.5 cm. The pump runs at 1200 rpm. The suction head is 6 m and the delivery head is 40 m. The frictional drop in suction is 2 m and in the delivery 8 m. The blade angle at out let is 30°. The manometric efficiency is 80% and the overall efficiency is 75%.* ***Determine the power required to drive*** *the pump. Also* ***calculate the pressures at the suction and delivery side of the pump****.*

- **Power = 95.3 kW**
- **P_2= 0.447 m absolute (vacuum)**
- *P_3* **= 40.1 m absolute**

---

6) *A centrifugal pump has been designed to run at 950 rpm delivering 0.4 m3/s against a head of 16 m. If the pump is to be coupled to a motor of rated speed 1450 rpm.*

Calculate the discharge, head and power input. *Assume that the overall efficiency is 0.82 remains constant.*

Hints and ans :

$$P_1 = \frac{1000 \times 0.4 \times 9.81 \times 16}{1000 \times 0.82} = 76.57 \text{ kW}$$

$$Q_2 = Q_1 \cdot \frac{N_2}{N_1} = 0.4 \times \frac{1450}{950} = 0.61 \text{ m}^3/\text{s}$$

$$H_2 = H_1 \cdot \left(\frac{N_2}{N_1}\right)^2 = 16 \times \left(\frac{1450}{950}\right)^2 = 37.27 \text{ m}$$

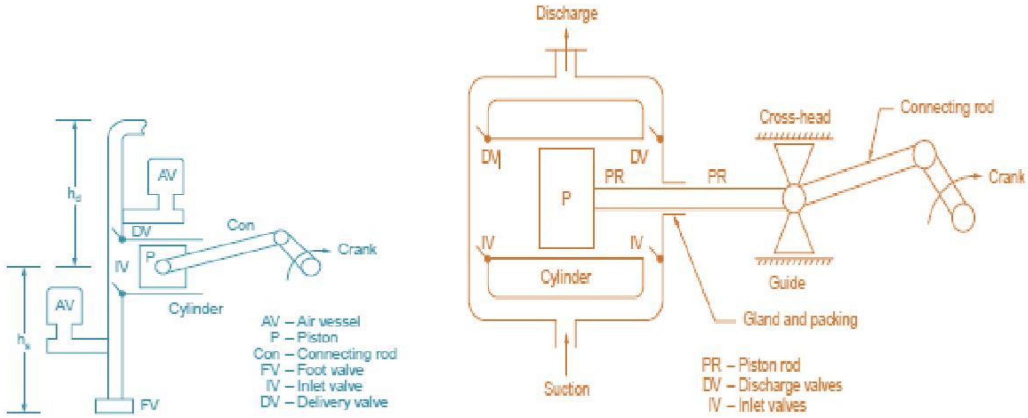
$$P_2 = 76.57 \times \left(\frac{1450}{950}\right)^3 = 272 \text{ kW}$$

Check : $P_2 = \frac{1000 \times 0.61 \times 37.27 \times 9.81}{1000 \times 0.82} = 272 \text{ kW}$

---

7) Explain the **description and working of reciprocating pump**

Hints
The main components are:
1. Cylinder with suitable valves at inlet and delivery.
2. Plunger or piston with piston rings.
3. Connecting rod and crank mechanism.
4. Suction pipe with one way valve.
5. Delivery pipe.
6. Supporting frame.
7. Air vessels to reduce flow fluctuation and reduction of acceleration head and friction Head



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. The discharge variation is shown in figure

8) 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 ?

hints and ans:

Theoretical flow volume = 8.247×10^{-3} m3/s or 8.247 l/s or 8.247 kg/s

Qactual = 7.422 l/s

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

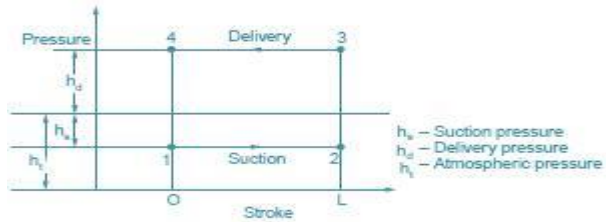
9) double acting reciprocating pump has a bore of 150 mm and stroke of 250 mm and runs at 35 rpm. The piston rod diameter is 20 mm. The suction head is 6.5 m and the delivery head is 14.5 m. The discharge of water was 4.7 l/s. Determine the slip and the power required.

- **Slip = 7.99%**
- **Theoretical power** = $m\,g\,h$ = 4.7 × 9.81 × (14.5 + 6.5) W = **968 W**
- The actual power will be higher than this value due to mechanical and fluid friction

10) Explain the indicator diagram and its applications

Hints:

The pressure variation in the cylinder during a cycle consisting of one revolution of the crank. When represented in a diagram is termed as indicator diagram. The same is shown in figure



and delivery pressures. Modifications due to other effects will be discussed later in the section.Point 1 represents the condition as the piston has just started moving during the suction stroke. 1-2 represents the suction stroke and the pressure in the cylinder is the suction pressure below the atmospheric pressure. The point 3 represents the condition just as the piston has started moving when the pressure increases to the delivery pressure. Along 3-4 representing the delivery stroke the pressure remains constant. The area enclosed represents the work done during a crank revolution to some scale

11) Explain the Air Vessels and its working principles

Air vessel is a strong closed vessel as shown in figure 16.5.1. The top half contains compressedair and the lower portion contains water or the fluid being pumped. Air and water are separatedby a flexible diaphragm which can move up or down depending on the difference in pressure between the fluids. The air charged at near total delivery pressure/suction pressure from thetop and sealed. The air vessel is connected to the pipe lines very near the pump, at nearly the pump level. On the delivery side, when at the beginning and up to the middle of the delivery stroke the head equals $hs + hf + ha$, higher than the static and friction heads. At this time part of the water from pump will flow into the air vessel and the remaining will flow through the delivery pipe. This will increase the compressed air pressure. At the middle stroke position the head will be sufficient to just cause flow.

The whole of the flow from pump will flow to thedelivery pipe. At the second half of the stroke the head will be equal to $hs + hf – ha$. At theposition the head will be not sufficient to cause flow. The compressed air pressure will act onthe water and water charged earlier into the air vessel will now flow out. Similar situationprevails on the suction side. At the start and up to the middle of the suction stroke the head atthe pump is higher than static suction head by the amount of acceleration head.

The flow willbe more and part will flow into the air vessel. The second half of the stroke water will flow outof the air vessel. In this process the velocity of water in the delivery pipe beyond the air vessel is uniform, and lower than the maximum velocity if air vessel is not fitted. Similar situation prevails in the suction side also. The effect is not only to give uniform flow but reduce the friction head to a considerable extent saving work. Without air vessel the friction head increases, reaches a maximum value at the mid stroke and then decreases to zero. With air vessel the friction head is lower and is constant throughout the stroke. This is due to the constant velocity in the pipe.

The advantages of installing air vessels are:
(*i*) The flow fluctuation is reduced and a uniform flow is obtained.
(*ii*) The friction work is reduced.
(iii) The acceleration head is reduced considerably.
(*iv*) Enables the use of higher speeds

12) A single acting reciprocating pump having a cylinder diameter of 150 mm and stroke of 300 mm is used to raise the water though a height of 20m. Its crank rotates at 60 rpm. Find the theoretical power required to run the pump and the theoretical discharge. If actual discharge I s5 lit/s find the percentage of slip. If delivery pipe is 100 mm in diameter and is 15 m long, find the acceleration head at the beginning of the stoke. **(Nov/Dec 2010)**
13) Discuss in detail the working of centrifugal pump. Also write on working of jet pump. **(Nov/Dec 2010)**
14) The impeller of a centrifugal pump having external and internal diameters 500 mm and 250 mm respectively, width at outlet 50 mm and running at 1200 rpm. Works against a head of 48 m. The velocity of flow through the impeller is constant and equal to 3.0 m/s. The vanes are set back at an angle of 45° at outlet. Determine **(April /May 2011)**
    (i) Inlet vane angle
    (ii) Work-done by the impeller and (iii) Manometeric efficiency.
15) A three throw pump has cylinders of 250 mm diameter and stroke of 500 mm each. The pump is required to deliver 0.1 m^2/sec at a head of 100 m. Friction losses are estimated to be 1 m in the suction pipe and 19 m in delivery pipe. Velocity of water in delivery pipe is 1 m/s, overall efficiency is 85% and the slip is 3%. Determine**(April /May 2011)**
    (i) Speed of the pump and (ii) Power required for running the pump.
16) (i) Explain the working principle of jet pump with a neat sketch. (6)
    (ii) A centrifugal pump delivers water against a head of 14.5 m at a speed of 1000 rpm. The vanes are curved back at an angle of 30° with the periphery. The impeller diameter is 300 mm and outlet width 50 mm. The manometric efficiency of the pump is 85%. Determine the discharge of the pump. (10)
    (Nov/Dec 2011)

17) (i)Explain the working principle of single acting reciprocating pump with a neat sketch. (8)

(ii) A single acting reciprocating pump having plunger diameter 125 mm and stroke length 300 mm is drawing water from a depth of 4 m from the axis of the cylinder at 24 rpm. The length and diameter of suction pipe is 9 m and 75mm respectively. Determine the pressure head on the piston at the beginning, middle and end of the suction stroke. (8) **(Nov/Dec 2011)**

18) Explain in detail about rotary positive displacement pumps

HINTS :

- **Gear Pump**
- **Lobe Pump**
  Vane Pump

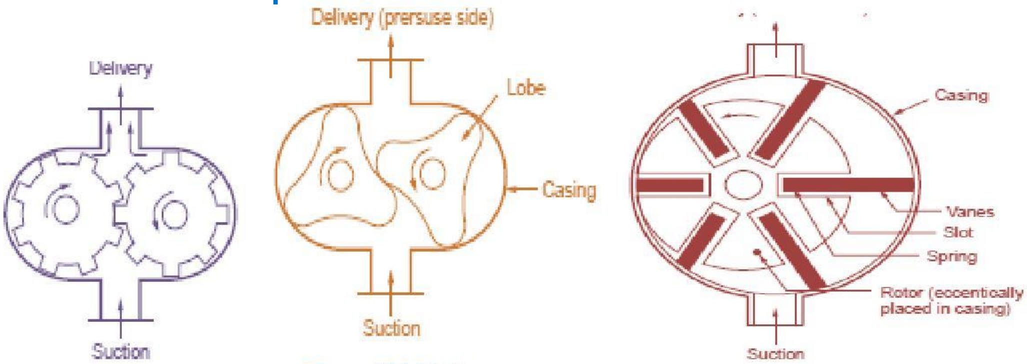


Figure 16.6.1 Gear pump

Figure 16.6.2 Lobe pump

Figure 16.6.3 Vane pump