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Director's Message

B. Singh (Ex. IES)

Engineering is one of the most chosen graduating field. Taking engineering is usually a matter of interest but this eventually develops into "purpose of being an engineer" when you choose engineering services as a career option.

Train goes in tunnel we don't panic but sit still and trust the engineer, even we don't doubt on signalling system, we don't think twice crossing over a bridge reducing our travel time; every engineer has a purpose in his department which when coupled with his unique talent provides service to mankind.

I believe *"the educator must realize in the potential power of his pupil and he must employ all his art, in seeking to bring his pupil to experience this power"*. To support dreams of every engineer and to make efficient use of capabilities of aspirant, MADE EASY team has put sincere efforts in compiling all the previous years' ESE-Pre questions with accurate and detailed explanation. The objective of this book is to facilitate every aspirant in ESE preparation and so, questions are segregated chapterwise and topicwise to enable the student to do topicwise preparation and strengthen the concept as and when they are read.

I would like to acknowledge efforts of entire MADE EASY team who worked hard to solve previous years' papers with accuracy and I hope this book will stand up to the expectations of aspirants and my desire to serve student fraternity by providing best study material and quality guidance will get accomplished.

B. Singh (Ex. IES)
CMD, MADE EASY Group

Volume-II

CIVIL ENGINEERING

Objective Solved Questions

of UPSC Engineering Services Examination

Contents

UNIT

I

Fluid Mechanics & Hydraulic Machines

Syllabus

Fluid Mechanics, Open Channel Flow, Pipe Flow: Fluid properties; Dimensional Analysis and Modeling; Fluid dynamics including flow kinematics and measurements; Flow net; Viscosity, Boundary layer and control, Drag, Lift, Principles in open channel flow, Flow controls. Hydraulic jump; Surges; Pipe networks.

Hydraulic Machines and Hydro power: Various pumps, Air vessels, Hydraulic turbines–types, classifications & performance parameters; Power house–classification and layout, storage, pondage, control of supply.

Contents

5 Fluid Kinematics

5.1 A two-dimensional flow is described by velocity components $u = 2x$ and $v = -2y$. The discharge between points (1, 1) and (2, 2) is equal to
(a) 9 units (b) 8 units
(c) 7 units (d) 6 units [ESE : 2000]

5.2 The stream function for a two-dimensional flow is given by $\psi = 2xy$. The resultant velocity at a point $P(2, 3)$ is
(a) 8.45 units/s (b) 7.21 units/s
(c) 6.44 units/s (d) 5.18 units/s
[ESE : 2003]

5.3 Consider the following parameters related to fluid flow:
1. Vorticity
2. Velocity potential
3. Stream function

Which of these parameters exist both in rotational and irrotational flows?
(a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3
[ESE : 2003]

5.4 Consider the following statements related to concept of continuity equation and the concept of control volume in deriving the equation:
1. Continuity equation relates velocity component and density of the fluid at a point in a fluid flow.
2. Continuity equation assumes that no void occurs in the fluid and fluid mass is neither created nor destroyed.
3. The shape of control volume for deriving the equation of continuity is assumed to be a parallelepiped.
4. For incompressible fluids the equation of continuity does not contain the viscosity terms.

Which of these statements are correct?
(a) 1, 2, 3 and 4 (b) 1 and 2
(c) 2, 3 and 4 (d) 1 and 4
[ESE : 2003]

5.5 Match **List-I** (Format of representation) with **List-II** (Context/Relevant to) and select the correct answer using the codes given below the lists:

List-I

A. $\dfrac{\partial u}{\partial x} + \dfrac{\partial v}{\partial y}$

B. $\dfrac{\partial v}{\partial x} - \dfrac{\partial u}{\partial y}$

C. $u\dfrac{\partial u}{\partial x} + v\dfrac{\partial u}{\partial y}$

D. $\dfrac{q\theta}{2\pi}$

List-II

1. Relevant to a velocity potential
2. Rate of rotation about a relevant axis
3. Pressure gradient in a relevant direction
4. Continuity of flow

Codes:

	A	B	C	D
(a)	3	2	4	1
(b)	4	1	3	2
(c)	3	1	4	2
(d)	4	2	3	1

[ESE : 2007]

5.6 If the stream function $\psi = 3x^2 - y^3$, what is the magnitude of velocity at point (2, 2)?
(a) 9 (b) 13
(c) 15 (d) 17 [ESE : 2007]

5.7 Consider the following statements:
1. Fluids of low viscosity are all irrotational.
2. Rotation of the fluid is always associated with shear stress.

Which of these statements is/are correct?
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2
[ESE : 2008]

5.8 Consider the following statements in respect of two-dimensional incompressible flow with velocity components u and v in x and y directions respectively:

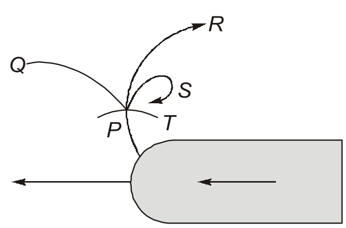
1. The continuity equation is $\frac{\partial u}{\partial x} = \frac{\partial v}{\partial y}$
2. The acceleration in x-direction is $a_x = \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}$
3. The condition of irrotationality is $\frac{\partial u}{\partial y} = \frac{\partial v}{\partial x}$
4. The equation of a streamline is $udy = -vdx$

Which of these statements are correct?

(a) 2 and 3 only (b) 1 and 2 only
(c) 1, 2 and 3 (d) 3 and 4

[ESE : 2009]

5.9 Match **List-I** (Name of curve) with **List-II** (Curve in figure) and select the correct answer using the codes given below the lists:



List-I		List-II	
A.	Equipotential line	**1.**	*PQ*
B.	Pathline	**2.**	*PR*
C.	Streakline	**3.**	*PS*
D.	Streamline	**4.**	*PT*

Codes:

	A	B	C	D
(a)	2	3	1	4
(b)	4	1	3	2
(c)	2	1	3	4
(d)	4	3	1	2

[ESE : 2010]

5.10 Consider the following statements:

1. A streamline is an imaginary line within the flow for which the normal at any point relates to the acceleration at that point.
2. Convective acceleration is the change in velocity with respect to distance only.
3. Temporal acceleration expresses variation of velocity with respect to time only.
4. Both convective acceleration and temporal acceleration can coexist.

Which of these statements are correct related to fluid kinematics?

(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 2 and 3 only (d) 2, 3 and 4 only

[ESE : 2010]

5.11 Consider the following statements:

1. There is no flow across a streamline.
2. Streamline spacing varies directly with velocity at the section.
3. Streamlines do not cross.
4. In steady flow, streamline pattern does not change with time.

Which of these statements in respect of stream flow pattern are correct?

(a) 1, 2, 3 and 4 (b) 1 and 2 only
(c) 1, 3 and 4 only (d) 2, 3 and 4 only

[ESE : 2011]

5.12 *X*-component of velocity in a two dimensional incompressible flow is given by $u = 2y^2 + 6xy$. If the *Y*-component of velocity v is zero at $y = 0$, the expression for *Y*-component of velocity is given by

(a) $v = 3y^2 + f(y)$ (b) $v = 3y^2 + f(x)$
(c) $v = -3y^2 + f(y)$ (d) $v = -3y^2 + f(x)$

[ESE : 2013]

5.13 In a two-dimensional flow, with its stream function $\psi = 2xy$, the velocity at a point (3, 4) is

(a) 12.0 units (b) 10.0 units
(c) 8.0 units (d) 6.0 units

[ESE : 2016]

5.14 A fluid flow is described by a velocity fluid $\bar{U} = 4x^2i - 5x^2yj + 1k$.

What is the absolute velocity (in magnitude) at the point (2, 2, 1)?

(a) $\sqrt{1802}$ (b) $\sqrt{1828}$
(c) $\sqrt{1840}$ (d) $\sqrt{1857}$

[ESE : 2016]

5.15 A line source of strength 15π m/s is situated within a uniform stream flowing at –12 m/s (i.e. right to left). At a distance of 0.6 m downstream from the source is an equal sink. How far will the stagnation points be from the nearest source/sink?

(a) 0.38 m (b) 0.46 m
(c) 0.52 m (d) 0.58 m

[ESE : 2016]

5.16 A fluid flow field is given by

$$U = 2xyi + yzj - \left(2yz + \frac{z^2}{2}\right)k.$$

1. The flow is viscous.
2. The flow is steady.
3. The flow is incompressible.
4. The magnitude of the total velocity vector at a point (1, 4, 3) is nearest to 27 units.

Which of the above statements are correct?

(a) 1 and 3 (b) 1 and 4
(c) 2 and 3 (d) 2 and 4

[ESE : 2017]

5.17 A steady, two dimensional, incompressible flow field is represented by

$u = x + 3y + 3$ and $v = 2x - y - 8$

In this flow field, the stagnation point is

(a) (3, 2) (b) (–3, 2)
(c) (–3, –2) (d) (3, –2)

[ESE : 2018]

5.18 The stream function of a doublet with horizontal axis and of strength μ is

(a) $\frac{\mu}{2\pi}r$ (b) $\frac{\mu}{2\pi r}\cos\theta$
(c) $\frac{\mu}{2\pi}r\sin\theta$ (d) $\frac{\mu}{2\pi}\frac{\sin\theta}{r}$

[ESE : 2018]

5.19 Which one of the following is the use of flow net analysis in fluid mechanics?

(a) To determine the streamlines and equipotential lines.
(b) To determine, downward lift pressure above hydraulic structure.
(c) To determine the viscosity for given boundaries of flow.
(d) To design the hydraulic structure.

[ESE : 2020]

5.20 A stream function is given by $\psi = 3x^2 - y^3$. What is the magnitude of velocity components at the point (2,1)?

(a) 8.52 (b) 9.17
(c) 10.81 (d) 12.37

[ESE : 2021]

5.21 The stream function is given by the expression $\psi = 2x^2 - y^2$. What is the resultant velocity at a point denoted by $x = 2$ and $y = 3$?

(a) 10 (b) 12
(c) 15 (d) 18

[ESE : 2022]

5.22 Statement I : The negative derivative of velocity potential function with respect to any direction gives the fluid velocity in that direction.

Statement II : The partial derivative of stream function in any direction gives the velocity component in that direction.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is ***not*** the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2023]

■■■■

Answers Fluid Kinematics

5.1 (d)	5.2 (b)	5.3 (c)	5.4 (a)	5.5 (d)	5.6 (d)	5.7 (b)	5.8 (a)	5.9 (d)
5.10 (d)	5.11 (c)	5.12 (d)	5.13 (b)	5.14 (d)	5.15 (a)	5.16 (c)	5.17 (d)	5.18 (d)
5.19 (d)	5.20 (d)	5.21 (a)	5.22 (c)					

Explanations Fluid Kinematics

5.1 (d)

$$v = \frac{\partial \psi}{\partial x} = -2y \quad ...(i)$$

$$u = -\frac{\partial \psi}{\partial y} = -2x \quad ...(ii)$$

Integrating (i), we get

$$\psi = -2xy + f(y) \quad ..(iii)$$

Differentiating (iii) w.r.t. y, we get

$$\frac{\partial \psi}{\partial y} = -2x + f'(y) \quad ...(iv)$$

Equating (ii) and (iv), we get

$$f'(y) = 0 \quad ...(v)$$

Inegrating (v), we get

$$f(y) = C$$

where C is a numerical constant which can be treated as zero.

From (iii), we get

$$\psi = -2xy$$

At (1, 1); $\psi_1 = -2$ units

At (2, 2); $\psi_2 = -8$ units

$$Q_{\text{per unit width}} = |\psi_2 - \psi_1|$$
$$= 8 - 2 = 6 \text{ units}$$

5.2 (b)

$$u = -\frac{\partial \psi}{\partial y} = -2x = -4\text{units}$$

$$v = \frac{\partial \psi}{\partial x} = 2y = 6\text{units}$$

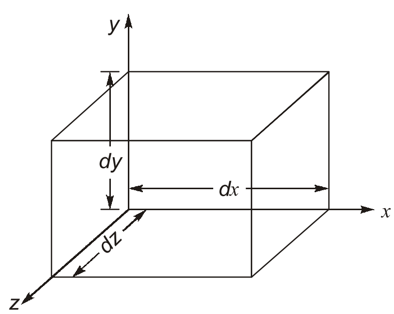
$$V = \sqrt{u^2 + v^2} = \sqrt{16 + 36}$$
$$= 7.21 \text{ units}$$

5.3 (c)

Velocity potential function can not be defined for rotational flow.

5.4 (a)

- Continuity equation is based on the conservation of mass. The continuity equation for 3D flow in Cartesian system is $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} + \frac{\partial \rho}{\partial t} = 0$.
- Continuity equation assumes that no void occurs in the fluid and fluid mass is neither created nor destroyed.
- In deriving the continuity equation a control volume of parallelepiped is taken



- In incompressible flow, the viscosity is not involved in continuity equation.

5.5 (d)

- Continuity equation is $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$.
- Rate of rotation about a relevant axis

$$w_z = \frac{1}{2}\left[\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right]$$

- $\frac{q\theta}{2\pi}$ is the stream function for source. As there is a relation between stream function and potential function so $\frac{q\theta}{2\pi}$ is related to potential function also.

5.6 (d)

Stream function, $\psi = 3x^2 - y^3$

$$\therefore \quad \frac{\partial \psi}{\partial x} = 6x \text{ and } \frac{\partial \psi}{\partial y} = -3y^2$$

But
$$u = -\frac{\partial \psi}{\partial y}$$
$$= -(-3y^2) = 3 \times 2^2 = 12$$
$$v = \frac{\partial \psi}{\partial x} = 6x = 6 \times 2 = 12$$

$$\therefore \text{Resultant velocity} = \sqrt{u^2 + v^2}$$
$$= \sqrt{(12)^2 + (12)^2}$$
$$= \sqrt{288} = 16.97 \approx 17$$

5.7 (b)

- Statement 1 is incorrect since the fluids having low viscosity may be rotational. Example flow of air (inside the boundary layer) over a flat plate.
- Rotation of fluid is always associated with shear stress.

5.8 (a)

For two dimensional incompressible flow,

- the continuity equation is $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$, so statement 1 is wrong.
- the equation of a stream line is $vdx - udy = 0$, so statement 4 is wrong.

5.9 (d)

- Equipotential line and stream line are orthogonal to each other. In the figure PT shown as equipotential line and perpendicular to PT, PR is shown as stream line.
- Path line is represented as PS.
- Streak line is represented as PQ. (It is the locus of different particles released from the same location at an instant).

5.10 (d)

- Statement 1 is wrong.
- Statement 2 and 3 are correct.
- Statement 4 is correct. For a nonuniform and unsteady flow both convective and temporal acceleration exist.

5.11 (c)

- Statement 1 is correct. Since the flow is along the streamline not across the streamline.
- Statement 2 is wrong. Streamline spacing is $|\psi_1 - \psi_2|$ which represent discharge per unit width area.

$$Q = AV \qquad (Q \text{ is constant})$$
$$A \propto \frac{1}{V}$$

So streamline spacing is inversely proportional to velocity at any section.

- Statement 3 is correct, streamlines never cut each other in a flow.
- Statement 4 is correct.

5.12 (d)

$$u = 2y^2 + 6xy$$

From continuity equation

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$
$$\frac{\partial}{\partial x}\left(2y^2 + 6xy\right) + \frac{\partial v}{\partial y} = 0$$
$$\Rightarrow \quad -6y = \frac{\partial v}{\partial y}$$
$$6y + \frac{\partial v}{\partial y} = 0$$

Int. it $\quad v = -3y^2 + F(x)$

5.13 (b)

$$\psi = 2xy$$
$$u = -\frac{\partial \psi}{\partial y} = -2x = -(2)(3)$$
$$= -6 \text{ units}$$
$$v = \frac{\partial \psi}{\partial x} = 2y = 2(4) = 8 \text{ units}$$

Velocity of (3, 4),

$$V = \sqrt{(-6)^2 + (8)^2} = 10 \text{ units}$$

5.14 (d)

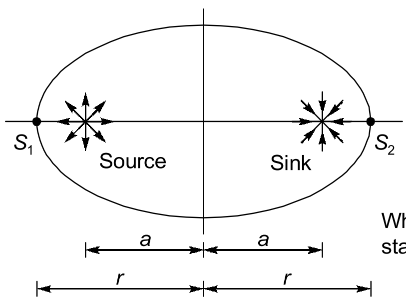
$$\vec{V} = 4x^2\hat{i} - 5x^2y\hat{j} + 1\hat{k}$$

At point (2, 2, 1)

$$u = 4(2)^2 = 16$$

$$v = -5x^2y = -5(2)^2(2) = -40$$
$$w = 1$$
$$V = \sqrt{16^2 + (-40)^2 + 1^2}$$
$$= \sqrt{1857} \text{ m/sec}$$

5.15 (a)



Where S_1 and S_2 are stagnation point.

Given, $a = \dfrac{0.6}{2} = 0.3$ m

$u = 12$ m/sec

Now, $r = a\sqrt{\dfrac{Q}{\pi a U_\infty} + 1}$

$$0.3 = \sqrt{\frac{15\pi}{\pi(0.3)(12)} + 1}$$
$$= 0.6819 \text{ m}$$

So, $r - a = 0.6819 - 0.3 = 0.381$ m

5.17 (d)

$u = x + 3y + 3$
$v = 2x - y - 8$

At stagnation point the velocity of net flow becomes to zero.

$$|\vec{V}| = 0$$

means $u = 0$ and $v = 0$

$x + 3y + 3 = 0$
$2x - y - 8 = 0$

By eq. (i) and (ii)

$x = 3$
$y = -2$

Point = 3, –2

5.20 (d)

Given stream function,
$$\psi = 3x^2 - y^3$$

Velocity component:

In x-direction, $u = -\dfrac{\partial\psi}{\partial y} = -\dfrac{\partial}{\partial y}(3x^2 - y^3)$

$$= -(0 - 3y^2)$$
$$u = 3y^2$$

In y-direction, $v = \dfrac{\partial\psi}{\partial x} = \dfrac{\partial}{\partial x}(3x^2 - y^3)$

$$= (3 \times 2x - 0)$$
$$v = 6x$$

At (2, 1)

$u = 3(1)^2 = 3$ units
$v = 6(2) = 12$ units

$\therefore$ $\vec{V} = u\hat{i} + v\hat{j} = 3\hat{i} + 12\hat{j}$

$$|\vec{v}| = \sqrt{u^2 + v^2}$$
$$= \sqrt{3^2 + 12^2} = \sqrt{153} \text{ m/s}$$
$$|\vec{v}| = 12.37 \text{ m/s}$$

5.21 (a)

Given: $\psi = 2x^2 - y^2$

$\therefore$ $u = -\dfrac{\partial\psi}{\partial y} = -\dfrac{\partial}{\partial y}(2x^2 - y^2) = 2y$

$\therefore$ $v = \dfrac{\partial\psi}{\partial x} = \dfrac{\partial}{\partial x}(2x^2 - y^2) = 4x$

At $(x, y) = (2, 3)$,

$\Rightarrow$ $u = 2 \times 3 = 6$ units

$\Rightarrow$ $v = 4 \times 2 = 8$ units

$\therefore$ $V_R = \sqrt{u^2 + v^2} = \sqrt{6^2 + 8^2}$

$\Rightarrow$ $V_R = \sqrt{100} = 10$ units

■■■■

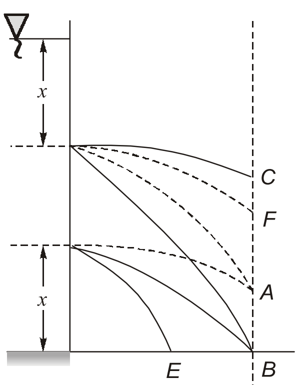
6 Fluid Dynamics, Flow Measurements

6.1 A 30 cm diameter, 90° elbow has one limb vertical. Average velocity of flow of water through the elbow is 5 m/s and the pressure intensity is 4 kPa. The vertical component of force to keep the elbow in position will be

(a) 0.28 kN (b) 1.49 kN
(c) 1.77 kN (d) 2.05 kN

[ESE : 2001]

6.2 One orifice is located at a distance 'x' from the free surface while another orifice is located at the same distance 'x' from the bottom of the tank as shown in the figure.



The water jets through the orifices

(a) intersect at point A
(b) intersect at point B
(c) strike the plane at point C and B respectively
(d) would be striking at E and F only

[ESE : 2002]

6.3 Match **List-I** (Equation/Principle) with **List-II** (Property) and select the correct answer using the codes given below the lists:

List-I
A. Energy equation
B. Continuity equation
C. Moment of momentum principle
D. Impulse-momentum principle

List-II
1. Force on a moving vane
2. Lawn sprinkler
3. Pressure at a point in a pipeline
4. Flow at two sections of a tapering pipe

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	3	4	1	2
(c)	4	3	1	2
(d)	3	4	2	1

[ESE : 2003]

6.4 Consider the following statements related to a horizontal venturimeter:

1. The velocity of flow in the main pipe is greater and the pressure is lesser than that at the throat section.
2. The velocity of flow in the main pipe is lower and the pressure is larger than that at the throat section.
3. The pressure difference between the main pipe and throat section is positive.
4. The pressure difference between the main pipe and throat section is negative.

Which of these statements are not correct?

(a) 1 and 4 (b) 1 and 2
(c) 2 and 3 (d) 3 and 4

[ESE : 2003]

6.5 When a body moves through still water at a constant velocity of 4.5 m/s, the velocity of water at 0.8 m ahead of the nose of the body is 3.0 m/s. What will be the difference in pressure between the nose and the point 0.8 m ahead of it?

(a) 875 N/m^2 (b) 1000 N/m^2
(c) 1125 N/m^2 (d) 1250 N/m^2

[ESE : 2003]

6.6 Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

List-I
A. The type of vortex flow in which no external torque rotates the fluid mass

B. Flow of liquid inside the impeller of a centrifugal pump
C. Free surface of forced vortex flow
D. In forced vortex, the rise of liquid level at ends

List-II
1. The fall of liquid at the axis of rotation
2. Free vortex flow
3. Parabolic
4. Forced vortex flow

Codes:

	A	B	C	D
(a)	4	2	3	1
(b)	2	4	3	1
(c)	4	2	1	3
(d)	2	4	1	3

[ESE : 2003]

6.7 Match **List-I** (Causes) with **List-II** (Effects) pertaining to rotation and vertical/horizontal motion of liquid masses at constant acceleration and select the correct answer using the codes given below the lists:

List-I
A. The form of the free surface of liquid in a rotating open vessel
B. The form of surface of the liquid in a tanker moving in the direction of its length
C. The pressure at any point in a container's base moving with upward acceleration
D. The pressure at any point in a container's base moving with downward acceleration

List-II
1. An inclined plane
2. A paraboloid of revolution
3. Greater than the hydrostatic value
4. Less than the hydrostatic value

Codes:

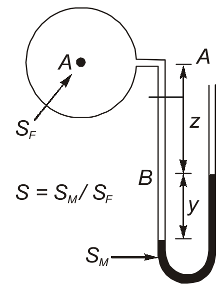
	A	B	C	D
(a)	4	1	3	2
(b)	4	3	2	1
(c)	2	3	1	4
(d)	2	1	3	4

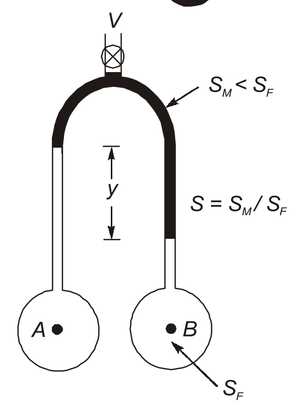
[ESE : 2004]

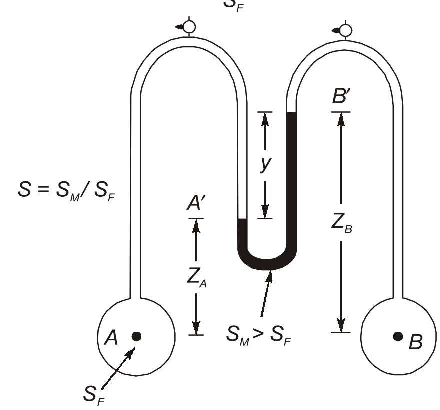
6.8 Match **List-I** (Features) with **List-II** (Type of manometers) and select the correct answer using the codes given below the lists:

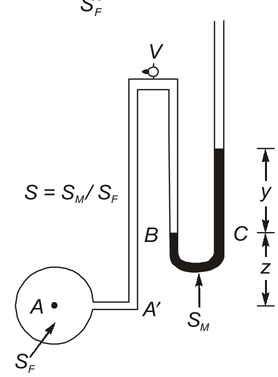
List-I
A. Open ended manometer for positive pressure
B. Negative pressure manometer
C. For measuring pressure in liquids or gases
D. For measuring pressure in liquids only

List-II

1. 

2. 

3. 

4. 

Codes:

	A	B	C	D
(a)	3	4	1	2
(b)	1	2	3	4
(c)	3	2	1	4
(d)	1	4	3	2

[ESE : 2004]

6.9 Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

List-I
A. Equation of motion along a streamline
B. Euler's equation
C. Pressure exerted by a free jet
D. Rotating lawn sprinkler

List-II
1. Principle of moment of momentum
2. Bernoulli's equation
3. Equation for conservation of momentum
4. Momentum equation

Codes:

	A	B	C	D
(a)	4	1	2	3
(b)	2	3	4	1
(c)	4	3	2	1
(d)	2	1	4	3

[ESE : 2005]

6.10 A Pitot-static tube, with a coefficient of 0.98 is used to measure the velocity of water in a pipe. The stagnation pressure recorded is 3 m and the static pressure is 0.5 m. What is the velocity of flow?
(a) 7.2 m/s (b) 6.8 m/s
(c) 5.9 m/s (d) 5.2 m/s [ESE : 2006]

6.11 **Assertion (A):** It takes longer to drain a reservoir with a long vertical pipe taken down from its bottom discharging into atmosphere than with an orifice at the bottom.
Reason (R): The relative height of the water surface elevation in the reservoir compensates for the friction loss in the pipe besides the entry and exit losses in the pipe.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true [ESE : 2006]

6.12 In an air flow the velocity is measured by a Pitot tube (coefficient = 1.0). The mass density of air can be taken as 1.2 kg/m^3. If the head difference in a vertical U-tube holding water is 12 mm, then what is the velocity of air in m/s?
(a) 10 (b) 14
(c) 17 (d) 20 [ESE : 2007]

6.13 Consider the following:
1. Force on pipe bends and transitions
2. Jet propulsion
3. Flow velocities in open channel
4. Vortex flow

Which of the above admit employing the moment of momentum equation?
(a) 1 and 2 only (b) 1, 2 and 3
(c) 1 and 3 only (d) 2, 3 and 4
[ESE : 2009]

6.14 Consider the following statements:
The moment of momentum equation in fluid dynamics can be used
1. to find the torque exerted on sprinklers by water
2. to determine the force in a flow passage, when stream changes direction/magnitude.

Which of these statements is/are correct?
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2
[ESE : 2010]

6.15 The movement of air mass in the case of Tornado can be described as
(a) Forced vortex throughout
(b) Free vortex throughout
(c) Forced vortex at the core and free vortex outside
(d) Free vortex at the core and forced vortex outside
[ESE : 2011]

6.16 Consider the following statements:
Euler's equation of motion
1. can be derived from Navier-Strokes equations.
2. refers to energy balance.
3. develops into Bernoulli's equation under appropriate conditions.
4. is applicable to rotational as well as irrotational flows.

Which of these statements are correct?
(a) 1, 2, 3 and 4 (b) 1 and 2 only
(c) 1 and 3 only (d) 3 and 4 only
[ESE : 2013]

6.17 At a distance of 20 cm from the axis of a whirlpool in an ideal liquid, the velocity is 10 m/s. At a radius of 50 cm, what will be the depression of the free surface of the liquid below that at a very large distance?
(Take $1/g = 0.102$ s^2/m)
(a) 0.408 m (b) 0.612 m
(c) 0.816 m (d) 1.224 m
[ESE : 2013]

6.18 The Bernoulli's equation is applicable to:
(a) Both steady and unsteady flows
(b) Real fluids
(c) All fluids and flows along a stream tube
(d) Steady flow of ideal fluids along a stream tube [ESE : 2013]

6.19 **Statement (I):** The integration of differential form of Euler's equation of motion yields to Bernoulli's equation.
Statement (II): Euler's equation is based on the assumption of conservation of mass.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true
[ESE : 2013]

6.20 Flow measurements with a Prandtl-Pitot tube showed that the tip readings varied only across the flow while the side-opening readings varied only in the direction of flow. The type of flow is
(a) Uniform irrotational
(b) Uniform rotational
(c) Non-uniform irrotational
(d) Non-uniform rotational [ESE : 2013]

6.21 An open cylindrical tank of 75 cm diameter and 1.5 m high contains water upto 1.2 m depth. If the cylinder is rotated about its vertical axis, what is the maximum angular velocity (in radians per second) that can be attained without spilling any water?
(a) 7.55 (b) 8.08
(c) 9.15 (d) 10.02 [ESE : 2013]

6.22 A horizontal venturimeter with inlet diameter of 30 cm and throat diameter of 15 cm is used to measure the flow of water. The reading on a differential manometer connected to the inlet and the throat is 20 cm of mercury. If $C_d = 0.98$, the rate of flow is nearly
(a) 12.5 *l*/s (b) 25 *l*/s
(c) 125 *l*/s (d) 250 *l*/s
[ESE : 2014]

6.23 A mercury water manometer has a gauge difference of 0.8 m. The difference in pressure measured in metres of water is
(a) 0.8 (b) 1.06
(c) 10.05 (d) 8.02 [ESE : 2015]

6.24 An orifice is located in the side of a tank with its centre 10 cm above the base of the tank. The constant water level is 1.0 m above the centre of orifice. The coefficient of velocity is 0.98. On the issuing jet, the horizontal distance from the vena-contracta to where the jet is 10 cm below vena-contracta is
(a) 1.62 m (b) 1.00 m
(c) 0.62 m (d) 0.32 m [ESE : 2016]

6.25 The velocity of water at the outer edge of a 60 cm diameter whirlpool, where the water level is horizontal is 2.5 m/s. The velocity of water at a level where the diameter of the whirlpool is 15 cm, is
(a) 1 m/s (b) 5 m/s
(c) 8 m/s (d) 10 m/s
[ESE : 2016]

6.26 A cylindrical vessel with closed bottom and open top is 0.9 m in diameter. What is the rotational speed about its vertical axis (with closed bottom below and open top above) when the contained incompressible fluid will rise 0.5 m at the inner circumference of the vessel and a space of 0.4 m diameter at the bottom will have no fluid thereon? Take $g = 10$ m/s^2.
(a) 650 rpm (b) 600 rpm
(c) 580 rpm (d) 470 rpm
[ESE : 2016]

Directions: The following items consists of two statements; one labelled as **'Statement (I)'** and the other as **'Statement (II)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

6.27 **Statement (I):** When flow through a pipeline is measured through fixing a venturimeter, the computed flow will not be sensitive to the alignment of the centre line of the set-up—horizontal or sloping, up or down, along the flow direction.

Statement (II) : The difference in the readings on the manometer limbs is by itself always adjusted for the ratio of the densities of the two liquids—the manometer liquid and the liquid whose flow rate is being measured—in the development of the formula for computing the discharge.

[ESE : 2017]

6.28 **Statement (I)) :** Bernoulli's equation is applicable to any point in the flow field provided the flow is steady and irrotational.

Statement (II) : The integration of Euler's equation of motion to derive Bernoulli's equation involves the assumptions that velocity potential exists and that the flow conditions do not change with time at any point.

[ESE : 2018]

6.29 A vertical cylindrical tank, 2 m diameter has, at the bottom, a 5 cm diameter, sharp-edged orifice, for which C_d = 0.6. Water enters the tank at a constant rate of 9 *l*/sec. At what depth above the orifice will the level in the tank become steady?

(a) 2.95 m (b) 2.75 m
(c) 2.60 m (d) 2.50 m

[ESE : 2018]

6.30 What is the rotational speed in rpm of a 0.8 m diameter cylindrical container, held with axis vertical, if the fluid contained in it rises to 0.6 m height at the sides and leaves a circular space 0.3 m diameter on the bottom uncovered?

(a) 90.2 rpm (b) 88.4 rpm
(c) 86.0 rpm (d) 83.7 rpm

[ESE : 2018]

6.31 For frictionless adiabatic flow of compressive fluid, the Bernoulli's equation with usual notations is

(a) $\frac{k}{k-1}\frac{p_1}{w_1}+\frac{v_1^2}{2g}+z_1=\frac{k}{k-1}\frac{p_2}{w_2}+\frac{v_2^2}{2g}+z_2+h_L$

(b) $\frac{k}{k-1}\frac{p_1}{w_1}+\frac{v_1^2}{2g}+z_1=\frac{k}{k-1}\frac{p_2}{w_2}+\frac{v_2^2}{2g}+z_2$

(c) $\frac{p_1}{w_1}+\frac{v_1^2}{2g}+z_1+H_m=\frac{p_2}{w_2}+\frac{v_2^2}{2g}+z_2$

(d) $\frac{k}{k-1}\frac{p_1}{w_1}+\frac{v_1^2}{2g}+z_1+H_m=\frac{p_2}{w_2}+\frac{v_2^2}{2g}+z_2+h_L$

[ESE : 2019]

6.32 Which one of the following is a device used for measuring the velocity of flowing water in pipes or open channels?

(a) Pitot tube (b) Piezometer
(c) Venturimeter (d) Venturi tube

[ESE : 2021]

6.33 Which one of the following is the correct assumption for the derivation of Bernoulli's equation?

(a) The flow is compressible
(b) Viscosity is zero
(c) The flow is unsteady
(d) The flow is rotational [ESE : 2023]

6.34 Consider the following statements regarding ultrasonic flowmeters :

1. There are no moving parts.
2. They cannot measure flow quantities in reverse flow.
3. There is no direct contact with the fluid, there is no danger of corrosion or clogging.

Which of the above statements are correct?

(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3

[ESE : 2024]

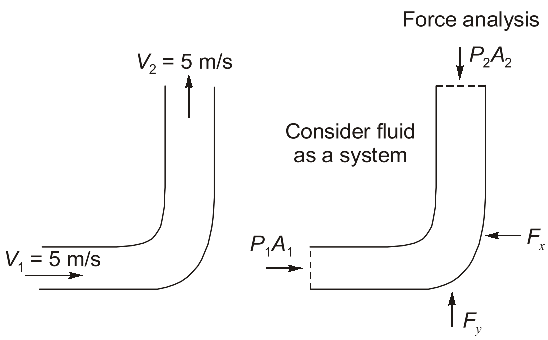
■■■■

Answers Fluid Dynamics, Flow Measurements

6.1 (d)	6.2 (b)	6.3 (d)	6.4 (a)	6.5 (*)	6.6 (b)	6.7 (d)	6.8 (d)	6.9 (b)
6.10 (b)	6.11 (d)	6.12 (b)	6.13 (d)	6.14 (a)	6.15 (c)	6.16 (c)	6.17 (c)	6.18 (d)
6.19 (c)	6.20 (d)	6.21 (c)	6.22 (c)	6.23 (c)	6.24 (c)	6.25 (d)	6.26 (*)	6.27 (a)
6.28 (a)	6.29 (a)	6.30 (b)	6.31 (b)	6.32 (a)	6.33 (b)	6.34 (b)		

Explanations Fluid Dynamics, Flow Measurements

6.1 (d)

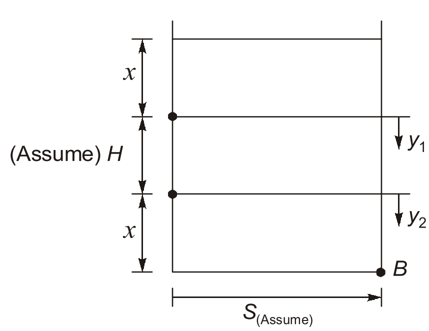


$$P_1 = P_2 = 4000 \text{ Pa}$$
$$D_1 = D_2 = 30 \text{ cm}$$
$$F_x\, F_y = \text{Force exerted on the fluid}$$

Momentum eq. in y-direction.

$$F_y - P_2A_2 = \dot{m}V_2 - \dot{m}(0)$$
$$F_y = \dot{m}V_2 + P_2A_2$$
$$= (\rho A_2V_2)V_2 + P_2A_2$$
$$= \left[(1000)(5)^2\right] + 4000\left[\frac{\pi}{4}(0.3)^2\right] = 2.05 \text{ kN}$$

6.2 (b)



Assume C_v is same for both the orifice and the horizontal distance travelled by both the jets is same (S).

$$C_v = \frac{S}{2\sqrt{x.y_1}} = \frac{S}{2\sqrt{(x+H)y_2}}$$

$$\frac{1}{\sqrt{x.y_1}} = \frac{1}{\sqrt{(x+H)y_2}}$$

$$\frac{y_1}{y_2} = \frac{x+H}{x}$$

It is possible if the jet intersect at 'B'.

6.4 (a)

The cross-section area of main pipe is more than that of throat section. Therefore, from continuity equation velocity of flow in main pipe will be lower than that at the throat section. The flow from main pipe to throat takes place due to pressure gradient and therefore pressure in main pipe is more.

So statement 1 is incorrect.

6.5 (*)

$$\frac{P_1 - P_2}{\rho g} = \frac{V_2^2 - V_1^2}{2g}$$

$$P_1 - P_2 = \frac{1000}{2}\left[4.5^2 - 3^2\right]$$

$$= 500\left[4.5^2 - 3^2\right] = 5625 \text{ N/m}^2$$

No any option is given in the problem.

6.6 (b)

In forced vortex flow:

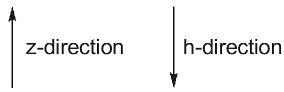
1. In free vortex flow no external torque rotates the fluid mass.
2. Flow of liquid inside impeller of a centrifugal pump is forced vortex flow.
3. The free surface of liquid is in parabolic shape.
4. Rise of liquid levels at the ends is equal to the fall of liquid at axis of rotation.

6.7 (d)

Form of surface of liquid in

1. Rotating open vessel- Paraboloid of revolution
2. Tanker moving along length- inclined plane

Container moving in the vertical direction



$$\frac{dP}{dh} = \rho(a_z + g)$$

For upward motion a_z is +ve so pressure is greater than the hydrostatic value. For downward motion a_z is – ve so pressure is lesser than the hydrostatic value.

6.9 (b)

The moment of momentum equation can be applied to analyze rotating systems, such as turbines, sprinklers, and fans. Bernoulli's equation is used to applicable to steady incompressible flow along a streamline. Euler's equation is based on conservation of momentum. Pressure exerted by free jet can be analyzed by momentum equation.

6.10 (b)

$$V = C_v\sqrt{2gh}$$

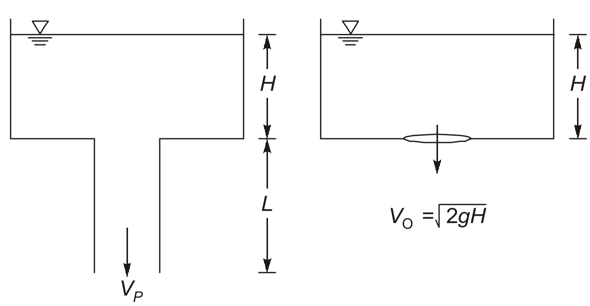
For horziontal

$$h = \frac{P_{stag}}{\rho g} - \frac{P_{static}}{\rho g}$$

$$= 3 - 0.5 = 2.5 \text{ m}$$

$$= 0.98 \times \sqrt{2 \times 9.81 \times 2.5} = 6.86 \text{ m/s}$$

6.11 (d)



Reservoir with a long vertical pipe of length L

$$V_P = \sqrt{2g(H + L) - h_f}$$

Since V_P is greater than V_O. So reservoir with long vertical pipe of length L will take less time to empty then the reservoir having an orifice at the bottom. Hence assertion is wrong.

6.12 (b)

$$V = C_v\sqrt{2gh}$$

$$h = x\left[\frac{\rho_w}{\rho_a} - 1\right]$$

$$= 0.012\left[\frac{10^3}{1.2} - 1\right]$$

$$= 9.988 \text{ m}$$

$$V = 1 \times \sqrt{2 \times 9.81 \times 9.988}$$

$$= 13.99 \text{ m/s}$$

$$\approx 14 \text{ m/s}$$

6.13 (d)

- Force on pipe bends employ the impulse momentum equation.
- Vortex flow employ the moment of momentum equation.

6.15 (c)

A combination of free and forced vortex is known as compound vortex or Rankine vortex. In a tornado inner core region experiences forced vortex while outer core region experiences free vortex.

6.17 (c)

Whirlpool is a example of free vortex flow.

So, $v \propto \frac{1}{r}$ i.e. vr = constant

Now, $v_1 = 10$ m/s, $r_1 = 20$ cm

When $r_2 = 50$ cm

$$v_2 = \frac{v_1 r_1}{r_2} = \frac{10 \times 20}{50} = 4 \text{ m/s}$$

According to fundamental equation of vortex flow,

$$dP = \frac{\rho v^2 dr}{r} - \rho g dz \left\{v = \frac{c}{r}\right\}$$

$$0 = \frac{\rho C^2}{r^2 r}dr - \rho g dz$$

$$dz = \frac{\rho C^2}{r^3 g}dr$$

Int. it

$$z = \frac{c^2}{g} \times -\frac{1}{2} \times \left[\frac{1}{r^2}\right]_{0.5}^{\infty}$$

$$[c = vr = 0.2 \times 10]$$

$$z = 0.816 \text{ m}$$

6.18 (d)

Bernoulli's equation is applicable to steady, incompressible flow along a streamline when the effect of viscous effect is neglected.

6.19 (c)

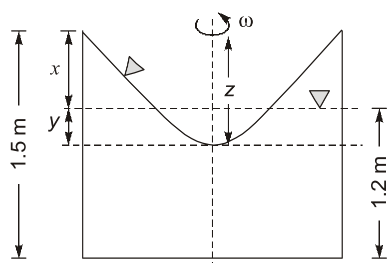
Statement (2) is wrong.

- Euler's equation based on the assumption of conservation of momentum.

6.20 (d)

As tip reading varied only across the flow while side-opening reading varied only in the direction of flow, velocity of flow is not same across the flow. Hence the flow is non-uniform rotational.

6.21 (c)



$$R = \frac{75}{2}\text{cm} = 0.375 \text{ m}$$

For conservation of volume

$$x = y$$

$$x = y = 1.5 - 1.2 = 0.3$$

$$z = 0.3 + 0.3 = 0.6 \text{ m}$$

$$z = \frac{\omega^2 R^2}{2g}$$

$$0.6 = \frac{\omega^2 (0.375)^2}{2g}$$

$$\omega = 9.15 \text{ rad/s}$$

6.22 (c)

In Venturimeter,

Rate of flow,

$$Q = \frac{C_d A_1 A_2}{\sqrt{A_1^2 - A_2^2}}\sqrt{2gh}$$

Here, $h = 20\left(\frac{\rho_{Hg}}{\rho_w} - 1\right)$

$$= 20\left(\frac{13.6 \times 10^3}{10^3} - 1\right)$$

$$= 20\,(13.6 - 1) = 252 \text{ cm}$$

$$\therefore \quad Q = \frac{0.98 \times \frac{\pi}{4} \times 30^2 \times \frac{\pi}{4} \times 15^2}{\sqrt{\left[\frac{\pi}{4} \times 30^2\right]^2 - \left[\frac{\pi}{4} \times 15^2\right]^2}}$$

$$\times \sqrt{2 \times 981 \times 252}$$

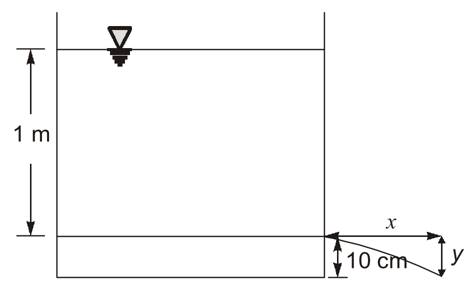
$$= \frac{0.98 \times 30^2 \times \frac{\pi}{4} \times 15^2}{\sqrt{30^4 - 15^4}} \times \sqrt{2 \times 981 \times 252}$$

$$= 125.76 \ l/\text{sec}$$

6.23 (c)

$$h = x\left(\frac{\rho_{Hg}}{\rho_w} - 1\right) = 0.8\left(\frac{13.6}{1} - 1\right) = 10.08 \text{ m}$$

6.24 (c)



Given, $y = 10$ cm $= 0.1$ m

We know that

$$C_v = \frac{x}{2\sqrt{y \cdot H}}$$

$$0.98 = \frac{x}{2\sqrt{0.1 \times 1}} = 0.62 \text{ m}$$

6.25 (d)

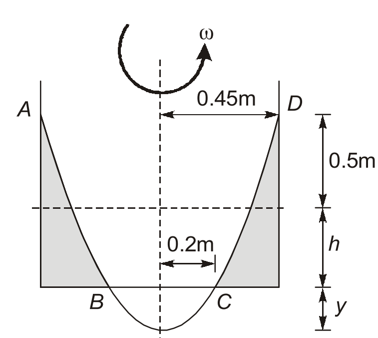
Whirlpool is an example free vortex.

So, $V \cdot r$ = constant

$$2.5 \times 30 = V \times 7.5$$

$$V = 10 \text{ m/sec}$$

6.26 (*)



We know that

$$y + h + 0.5 = \frac{\omega^2 (0.45)^2}{2g} \quad \text{...(i)}$$

$$y = \frac{\omega^2 (0.20)^2}{2g} \quad \text{...(ii)}$$

By eq. (i) and (ii)

$$h + 0.5 = \frac{\omega^2}{2g}\left[0.45^2 - 0.2^2\right] \quad \text{...(iii)}$$

Since there is no fluid.

Spillout so initial and final volume remains same.

So $\quad V_{Initial} = V_{Final}$

$$\pi(0.45)^2 h = \pi(0.45)^2 (0.5 + h) - V_{ABCD}$$

$$V_{ABCD} = \pi(0.45)^2 (0.5)$$

$$\frac{\pi(0.45)^2 (0.5 + h + y) - \pi(0.2)^2 y}{2}$$

$$= \pi(0.45)^2 (0.5)$$

$$\pi(0.45)^2 (0.5) + \pi(0.45)^2 h + \pi(0.45)^2 y - \pi(0.2)^2 y$$
$$= 2\pi(0.45)^2 (0.5)$$

$$(0.45)^2 h + [(0.45)^2 - (0.2)^2]y = (0.45)^2 (0.5)$$

$$h + \left[\frac{0.45^2 - 0.2^2}{0.45^2}\right] y = 0.5$$

$$h + 0.8y = 0.5$$

$$h = 0.5 - 0.8y \qquad y = \frac{\omega^2 (0.2)^2}{2g}$$

$$h = 0.5 - 0.8\left[\frac{\omega^2 (0.2)^2}{2g}\right]$$

Put the value in eq. (3)

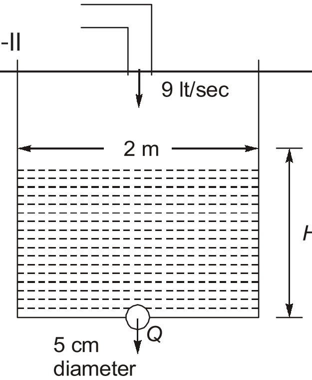
$$0.5 - \frac{0.8\omega^2 (0.2)^2}{2g} + 0.5$$

$$\omega = 10.14 \text{ rad/s}$$

$$\frac{2\pi N}{60} = 100.14$$

$$N = 96.834 \text{ rad/s}$$

6.29 (a)



For steady level in the tank discharge released from the tank is equal to the water enter in the tank.

$$Q = 9 \times 10^{-3}$$

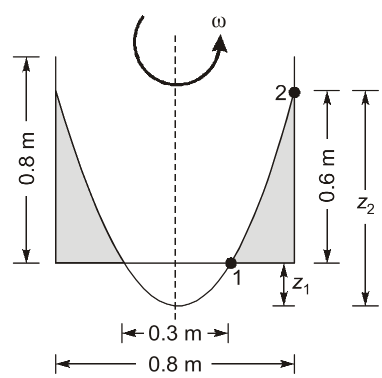
$$C_d \left(\frac{\pi}{4} d^2\right) \sqrt{2gH} = 9 \times 10^{-3}$$

$$C_d a \sqrt{2gh} = 9 \times 10^{-3}$$

$$0.6 \times \frac{\pi}{4}(0.05)^2 \times \sqrt{2 \times 9.81 \times H} = 9 \times 10^{-3}$$

$$H = 2.97 \text{ m}$$

6.30 (b)



$$z_2 - z_1 = \frac{\omega^2}{2g}\left[R_2^2 - R_1^2\right]$$

$$0.6 = \frac{\omega^2}{2g}\left[0.4^2 - 0.15^2\right]$$

$$\omega = 9.253 \text{ rad/sec}$$

$$\frac{2\pi N}{60} = 9.253$$

$$N = 88.36 \text{ rpm}$$

6.31 (b)

As we know that,

$$\int \frac{dP}{\rho g} + \frac{V^2}{2g} + z = \text{constant} \qquad \text{...(i)}$$

For a compressible flow, undergoing an adiabatic process

$$\frac{P}{\rho^k} = c \text{ (constant)}$$

$$dP = K \,.\, C \,.\, \rho^{k-1} \,.d\rho$$

By equation (i)

$$\int \frac{K.C.\rho^{k-1}.d\rho}{\rho g} + \frac{V^2}{2g} + z = \text{constant}$$

$$\frac{KC}{g}\int \rho^{k-2}\, d\rho + \frac{V^2}{2g} + z = \text{constant}$$

$$\frac{K.C.\rho^{k-1}}{g(k-1)} + \frac{V^2}{2g} + z = \text{constant}$$

$$\frac{K.C.\rho^{k-1}}{g(k-1)} \cdot \frac{\rho}{\rho} + \frac{V^2}{2g} + z = \text{constant}$$

$$\frac{K}{K-1} \cdot \frac{C.\rho^k}{\rho.g} + \frac{V^2}{2g} + z = \text{constant} \left(\because P = C.\rho^k \right)$$

$$\frac{K}{K-1} \cdot \frac{\rho}{\rho.g} + \frac{V^2}{2g} + z = \text{constant}$$

6.32 (a)

Pitot tube working

The liquid flows up the tube and when equilibrium is attained, the liquid reaches a height above the free surface of the water stream.

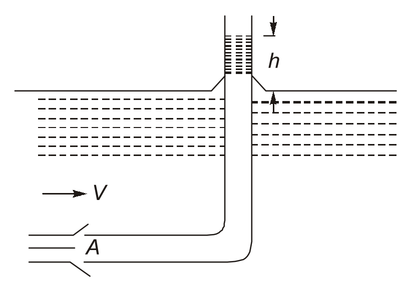
Since the static pressure, under this situation, is equal to the hydrostatic pressure due to its depth below the free surface, the difference in level between the liquid in the glass tube and the free surface becomes the measure of dynamic pressure. Therefore, we can write, neglecting friction.

$$p_0 - p = \frac{pV^2}{2} = h\rho g$$

where p_0, p and V are the stagnation pressure, static pressure and velocity respectively at point A.

$$V = \sqrt{2gh}$$

Such a tube is known as a Pitot tube and provides one of the most accurate mean of measuring the fluid velocity.



- Venturimeter is used to measure flow rate.
- Piezometer is used to measure pressure head.

■■■■