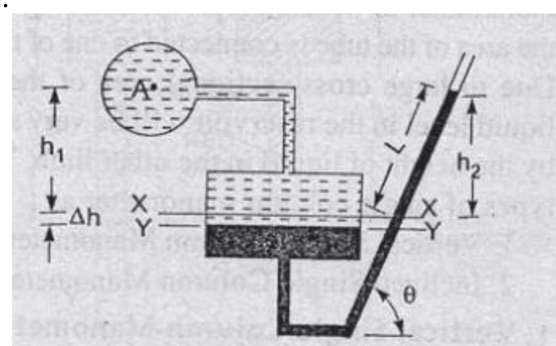
Fluid Mechanics

Q.No.	Question and Answer	Course Outcome	Knowledge Level
1	**Differentiate Newtonian and Non Newtonian fluid. (A/M 2019)**	**CO1**	**K1**
	Fluids that obey Newton's law of viscosity are called Newtonian fluids. Eg: water, benzene, alcohol, carbon tetrachloride, hexane, ether etc... Fluids that do not obey Newton's law of viscosity are called Non-Newtonian fluids. Eg: Toothpaste, paints, jellies, gels, slurries, polymer solutions etc…		
2	**Define the term viscosity. State Newton's law of viscosity. (A/M 2019)**	**CO1**	**K1**
	Viscosity is defined as the property of a fluid which offers resistance to the movement of one layer of fluid over other layer of the fluid. The unit of viscosity in SI is kg/m.s $\mu = \frac{\tau}{\left(\frac{du}{dy}\right)}$ In other words, Shear stress required to produce unit rate of shear strain.		
3	**What is a static fluid? State the function of piezometer tube (A/M 2019)**	**CO2**	**K1**
	Fluid at rest is referred as static fluid. A piezometer is designed to measure static pressures. It is a simple manometer which consists of a glass tube, whose one end is connected to a point where pressure is to be measured and the other end is open to atmosphere		
4	**List the assumptions made in deriving the Bernoulli's equation and write the Bernoulli's equation. (A/M 2019)**	**CO2**	**K1**
	The flow must be steady, i.e. the fluid properties (velocity, density, etc...) at a point cannot change with time. The flow must be incompressible – even though pressure varies, the density must remain constant along a streamline. Friction by viscous forces has to be negligible. **$(P/\rho g)+(V^2/2g)+Z$ = Constant**		
5	**Mention the need of dimensional analysis. (A/M 2019)**	**CO3**	**K1**
	Deriving the new relation between physical quantities To convert a unit from one form to another Perform the mathematical operations easily as we use conversion factor in order to get same units		
6	**What is Rayleigh's method of dimensional analysis? (A/M 2019)**	**CO3**	**K1**
	Rayleigh's method of dimensional analysis expresses a functional relationship of some variables in the form of an exponential equation. It doesn't provide any information regarding number of dimensionless groups to be obtained as a result of dimension analysis		
7	**Distinguish between laminar and turbulent flow. (A/M 2019)**	**CO4**	**K1**
	The flow in which the adjacent layers do not cross each other and move along a well defined path is called as laminar flow. E.g.: flow of blood in small veins, flow of oil in bearings, flow in porous media etc… The flow in which the adjacent layers cross each other and do not move along the well define path is called as turbulent flow. E.g.: flow through a river or canal, smoke from chimney, smoke from a cigarette etc…		
8	**What is tube of flow? How does pipe diameter affect flow rate. (A/M 2019)**	**CO4**	**K1**
	Pipe or tube flow is a type of liquid flow within a closed conduit. Pipe flow does not have a free surface		

<table>
<tr><td></td><td colspan="3">which is found in open-channel flow. Pipe flow, being confined within closed conduit, does not exert direct atmospheric pressure, but does exert hydraulic pressure on the conduit.</td></tr>
<tr><td>9</td><td>Differentiate between venture meter and orifice meter. (A/M 2019)</td><td>CO5</td><td>K1</td></tr>
<tr><td></td><td colspan="3"><table>
<tr><th>Venturi meter</th><th>Orifice meter</th></tr>
<tr><td>Costlier method to measure the rate flow of fluid through the pipe</td><td>Cheaper method to measure the rate of flow through the pipe</td></tr>
<tr><td>Requires large space</td><td>requires relatively smaller space.</td></tr>
</table></td></tr>
<tr><td>10</td><td>What is the basis difference between a compressor and a pump? (A/M 2019)</td><td>CO5</td><td>K1</td></tr>
<tr><td></td><td colspan="3">A pump is a machine that moves a fluid (either liquid or gas) from one place to another.
A compressor is a machine that squeezes a gas into a smaller volume and (often) pumps it somewhere else at the same time</td></tr>
<tr><td>11</td><td>State Newton's law of viscosity. (A/M 2018)</td><td>CO1</td><td>K1</td></tr>
<tr><td></td><td colspan="3">'Shear stress' (τ) on a fluid element layer is directly proportional to the 'rate of shear strain' (du/dy).
$$\tau = \mu\ (du/dy)$$
Where, μ is the constant of proportionality and is called as coefficient dynamic viscosity.</td></tr>
<tr><td>12</td><td>What is shear stress? (A/M 2018)</td><td>CO1</td><td>K1</td></tr>
<tr><td></td><td colspan="3">Stress developed due to the existence of velocity gradient, which retards the fluid on the boundary wall in the direction of flow.
The shear stress (τ) is the applied force upon area (F/A).</td></tr>
<tr><td>13</td><td>What is the importance of using the inclined tube manometer? (A/M 2018)</td><td>CO2</td><td>K1</td></tr>
<tr><td></td><td colspan="3">Due to inclination, the distance moved by the heavy liquid in the right limb will be more. Thus the manometer is more sensitive.

</td></tr>
<tr><td>14</td><td>How do you obtain dimensions for secondary quantities? (A/M 2018)</td><td>CO3</td><td>K1</td></tr>
<tr><td></td><td colspan="3">Secondary quantities are obtained by combining one or more primary quantities such as Length (L), Mass (M), Time (T), Temperature (Θ). For example the Velocity(m/s) is a secondary quantity which is obtained by dividing Length (L) and Time (Θ) i.e L/T. Volumetric flow rate (m^3/s) as L^3/T.</td></tr>
<tr><td>15</td><td>Write the dimensions for kinematic viscosity of a liquid. (A/M 2018)</td><td>CO3</td><td>K1</td></tr>
<tr><td></td><td colspan="3">Kinematic viscosity is the ratio of dynamic viscosity to the density. Generally denoted in stokes. Its SI unit is m^2/s and the dimension is L^2T^{-1}</td></tr>
<tr><td>16</td><td>How do you determine porosity? (A/M 2018)</td><td>CO4</td><td>K1</td></tr>
<tr><td></td><td colspan="3">Porosity (ϕ) of a particular porous medium is the fraction of the overall volume that is occupied by the pores or voids to that of the liquid filled for a saturated medium. It is determined from Darcy's equation.</td></tr>
<tr><td>17</td><td>What is minimum fluidization velocity? (A/M 2018)</td><td>CO4</td><td>K1</td></tr>
<tr><td></td><td colspan="3">Fluidization will be considered to begin at the gas velocity at which the weight of the solids gravitational force exerted on the particles equals the drag on the particles from the rising gas. i.e the bed is just beginning to become fluidized At the point of minimum fluidization the weight of the bed just equals the pressure drop across the bed.</td></tr>
<tr><td>18</td><td>What is pitot tube? (A/M 2018)</td><td>CO5</td><td>K1</td></tr>
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	Pitot tube also known as pitot probe is a flow measurement device used to measure fluid flow velocity. It is widely used to determine the airspeed of an aircraft, water speed of a boat, and to measure liquid, air and gas flow velocities in certain industrial applications.		
19	**What is volumetric efficiency? (A/M 2018)**	**CO5**	**K1**
	Volumetric Efficiency is the ratio of the liquid actually pumped to that which theoretically should be moved on the basis of piston displacement		
20	**State Newton's law of viscosity. (N/D 2018)**	**CO1**	**K1**
	Refer Q.No. 2 for answer		
21	**Define the term static fluid. (N/D 2018)**	**CO2**	**K1**
	Fluid at rest is referred as static fluid. The pressure at a point in a fluid at rest is obtained by hydrostatic law which states that, Rate of increase of pressure in a vertically downward direction must be equal to the specific weight of fluid at that point.		
22	**State Bernoulli's equation. Write dimensions for each terms involved.**	**CO4**	**K1**
	$(P/\rho g)+(V^2/2g)+Z = \text{Constant}$ $P – ML^{-1}T^{-2}$ $\rho – ML^{-3}$ $g – MT^{-2}$ $V – MT^{-1}$ $Z – L$		
23	**What do you understand by Hydrostatic law? (N/D 2018)**	**CO2**	**K1**
	Rate of increase of pressure in a vertically downward direction must be equal to the specific weight of fluid at that point. $$Z = \frac{p}{\rho \times g}$$		
24	**Define the term similitude. (N/D 2018)**	**CO3**	**K1**
	The similarity between model and prototype is called similitude. In other words, Principles which are used in the design and interpretation of laboratory experiments on ''model'' systems to predict the behavior of large-scale (''field'') systems is known as similitude.		
25	**Mention the significance of dimensional analysis. (N/D 2018)**	**CO3**	**K1**
	Relationship involving dimensionless variables is independent of the size or scale of the system and thus translation of information directly from laboratory models to large-scale equipment or plant operations is quite easy. The number of dimensionless groups is invariably less than the number of original variables involved in the problem. Thus the relations that define the behavior of a given system are much simpler when expressed in terms of the dimensionless variables.		
26	**Differentiate pipes with tubes. (N/D 2018)**	**CO4**	**K1**
	Tubes can come in different shapes such as square, rectangular and cylindrical, whereas Pipe is always rounded. The circular shape of the pipe make the pressure force evenly distributed. Pipes accommodate larger applications with sizes that range from a 0.5 inch to several meters.		
27	**Write Burke-Plummer equation for packed beds. (N/D 2018)**	**CO4**	**K1**
	Energy dissipated per unit mass of fluid, $$e_f = 1.75\frac{V_s^2}{d}\left(\frac{1-\varepsilon}{\varepsilon^3}\right)L + 180\frac{V_s\mu(1-\varepsilon)^2 L}{d^2\varepsilon^3\rho}$$		
28	**Differentiate between venturi and orifice meter. (N/D 2018)**	**CO5**	**K1**
	Refer Q.No. 9 for answer		
29	**Define slip, Percentage slip and negative slip of a reciprocating pump. (N/D 2018)**	**CO5**	**K1**
	Slip is the difference between theoretical discharge and actual discharge		

	$$\%SLIP = \frac{Q_{th} - Q_{ac}}{Q_{th}}(100)$$ If actual discharge is greater than theoretical discharge, we get negative value and thus it is called negative slip.		
30	**What is deformation rate or shear rate? (N/D 2017)**	**CO1**	**K1**
	Deformation rate or Shear rate is the rate of change of velocity at which one layer of fluid passes over an adjacent layer.		
31	**What is barometric equation? (N/D 2017)**	**CO2**	**K1**
	The barometric equation or formula, sometimes called the exponential atmosphere or isothermal atmosphere, is a formula used to model how the pressure (or density) of the air changes with altitude		
32	**State the equation of continuity. (N/D 2017)**	**CO3**	**K1**
	$$\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} = 0$$		
33	**What is form friction? (N/D 2017)**	**CO1**	**K1**
	Friction inside pipes due to geometrical characteristics of the piping system such as fittings, bends, valves, etc. where flow is disturbed resulting in increased pressure loss is referred as form friction.		
34	**What is geometric similarity? (N/D 2017)**	**CO3**	**K1**
	The similarity that exists between model and prototype based on the linear dimensions. i.e. the ratio of all corresponding dimensions in the model and prototype are equal. $L_p/L_m = D_p/D_m = L_r$ (Scale ratio)		
35	**Define model and prototype. (N/D 2017)**	**CO3**	**K1**
	The model is the small scale replica of the actual structure or machine. The actual structure or machine is called prototype.		
36	**List the minor energy losses in pipe. (N/D 2017)**	**CO4**	**K1**
	* Entrance of the pipe * Exit of the pipe * Pipe Bends * Pipe fittings * Pipe Expansions * Pipe Contractions		
37	**Write Darcy-Weishbach equation. (N/D 2017)**	**CO4**	**K1**
	Head loss due to friction, $h_f = 4fLV2/2dg$ f-Friction factor L-Length of pipe V-Mean velocity of flow d-Diameter of pipe		
38	**How do pitot tubes function? (N/D 2017)**	**CO5**	**K1**
	Pitot tube works by the principle that, If the velocity of flow at a point becomes zero, the pressure there is increased due to the conversion of the kinetic energy into pressure energy.		
39	**How to avoid cavitation? (N/D 2017)**	**CO5**	**K1**
	To avoid cavitation, i. The pressure of the flowing liquid in any part of the hydraulic system should not be allowed to fall below its vapour pressure. ii. Special materials or coatings such as aluminium-bronze and stainless steel, which are cavitation resistant materials.		
40	**What are Newtonian fluids? Give two examples. (A/M 2015)**	**CO1**	**K1**
	Refer Q.No. 1 for answer		
41	**Give the classification of fluids. (A/M 2015)**	**CO1**	**K1**
	i. Ideal Fluid ii. Real Fluid iii. Newtonian fluid iv. Non-Newtonian fluid		

	v. Ideal plastic fluid.		
42	**Write down the limitations of Bernoulli's equation. (A/M 2015)**	**CO2**	**K1**
	i. Uniform velocity is considered but practically, it is not true. ii. The viscous drag of the liquid has not been taken into consideration but it comes into play when a liquid is in motion. iii. No loss of energy is assumed but some kinetic energy is converted into heat energy and a part of it is lost due to shear force. iv. If the liquid is flowing along a curved path, the energy due to centrifugal force should also be taken into consideration.		
43	**Define fluid rotation, vorticity and circulation. (A/M 2015)**	**CO1**	**K1**
	Rotation: The movement of fluid element in such a way that both of its axes (Horizontal and Vertical) rotate in the same direction. **Vorticity:** Value twice that of the rotation is referred as Vorticity. **Circulation:** Flow along a closed curve. Mathematically it is the product of the velocity component along the curve at any point and the length of the small element containing that point is integrated around the curve.		
44	**Classify the losses in pipe. (A/M 2015)**	**CO4**	**K1**
	1.Major losses due to friction 2.Minor losses due to, Refer Q.No. 37 for answer		
45	**What is meant by laminar boundary layer? (A/M 2015)**	**CO4**	**K1**
	Boundary layer begins from the leading edge of a flat, smooth, stationary plate exposed to flowing fluid in one side and the boundary layer grows in thickness downstream as the fluid gets continually retarded by the shear stress. However upto a certain distance measured downstream from the leading edge, the flow within the boundary layer is laminar. This distance is called laminar zone and the boundary layer above it is called laminar boundary layer.		
46	**Distinguish between static head and manometric head of a pump. (A/M 2015)**	**CO5**	**K1**
	Static head (Hs) is the sum of Suction and Delivery head whereas, manometric head is the head against which a centrifugal pump has to work.		
47	**What is the function of volute in centrifugal pump? (A/M 2015)**	**CO5**	**K1**
	Volute casing is of spiral type in which area of flow increases gradually. The increase in area of flow decreases the velocity of flow. The decrease in velocity increases the pressure of water flowing through the casing.		
48	**Define Kinematic viscosity and Write its unit.(A/M 2012)**	**CO1**	**K1**
	Kinematic viscosity (ν) is the ratio of dynamic viscosity (μ) and density (ρ) of the fluid. Unit: m^2/s $\nu = \mu/\rho$		
49	**What is meant by Hydrostatic equilibrium? (N/D 2012)**	**CO2**	**K1**
	Refer Q.No. 24 for answer		
50	**Write general continuity equation. (Nov/Dec 2012)**	**CO2**	**K1**
	$(P/\rho g) + (V^2/2g) + Z = \text{Constant}$		
51	**Mention four types of pressure measurement manometers. (Nov/Dec 2012)**	**CO2**	**K1**
	Piezometer U-Tube Manometer Vertical Single Column Manometer Inclined Single Column Manometer		
52	**Define Viscosity and Write its units. (N/D 2011)**	**CO1**	**K1**
	Viscosity is defined as the property of a fluid which offers resistance to the movement of one layer of fluid over other layer of the fluid. $\mu = \tau / (du/dy)$ Unit: kg/m.s or Poise or Ns/m^2		
53	**Distinguish between Laminar and Turbulent flow. (N/D 2011)**	**CO1**	**K1**
	Refer Q.No. 7 for answer		

54	**Explain briefly the concept of continuum. (*April/May 2010*)**	**CO1**	**K1**
	Fluid is made of molecules. Fluid's properties such as density, or conditions such as pressure and temperature, are considered as a whole, instead of conditions of individual molecules. In other words, we refer to the average or macroscopic aggregate effects of the fluid- molecules, reflected in pressure, temperature, density, etc. Such an approach to treating a fluid is called continuum based approach. In other words, fluid is treated as continuum.		
55	**List out the laws of dimensional homogeneity? (*April/May 2010*)**	**CO3**	**K1**
	1. Reynolds model law 2. Froude model law 3. Euler model law 4. Weber model law 5. Mach model law		
56	**What is meant by Hydrostatic equilibrium? (*April/May 2010*)**	**CO2**	**K1**
	Refer Q.No. 24 for answer		
57	**What is similitude? (*April/May 2010*)**	**CO3**	**K1**
	Refer Q.No. 25 for answer		
58	**Give any two uses of dimensional analysis in scale-up studies. (*April/May 2010*)**	**CO3**	**K1**
	Refer Q.No. 26 for answer		
59	**What do you mean by drag coefficient? (*April/May 2010*)**	**CO4**	**K1**
	Drag coefficient, $C_D = F_D/0.5\rho u^2$		
60	**What is the physical significance of Reynolds number? (*April/May 2010*)**		
	To assess the flow condition of fluids whether bounded or unbounded based on empirical results. The higher this number signifies the degree to which the inertial forces takes over the viscous forces that arise due to boundary conditions, fluid characteristics etc.. Assessment of the flow should be conducted via experimentally available data as there are no direct methods of evaluating the characteristics of turbulent flow.		
61	**Give the classification of pumps. (*April/May 2010*)**	**CO5**	**K1**
	Basic types of pumps are, i. Positive displacement pump a. Rotary type positive displacement pump b. Reciprocating type positive displacement pump c. Linear type positive displacement pump **ii.** Centrifugal pumps.		
62	**Define Non-Newtonian fluids. Give one examples. (*Nov/Dec 2010*)**	**CO1**	**K1**
	Refer Q.No. 1 for answer		
63	**Distinguish between notches and weirs. (*Nov/Dec 2010*)**	**CO5**	**K1**

Notches	Weirs
Smaller in size	Bigger in size
Generally made of metallic plate	Made of concrete or masonary structure
The liquid surface in the tank or channel is below the top edge of the opening.	Placed in an open channel over which the flow occurs.

64	**List the minor losses encountered in pipe systems (*Nov/Dec 2010*)**	**CO4**	**K1**
	Refer Q.No. 37 for answer		
65	**Name the velocity ranges for which a fluidized bed can exist. (*Nov/Dec 2010*)**	**CO4**	**K1**
	For particle size range of 150 to 350 microns, the velocity ranges from 3.5 to 5.0 m/s		
66	**Why is diaphragm pumps widely used as metering pumps? (*Nov/Dec 2010*)**	**CO5**	**K1**
	They are less expensive to operate long-term. They are designed to use more motor torque on the forward stroke, but significantly less on the backstroke. Diaphragm pumps are ideal for pumping harsh, damaging liquids or chemicals because they rarely leak or		

	damage the surrounding area. They can overcome standing pressure in the flow line.		
67	**What do you mean by kinematic viscosity of a fluid? (*Nov/Dec 2009*)**	**CO1**	**K1**
	Refer Q.No. 51 for answer		
68	**How will you measure the pressure head of a static fluid? (*Nov/Dec 2009*)**	**CO2**	**K1**
	Pressure head, $Z= p/\rho g$ Where, p – Pressure acting on the static fluid ρ – Density of the fluid g – gravitational constant		
69	**Distinguish between Laminar and Turbulent flow. (*Nov/Dec 2009*)**	**CO1**	**K1**
	Refer Q.No. 7 for answer		
70	**Define the term friction factor. (*Nov/Dec 2009*)**	**CO4**	**K1**
	Dimensionless quantity used for the description of friction losses in pipe flow and in open channel flow. $f = 2\tau_o/\rho V^2$		
71	**What is meant by dimensional homogeneity? (*Nov/Dec 2009*)**	**CO3**	**K1**
	Dimension of each term in the equation on both sides are equal. Thus if the dimensions of each term on both sides of an equation are the same the equation is known as dimensionally homogenous equation.		
72	**What is the use of rotameter? (*Nov/Dec 2009*)**	**CO5**	**K1**
	The rotameter is an industrial flowmeter used to measure the flowrate of liquids and gases. The rotameter consists of a tube and float. The float response to flowrate changes is linear.		
73	**What are the minor losses in pipe systems? (*Nov/Dec 2009*)**	**CO4**	**K1**
	Refer Q.No. 37 for answer		
74	**What is known as equivalent pipe diameter? (*Nov/Dec 2009*)**	**CO4**	**K1**
	The equivalent diameter is the diameter of a circular duct or pipe that for equal flow gives the same pressure loss or resistance as an equivalent rectangular duct or pipe.		
75	**What are the desirable pump characteristics? (*Nov/Dec 2009*)**	**CO5**	**K1**
	1. Head- Résistance to flow 2. Friction head 3. Velocity head 4. Pressure head 5. Total dynamic suction 6. Total dynamic discharge 7. Total head or total dynamic head		
76	**Distinguish between blowers and compressors (*Nov/Dec 2009*)**	**CO5**	**K1**
	Air Compressors are generally used in a wide range of situations from corner gas stations to major manufacturing plants. The main purpose of a compressor is to compress the air to a high pressure. Blowers are used for circulation of gas.		
77	**What is the effect of pressure on viscosity of gasses? (*Nov/Dec 2009*)**	**CO1**	**K1**
	The viscosity of an ideal gas is independent of pressure, and this is almost true for real gases. In gases, Viscosity arises mainly because of the transfer and exchange of molecular momentum		
78	**Convert 1N/m^2 to poise. (*Nov/Dec 2009*)**	**CO1**	**K1**
	$1N/m^2 = 2x10^6$poise		
79	**What is similitude? (*Nov/Dec 2009*)**	**CO3**	**K1**
	Refer Q.No. 25 for answer		
80	**State Buckingham's pi theorem? (*Nov/Dec 2009*)**	**CO3**	**K1**
	If there are n variables (independent and dependent variables) in a physical phenomenon and if these variables contain m fundamental dimensions (M, L, T) then the variables are arranged into (n-m) dimensionless terms.		
81	**What do you mean by boundary layer separation? (*Nov/Dec 2009*)**	**CO4**	**K1**
	Boundary layer separation is the detachment of a boundary layer from the surface into a broader wake. It occurs when the portion of the boundary layer closest to the wall or leading edge reverses in flow direction.		

	The separation point is defined as the point between the forward and backward flow, where the shear stress is zero.		
82	**Distinguish interstitial velocity from superficial velocity. (*Nov/Dec 2009*)**		
	Interstitial Velocity is the speed at which the molecules of water are progressing in the direction of movement. Superficial velocity is a hypothetical (artificial) flow velocity calculated as if the given phase or fluid was the only one flowing or present in a given cross sectional area. Other phases, particles, the skeleton of the porous medium, etc. present in the channel are disregarded.		
83	**What is the basic principle involved in variable area meters? (*Nov/Dec 2009*)**	**CO5**	**K1**
	Variable area flow meters operate at a constant pressure difference (Δp) and the area changes with the flowrate. The area will increase as the flowrate through the meter increases to preserve a constant Pressure difference (Δp).		
84	**Explain priming in pumps (*Nov/Dec 2009*)**		
	Priming in a centrifugal pump is defined as the operation in which the suction pipe, casing and a portion of the delivery pipe upto the delivery valve is completely filled up from outside source with the liquid to be raised by the pump before starting the pump.		
85	**Define stream line, Streak line and Path line. (M/J 2009)**	**CO1**	**K1**
	A streamline refers to an instantaneous picture of the velocity directions of a number of particles A streak line is the line made by a dye injected into a fluid at one point, and thus, marks the positions of all the particles of fluid which have passed that point. A path line is a line made by a single particle as it moves during a period of time. It refers to the path of a single particle		
86	**Differentiate gauge pressure from absolute pressure (May/June 2009, Nov/Dec 2007)**	**CO1**	**K1**

Gauge pressure	Absolute pressure
Atmospheric pressure is taken as datum/reference	Absolute vacuum pressure is taken as datum/reference
Gauge pressure = Absolute pressure – Atmospheric pressure	Absolute pressure = Atmospheric pressure + Gauge pressure

87	**Define metacentric height (*May/ June 2009*)**		
	Distance between the metacentre of a floating body and centre of gravity of the body is called metacentric height. Metacentre point is defined as the point about which a body starts oscillating when the body is tilted by a small angle.		
88	**What is the principle of dimensional homogeneity? (*May/ June 2009*)**		
	Refer Q.No. 78 for answer		
89	**What are scale effects in model studies? (*May/ June 2009*)**		
	Scale effect occurs when a prototype hydraulic process is simulated at a laboratory scale due to dissatisfaction of similarity laws. It might lead to considerable deviation when the model scour depth is extrapolated to prototype value		
90	**List the minor losses in a pipe flow. (*May/ June 2009*)**		
	Refer Q.No. 37 for answer		
91	**Define momentum thickness and energy thickness of a boundary layer. (*May/ June 2009*)**		
	What is Net Positive Suction Head (NPSH)? (*May/ June 2009, Nov/Dec 2003*)	**CO5**	**K1**
92	NPSH = Absolute pressure head at the inlet of the pump – vapour pressure + velocity head.		
	Differentiate Compressible and Incompressible fluid. (N/D 2013, N/D 2003)	**CO1**	**K1**
93	Compressible - Density changes significantly with changes in temperature and pressure. E.g.: CNG, LPG Incompressible - Density changes slightly or does not change with moderate changes in temperature and pressure. E.g.: Almost all real liquids (Water) are incompressible.		

	What is Capillarity? (A/M 2008)	**CO1**	**K1**
94	Phenomenon of fall or rise of a liquid surface in a small tube relative to the adjacent general level of liquid when the tube is held vertically in the liquid. Rise of liquid surface is called capillary rise and fall of liquid surface is called capillary depression.		
	What happens to viscosity of fluids when its temperature is increased? (N/D 2003, N/D 2007)	**CO1**	**K1**
95	Liquid viscosity decreases with increase in temperature. Gas viscosity increases with increase in temperature. **Reason:** Cohesive force and Molecular momentum transport are responsible factors. In liquids, cohesive force is predominant which decreases when temperature is increased. In gasses, Molecular momentum transport is predominant which increases when temperature is increased.		

Part B

1	Explain in detail about Viscosity	CO1	K2

The viscosity of a fluid is a measure of its resistance to flow. Consider two long, solid plates separated by a thin film of fluid. To make the upper plate move steadily at a velocity of u_0 m/s relative and parallel to the lower plate, a force is required to overcome the fiction in the fluid between the plates and to maintain the viscosity u_0. This force change with different velocities, plate sizes, fluids, and distances between the plates. The shear stress τ is the force per unit area of the plate.

For low values of u_0 the velocity profile in the fluid between the plates is found to be linear and

$$u = \frac{u_0 y}{y_0}$$

Thus, $$\frac{du}{dy} = \frac{u_0}{y_0}$$

For most fluids the results of this experiment can be shown most conveniently on a plot of τ versus du/dy du/dy is variously called the rote of strain, shear rate, and rat of shear deformation, all of which mean exactly the same thing. The behaviour of most commonly known fluids can be graphically represented by a straight line passing through the origin.
Such a fluid is called Newtonian because it is described by Newton's law of viscosity:

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

The viscosity of the coefficient of viscosity μ is defined as

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

and has the units of Pa s.
The kinematics viscosity v is defined as

$$V = \frac{\mu}{\rho}$$

sad has the units of m^2/s.

Fluids that obey Newton's law of viscosity are called Newtonian fluids. All the others are non-Newtonian fluids. All gases and liquids with a simple chemical formula, such as water, benzene, alcohol, carbon tetrachloride, hexane and ether, are Newtonian. Most solutions of simple molecules are Newtonian, such as solutions of inorganic salts, and of sugar in water, Non-Newtonian fluids, on the other much larger than water molecules. Toothpaste, paints, jellies, gels, slurries and polymer solutions are common examples of non – Newtonian fluids.

From τ versus du/dy plots, it is obvious that are viscosity of a non – Newtonian fluid cannot be considered a constant independent of du/dy for a given temperature, but must be considered a function of du/dy. There are three common types of non – Newtonian fluids.

(a) Bingham fluids or Bingham plastics resist a small shear stress indefinitely, but flow easily under larger shear stresses. Examples are jellies, toothpaste, paints and some slurries.

(b) Pseuaoplastic fluids have a viscosity that decreases with an increasing velocity gradient. Examples are blood, polymer solutions, muds and most slurries.

(c) Dilatent fluids have a viscosity that increases with an increasing velocity gradient. They are not common, but starch suspensions in water and suspensions of paper pulp are two examples.

The Bingham fluid can be represented by

$$\tau < \tau_0, \frac{du}{dy} = 0 \qquad \tau > \tau_0, \tau - \tau_0 = \eta \frac{du}{dy}$$

Where τ_0 is the yield stress, and η is commonly called the coefficient of rigidity.

The experimental curves for both pseudoplastic and dilatant fluids can be represented reasonably well by the power law, also called the Ostwald – de Waele equation

$$\tau = K\left(\frac{du}{dy}\right)^n$$

where K and n are arbitrary constants. For Newtonian fluids n=1 and K=μ.

For pseudoplastic fluids n<1, and for dilatant fluids n>1.

Viscosity can change with time: apparent viscosity may decrease with time under shear stress but recover when the shear stress is removed, in which case the substance is said to thixotropic. When it increases with time under may constant shear rate, the fluid is said to be rheopectic. A good paint or printer's ink should be thixotropic in nature. Bentonite sols are examples of rheopectic fluids.

Most applications of fluid flow involve water, air, gases and simple fluids which are Newtonion in behavior. The flow of Newtonian fluids through circular pipes is considered in the following sections.

2	**A 15cm long cylindrical metal rod slides inside a tube filled with oil. The inner diameter of the tube is 5cm and the clearance is 0.05 mm. the mass of the bar is 0.5 kg when immersed in the oil. What is the viscosity of the oil, if the steady-state velocity of the rod is 0.1 m/s?**	**CO1**	**K3**

Force acting on the rod,

$$F = mg = 0.5 \times 9.8 N$$
$$= 4.9 N$$

The area of the rod,

$A = \pi dl$
$= \pi(0.05)(0.15)$
$= 0.02356\ m^2$

The shear stress acting on the oil,

$$\tau = \frac{F}{A} = 208 Pa$$

Assuming linear velocity distribution

$$\frac{du}{dy} = \frac{\Delta u}{\Delta y} = \frac{0.1}{0.05 \times 10^{-3}} = 2000 1/s$$

Therefore, the viscosity of the oil is given by

$$\mu = \frac{\tau}{du/dy} = \frac{208}{2000} Pas$$

=0.104 Pa s

3	**Derive the Bernoulli's theorem.**	**CO3**	**K3**

Mechanical Energy Balance for steady Flow: Bernoulli's theorem

When a given element of a moving fluid undergoes expansion, it does mechanical work. Clearly, this work must be expended on the fluid immediately ahead of it, but the fluid element in question also picks up an equivalent amount of mechanical energy at the expense of the internal energy of the fluid or externally derived heat. Granting reversibility of expansion, this self – expansion work $\int P\,dv$ is to be included in a mechanical energy balance. Also, when the fluid flows from A to b, some of the energy available at A is converted into frictional heat and becomes unavailable at B. Let this loss due to friction be FJ/kg of the fluid. The mechanical energy balance equation, then, becomes

$$Z_{Ag} + P_A v_A + \frac{u_A^2}{2} - w_s + \int_A^B Pdv = Z_{Bg} + P_B V_B + \frac{u_B^2}{2} F$$

since $$d(Pv) = Pdv + vdP$$

$$P_A V_A - P_B V_B = -\int_A^B Pdv - \int_A^B VdP$$

$$\therefore \quad Z_{Ag} - \int_A^B VdP + \frac{u_B^2}{2} - w_s = Z_{Bg} + \frac{u_B^2}{2} + F$$

or $$\Delta\left(\frac{u^2}{2}\right) + g\Delta Z + \int_A^B VdP + w_s + F = 0$$

Equation is known as Bernoulli's equation.

When a fluid flows through a pipeline, the velocity at a point varies over the cross-section of the pipe. When the velocity distribution is uniform across the pipe section, the kinetic energy term is $u^2/2$. where u is the average linear velocity. For the unidirectional flow of a fluid, allowance must be made for the velocity profile in the kinetic energy term. Introducing a correction factor α into the kinetic energy term, Bernoulli's equation becomes

$$\frac{\Delta u^2}{2\alpha} + g\Delta Z + \int vdP + w_s + F = 0$$

where α=0.5 if the flow is streamline

$\approx$1.0 if the flow is turbulent

4	**Flow of a Fluid past a solid surface**		

The local velocities in a fluid stream are profoundly affected when the stream is brought into contact with a solid object or with the wall of a conduit. Consider the flow of a fluid parallel to a thin plate, as shown in fig.

The velocity of the fluid upstream from the leading edge of the plate is uniform across the entire fluid stream and has the value U. The fluid in immediate contact with the plate adheres to it and therefore, the velocity of the fluid at the interface between the solid and the fluid is zero. A velocity gradient at right angles to the surface is set up in the neighborhood of the interface because of the viscous forces acting within the fluid, and the velocity changes in a direction perpendicular to the flow. For a given distance x from the leading edge of the plate, the local velocity u will increase from zero at the surface (y=0) and will gradually approach the free stream velocity U at some distance from the surface. There is a rapid change in velocity near the surface and the thickness of the layer in which the fluid is retarded by i.e. viscous drag becomes grater with the distance form the leading edge in the direction of the flow. The line AB represents an imaginary surface which separates the fluid stream into two parts: one in which the fluid velocity is constant, and the other in which the velocity varies from zero at the wall to a velocity substantially equal to that of the undisturbed flow. This imaginary surface, therefore, separates the fluid that is directly affected by the plate from that in which the local velocities are constant and unaffected by the plate. The layer between the dotted line and the plate is called the prandtl boundary layer. The boundary layer thickness is so defined that the velocity at its outer edge equals 99% of the free stream velocity. The boundary layer thickness is zero at the leading edge and is maximum at the trailing edge.

Any solid body in contact with a flowing fluid will develop a boundary layer, regardless of the shape of the body. Towards the leading edge of the solid, where the boundary layer is thin, the flow in the boundary layer is laminar. As the layer thickness, however, at distances further from the leading edge, a point is reached where turbulence appears. The onset of turbulence is characterized by a sudden increase in the boundary layer thickness.

There is a small region near the surface in the turbulent layer where the flow remains laminar because the velocity in this region, adjacent to the surface, is insufficient to develop turbulence. This is known as the laminar sub-layer. The viscous sub-layer is separated from the highly turbulent zone of the boundary layer by the buffer layer, in which the flow is neither entirely laminar nor entirely turbulent.

For the flow of a fluid past a flat plate at zero incidence, the thickness δ or the boundary layer is given by

$$\frac{\delta}{x} = 4.64 Re_x^{-0.5}$$

If the boundary layer is laminar, and

$$\frac{\delta}{x} = 0.376 Re_x^{-0.2}$$

If the boundary layer is turbulent.

The thickness of the laminar sub-layer δ_1 is given by

$$\frac{\delta_l}{x} = 715 Re_x^{-0.9}$$

This is, $\delta_l \ \alpha \ x^{0.1}$, and therefore, it increases very slowly as x increases, also, $\delta_l \ \alpha \ U^{-0.9}$, and therefore, it decreases rapidly as the free stream velocity increases. Re_x is defined as

$$Re_x = \frac{xU\rho}{\mu}$$

5	**Fluid meters and flow measurement: Orifice Meter**	**CO5**	**K2**

An orifice meter is extremely simple apparatus. Normally it is a flat plate with a centrally drilled hole beveled to a sharp edge. This drilled plate is inserted perpendicularly to the flow in a duct and the fluid flows right through the hole.

Boundary layer separation occurs down – stream of orifice plate and as a result pressure loss due to form friction is considerable. And at about one half to two duct diameters downstream from the plate, the flow lines reach a minimum cross – sectional area.

This point is called vena contracta. The location of this point depends on the fluid velocity as well as the duct diameter.

The downstream pressure should be tapped closest to this vena contracta to ensure a maximum reading on the pressure – difference indicator.

Applying energy balance between points 1 and 2

$$\left(P_2 - P_1\right).V + \frac{\nu_2^2 - \nu_1^2}{2} + \sum F = 0$$

$$\therefore \quad \nu = \left\{2\left[\frac{\Delta P}{\rho} - \sum F\right] / \left[\left(A_1 / A_2\right)^2 - 1\right]\right\}^{0.5}$$

The sum of $\left(\frac{\Delta P}{\rho}\right)$ and $\sum F$ can be expressed in terms of total pressure drop $\left(\Delta P\right)$ as

$$\left[\left(\Delta P / \rho\right) + \left(-\sum F\right)\right] = c_1^2\left(\Delta P / \rho\right)$$

$$\therefore \quad \nu_1 = C_1\left\{2\left(\Delta P / \rho\right) / \left[\left(A_1 / A_2\right)^2 - 1\right]\right\}^{0.5}$$

Putting $\nu_1 = \nu; \;\; A_1 = A$ and $A_2 = C_2 A_0$

where A_0 = cross – sectional area of the orifice hole and A_2 = cross – sectional area of the vena contracta

$$\nu = C_1 \cdot \left[\frac{2\left(\Delta P / \rho\right)}{\frac{A^2}{C_2 A_0^2} - 1}\right]^{1/2} = C_d \cdot \left[\frac{2\left(\Delta P / \rho\right)}{\frac{A^2}{A_0^2} - 1}\right]^{1/2} = C_d \frac{A_0 \sqrt{2\Delta P / \rho}}{\sqrt{A^2 - A_0^2}}$$

where C_2 = a constant of geometry;

C_d = discharge coefficient of orifice and it is such that

$$C_1 \cdot \left[\frac{1}{\frac{A^2}{C_2 A_0^2} - 1}\right]^{1/2} = C_d \cdot \left[\frac{1}{\frac{A^2}{A_0^2} - 1}\right]^{1/2}$$

The volumetric flow rate through a normal orifice plate

$$Q_v = C_d.\frac{A_0.A.k}{\sqrt{A^2 - A_0^2}}.\sqrt{2\Delta P/\rho}$$

For >> A_0 the above equation simplifies to

$$Q_v = C_d.k.A_0\sqrt{2\Delta P/\rho} = C_d.k.A_0.\sqrt{2.g.H\left(\frac{\rho_{MAN} - \rho}{\rho}\right)}$$

The coefficient of discharge C_d for given orifice is the function of Reynolds number (Re) and diameter ratio ($\beta = d_0 / d$).

Coefficient of Discharge for Orifice Plate

$Re = \frac{d.\nu.\rho}{\mu}$	$C_d \times 10^3$						
	$(d_0 / d)^2$ 0.05	0.1	0.2	0.3	0.4	0.5	0.6
5×10^3	603.2	611	634.1	–	–	–	–
1×10^4	602.6	609.2	626.1	653	689	736.7	797.5
2×10^4	599.6	605	621.2	645.4	676.5	718.6	775.3
3×10^4	599	603.8	618.7	640.3	672	712.4	765
5×10^4	598.4	603.2	616.8	638.4	666.6	705	755
1×10^5	598	602.6	616.2	635.9	662	699	747
4×10^5	597.8	602	615	634	660	695	739.8

d_0 = diameter of normal orifice plate, m
d = pipe dia (ID), m

For > 30 000, the value of C_d for square – edged or sharp – edged orifice fall in the range 0.595 – 0.620 for up to 0.8

In the transition resion, Re = 50 – 30000, the coefficient of discharge is higher than the above values.
In the laminar region (Re < 50), $C_d \propto \sqrt{Re}$

k = roughness coefficient ot account for roughness of the pipe wall. For smooth pipe, k = 1. For rough pipe, the values of k are tabulated below.

Pipe Dia (ID) mm	$k \times 10^3$					
	$(d_0 / d)^2$ 0.1	0.2	0.3	0.4	0.5	0.6
50	1003	1006	1011	1014	1014	1017
100	1002	1004	1006	1011	1011	1013
200	1001	1002	1004	1005	1005	1006
300	1000	1001	1001	1001	1001	1001

A_0 = cross – section area of orifice plate $= \frac{\pi}{4}.d_0^2 = 0.785.\left(d_0^2\right)$

A = cross – section area of pipe = $\frac{\pi}{4}.d^2 = 0.785\ d^2, m^2$

H = level difference of the liquid in the differential manometer connected to the orifice plate, m
ρ_{man} = density of manometric liquid, kg / m^3

Other than sharp – edged or square – shaped orifice, there are:

(i) **Quadrant – Edge Orifices:** which, it has been claimed, the more advantageous than their sharpedged / square – shaped counterparts in the sense that they have constant discharge coefficients in the lower values of Reynolds number. They have holes with round edges on the up stream side of the plate. The diameter of quadrant – edge orifice is equal to half the plate thickness at the orifice location.

(ii) **Segmental and Eccentric Orifices:** are frequently used for metering gas flow, particularly in those cases, where there is the likelihood of entrainment of liquids or solids.

Orifice	Reynolds Number	β	C_d
Square – edged mental Square – edged eccentric circular	> 10000 > 10000	0.3 – 0.5 0.3 – 0.5	0.63 – 0.64 0.61 – 0.63

(iii) **Annular Orifices** have proved to be useful for metering Paragraph
(1) gas where there are chances of liquid or solid entrainment paragraph
(2) liquid with entrained gas present in minor concentrations.

$$C_d = 0.63 - 0.67 \text{ for Re=100 - 20000 and for } \frac{2\Delta}{d\text{-}d_0} < 1$$

where Δ = thickness of orifice at outer edge, m; d= inside pipe dia, m;

d_0 = orifice disk dia, m

6	**Fluid meters and flow measurement: Pitot Tube**	**CO5**	**K2**

It is a simple apparatus that measures a point velocity by measuring the difference between impact pressure and static pressure.

It consists to two concentric tubes. The outer tube has a few small perforations perpendicular to the flow direction. There are called static pressure openings. The inner tube has a small opening pointed to the flow.

When fitted to a flow duct, the Pitot – tube has its two concentric tubes arranged parallel to the flow and the fluid is led through the perforations of the outer tube to the annular space which is otherwise sealed except for a manometric lead. The other side of the manometer is connected the inner tube figure. The annular space serves to transmit the static pressure.

At the entrance to the inner tube, the flowing fluid is brought to rest and the tube transmits the impact pressure equivalent to the kinetic energy of the flowing fluid. When the equilibrium is reached there is no fluid motion within the Pitot tube.

The Pitot tube, also known as Pitot – Pradt1 tube, is installed exactly along the axis of the pipe figure through which the fluid is flowing. And an energy balance may be drawn between points 1 and 2. At point 2 the fluid velocity is zero and also $Z_1 = Z_2$ and therefore, the energy balance simplifies to

$$\frac{(P_2 - P_1)}{\rho} + \frac{v_1^2}{2} + \sum F = 0$$

$$\therefore \quad v_1^2 = 2\left[(\Delta P/\rho) - \sum F\right] \qquad \text{where } P_1\text{-}P_2 = \Delta P$$

The bracketed term of the right hand side of the equation can be expressed in terms of total pressure difference (ΔP) i.e.

$$\left[(\Delta P/\rho) - \sum F\right] = C_1^2.(\Delta P/\rho)$$

Putting $v_1 = v$, the average velocity of flow through the orifice

$$\nu = C_1.\sqrt{2(\Delta P/\rho)} = C_1.\sqrt{2.g.H.(\rho_{man} - \rho)/\rho}$$

The rate of flow

Where, A = cross, sectional area of the pipe, m^2

v = mean velocity of flow through the pipe, m/s. It is calculated from ν / ν_{max} ratio obtained from the ν / ν_{max} vs. Re graph where

$$Re = d.v_{max}.\rho/\mu$$

$$\nu_{max} = \sqrt{2.g.H\frac{(\rho_{man} - \rho)}{\rho}}, m/s$$

$$(\text{taking } C_1 \approx 1)$$

The differential manometer is attached to the Pitot tube to determine the value of

$$\Delta P = H.(\rho_{man} - \rho).g = \Delta P_{vel}$$

Pitot – tubes have certain limitations on the range of their usefulness. With gases, the differential pressure Δ P is very small at low velocities introducing significant degree of error even using a micro – manometer with a precision of 0.25 mm of water.

With liquids, operation at low Reynolds number needs prior calibration of the probe. $C_d < 1$ for Re < 2300.

7	**Fluid meters and flow measurement: Venturimeter**	**CO5**	**K2**

A venturimeter is a flow – metering device. It measures a flow rate of the fluid flowing through a pipe. It consists of:

(a) A short converging part (b) a throat (c) a long diverging part

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

$$\frac{P_1}{\rho.g} + \frac{v_1^2}{2g} + Z_1 = \frac{P_2}{\rho.g} + \frac{v_2^2}{2g} + Z_2$$

assuming the flow to be non –compressible and isothermal.

It can be installed horizontally, vertically or inclined to a pipeline.

Since the pipe is horizontal, $Z_1 = Z_2$

$$\therefore \quad \frac{P_1 - P_2}{\rho.g} = \frac{\nu_2^2 - \nu_1^2}{2g}$$

But $P_1 - P_2 = H.\rho.g$ where H is the manometer reading.

$$\therefore \quad v_2^2 - v_1^2 = 2.g.H$$

For continuity of mass flow $\nu_1 . \rho_1 . A_1 = \nu_2 . \rho_2 . A_2$

$$\therefore \quad v_1 = A_2.v_2 / A_1 \quad [cf. \rho_1 = \rho_2 \text{ for incompressible fluid}]$$

$$\therefore \quad v_2 = \frac{A_1}{\sqrt{A_1^2 - A_2^2}}.\sqrt{2g.H}$$

$$\text{Therefore, volumetric flowrate } Q'_v = v_2.A_2 = \frac{A_1}{\sqrt{A_1^2 - A_2^2}}.\sqrt{2g.H}$$

This is the theoretical volumetric flowrate. Therefore, actual volumetric flowrate

$$Q_v = C_d.\frac{A_1.A_2}{\sqrt{A_1^2 - A_2^2}}.\sqrt{2g.H}$$

$$Q_m = C_d.\frac{A_1.A_2.\rho}{\sqrt{A_1^2 - A_2^2}}.\sqrt{2g.H}$$

$$= C_d.\frac{A_2.\rho}{\sqrt{1-(A_2/A_1)^2}}.\sqrt{2g.H}$$

$$= C_d.C.\rho.\sqrt{2g.H}$$

where, C_d=coefficient of discharge; C' = constant for the meter = $A_2 / \sqrt{1-(A_2/A_1)^2}$

H_v=loss of head over the converging cone, m

8	**Dry air at 20°C and 1 atm pressure flows through a pipe of ID 320 mm. A Pitot-Prandtl tube is installed at the middle of the pipe. Its differential manometer with water shows a level difference of,** **H=5.8 mm** **Calculate the mass flowrate of air.**		

Solution: First we're to calculate the v_{max} with the help of the equation.

Next we're to determine the Reynolds number at this value of maximum velocity

Finally we're to determine the ratio of v/v_{max} from the figure for the corresponding value of Reynolds number.

The mean velocity (v) of flow through the pipe being known, the volumetric flowrate and mass flowrate of air can be easily computed.

Step-(I). Minimum Flow Velocity

$$v_{max} = \sqrt{2g.H\left[\frac{\rho_{man} - \rho}{\rho}\right]}$$

$$= \sqrt{2(9.81)\left(\frac{5.8}{1000}\right)\frac{(1000 - 1.205)}{1.205}} m/s = 9.712 \text{ m/s.}$$

Step-(II). Reynolds Number

$$Re = d.v_{max}.\rho/\mu = (320/1000)(9.712)1.205/(18 \times 10^{-6}) = 2.08 \times 10^5$$

Step-(III) Average Velocity of Air

From the graph figure v/v_{max} =0.85 for the corresponding value of Re= 2×10^5
V =(0.83) (9.712 = 8.0609 m/s

Step-(IV) Volumetric Flowrate (Q_v)

$$Q_v = A.v = \frac{\pi}{4}.D^2.v = \frac{\pi}{4}\left[\frac{320}{1000}\right]^2 (8.0609) = 0.64829\ m^3/s$$

Step-(V) Mass Flowrate (Q_m)

$Q_m = Q_v$; ρ = 0.64829 (1.205)=0.78119 kg/s = 2812.30 kg/h

9	**Crude oil, specific gravity 60°F/60°F = 0.887, flows through the piping shown in figure. Pipe A is 2-in. (50-mm) Schedule 40, pipe B is 3-in. (75-mm) Schedule 40, and each of pipes C is 1½-in. (38-mm) Schedule 40. An equal quantity of liquid flows through each of the pipes C. The flow through pipe A is 30 gal/min (6.65 m^3/h). Calculate (a) the mass flow rate in each pipe, (b) the average linear velocity in each pipe, and (c) the mass velocity in each pipe.**		

Solution:-

Dimensions and cross-sectional areas of standard pipe are given in Appendix 5. Cross-sectional areas needed are, for 2-in. pipe, 0.0233 ft^2; for 3-in. pipe, 0.0513 ft^2; and for 1½-in. pipe, 0.01414 ft^2.

(a) The density of the fluid is

$$\rho = 0.887 \times 62.37 = 55.3\ lb/ft^3$$

Since there are 7.48 gal in 1 ft^3 (Appendix 3), the total volumetric flow rate is

$$q = \frac{30 \times 60}{7.48} = 240.7\ ft^3/h$$

The mass flow rate is the same for pipes A and B and is the product of the density and the volumetric flow rate, or

$$\dot{m} = 240.7 \times 55.3 = 13{,}300\ lb/h$$

The mass flow rate through each of pipes C is one-half the total or 13,300/2 = 6650 lb/h (0.8379 kg/s).

(b) The velocity through pipe A is

$$\overline{V}_A = \frac{240.7}{3600 \times 0.0233} = 2.87 ft/s.$$

through pipe B is

$$\overline{V}_B = \frac{240.7}{3600 \times 0.0513} = 1.30\ ft/s$$

and through each of pipes C is

$$\overline{V}_C = \frac{240.7}{2 \times 3600 \times 0.01414} = 2.36 \text{ ft/s.}$$

(c) The mass velocity through pipe A is

$$G_A = \frac{13{,}300}{0.0233} = 571{,}000 \text{ lb/ft}^2 - \text{h } (744 \text{ kg/m}^2 - \text{s})$$

through pipe B is

$$G_B = \frac{13{,}300}{0.0513} = 259{,}000 \text{ lb/ft}^2 - \text{h } (351 \text{ kg/m}^2 - \text{s})$$

and through each of pipes C is

$$G_C = \frac{13{,}300}{2 \times 0.01414} = 470{,}000 \text{ lb/ft}^2 - \text{h } (637 \text{ kg/m}^2 - \text{s})$$

10 Momentum Balance In Potential Flow; The Bernoulli Equation Without Friction

An important relation, called the Bernoulli equation without friction, can be derived by applying the momentum balance to the steady flow of a fluid in potential flow.

Consider a volume element of a stream tube within a larger stream of fluid in steady potential flow, as shown in figure. Assume that the cross section of the tube increases continuously in the direction of flow. Also, assume that the axis of the tube is straight and inclined upward at an angle ϕ from the vertical. Denote the cross section, pressure, linear velocity, and elevation at the tube entrance by S, p, u, and Z, respectively, and let the corresponding quantities at the exit be $S + \Delta S$, $p + \Delta p$, $u + \Delta u$, and $Z + \Delta Z$. The axial length is ΔL, and the constant fluid density is ρ. The constant mass flow rate through the tube is $\dot{m}$.

The rate of momentum flow at the tube entrance $\dot{M}_a$ is $\dot{m}u$, and that at the exit $\dot{M}_b$ is $\dot{m}(u + \Delta u)$. Equation can therefore be written

$$\sum F = \frac{\dot{m}\Delta u}{g_c}$$

The pressure forces normal to the cross section of the tube at the inlet and outlet of the tube, with the terminology of Equation, are

$$p_a S_a = pS \qquad p_b S_b = (p + \Delta p)(S + \Delta S)$$

Since the side of the tube is not parallel to the axis, the pressure at the side possesses a component in the axial direction acting to increase momentum. Let dA be an element of side area. Since the flow is potential, there is no shear force and the local pressure p' is normal to the surface element. The pressure force is p' dA. Its component in the direction of flow is p' dA sin ψ, where ψ is the angle between the axis and the pressure vector at element dA. But dA sin ψ is also the projection of area dA on the cross section at the discharge, so that the pressure acting in the direction of flow is p' dS. Since the total projected area from the side of the tube is exactly ΔS, the total side force is

$$F_w = \int_o^{\Delta s} p' \, dS = \overline{p}' \Delta S$$

where $\bar{p}$, the average value of the pressure surrounding the tube, has a value between p and p + Δp.

The only other force acting on the flowing fluid is the component of gravity acting along the axis. The volume of the tube may be written as $\bar{S}\,\Delta L$, where $\bar{S}$ is the average cross section, which has a value between S and S + ΔS. Then the mass of fluid in the tube is $\bar{S}\rho\,\Delta L$. The component of the gravitational force opposite to the direction of flow is

$$F_g = \frac{g}{g_c}\bar{S}\rho\,\Delta L\cos\phi$$

Since cos ϕ = ΔZ/ΔL,

$$F_g = \frac{g}{g_c}\bar{S}\rho\,\Delta L\frac{\Delta Z}{\Delta L} = \frac{g}{g_c}\bar{S}\rho\,\Delta Z$$

Substitution from Equation gives

$$\frac{\dot{m}}{g_c}\Delta u = \Delta S\left(\bar{p}' - p\right) - S\,\Delta p - \Delta p\,\Delta S - \frac{g}{g_c}\bar{S}\rho\,\Delta Z$$

Dividing equation by ρS ΔL yields

$$\frac{\dot{m}}{g_c\rho S}\frac{\Delta u}{\Delta L} = \frac{\bar{p}' - p}{\rho S}\frac{\Delta S}{\Delta L} - \frac{1}{\rho}\frac{\Delta p}{\Delta L} + \frac{\Delta S}{\rho S}\frac{\Delta p}{\Delta L} - \frac{g}{g_c}\frac{\bar{S}\Delta Z}{S\Delta L}$$

Now find the limits of all terms in equation as ΔL → 0. Then ΔS → 0, $\bar{S} \to S$, $\bar{p}' - p \to 0$, and the ratios of increments all become the corresponding differential coefficients, so that, in the limit,

$$\frac{\dot{m}}{g_c\rho S}\frac{du}{dL} = -\frac{1}{\rho}\frac{dp}{dL} - \frac{g}{g_c}\frac{dZ}{dL}$$

The mass flow rate is

$$\dot{m} = u\rho S$$

Substituting in equation gives

$$\frac{u\rho S}{g_c\rho S}\frac{du}{dL} = -\frac{1}{\rho}\frac{dp}{dL} - \frac{g}{g_c}\frac{dZ}{dL} = 0$$

and

$$\frac{1}{\rho}\frac{dp}{dL} + \frac{g}{g_c}\frac{dZ}{dL} + \frac{d\left(u^2/2\right)}{g_c dL} = 0$$

Equation is the point form of the Bernoulli equation without friction. Although derived for the special situation of an expanding cross section and an upward flow, the equation is applicable to the general case of constant or contracting cross section and horizontal or downward flow (the sign of the differential dZ corrects for change in direction).

When the cross section is constant, u does not change with position, the term $d(u^2/2)/dL$ is zero, and equation becomes identical with equation for a stationary fluid. In unidirectional potential flow at a constant velocity, then, the magnitude of the velocity does not affect the pressure drop in the tube; the pressure drop depends only on the rate of change of elevation. In a straight horizontal tube, in consequence, there is no pressure drop in steady constant-velocity potential flow.

The differential form of equation is

$$\frac{dp}{\rho}+\frac{g}{g_c}dZ+\frac{1}{g_c}d\left(\frac{u^2}{2}\right)=0$$

Between two definite points in the tube, say stations *a* and *b*, equation can be integrated, since ρ is constant, to give

$$\frac{p_a}{\rho}+\frac{gZ_a}{g_c}+\frac{u_a^2}{2g_c}=\frac{p_b}{\rho}+\frac{gZ_b}{g_c}+\frac{u_b^2}{2g_c}$$

Equation is known as the Bernoulli equation without friction.

11 **Water with a density of 998 kg/m^3 (62.3 lb/ft^3) enters a 50-mm (1.969-in.) pipe fitting horizontally, as shown in figure, at a steady velocity of 1.0 m/s (3.28 ft/s) and a gauge pressure of 100 kN/m^2 (2088.5 lb_f/ft^2). It leaves the fitting horizontally, at the same elevation, at an angle of 45° with the entrance direction. The diameter at the outlet is 20mm (0.787 in.). Assuming the fluid density is constant, the kinetic-energy and momentum correction factors at both entrance and exit are unity, and the friction loss in the fitting is negligible, calculate (a) the gauge pressure at the exit of the fitting and (b) the forces in the x and y directions exerted by the fitting on the fluid.**

Solution:-

(a) $\bar{V}_a = 1.0\ m/s$. From equation,

$$\bar{V}_b=\bar{V}_a\left(\frac{D_a}{D_b}\right)^2=1.0\left(\frac{50}{20}\right)^2=6.25\ m/s.$$

$$p_a=100\ kN/m^2$$

The outlet pressure p_b is found from equation. Since $Z_a = Z_b$ and h_f may be neglected, equation becomes,

$$\frac{p_a-p_b}{\rho}=\frac{\bar{V}_b^2-\bar{V}_a^2}{2}$$

from which

$$p_b=p_a-\frac{\rho\left(\bar{V}_b^2-\bar{V}_a^2\right)}{2}=100-\frac{998\left(6.25^2-1.0^2\right)}{1000\times 2}$$

$$= 100 - 18.99 = 81.01\ kN/m^2\left(11.75 lb_f/in.^2\right)$$

Note that g_c is omitted when working in SI units (but g is not).

(b) The forces acting on the fluid are found by combining equations.

For the x direction, since $F_g = 0$ for horizontal flow, this gives

$$\dot{m}\left(\beta_b \overline{V}_{b,x} - \beta_a \overline{V}_{a,x}\right) = p_a S_{a,x} - p_b S_{b,x} + F_{w,x}$$

Where $S_{a,x}$ and $S_{b,x}$ are the projected areas of S_a and S_b on planes normal to the initial flow direction. (Recall that pressure p is a scalar quantity.) Since the flow enters in the x direction, $\overline{V}_{a,x} = \overline{V}_a$ and

$$S_{a,x} = S_a = \frac{\pi}{4} 0.050^2 = 0.001964 \text{ m}^2$$

$$\overline{V}_{b,x} = \overline{V}_b \cos\theta = 6.25 \cos 45° = 4.42 \text{ m/s.}$$

Also

$$S_{b,x} = S_b \sin\ \theta = \frac{\pi}{4} 0.020^2 \sin 45° = 0.000222 \text{ m}^2$$

From equation

$$\dot{m} = \overline{V}_a \rho S_a = 1.0 \times 998 \times 0.001964 = 1.960 \text{ kg/s.}$$

Substituting in equation and solving for $F_{w,x}$, assuming $\beta_a = \beta_b = 1$, gives

$$F_{w,x} = 1.96(4.42 - 1.0) - 100{,}000 \times 0.001964 + 81{,}010 \times 0.000222$$
$$= 6.7 - 196.4 + 18.0 = -171.7 \text{N} (-38.6 \text{ lb}_f)$$

Similarly for the y direction, $\overline{V}_{a,y} = 0$ and $S_{a,y} = 0$, and

$$\overline{V}_{b,y} = \overline{V}_b \sin\theta = 4.42 \text{ m/s} \qquad S_{b,y} = S_b \cos\theta = 0.000222 \text{ m}^2$$

Hence

$$F_{w,y} = \dot{m}\left(\beta_b \overline{V}_{b,y} - \beta_a \overline{V}_{a,y}\right) - p_a S_{a,y} + p_b S_{b,y}$$
$$= 1.96\ (4.42 - 0) - 0 + 81.01 \times 0.000222 \times 1000$$
$$= 8.66 + 17.98 = 26.64 \text{ N } (5.99 \text{ lb}_f)$$

A pump draws a solution of specific gravity 1.84 from a storage tank through a 3-in. (75-mm) Schedule 40 steel pipe. The efficiency of the pump is 60 percent. The velocity in the suction line is 3 ft/s (0.914 m/s). The pump discharges through a 2-in. (50-mm) Schedule 40 pipe to an overhead tank. The end of the discharge pipe is 50 ft (15.2 m) above the level of the solution in the feed tank. Friction losses in the entire piping system are 10ft-lb_f/lb (29.9 J/kg). What pressure must the pump develop? What is the power of the pump?

Solution:-

Take station *a* at the surface of the liquid in the tank and station b at the discharge end of the 2-in. pipe. Take the datum plane for elevations through the station *a*. Since the pressure at both stations is atmospheric, $p_a = p_b$. The velocity at station *a* is negligible because of the large diameter of the tank in comparison with that of the pipe. For turbulent flows the kinetic-energy factor α can be taken as 1.0 with negligible error. Equation becomes

$$W_p\eta = \frac{g}{g_c}Z_b + \frac{\overline{V}_b^2}{2g_c} + h_f$$

By Appendix 5, the cross-sectional areas of the 3- and 2-in. pipes are 0.0513 and 0.0233 ft^2, respectively. The velocity in the 2-in. pipe is

$$\overline{V}_b = \frac{3\times 0.0513}{0.0233} = 6.61 \text{ ft/s.}$$

Then

$$0.60W_p = 50\frac{g}{g_c} + \frac{6.61^2}{64.34} + 10 = 60.68$$

and

$$W_p = \frac{60.68}{0.60} = 101.1 \text{ ft-lb}_f/\text{lb}$$

The pressure developed by the pump can be found by writing Equation over the pump itself. Station *a* is in the suction connection and station b is in the pump discharge. The difference in level between suction and discharge can be neglected, so $Z_a = Z_b$ and equation becomes

$$\frac{p_b - p_a}{\rho} = \frac{\overline{V}_a^2 - \overline{V}_b^2}{2g_c} + W_p\eta$$

The pressure developed by the pump is

$$p_b - p_a = 1.84\times 62.37\left(\frac{3^2 - 6.61^2}{2\times 32.17} + 60.68\right)$$

$$= 6902 \text{ lb}_f/\text{ft}^2 \text{ or } \frac{6902}{144} = 47.9 \text{ lb}_f/\text{in}^2 (330 \text{ kN/m}^2)$$

The power used by the pump is the product of W_p and the mass flow rate divided by the conversion factor, 1 hp = 550 ft-lb$_f$/s. The mass flow rate is

$$\dot{m} = 0.0513\times 3\times 1.84\times 62.37 = 17.66 \text{ lb/s}$$

and the power is

$$P = \frac{\dot{m}W_p}{550} = \frac{17.66\times 101.1}{550} = 3.25\text{hp (2.42 kW)}$$

1. Derive the Hagen – Poiseuille's formula for pressure drop over a length of a pipeline. (April/May 2010, May/June 2009, Nov/Dec 2007) (16)
2. Draw a neat sketch for centrifugal pump and explain its working principle and give its application. (16) (*Nov/Dec 2009*) (16)
3. Derive the working principle of reciprocating pump with neat sketch showing all components (*Nov/Dec 2009*)