SUMMER-19 EXAMINATION

Model Answer

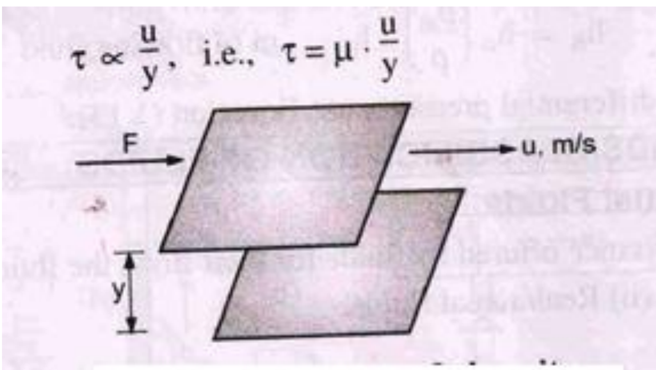
Subject title: Fluid Flow Operation

Subject code 22409

Important Instructions to examiners:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more Importance (Not applicable for subject English and Communication Skills.
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept.

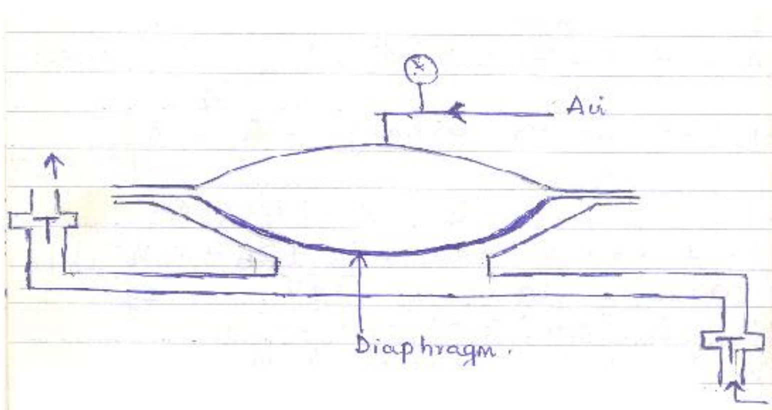
Q No.		Answer	Marking scheme
1		**Attempt any FIVE of the following**	**10**
1	a	**Average velocity:** It is the ratio of volumetric flow rate to the cross sectional area of the pipe	2
1	b	**Critical velocity:** It is the velocity at which the flow changes from laminar to transition.	2
1	c	**Different flow meters used in chemical industry:** Orifice meter, venturimeter, rotameter, pitot tube	½ mark each
1	d	**Schedule number:** **Definition:** They are American Standard Association designation for classifying the strength of the pipe. It indicates the wall thickness of the pipe.	1 1
1	e	**Minimum fluidization velocity:** Fluidization is the balance of gravity, drag and buoyant forces. The minimum velocity at which fluidization occurs is the minimum fluidization velocity.	2
1	f	**Application of gear pump:** It is used for the transportation of viscous liquids.	2
1	g	**Eg of incompressible fluid (any one)** Water, sodium chloride solution , sugar solution **Eg of compressible fluid (any one)** Oxygen, nitrogen, carbon dioxide (any gas)	1 1
2		**Attempt any THREE of the following**	**12**
2	a	**Newton's law of viscosity :**	

		It states that the shear stress on a layer of fluid is directly proportional to the rate of shear. **Derivation:**  Consider two layer of fluid 'y' cm apart as shown in fig. Let the area of each of these layer be A cm^2. Assume that top layer is moving parallel to the bottom layer at a velocity u cm/s relative to the bottom layer. To maintain this motion i.e. the velocity 'u' and to overcome the fluid friction between these layers, for any actual fluid, a force of 'F' dyne is required. Experimentally it has been found that the force F is directly proportional to the velocity u and area A and inversely proportional to the distance y. Therefore , mathematically it becomes $$F \propto u.A/y$$ Introducing a proportionality constant μ , $$F = \mu u A/y$$ $$F/A = \mu u/y$$ Shear stress ,τ equal to F/A between any two layers of fluid may be expressed as $$\tau = F/A = \mu .u/y$$	2

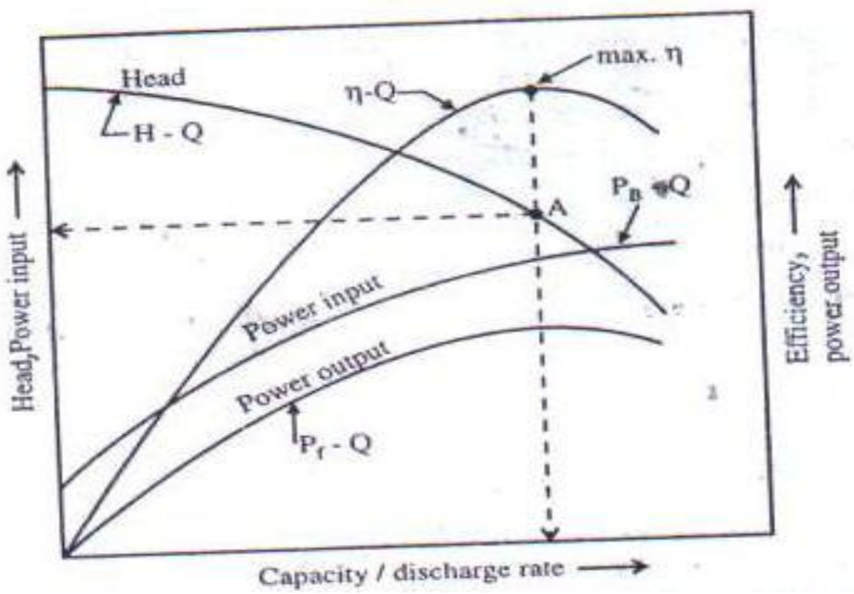
		The above equation in a differential form becomes $\tau = \mu.\frac{du}{dy}$ …… Newton's law of viscosity.	2
2	b	**Difference between orificemeter and venturimeter:**	1 mark each for any 4 points

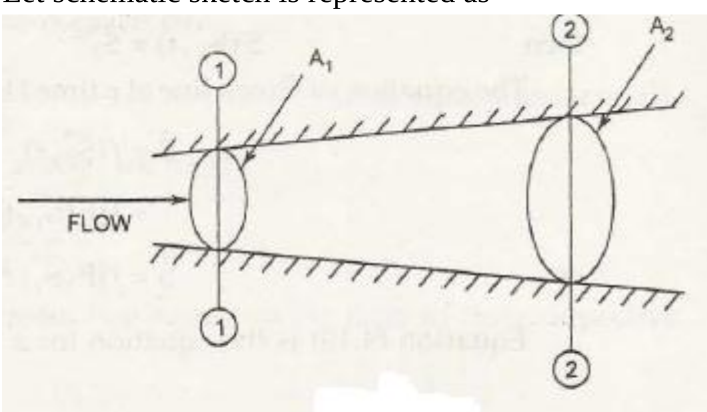
Venturimeter	orificemeter
1. Construction is complex	1. Simple
2. Costly	2. Cheap
3. More space	3. Less space
4. Coefficient of discharge Cv > 0.9	4. Coefficient of discharge Co is 0.6
5. Pressure loss is less	5. Pressure loss is more
6. Pressure recovery is more	6. Pressure recovery is less
7. can be used when only small pressure head is available	7. cannot be used when only small pressure head is available
8. Change of area is gradual.	8. Area changes suddenly

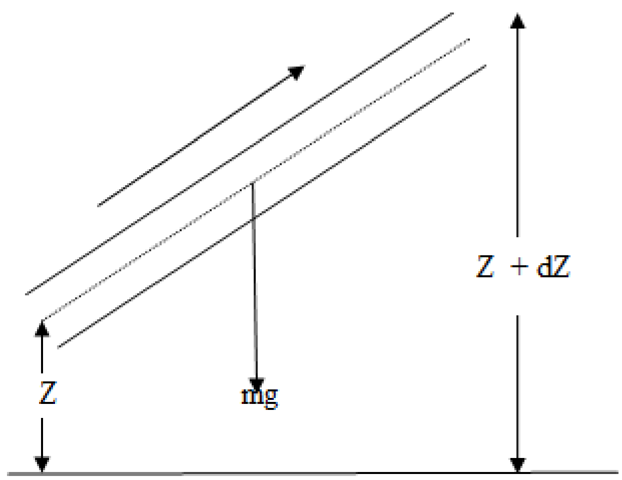
2	c	**Diagram of Diaphragm valve**	4



2	d	**Characteristic curves of a centrifugal pump :**	

			2
		The H-Q curve shows the relationship between head and capacity rate .it is clear from the curve that the head decreases continuously as the discharge rate is increased. The optimum conditions for operation are those at which the ordinate through the point of maximum efficiency cuts the head curve. The point A is called as duty point. The head corresponding to zero or no discharge is known as the shut off head of the pump. From H-Q curve, it is possible to determine whether the pump will handle the necessary quantity of liquid against a desired head or not and the effect of increase or decrease of head. The P_B- Q curve gives us an idea regarding the size of motor required to operate the pump at the required conditions and whether or not motor will be overloaded under any other operating conditions. The η-Q curve shows the relationship between pump efficiency and capacity. It is clear from η-Q curve that efficiency rises rapidly	2

		with discharge at low discharge rate, reaches a maximum in the region of the rated capacity and then falls.	
3		**Attempt any THREE of the following**	**12**
3	a	**Equation of continuity:** **Statement:** It is law of conservation of mass applicable for flowing fluid. It states that mass flow rate of fluid flowing through a stream tube is conserved. In other words, mass flow rate of fluid entering the stream tube is equal to mass flow rate of fluid leaving the stream tube. Mathematically : $\dot{m} = \rho U A = constant$ (1) For cross stream tube of varying cross section, it can be written as $\dot{m} = \rho_1 U_1 A_1 = \rho_2 U_2 A_2 = \rho_3 U_3 A_3 = constant$ (2) For incompressible fluid, above equation can be used to calculate volumetric flow rate or velocity through various cross sections. Let schematic sketch is represented as  Let Mass flow rate across section 1-1 is :$\dot{m}_1$ Mass flow rate across section 2-2 is : $\dot{m}_2$ As per continuity equation , $\dot{m}_1 = \dot{m}_2$	Statement 1 mark Schematic sketch : 1 mark Mathematical manipulation : 2marks

		Substituting , the expression using eq.(1) and after simplification, we can prove Mass flow rate of fluid = constant.	
3	b	**Derivation of Bernoulli's equation:** Statement : For steady, irrotational flow of incompressible and ideal fluid, total energy associated with flowing fluid is conserved. Schematic sketch is as shown below  Assumptions made: 1. Velocity is constant over the entire cross sectional area. 2. No pump work. 3. Frictional losses are negligible Consider a flow of fluid through a pipe of cross sectional area A. Let 1. PA is the force acting on the fluid at entrance. 2. (P + dP)A is force acting on fluid at exit of fluid. 3. U is the velocity of flowing fluid at entrance 4. (U + dU) is the velocity at exit.	Assumption and definition of various energy terms : 2 marks, Substitution and final expression : 2 marks

5. Z is elevation from datum at entrance
6. Z + dZ is Elevation at the exit
7. Compoment of gravity force acting along the direction of flow : mgcosθ
8. Rate of change of momentum : $\dot{m}$ ((U + dU)-(U)) =$\dot{m}dU$

As it is not possible to measure mass flow rate of flowing fluid easily, we can write, $\dot{m} = \rho UA$

Applying the Newtons second law of motion assuming incompressible fluid, we can write,
Net force acting on fluid = rate of change of momentum

PA - (P +dP)A - ρAdLgcosθ = ρ.UA dU

-dPA - ρAdLgcosθ = ρ UA dU

dPA + ρAdLgcosθ + ρUAdU = 0 Eq.I

Dividing each term of eq.I by AdLρ we get

$$\frac{dP}{\rho dL} + g\cos\theta + \frac{UdU}{dL} = 0$$

As $\cos\theta = \frac{dZ}{dL}$,we can write

$$\frac{1}{\rho}\frac{dP}{dL} + g\frac{dZ}{dL} + u\frac{dU}{dL} = 0 \qquad Eq.II$$

$$\frac{1}{\rho}\frac{dP}{dL} + g\frac{dZ}{dL} + \frac{d\left(\frac{U^2}{2}\right)}{dL}$$

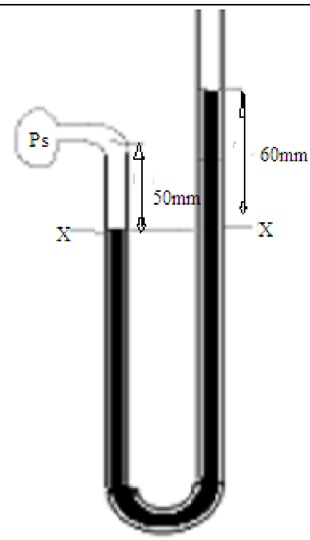
Which can be written as

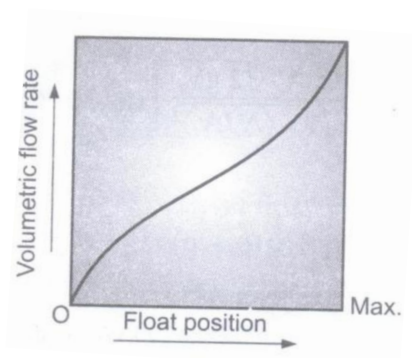
$$\frac{dP}{\rho} + g\,.dZ + d\left(\frac{U^2}{2}\right) = 0 \qquad Eq.III$$

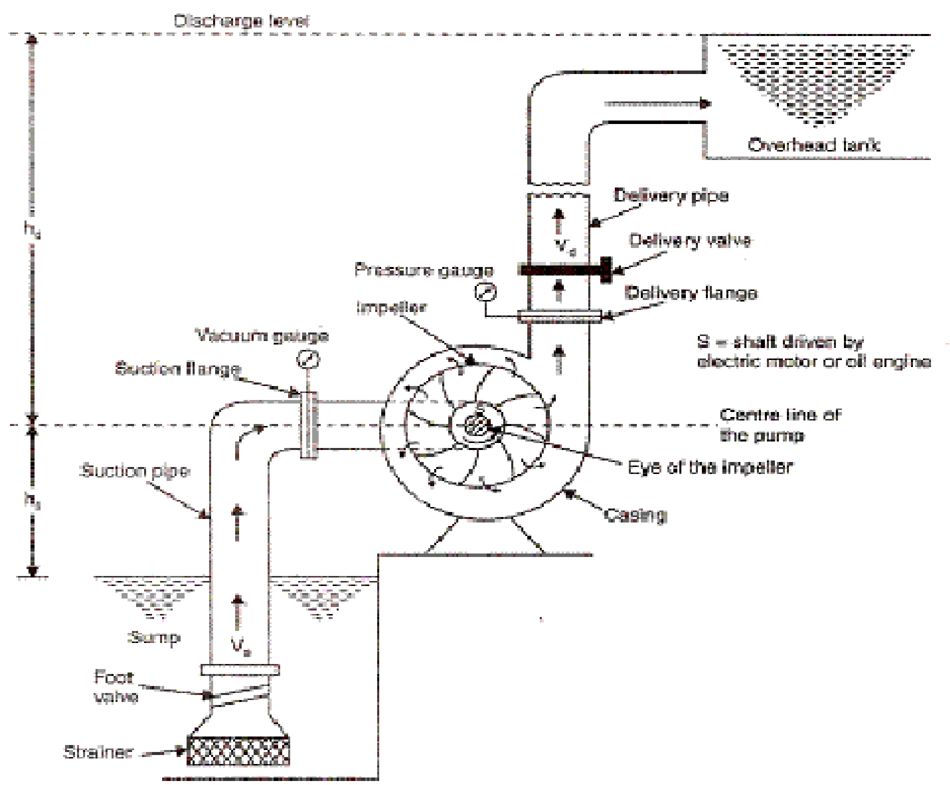
Eq.III is called Bernoulli Equation. It is differential form of the Bernoulli

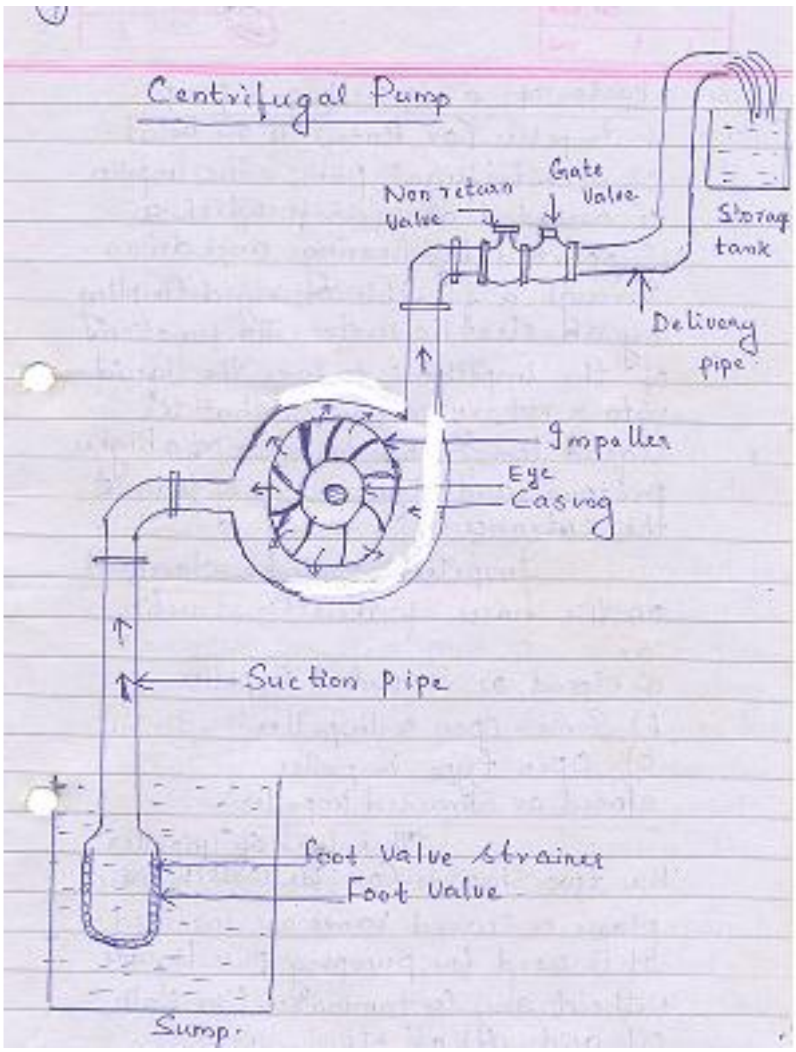
		Equation. For incompressible fluid, density is independent of pressure & hence ,the integrated form of eq.III is $$\frac{P}{\rho} + gZ + \frac{u^2}{2} = constant$$ Applying boundary condition at the entrance and exit of the pipe, above equation can be rewritten as , $$\frac{P_1}{\rho} + \frac{U_1}{2} + Z_1 = \frac{P_2}{\rho} + \frac{U_2}{2} + Z_2$$	
3	c	**Fittings used for** **(i) Changing the size of pipe line:** Reducer, expander **(ii) Branching the pipe line:** Tee, cross **(iii) Termination of pipe line:** Plug or end cap. **(iv) Changing the direction of pipe line:** Bend, elbow	1mark each
3	d	**Comparison of reciprocating compressor and centrifugal compressor:** (see table below)	2 marks each
4		**Attempt any THREE of the following**	**12**
4	a	Data: Density of water : 1000 kg/m^3 Density of mercury : 13600 kg/m^3	

Points	Reciprocating compressor	Centrifugal compressor
(i)Speed	Rotational speed is low	Rotational speed is high
(ii)Rate of flow	Flow rate is high due to high discharge pressure	Flow rate is less due to low discharge pressure

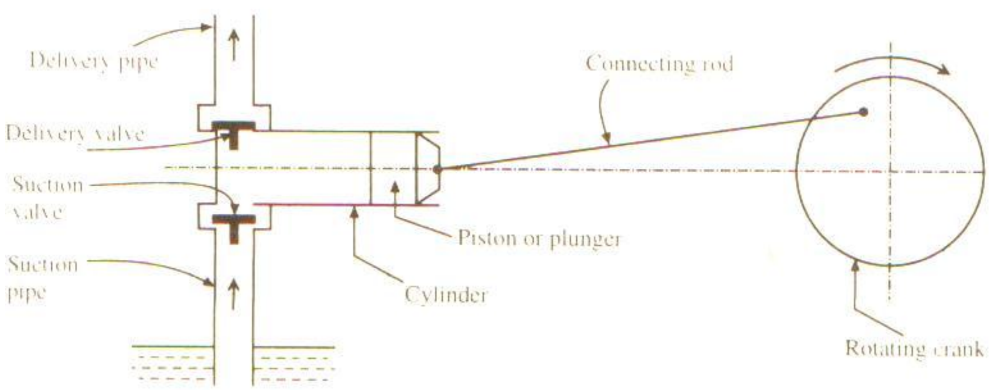
		 Taking force balance at common point X-X Pressure acting on left limb = Pressure acting on right limb $P_a + P_S + h_w \rho g = P_a + h_m \rho_m g$ Where P_a : Atmospheric pressure (N/m^2) P_S : System pressure (N/m^2) h_w : Height of water column(m) h_m : Height of mercury column (m) ρ : Density of water(kg/m^3) ρ_m : Density of mercury column (kg/m^3) g : gravitational acceleration (m/s^2) Substituting values in above equation we get, 101325 + P_S + 0.05 X 1000 X 9.81 = 101325 + 0.06 X 13600 X 9.81 **P_S : 7514.46 N/m^2**	1 2 1
4	b	Q = 30 l / s = 30*10^{-3} m^3 / s Kinematic viscosity : $\vartheta = 1.2 \text{ X } 10^{-4} \frac{\text{m2}}{\text{s}}$ Diameter of pipe : D : 0.075 m	

		Cross sectional area : A = $\frac{\pi d^2}{4}$ = 3.14* 0.075^2 / 4 =0.004417 m^2 Linear velocity : U : Q/A = 30*10^{-3} / 0.004417 = 6.792 m/s $N_{Re} = \frac{DU\rho}{\mu} = \frac{DU}{\frac{\mu}{\rho}} = \frac{DU}{\vartheta}$ N_{Re} = 0.075 * 6.792 / (12 *10^{-4}) = **4245** As N_{Re} > 4000, **Flow is turbulent**	1 2 1
4	c	**Calibration of rotameter**: 1. Start the flow by opening the valve and adjust float position. 2. Collect volume of fluid and note down the time required. 3. Using the data obtained in 2, calculate volumetric flowrate. 4. From the scale attached, note down the float position. 5. Repeat the procedure by changing the float position. 6. Plot the graph of flowrate versus float position. 	Stepwise procedure : 2 marks Calibration plot: 2 marks
4	d	**Difference between compressor and fan:** <table><tr><td>Criteria</td><td>Compressor</td><td>Fan</td></tr><tr><td>Speed</td><td>Operates at relative less speed</td><td>Operating speed is higher than compressor</td></tr><tr><td>Pressure developed</td><td>Develops pressure up to 1000 bar</td><td>These are just pushers of air, develops pressure up to few mm of water column</td></tr></table>	1 marks per criteria

		Flow rate	Owing to higher pressure, flow rate is higher.	Flowrate is lower compared to compressor	
		Efficiency	It depends upon design and type. Typically between 50 to 90 %	It depends upon design and type. Typically between 60 to 80%	
4	e	**Diagram of centrifugal pump:** 			Sketch: 2 marks Labeling: 2 marks

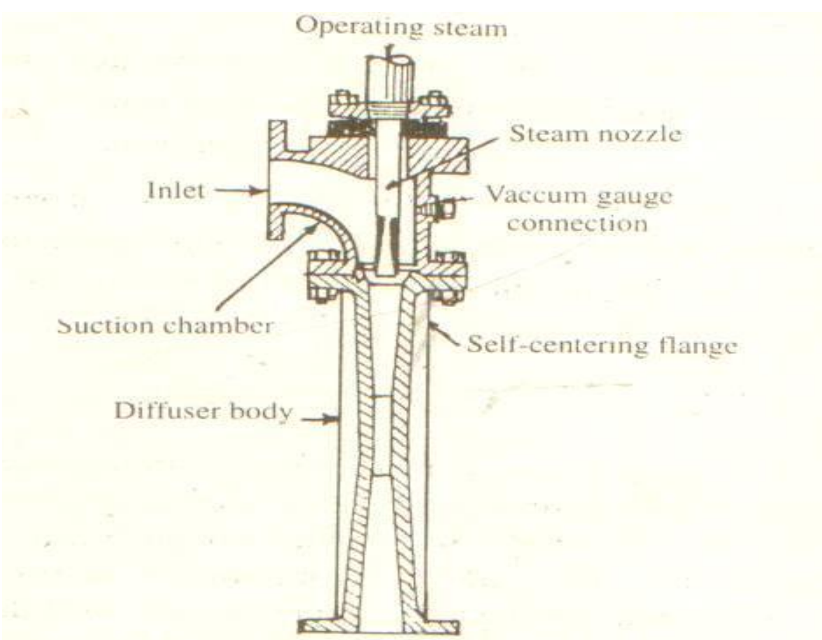
		OR  	
5		**Attempt any TWO of the following**	**12**
5	a	Data: Density of acetic acid = 1060 kg/ m^3 Viscosity of acetic acid = 0.0025 N.s/m^2	

		Volumetric flow rate of acetic acid = Q = 0.02 m^3/s Inside diameter of pipe = D = 0.075 m Area of pipe =A= $\pi/4\ D^2 = \pi/4\ (0.075)^2$ = **4.418 x 10^{-3} m^2** Average velocity of acid through pipe = u = Q / A $u = \frac{0.02}{4.418\ x\ 10^{-3}}$ = **4.53 m/s**	2
		To calculate pressure drop, we need to calculate the value of Reynolds no. & hence friction factor $N_{Re} = \frac{D.u\rho}{\mu}$ $N_{Re} = \frac{0.075x4.53x1060}{0.0025}$ = **144054** As N_{Re} > 4000,flow is turbulent Friction factor for turbulent flow $f = \frac{0.078}{(N_{Re})^{0.25}}$ $f = \frac{0.078}{(144054)^{0.25}} = \mathbf{0.004}$	2
		$\Delta P = \frac{4f\rho Lu^2}{2D}$ $\Delta P = \frac{4x0.004x1060x70x(4.53)^2}{2x0.075} = \mathbf{162416.08\frac{N}{m^2} = 162.416\ \frac{kN}{m^2}}$	2
5	b	D_1 = 100 cm = 1m D_2 =50cm = 0.5 m P_A= 3 kgf /cm^2 = 294199 N /m^2 P_B = ? Z_A= 0 m (assumed as datum level) Z_B= 30 m	

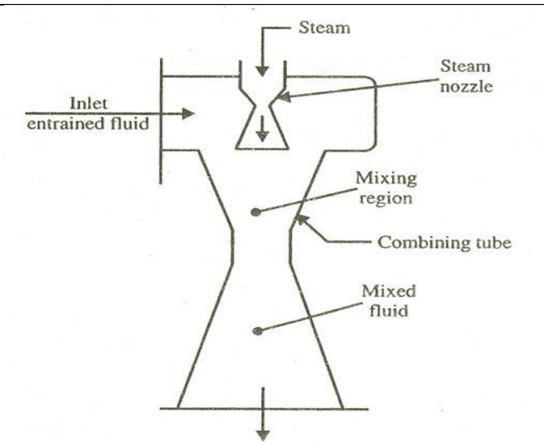
		$Q = 0.08\ m^3/s$ Frictional loss = hf= 0 Let us calculate velocities at point A and point B Area at point A , $=A_A = \pi/4\,(D_1)^2 = \pi/4\,(1)^2 =$ **$0.785 m^2$** Area at point B, $A_B = \pi/4\,(D_2)^2 = \pi/4\,(0.5)^2 =$ **$0.1963 m^2$** $U_A = Q/A_A = \frac{0.08}{0.785} =$ **0.1 m/s** $U_B = Q/A_B = \frac{0.08}{0.1963} =$ **0.4 m/s** As per Bernoulli's equation , Total energy at point A = Total energy at point B (neglecting frictional losses) $\frac{P_A}{\rho} + \frac{u_A^2}{2} + gZ_A = \frac{P_B}{\rho} + \frac{u_B^2}{2} + gZ_B$ $\frac{294199}{1000} + \frac{0.1^2}{2} + 0 = \frac{P_2}{1000} + \frac{0.4^2}{2} + 9.81 * 3$ $P_B = \mathbf{264598\ N/m^2 = 2.6981\,kgf/cm^2}$	3 3
5	c	**Single acting reciprocating pump:** **Diagram:**  	3

		Working Reciprocating pump consists of a piston or plunger which reciprocates in stationary cylinder. Suppose the piston is initially at extreme left position and when crank rotates through 180^0, piston moves to extreme right position. Therefore due to outward movement of piston, a partial vacuum is created in cylinder, which enables the atmospheric pressure acting on the liquid surface in the sump below to force the liquid up the suction pipe & fill the cylinder by forcefully opening the suction valve (it is called as a suction stroke).When the crank rotates through further 180^0 ,piston moves inwardly from its extreme right position towards left. The inward movement of piston causes the pressure of liquid in the cylinder to rise above atmospheric pressure, because of which the suction valve closes & delivery valve opens .The liquid is then forced up the delivery valve & raised to the required height.(Delivery stroke).	3
6		**Attempt any TWO of the following**	**12**
6	a	Data: Diameter of pipe= D = 75 mm = 0.075 m Diameter of throat = D_T =25 mm = 0.025 m Density of water = ρ_{H2O}= 1000 kg /m^3 Density of mercury = ρ_{Hg}= 13600 kg /m^3 Coefficient of venturimeter = C_v= 0. 98 Δh = Difference in levels in mercury manometer = 10 cm =0.1m The flow equation of venturimeter $$Q = \frac{C_v A_T \sqrt{2 * g * \Delta H}}{\sqrt{1-\beta^4}}$$ Area of throat = $A_T = \pi/4 * D_T^2$ = π/4 *(0.015)2 = **1.767 X 10^{-4} m^2**	2

		$\beta = \frac{DT}{D}$ = 0.015 /0.025 = **0.6** ΔH= Difference in levels in terms of water $\Delta H = \Delta h \frac{(\rho_{Hg} - \rho_{H2O})}{\rho_{H2O}} = 0.1 \frac{(13600-1000)}{1000} = \mathbf{1.26\ m\ of\ water}$ The flow equation becomes $Q = \frac{0.98*1.767 \text{ X } 10-4 \sqrt{2*9.81*1.26}}{\sqrt{1-0.6^4}}$ = **9.23 *10^{-4} m^3/s**	 2 2
6	b	**Data**: Water flow rate (Q) = 8 m^3/hr = 8/3600 = **0.00222** m^3/s Diameter of pipe: D = 50 mm = 0.05 m Area of pipe = A = π /4 D^2 = π /4 $(0.05)^2$ = **1.963* $10^{-3}$$m^2$** Let's find out the velocity of water through discharge pipe u_2= Q/A = $\frac{0.00222}{1.963 \text{ X } 10-3}$ = **1.131 m/s** Bernoulli's equation for pump work is $$\frac{P_1}{\rho} + \frac{\alpha_1 . u_1^2}{2} + gZ_1 + \eta W_p = \frac{P_2}{\rho} + \frac{\alpha_2 . u_2^2}{2} + gZ_2 + h_f$$ $P_1 = P_2 = 101.325\ kN/m2$ as both open to atmosphere $\alpha_{1.} = \alpha_{2.}$ u_1 =Negligible as compared to velocity at station 2 u_2 = 1.131 m/s Z_1 = ? Z_2 = 5 m $\eta = 1$	2

		$\dot{m}\ W_p$ = Power developed by pump = 94 W =94 J/s $\dot{m}$ == ρQ = 1000 ∗ 0.00222 = **2.22kg/s** $$W_p = \frac{94}{2.22} = \mathbf{42.34\ J/kg}$$ $$\eta W_p = 1 * 42.34 = 42.34\ J/kg$$ By putting $P_1 = P_2$ and $u_1 = 0$ Bernoulli's equation becomes $gZ_1 + \eta W_p = gZ_2 + \frac{u_2^2}{2} + h_f$ 9.81 *Z_1 + 42.34 = 9.81*5 + $\frac{(1.131)^2}{2}$ + 2.5 9.81 *Z_1 + 42.34 = 52.18 Z_1 = 9.849/9.81 =1.004 =**1 m**	2 2
6	c	**Steam Jet Ejector** **Diagram** 	3 marks for diagram and 3 marks for working

		Working: An ejector has two inlets: one to admit the motive fluid, usually steam (inlet 1), and the other to admit the gas/vapor mixture to be evacuated or pumped (inlet 2). Motive steam, at high pressure and low velocity, enters the inlet 1 and exits the steam nozzle at design suction pressure and supersonic velocity, entraining the vapor to be evacuated into the suction chamber through inlet 2. The nozzle throat diameter controls the amount of steam to pass through the nozzle at a given pressure and temperature. The entrained gas/vapor flow and the motive fluid (steam) flow mix while they move through the converging section of the diffuser, increasing pressure and reducing velocity. The velocity of this mixture is supersonic and the decreasing cross sectional area creates an overall increase in pressure and a decrease in velocity. The steam slows down and the inlet gas stream picks up speed and, at some point in the throat of the diffuser, their combined flow reaches the exact speed of sound. A stationary, sonic-speed shock wave forms there and produces a sharp rise in absolute pressure. Then, in the diverging section of the diffuser, the velocity of the mixture is sub-sonic and the increasing cross sectional area increases the pressure but further decreases the velocity. **OR**	

		 An ejector is a pumping device. It has no moving parts. Instead, it uses a fluid or gas as a motive force. Very often, the motive fluid is steam and the device is called a "steam jet ejector." Basic ejector components are the steam chest, nozzle, suction, throat, diffuser and the discharge. Steam at about 7 atm is admitted to a converging-diverging nozzle, from which it issues at supersonic velocity into a diffuser cone. The air or other gas to be moved is mixed with the steam in the first part of the diffuser, lowering the velocity to acoustic velocity or below. In the diverging section of the diffuser, the kinetic energy of the mixed gas is converted to pressure energy so that the mixture can be discharged directly to atmosphere.	