CH : CHEMICAL ENGINEERING

Duration : Three Hours *Maximum Marks* :150

Read the following instructions carefully

1. This question paper contains **24** printed pages including pages for rough work. Please check all pages and report discrepancy, if any.
2. Write your registration number, your name and name of the examination centre at the specified locations on the right half of the ORS.
3. Using HB pencil, darken the appropriate bubble under each digit of your registration number and the letters corresponding to your paper code.
4. All the questions in this question paper are of objective type.
5. Questions must be answered on **O**bjective **R**esponse **S**heet (**ORS**) by darkening the appropriate bubble (marked A, B, C, D) using HB pencil against the question number on the left hand side of the ORS. **Each question has only one correct answer**. In case you wish to change an answer, erase the old answer completely. More than one answer bubbled against a question will be treated as a wrong answer.
6. Questions 1 through 20 are 1-mark questions and questions 21 through 85 are 2-mark questions.
7. Questions 71 through 73 is one set of common data questions, questions 74 and 75 is another pair of common data questions. The question pairs (76, 77), (78, 79), (80, 81), (82, 83) and (84, 85) are questions with linked answers. The answer to the second question of the above pairs will depend on the answer to the first question of the pair. If the first question in the linked pair is wrongly answered or is un-attempted, then the answer to the second question in the pair will not be evaluated.
8. Un-attempted questions will carry zero marks.
9. **NEGATIVE MARKING**: For Q.1 to Q.20, ***0.25*** mark will be deducted for each wrong answer. For Q.21 to Q.75, ***0.5*** mark will be deducted for each wrong answer. For the pairs of questions with linked answers, there will be negative marks only for wrong answer to the first question, i.e. for Q.76, Q.78, Q.80, Q.82 and Q.84, ***0.5*** mark will be deducted for each wrong answer. There is no negative marking for Q.77, Q.79, Q.81, Q.83 and Q.85.
10. Calculator **without data connectivity** is allowed in the examination hall.
11. Charts, graph sheets and tables are NOT allowed in the examination hall.
12. Rough work can be done on the question paper itself. Additional blank pages are given at the end of the question paper for rough work.

Q. 1 – Q. 20 carry one mark each.

Q.1 Which **ONE** of the following is **NOT** an integrating factor for the differential equation $xdy - ydx = 0$?

(A) $\frac{1}{x^2}$ (B) $\frac{1}{y^2}$ (C) $\frac{1}{xy}$ (D) $\frac{1}{(x+y)}$

Q.2 Which **ONE** of the following is **NOT** a solution of the differential equation $\frac{d^2y}{dx^2} + y = 1$?

(A) $y = 1$ (B) $y = 1 + \cos x$ (C) $y = 1 + \sin x$ (D) $y = 2 + \sin x + \cos x$

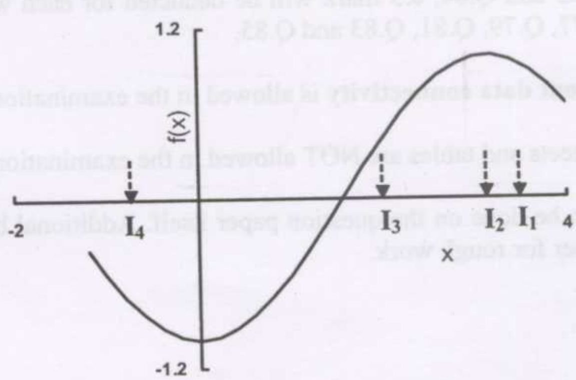
Q.3 The limit of $\frac{\sin x}{x}$ as $x \to \infty$ is

(A) -1 (B) 0 (C) 1 (D) ∞

Q.4 The unit normal vector to the surface of the sphere $x^2 + y^2 + z^2 = 1$ at the point $\left(\frac{1}{\sqrt{2}}, 0, \frac{1}{\sqrt{2}}\right)$ is ($\hat{i}, \hat{j}, \hat{k}$ are unit normal vectors in the cartesian coordinate system)

(A) $\frac{1}{\sqrt{2}}\hat{i} + \frac{1}{\sqrt{2}}\hat{j}$ (B) $\frac{1}{\sqrt{2}}\hat{i} + \frac{1}{\sqrt{2}}\hat{k}$ (C) $\frac{1}{\sqrt{2}}\hat{j} + \frac{1}{\sqrt{2}}\hat{k}$ (D) $\frac{1}{\sqrt{3}}\hat{i} + \frac{1}{\sqrt{3}}\hat{j} + \frac{1}{\sqrt{3}}\hat{k}$

Q.5 A nonlinear function f(x) is defined in the interval $-1.2 < x < 4$ as illustrated in the figure below. The equation f(x) = 0 is solved for x within this interval by using the Newton-Raphson iterative scheme. Among the initial guesses (I_1, I_2, I_3 and I_4), the guess that is likely to lead to the root most rapidly is



(A) I_1 (B) I_2 (C) I_3 (D) I_4

Q.6 For a Carnot refrigerator operating between 40°C and 25°C, the coefficient of performance is

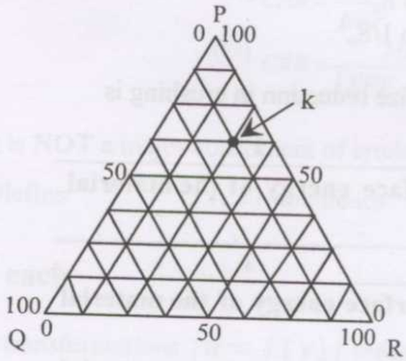
(A) 1 (B) 1.67 (C) 19.88 (D) 39.74

Q.7 The work done by one mole of a van der Waals fluid undergoing reversible isothermal expansion from initial volume V_i to final volume V_f is

(A) $RT\ln\left(\frac{V_f}{V_i}\right)$ (B) $RT\ln\left(\frac{V_f-b}{V_i-b}\right)$

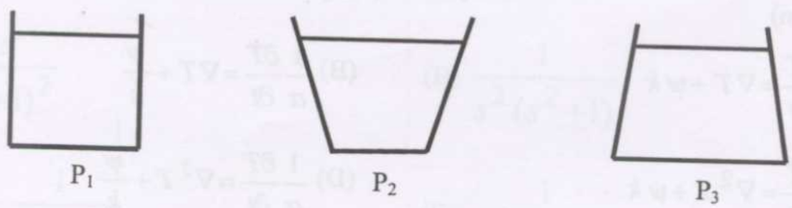
(C) $RT\ln\left(\frac{V_f-b}{V_i-b}\right)-a\left(\frac{1}{V_f}-\frac{1}{V_i}\right)$ (D) $RT\ln\left(\frac{V_f-b}{V_i-b}\right)+a\left(\frac{1}{V_f}-\frac{1}{V_i}\right)$

Q.8 For a system containing species P, Q and R, composition at point k on the ternary plot is



(A) 62.5% P, 12.5% Q, 25% R (B) 25% P, 62.5% Q, 12.5% R
(C) 12.5% P, 62.5% Q, 25% R (D) 12.5% P, 25% Q, 62.5% R

Q.9 Three containers are filled with water up to the same height as shown. The pressures at the bottom of the containers are denoted as P_1, P_2 and P_3. Which **ONE** of the following relationships is true?



(A) $P_3 > P_1 > P_2$ (B) $P_2 > P_1 > P_3$ (C) $P_1 > P_2 = P_3$ (D) $P_1 = P_2 = P_3$

Q.10 Losses for flow through valves and fittings are expressed in terms of

(A) drag coefficient (B) equivalent length of a straight pipe
(C) shape factor (D) roughness factor

Q.11 To determine the performance of a compressor, a standardized test is performed. In the testing process, when the compressor is under operation, “shut off” term signifies

(A) maximum flow
(B) zero flow
(C) steady flow
(D) intermittent flow

Q.12 Given a pipe of diameter D, the entrance length necessary to achieve fully developed laminar flow is proportional to (N_{Re} is Reynolds number)

(A) $D N_{\mathrm{Re}}$
(B) $\dfrac{D}{N_{\mathrm{Re}}}$
(C) $D N_{\mathrm{Re}}^2$
(D) $\dfrac{D}{N_{\mathrm{Re}}^2}$

Q.13 For laminar flow conditions, the relationship between the pressure drop (ΔP_c) across an incompressible filter cake and the specific surface area (S_o) of the particles being filtered is given by **ONE** of the following

(A) ΔP_c is proportional to S_o
(B) ΔP_c is proportional to $1/S_o$
(C) ΔP_c is proportional to S_o^2
(D) ΔP_c is proportional to $1/S_o^2$

Q.14 The power required for size reduction in crushing is

(A) proportional to $\dfrac{1}{\textbf{Surface energy of the material}}$

(B) proportional to $\sqrt{\dfrac{1}{\textbf{Surface energy of the material}}}$

(C) proportional to **Surface energy of the material**

(D) independent of the **Surface energy of the material**

Q.15 Transient three-dimensional heat conduction is governed by **ONE** of the following differential equations (α - thermal diffusivity, k - thermal conductivity and ψ - volumetric rate of heat generation)

(A) $\dfrac{1}{\alpha}\dfrac{\partial T}{\partial t}=\nabla T+\psi k$
(B) $\dfrac{1}{\alpha}\dfrac{\partial T}{\partial t}=\nabla T+\dfrac{\psi}{k}$
(C) $\dfrac{1}{\alpha}\dfrac{\partial T}{\partial t}=\nabla^2 T+\psi k$
(D) $\dfrac{1}{\alpha}\dfrac{\partial T}{\partial t}=\nabla^2 T+\dfrac{\psi}{k}$

Q.16 In a countercurrent gas absorber, both the operating and equilibrium relations are linear. The inlet liquid composition and the exit gas composition are maintained constant. In order to increase the absorption factor

(A) the liquid flow rate should decrease
(B) the gas flow rate should increase
(C) the slope of the equilibrium line should increase
(D) the slope of the equilibrium line should decrease

Q.17 A species (A) reacts on a solid catalyst to produce R and S as follows:

$$1)\ A \rightarrow R \qquad r_R = k_1 C_A^2$$

$$2)\ A \rightarrow S \qquad r_S = k_2 C_A^2$$

Assume film resistance to mass transfer is negligible. The ratio of instantaneous fractional yield of R in the presence of pore diffusion to that in the absence of pore diffusion is

(A) 1 (B) >1 (C) <1 (D) Zero

Q.18 For the case of single lump-sum capital expenditure of Rs. 10 crores which generates a constant annual cash flow of Rs. 2 crores in each subsequent year, the payback period (in years), if the scrap value of the capital outlay is zero is

(A) 10 (B) 20 (C) 1 (D) 5

Q.19 The relation between capital rate of return ratio (CRR), net present value (NPV) and maximum cumulative expenditure (MCE) is

(A) $CRR = \dfrac{NPV}{MCE}$ (B) $CRR = \dfrac{MCE}{NPV}$

(C) $CRR = NPV \times MCE$ (D) $CRR = \dfrac{MCE}{(NPV + MCE)}$

Q.20 Which **ONE** of the following is **NOT** a major constituent of crude oil?

(A) Paraffins (B) Olefins (C) Naphthenes (D) Aromatics

Q. 21 to Q.75 carry two marks each

Q.21 Which **ONE** of the following transformations $\{u = f(y)\}$ reduces

$\dfrac{dy}{dx} + Ay^3 + By = 0$ to a linear differential equation? (A and B are positive constants)

(A) $u = y^{-3}$ (B) $u = y^{-2}$ (C) $u = y^{-1}$ (D) $u = y^2$

Q.22 The Laplace transform of the function $f(t) = t \sin t$ is

(A) $\dfrac{2s}{(s^2+1)^2}$ (B) $\dfrac{1}{s^2(s^2+1)}$

(C) $\dfrac{1}{s^2} + \dfrac{1}{(s^2+1)}$ (D) $\dfrac{1}{(s-1)^2+1}$

Q.23 The value of the surface integral $\oiint_S (x\hat{i} + y\hat{j}) \cdot \hat{n}\, dA$ evaluated over the surface of a cube having sides of length a is ($\hat{n}$ is unit normal vector)

(A) 0 (B) a^3 (C) $2a^3$ (D) $3a^3$

Q.24 The first four terms of the Taylor series expansion of $\cos x$ about the point $x = 0$ are

(A) $1 + x + \frac{x^2}{2!} + \frac{x^3}{3!}$

(B) $1 - x + \frac{x^2}{2!} - \frac{x^3}{3!}$

(C) $1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!}$

(D) $x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!}$

Q.25 If $A = \begin{bmatrix} 1 & 2 \\ 2 & 1 \end{bmatrix}$, then the eigenvalues of A^3 are

(A) 5, 4 (B) 3, -1 (C) 9, -1 (D) 27, -1

Q.26 An analytic function w(z) is defined as w=u+iv, where $i = \sqrt{-1}$ and $z = x + iy$. If the real part is given by $u = \frac{y}{x^2 + y^2}$, w(z) is

(A) $\frac{1}{z}$ (B) $\frac{1}{z^2}$ (C) $\frac{i}{z}$ (D) $\frac{1}{iz}$

Q.27 The normal distribution is given by

$$f(x) = \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right), \quad -\infty < x < \infty$$

The points of inflexion to the normal curve are

(A) $x = -\sigma, +\sigma$

(B) $x = \mu + \sigma, \mu - \sigma$

(C) $x = \mu + 2\sigma, \mu - 2\sigma$

(D) $x = \mu + 3\sigma, \mu - 3\sigma$

Q.28 Using Simpson's 1/3 rule and FOUR equally spaced intervals (n = 4), estimate the value of the integral $\int_0^{\frac{\pi}{4}} \frac{\sin x}{\cos^3 x}\, dx$

(A) 0.3887 (B) 0.4384 (C) 0.5016 (D) 0.5527

Q.29 The following differential equation is to be solved numerically by the Euler's explicit method.

$$\frac{dy}{dx} = x^2 y - 1.2\, y \text{ with } y(0) = 1$$

A step size of 0.1 is used. The solution for y at $x = 0.1$ is

(A) 0.880 (B) 0.905 (C) 1.000 (D) 1.100

Q.30 The Poisson distribution is given by $P(r) = \frac{m^r}{r!} \exp(-m)$. The first moment about the origin for this distribution is

(A) 0 (B) m (C) $1/m$ (D) m^2

Q.31 Air (79 mole % nitrogen and 21 mole % oxygen) is passed over a catalyst at high temperature. Oxygen completely reacts with nitrogen as shown below

$$0.5\, N_{2\,(g)} + 0.5\, O_{2\,(g)} \rightarrow NO_{(g)}$$

$$0.5\, N_{2\,(g)} + O_{2\,(g)} \rightarrow NO_{2\,(g)}$$

The molar ratio of NO to NO_2 in the product stream is 2:1. The fractional conversion of nitrogen is

(A) 0.13 (B) 0.20 (C) 0.27 (D) 0.40

Q.32 A 35 wt% Na_2SO_4 solution in water, initially at 50°C, is fed to a crystallizer at 20°C. The product stream contains hydrated crystals $Na_2SO_4 \cdot 10H_2O$ in equilibrium with a 20 wt% Na_2SO_4 solution. The molecular weights of Na_2SO_4 and $Na_2SO_4 \cdot 10H_2O$ are 142 and 322, respectively. The feed rate of the 35% solution required to produce 500 kg/hr of hydrated crystals is

(A) 403 kg/hr (B) 603 kg/hr (C) 803 kg/hr (D) 1103 kg/hr

Q.33 600 kg/hr of saturated steam at 1 bar (enthalpy 2675.4 kJ/kg) is mixed adiabatically with superheated steam at 450°C and 1 bar (enthalpy 3382.4 kJ/kg). The product is superheated steam at 350°C and 1 bar (enthalpy 3175.6 kJ/kg). The flow rate of the product is

(A) 711 kg/hr (B) 1111 kg/hr (C) 1451 kg/hr (D) 2051 kg/hr

Q.34 Carbon black is produced by decomposition of methane:

$$CH_{4\,(g)} \rightarrow C_{(s)} + 2H_{2\,(g)}$$

The single pass conversion of methane is 60%. If fresh feed is pure methane and 25% of the methane exiting the reactor is recycled, then the molar ratio of fresh feed stream to recycle stream is

(A) 0.9 (B) 9 (C) 10 (D) 90

Q.35 The molar volume (v) of a binary mixture, of species 1 and 2 having mole fractions x_1 and x_2 respectively is given by

$$v = 220\, x_1 + 180\, x_2 + x_1 x_2 (90\, x_1 + 50\, x_2)$$

The partial molar volume of species 2 at $x_2 = 0.3$ is

(A) 183.06 (B) 212.34 (C) 229.54 (D) 256.26

Q.36 The standard Gibbs free energy change and enthalpy change at 25°C for the liquid phase reaction

$$CH_3COOH_{(l)} + C_2H_5OH_{(l)} \rightarrow CH_3COOC_2H_{5\,(l)} + H_2O_{(l)},$$

are given as $\Delta G^\circ_{298} = -4650$ J/mol and $\Delta H^\circ_{298} = -3640$ J/mol. If the solution is ideal and enthalpy change is assumed to be constant, the equilibrium constant at 95°C is

(A) 0.65 (B) 4.94 (C) 6.54 (D) 8.65

Q.37 A cylindrical vessel with hemispherical ends is filled with water as shown in the figure. The head space is pressurized to a gauge pressure of 40 kN/m^2. The vertical force F (in kN) tending to lift the top dome and the absolute pressure P (in kN/m^2) at the bottom of the vessel are
($g = 9.8$ m/s^2, density of water = 1000 kg/m^3)

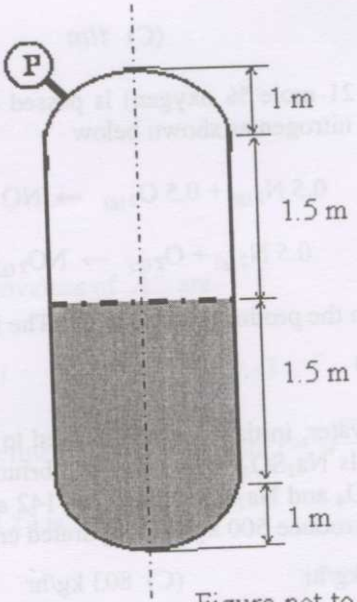


Figure not to scale

(A) F = 83.6 ; P = 64.5 (B) F = 83.6 ; P = 165.8
(C) F = 125.7 ; P = 64.5 (D) F = 125.7 ; P = 165.8

Q.38 A pump draws oil (specific gravity 0.8) from a storage tank and discharges it to an overhead tank. The mechanical energy delivered by the pump to the fluid is 50 J/kg. The velocities at the suction and the discharge points of the pump are 1 m/s and 7 m/s, respectively. Neglecting friction losses and assuming kinetic energy correction factor to be unity, the pressure developed by the pump (in kN/m^2) is

(A) 19.2 (B) 20.8 (C) 40 (D) 80

Q.39 Match the following

GROUP 1	GROUP 2
(P) Euler number	(1) Viscous force / Inertial force
(Q) Froude number	(2) Pressure force / Inertial force
(R) Weber number	(3) Inertial force / Gravitational force
	(4) Inertial force / Surface tension force

(A) P-1, Q-2, R-3 (B) P-2, Q-3, R-4 (C) P-3, Q-2, R-1 (D) P-4, Q-3, R-2

Q.40 A steady flow field of an incompressible fluid is given by $\vec{V}=(Ax+By)\hat{i}-Ay\hat{j}$, where $A = 1\ s^{-1}$, $B = 1\ s^{-1}$, and x, y are in meters. The magnitude of the acceleration (in m/s^2) of a fluid particle at (1, 2) is

(A) 1 (B) $\sqrt{2}$ (C) $\sqrt{5}$ (D) $\sqrt{10}$

Q.41 Two identically sized spherical particles A and B having densities ρ_A and ρ_B, respectively, are settling in a fluid of density ρ. Assuming free settling under turbulent flow conditions, the ratio of the terminal settling velocity of particle A to that of particle B is given by

(A) $\sqrt{\dfrac{(\rho_A-\rho)}{(\rho_B-\rho)}}$ (B) $\sqrt{\dfrac{(\rho_B-\rho)}{(\rho_A-\rho)}}$

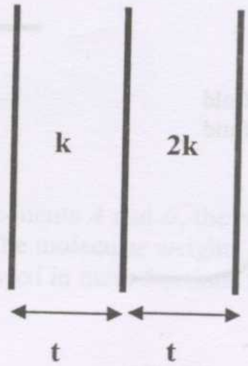
(C) $\dfrac{(\rho_A-\rho)}{(\rho_B-\rho)}$ (D) $\dfrac{(\rho_B-\rho)}{(\rho_A-\rho)}$

Q.42 Consider the scale-up of a cylindrical baffled vessel configured to have the standard geometry (i.e. Height = Diameter). In order to maintain an equal rate of mass transfer under turbulent conditions for a Newtonian fluid, the ratio of the agitator speeds should be
(Given N_1, D_1 are agitator speed and vessel diameter before scale-up; N_2, D_2 are agitator speed and vessel diameter after scale-up)

(A) $\dfrac{N_1}{N_2}=\dfrac{D_1}{D_2}$ (B) $\dfrac{N_1}{N_2}=\dfrac{D_2}{D_1}$

(C) $\dfrac{N_1}{N_2}=\left(\dfrac{D_1}{D_2}\right)^{\frac{2}{3}}$ (D) $\dfrac{N_1}{N_2}=\left(\dfrac{D_2}{D_1}\right)^{\frac{2}{3}}$

Q.43 Two plates of equal thickness (t) and cross-sectional area, are joined together to form a composite as shown in the figure. If the thermal conductivities of the plates are k and 2k then, the effective thermal conductivity of the composite is



(A) 3k/2 (B) 4k/3 (C) 3k/4 (D) 2k/3

Q.44 A metallic ball (ρ = 2700 kg/m^3 and C_p = 0.9 kJ/kg °C) of diameter 7.5 cm is allowed to cool in air at 25°C. When the temperature of the ball is 125°C, it is found to cool at the rate of 4°C per minute. If thermal gradients inside the ball are neglected, the heat transfer coefficient (in W/m^2 °C) is

(A) 2.034 (B) 20.34 (C) 81.36 (D) 203.4

Q.45 Hot liquid is flowing at a velocity of 2 m/s through a metallic pipe having an inner diameter of 3.5 cm and length 20 m. The temperature at the inlet of the pipe is 90°C. Following data is given for liquid at 90°C

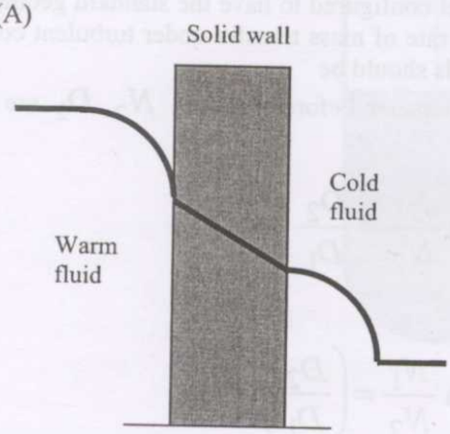
Density = 950 kg/m^3;
Specific heat = 4.23 kJ/kg °C;
Viscosity = 2.55 x 10^{-4} kg/m.s;
Thermal conductivity = 0.685 W/m °C

The heat transfer coefficient (in W/m^2 °C) inside the tube is

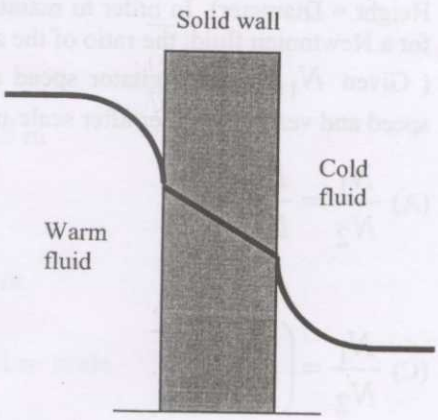
(A) 222.22 (B) 111.11 (C) 22.22 (D) 11.11

Q.46 The temperature profile for heat transfer from one fluid to another separated by a solid wall is

(A)



(B)



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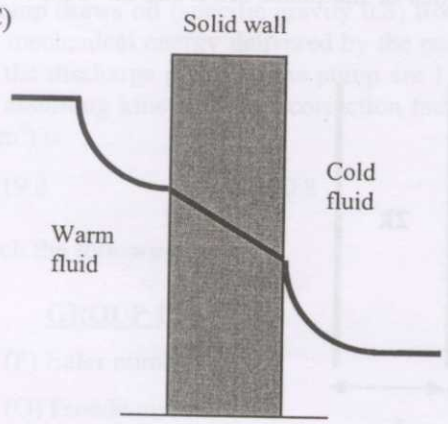

(D)