B.Tech IV sem. Leather Technology

Mid Semester Examination-2019

Subject: Chemical Engineering - I **Code: LT-071404**

Max .mark:20 **Time** :2Hours

Note: Attempt any **four** question. All question has equal marks. Assume any missing data

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Q1. Explain the Euler's equation. Derive Bernoulli's equation for incompressible fluid.

Q2. Draw the temperature length curve for co- current and counter current flow in double pipe heat exchanger. With necessary assumption derive the formula for LMTD.

Q3. Derive the heat flux equation of conduction through composite slab and cylinder..

Q4. What are Newotonian and non- Newtonian fluids. Show that shear stress verses velocity gradient profile for these fluids.

Q5. The diameter of a pipe at a section 1-1 and 2-2 are 200 mm and 300 mm respectively. If the velocity of water flowing through pipe at section 1-1 is 8m/s, then find-

(a) Discharge through the pipe

(b) Velocity of water section 2-2

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Model answer

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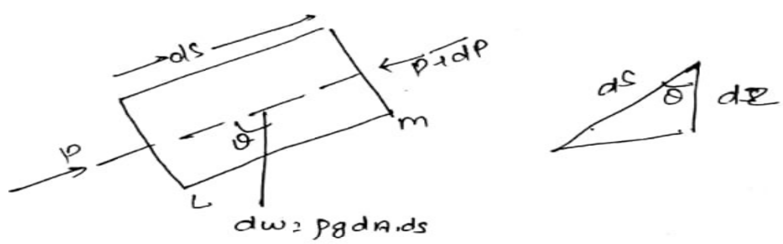
Ans.1

Euler's Equation for motion →

Consider steady flow of an ideal fluid along the stream tube. Seperate a small elements of fluid of cross-sectional area dA and lengths ds from stream tube as a free body from moving fluid.



P = Pressure on the element at L,

P+dP = Pressure on the element at M

v = velocity of the fluid element.

① Net pressure force in the direction of flow is_

$$P.dA - (P+dP)dA = \underline{-dP\,dA}$$

② component of the weight of the fluid element in the direction of flow is ______

$$= -\rho g\, dA\, ds \cos\theta$$
$$= -\rho g\, dA.ds \frac{dz}{ds} \qquad \cos\theta = \frac{dz}{ds}$$
$$= \underline{-\rho g\, dA.dz}$$

By Newton's second law

Sum of all forces acting in the direction of flow = mass x acceleration

$$a = \frac{dv}{dt} = \frac{dv}{ds} \times \frac{ds}{dt} = v\frac{dv}{ds}$$

$$-dP\,dA - \rho g\,dA\,dz = \rho\,dA\,ds \times v\frac{dv}{ds}$$

By dividing both side by $\rho\,dA$ we get –

$$-\frac{dP}{\rho} - g\,dz = v\,dv$$

$$\frac{dP}{\rho} + v\,dv + g\,dz = 0$$

this is required euler equation for motion and it is in form of differential equation.

$$\frac{1}{\rho}\int dP + \int v\,dv + \int g\,dz = \text{constant}$$

$$\frac{P}{\rho} + \frac{v^2}{2} + gz = \text{constant}$$

Dividing by g, we get.

$$\frac{P}{\rho g} + \frac{v^2}{2g} + z = \text{constant}$$

$$\boxed{\frac{P_1}{w} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{w} + \frac{v_1^2}{2g} + z_2}$$

Bernoulli's equation

Ans. 2

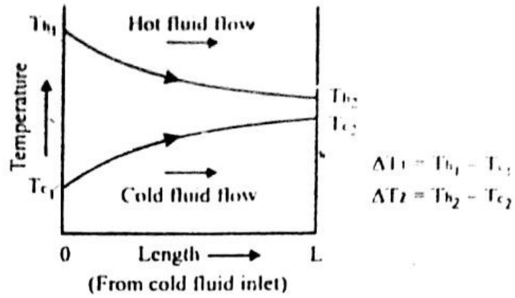


Fig. 3.2 (b) : Temperature - length curve for parallel flow

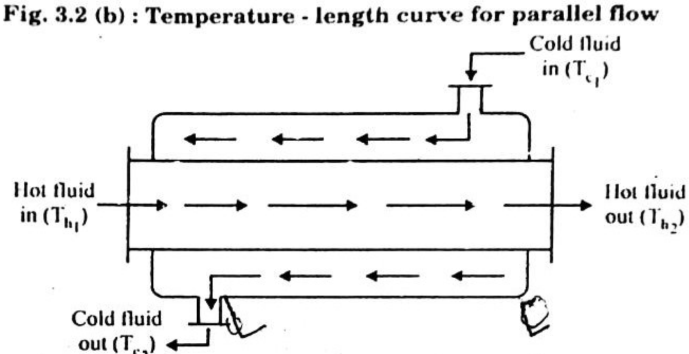


Fig. 3.3 (a) : Counter-current flow in heat exchanger

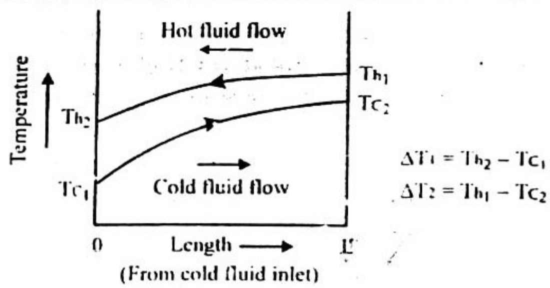


Fig. 3.3 (b) : Temperature - length curve for counter-current flow

Log mean temperature difference : OMD (LMTD)

The heat transfer flux is directly proportional to a driving force. The driving force for heat flow is taken as $T_h - T_c$, where T_h and T_c are the temperatures of hot and cold fluids respectively. As the $\Delta T = T_h - T_c$ varies along the length of heat exchanger, the flux also varies over the entire length. If we consider the differential element of area dA through which dQ amount of heat flows under the driving force of ΔT then :

$$\frac{dQ}{dA} = U \cdot (\Delta T) = U \cdot (T_h - T_c) \quad \ldots (3.31)$$

where U is the local overall heat transfer coefficient.

The equation (3.31) needs to be integrated for its application to entire area of heat transfer.

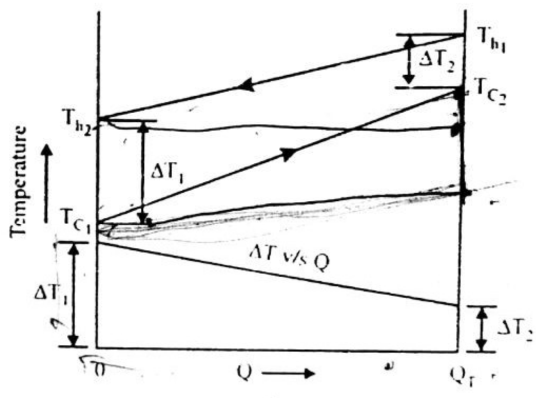


Fig. 3.7 : Temperature v/s heat flow rate (counter current flow)

Assumptions thus made are :

1. Overall coefficient U is constant.
2. Specific heats of hot and cold fluids are constant

3. Heat flow to and from ambient is negligible and

4. The flow is steady and may be parallel or counter current type.

Based upon assumptions (2) and (4), we get straight lines if T_c and T_h are plotted against Q and also the plot of ΔT v/s Q is a straight line. Such plots are shown in Fig. 3.11.

The slope of the graph of ΔT v/s Q is constant.

$$\text{Slope} = \frac{d\,(\Delta T)}{dQ} = \frac{\Delta T_2 - \Delta T_1}{Q_T} \quad \text{(3.32)}$$

where ΔT_1 and ΔT_2 are terminal temperature differences (i.e. approaches)

and Q_T - rate of heat transfer in entire heat exchanger.

Put the value of dQ from equation (3.31) into the equation (3.32)

$$\frac{d\,(\Delta T)}{U \cdot \Delta T\, dA} = \frac{\Delta T_2 - \Delta T_1}{Q_T} \quad \text{(3.33)}$$

Rearranging the equation (3.33)

$$\frac{d\,(\Delta T)}{\Delta T} = \frac{(\Delta T_2 - \Delta T_1)\, U}{Q_T} \cdot dA \quad \text{... (3.34)}$$

Integrating the above equation over the limits :

$A = 0,\ \Delta T = \Delta T_1$ and $A = A,\ \Delta T = \Delta T_2$

$$\int_{\Delta T_1}^{\Delta T_2} \frac{d\,(\Delta T)}{\Delta T} = \frac{(\Delta T_2 - \Delta T_1)\, U}{Q_T} \int_0^A dA \quad \text{... (3.35)}$$

$$\ln\left(\frac{\Delta T_2}{\Delta T_1}\right) = \frac{(\Delta T_2 - \Delta T_1)}{Q_T}\, U \cdot A \quad \text{(3.36)}$$

$$Q_T = U.A\, \frac{(\Delta T_2 - \Delta T_1)}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)} \quad \text{... (3.37)}$$

$\Delta T_1 = \Delta T_2$

$\boxed{\Delta T_{lm} = \frac{\Delta T_1 + \Delta T_2}{2}}$

The heat transfer rate in entive heat exchanger can be denoted by symbol Q

$$\therefore \qquad Q = U.A\, \frac{(\Delta T_2 - \Delta T_1)}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)} \quad \text{... (3.38)}$$

$$Q = U.A.\ \Delta T\text{lm} \quad \text{(3.39)}$$

where
$$\Delta T\text{lm} = \frac{(\Delta T_2 - \Delta T_1)}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)} \quad \text{... (3.40)}$$

ΔTlm is referred to as logarithmic mean or log mean temperature difference (LMTD).

In counter current flow, the hot end approach ΔT_2 may be less than cold end approach ΔT_1 so the subscripts may be interchanged for eliminating confusion due to negative (–) signs.

In 1.2 heat exchanger wherein-current and counter current flow occurs, when tube side fluid is flowing through the tubes, with respect to shell side fluid, the equation for this case may be written as :

$$Q = U.A.\ F_T\,(\Delta T\text{lm}) \quad \text{(3.41)}$$

Ans.3

Compound resistances in series / conduction through a composite plane wall :

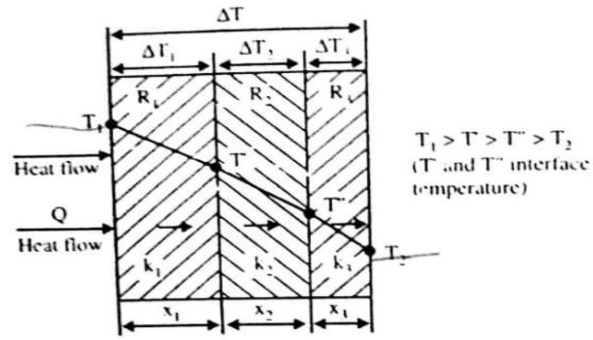


Fig. 2.2 : Conduction through resistances in series

When a wall is formed out of series of layers of different materials it is called as a **composite wall.**

Consider a flat wall constructed of a series of layers of three different materials as shown in Fig. 2.2. Let k_1, k_2 and k_3 be the thermal conductivities of the materials of which layers are made. Let thicknesses of the layers be x_1, x_2 and x_3 respectively.

Let ΔT_1 be the temperature drop across the first layer, ΔT_2 that across the second and ΔT_3 that across/over third layer. Let ΔT be the temperature drop across the entire composite wall.

Let T_1, T', T'' and T_2 be the temperatures at the faces as shown in Fig. 2.2.

T_1 is the temperature of hot face and T_2 is the temperature of cold face.

Assume further that the layers are in excellent thermal contact.

Furthermore, let the area of the compound wall, at right angles to the plane of illustration, be A.

Overall temperature drop is related to individual temperature drops over layers by equation

$$\boxed{\Delta T = \Delta T_1 + \Delta T_2 + \Delta T_3} \quad \ldots (2.13)$$

It is desired to derive an equation / formula giving the rate of heat flow through series of resistances.

Rate of heat flow through layer -1 i.e. through the material of thermal conductivity k_1 is given by

$$Q_1 = \frac{k_1 A}{x_1}(T_1 - T') \qquad \text{...(2.14)}$$

$$(T_1 - T') = \frac{Q_1}{(k_1 A/x_1)} \qquad \text{...(2.15)}$$

$$\Delta T_1 = T_1 - T' \qquad \text{...(2.16)}$$

$$\Delta T_1 = \frac{Q_1}{(k_1 A/x_1)} \qquad \text{...(2.17)}$$

$\Delta T_2 = \frac{Q}{k_B A/x_2}$

Similarly for layer-2

$$\Delta T_2 = (T' - T'') = \frac{Q_2}{(k_2 A/x_2)} \qquad \text{...(2.18)}$$

and for layer-3

$$\Delta T_3 = (T'' - T_2) = \frac{Q_3}{(k_3 A/x_2)} \qquad \text{...(2.19)}$$

Adding equations (2.17), (2.18) and (2.19), we get

$$\boxed{\Delta T_1 + \Delta T_2 + \Delta T_3 = \frac{Q_1}{(k_1 A/x_1)} + \frac{Q_2}{(k_2 A/x_2)} + \frac{Q_3}{(k_3 A/x_3)} = \Delta T} \qquad \text{...(2.20)}$$

Under steady state conditions of heat flow, all the heat passing through layer-1 (first resistance) must pass through layer-2 (second resistance) and in turn pass through layer-3 (third resistance), therefore Q_1, Q_2 and Q_3 must be equal and can be denoted by Q. Thus, using this fact, equation (2.20) becomes

$$\frac{Q}{(k_1 A/x_1)} + \frac{Q}{(k_2 A/x_2)} + \frac{Q}{(k_3 A/x_3)} = \Delta T \qquad \text{...(2.21)}$$

$$Q\left[\frac{1}{(k_1 A/x_1)} + \frac{1}{(k_2 A/x_2)} + \frac{1}{(k_3 A/x_3)}\right] = \Delta T \qquad \text{...(2.22)}$$

$$Q = \frac{\Delta T}{\left[\frac{1}{k_1 A/x_1} + \frac{1}{k_2 A/x_2} + \frac{1}{k_3 A/x_3}\right]} \qquad \text{...(2.23)}$$

$$\boxed{Q = \frac{\Delta T}{\left[\frac{x_1}{k_1 A} + \frac{x_2}{k_2 A} + \frac{x_3}{k_3 A}\right]}} \qquad \text{...(2.24)}$$

Let R_1, R_2 and R_3 be the thermal resistances offered by layer-1, 2 and 3 respectively R_1, R_2 and R_3 are given as

$$R_1 = x_1/k_1 A \qquad \text{...(2.25)}$$

$$R_2 = x_2/k_2 A \qquad \text{...(2.26)}$$

and

$$R_3 = x_3/k_3 A \qquad \text{...(2.27)}$$

Equation (2.24), becomes :

$$Q = \frac{\Delta T}{R_1 + R_2 + R_3} \qquad \text{...(2.28)}$$

If R is the overall resistance, then for resistances in series, we have :

$$R = R_1 + R_2 + R_3 \qquad \text{...(2.29)}$$

Heat flow through a cylinder :

Consider the thick walled hollow cylinder as shown in Fig. 2.3. The inside radius of cylinder is r_1 and the outside radius is r_2 and length of cylinder is L. Assume that thermal conductivity of the material of which cylinder is made be k.

Let the temperature of the inside surface be T_1 and that of the outside surface be T_2. Assume that $T_1 > T_2$, therefore the heat flows from the inside of cylinder to outside. It is desired to calculate the rate of heat flow for this case.

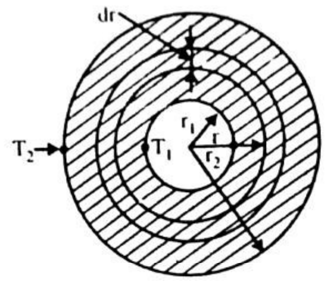


Fig. 2.3 : Heat flow through thick walled cylinder

Consider a very thin cylinder (cylindrical element), concentric with the main cylinder, of radius r, where r is between r_1 and r_2. The thickness of wall of this cylindrical element is dr.

The rate of heat flow at any radius r is given by

$$\boxed{Q = -k\,2\pi rL\left(\frac{dT}{dr}\right)} \qquad \ldots (2.32)$$

Equation (2.32) is similar to equation (2.4). Here area perpendicular to heat flow is $2\pi rL$ and dx of equation (2.4) is equal to dr.

Rearranging the equation (2.32), we get

$$\frac{dr}{r} = \frac{-k(2\pi L)}{Q}\, dT \qquad \dots (2.33)$$

only variables in equation (2.33) are r and T (assuming k to be constant).

Integrate the equation (2.33) between the limits

when $r = r_1$, $T = T_1$

when $r = r_2$, $T = T_2$

$$\int_{r_1}^{r_2} \frac{dr}{r} = \frac{-k(2\pi L)}{Q} \int_{T_1}^{T_2} dT \qquad \dots (2.34)$$

$$\ln r_2 - \ln r_1 = \frac{-k(2\pi L)(T_2 - T_1)}{Q} \qquad \dots (2.35)$$

$$\ln (r_2/r_1) = \frac{k(2\pi L)(T_1 - T_2)}{Q} \qquad \dots (2.36)$$

Rate of heat flow through thick walled cylinder :

$$\therefore \quad Q = \frac{k(2\pi L)(T_1 - T_2)}{\ln (r_2/r_1)} \qquad \dots (2.37)$$

Equation (2.3) can be used to calculate the flow of heat through a thick walled cylinder. It can be put into more convenient form by expressing the rate of heat flow as

$$Q = \frac{k(2\pi r_m L)(T_1 - T_2)}{(r_2 - r_1)} \qquad \dots (2.38)$$

where r_m is the logarithmic mean radius and is given by

$$r_m = \frac{(r_2 - r_1)}{\ln (r_2/r_1)} = \frac{(r_2 - r_1)}{2.303 \log (r_2/r_1)} \qquad \dots (2.39)$$

$$A_m = 2\pi r_m L \qquad \dots (2.40)$$

A_m is called as logarithmic mean area.

Equation (2.38) becomes

$$Q = \frac{k A_m (T_1 - T_2)}{(r_2 - r_1)} \qquad \dots (2.41)$$

$$Q = \frac{(T_1 - T_2)}{(r_2 - r_1)/k A_m} = \frac{\Delta T}{R}$$

where $\quad R = (r_2 - r_1)/kA_m$

R.H.S. of equation (2.39) is known as the logarithmic mean and in particular case of equation (2.39), r_m is known as the logarithmic mean radius. It is radius which when applied to the integrated equation for a flat wall, will give correct rate of heat flow through a thick-walled cylinder.

The logarithmic mean is less convenient than the arithmetic mean, and arithmetic mean is used without appreciable error in case of thin-walled cylinders.

Ans.4

Newton's law of viscosity -

This law states that the shear stress (τ) on a fluid element layer is directly proportional to the rate of shear strain. The constant of proportionality is called the co-efficient of viscosity.

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

The fluid which follow this law are known as Newtonian fluids

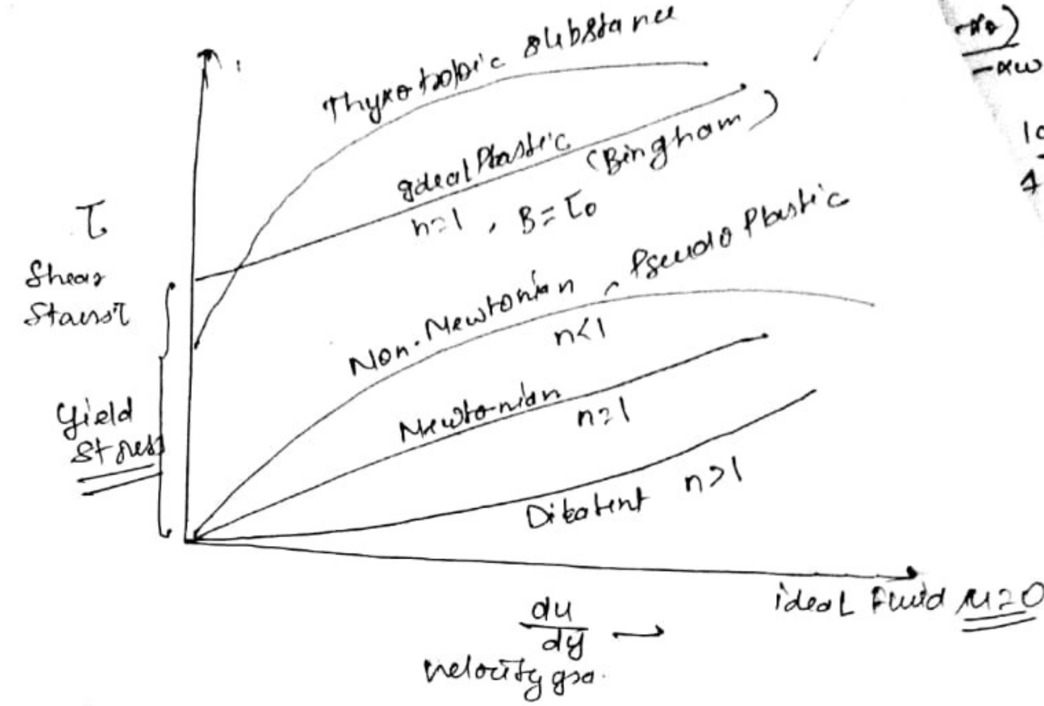
Types of fluids :-

(1) Newtonian fluids ⇒ these fluids follow Newton's viscosity equation. For such fluids μ does not change with rate of deformation.

Examples : water, kerosene, air etc.

(2) Non - Newtonian fluids : Fluids which do not follow the linear relationship b/t shear stress and rate of deformation are termed as

example - solutions or suspension (slurries), mud flows, polymer solution



Plastic fluid :-

In case of plastic substance which is non newtonian fluid , an initial yield stress is to be exceeded to cause a continous deformation. These substance is represented by a straight line. It has linear relation between shear stress and the rate of angular deformation.

Example :- sewage sludge, drilling muds etc.

Ideal Plastic (Bingham Plastic) :-

It has a definite yield stress and a constant linear relation between shear stress and the rate of angular deformation.

(3) Plastic Fluid -

Example. Sewage sludge.

Thyxotropic substances which is non-newtonian fluid, has a non-linear relationship b/t the shear stress and the of angular deformation, beyond an initial yield stress. Examp - Painter's ink

(4) Ideal Fluids which is incompressible and has zero viscosity. (or in other words shear stress is always zero regardless of the motion of the fluid).

$\boxed{\tau = 0}$

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(1) Ideal Fluid. $\tau = 0$

(2) Newtonian fluid $\tau = \mu \cdot \frac{du}{dy}$

(3) Ideal Plastic (Bingham) ; $\tau = \text{const} + \mu \cdot \frac{du}{dy}$

(4) Thyxotropic Fluid, $\tau = \text{const} + \mu \left(\frac{du}{dy}\right)^n$

(5) Non. New $\tau = \left(\frac{du}{dy}\right)^n$

$\tau = A\left(\frac{du}{dy}\right)^n + B$

$n > 1$, and $B = 0$ — Dilatant

$n < 1$, $B = 0$, Pseudo Plastic

$n = 1$, $B = \tau_0$ - Bingham Fluid or Ideal Plastic

Ans-5. $A_1V_1 = A_2V_2$

(b) $V_2 = \frac{A_1 \times V_1}{A_2} = \frac{0.0314 \times 8}{0.07065} = \underline{3.55 \text{ m/s}}$

(a) $Q = A_1V_1$

$= 0.0314 \times 8$

$= \underline{0.2512 \text{ m}^3/\text{s}}$