Practical Manual

Course Title

Heat & Mass Transfer

Course No. FE 124
B.Tech. - II Semester

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Certificate

This is to certify that Shri/ku.______________________________________

Reg. No.__________ has completed the practical read book of Course No. FE-124 (Heat and Mass Transfer) as per the syllabus for B. Tech. (Food Tech.) first year II semester as prescribed by MCAER, Pune and his attendance is _____________ percent.

Date: Course Teacher

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Heat Transfer Analysis During conduction

Heat :

Heat is a form of energy which is used to transfer energy from hot body to cold body due to temperature difference.

Heat transfer:

Heat transfer deals with the study of rate at which exchange of heat takes place between hot sources to cold receiver due to temperature gradient.

There are three modes of heat transfer

1) **Conduction**
2) **Convection**
3) **Radiation**

1. Conduction:

The transfer of heat from one part of the body to the other part of the same body or another body which is in physical contact with it or without displacement of the particles of the body is called as conduction.

Ex- Heat flow through brick wall of furnace and metal sheet of boiler and metal wall of exchanger tube.

2. Convection:

To transfer of heat from one point to another mainly in fluid (Liquid/gases) with bulk transfer (mixing of hot and cold portion) of a liquid is called as convection.

It is of two types:

(a) **Natural convection:** In a natural convection the motion of a fluid is a result of difference in the density of a warmer and cooler fluid element arising from the temperature gradient in a fluid mass.

(b) **Forced convection:** In a forced convection motion of a fluid is produced by mechanical means of agitator, fan or pumps.

Ex- Heating of room by steam radiators, heating of water in cooking pans

3. Radiation:

The transfer of heat energy from one body to another not in contact with it by electromagnetic waves through space is called as radiation.

Ex- Transfer of heat from sun to earth.

Fourier's law of conduction:

The rate of heat transfer is directly proportional to the over all temperature difference and area of heat transfer but it is inversely proportional to the length of path of heat flow

i.e.

$$dQ \, \alpha \, \frac{Adt}{dx}$$

$$dQ = -KA \frac{dt}{dx}$$

K-Thermal conductivity/ proportionality constant

$$\frac{dt}{dx} = \text{Tempt. gradient}$$

*** Thermal conductivity (k):**

The conductance of a quantity of a material in a thick solid with heat flow area $1m^2$, time unit 1 hr and tempt. diff. is 1^oC

unit of Q and K.

Q= Kcal/hr or watt (W)

$$K = \frac{Kcal}{m^oC\ hr} \text{ or } \frac{W}{m^ok} \text{ or } \frac{J}{s\ ^oK}$$

Numericals :

1) The interior of wall of furnace is maintained at a temperature of 900°C and wall is 60 cm thick, I m wide and 1.5 cm broad. The K value of raw material is 0.4Kcal/hr m°c. The temp of outer wall is 200°C. Determine the heat flow through the wall and also determine thermal resistance (Rt).

Solve :

2) Estimate the rate at which energy is conducted through 1m^2 of the wall of a oven insulated with 5 cm glass wool where inside temp is 200°C and outside temp is 30°C . The thermal conductivity of glass wool is 0.038 W/m°c.

Solve :

3) One face of stainless steel plate 1cm thick is maintained at 110°C while other face is 90°C. Assume steady state heat conduction. Calculate the rate of heat transfer per unit area through plate. K of Stainless steel is 17w/m°c.

Solve :

Numerical for Rate of Heat Transfer During conduction in different systems (Plane wall, Composite wall and Sphere)

Formula :

1. **Heat flow/ conduction through flat/ plane homogeneous wall**

$$Q = \frac{(t_1 - t_2)}{\frac{\Delta x}{KA}}$$

$$Q = \frac{(t_1 - t_2)}{Rt}$$

[$\Delta x/KA = Rt$ i.e. thermal resistance of wall

2. **Heat flow/ conduction through composite/ multilayer wall:**

$$Q = \frac{t_1 - t_4}{[\Delta x_1/ k_1A + \Delta x_2/ k_2A + \Delta x_3/ k_3A]} = \frac{(t_1 - t_4)}{(Rt_1 + Rt_2 + Rt_3)}$$

3. **Heat flow or conduction through cylinder:**

$$Q = \frac{K2\pi rl(t_1 - t_2)}{\ln (r_2/r_1)}$$

$$Q = \frac{K2\pi r_m l\ (t_1 - t_2)}{r_2 - r_1}$$

$$r_m = \frac{r_2 - r_1}{\ln(r_2/r_1)} \quad \text{or} \quad r_m = \frac{r_2 - r_1}{2.303 \log_{10} r_2/r_1}$$

$$Q = \frac{K\ Am\ (t_1 - t_2)}{(r_2 - r_1)}$$

4. Heat flow or conduction through sphere:

$$Q = \frac{4\pi(r_1 r_2)\, k\, (t_1 - t_2)}{(r_2 - r_1)}$$

$$Q = \frac{k 4\pi\, r_m^2\, (t_1 - t_2)}{(r_2 - r_1)}$$

Numerical :

1. Calculate the heat loss per m^2 of a surface area for furnace wall of 25 cm thick which as inside temp. is $1050^{\circ}C$ and outside temp. $50^{\circ}C$.

Calculate :

i) Rt and Rc

ii) Hourly heat loss through the wall per m^2 given that $K = (1.1 + 0.00116\, tm)$ $w/m^{\circ}c$)

Solve :

2. A cold room has one of the wall 5 x 2.5 m made up of bricks 12 cm thick insulated externally by cork stabbing 8 cm thick. Cork is protected externally by 2.5 cm wood Estimate the heat in filtration through wall in 24 hr in KJ if interior of cold room is maintained at temp. of $0^{\circ}c$ and the outside temp. is $20^{\circ}c$. Thermal conductivities for brick, cork and wood are 0.93, 0.044 and 0.175 $w/m^{\circ}c$ respectively. What will be the inter phase temperature?

Solve :

3. The furnace is constructed with 200mm fire brick, 100mm of insulating brick and 200 mm building brick. Inside temp. $650^{\circ}c$ and outside $165^{\circ}c$. Find the heat loss per unit area and also determine the temp at the junction of fire brick and insulating brick. $K_1 = 5.2$ $Kcal/hrm^{\circ}c$, $K_2 = 0.5$ $Kcal/hrm^{\circ}c$, $K_3 = 2.0$ $Kcal/hr\, m^{\circ}c$.

Solve :

EXPERIMENT NO. 2

4. A cold storage wall 3 x 6 cm is constructed of 15 cm concrete whose (K) thermal conductivity is1.37 w/m°c and insulation must be provided to maintain the heat transfer rate through the wall is 500 watt. if the K of insulation is 0.04 w/m°c. Compute the required thickness of insulation. The outside surface temp of the wall 38°c and the inside temp is 5°c.

Solve :

5. A cylindrical tube has inner diameter of 20mm, outer diameter of 30mm. Find out the rate of heat flow from tube of length 5m, if inner surface is at 100°c, outer surface is at 35°c. Take the thermal conductivity of tube material as 0.25 Kcal/hr m°c.

Solve :

6. A 2cm thick steel pipe having K value of 43 w/m°c with 6 cm inside diameter is being used to convey steam from a boiler to process equipment for a distance of 40 m. The inside pipe temp. is 115°c and outside temp is 90°c. Assume steady state condition and calculate the total heat loss.

Solve :

6. A 2cm thick steel pipe having K value of 43 w/m°c with 6 cm inside diameter is being used to convey steam from a boiler to process equipment for a distance of 40 m. The inside pipe temp. is 115°c and outside temp is 90°c. Assume steady state condition and calculate the total heat loss.

Solve :

Study of heat transfer through composite wall apparatus

Aim:

- o To determine total thermal resistance and thermal conductivity of composite wall
- o To Plot temperature gradient along composite wall structure.

Description

The apparatus consists of a heater sandwiched two asbestos sheets. Three slabs of different material are provided on both sides of heater, which forms a composite structure. A small press frame is provided to ensure the perfect contact between the slabs. A variac is provided for varying the input to the heater and measurement of input power is carried out by a Digital Watt meter. Temperatures sensors are embedded between inter faces of the slab, to read the temperature at the surface. The experiment can be conducted at various values of power input and calculations can be made accordingly.

Specifications

Slab size:

Cast Iron	:	150 mm diameter
	:	12.5 mm thick
Bakelite	:	150 mm diameter
	:	12.5 mm thick
Press Wood	:	150 mm diameter
	:	12.5 mm thick
Heater	:	Nichrome heater wounded on mica and insulated with mica and asbestos is provided.
Control Panel	:	The control panel consists of Digital voltmeter. Digital Ammeter. Digital temperature indicator with Multi channel switch, dimmer stat to control the heat input to the heater
Temp. sensors	:	Thermocouple type (6 Nos.)

Wooden cabinet is provided to accommodate the slab assembly

Whole assembly is fitted on a MS powder coated base plate to give the setup more strength and rigidness.

Procedure

1. Operate the hand press properly to insure perfect contact between the plates.
2. Close the box by cover sheet to achieve steady environment conditions.
3. Start the supply of heater by varying the dimmer stat. Adjust the power input at the desired value.
4. Tale readings of all the temperature sensors fairly steady temperature are achieved and rate of rise is negligible.
5. Note down readings in the observation table

Precautions

1. Use the stabilize AC single phase supply only.
2. Keep dimmer stat to zero before start and increase the voltage slowly.
3. Keep all the assembly undisturbed.
4. Remove air gap between plates by moving hand press gently
5. Operate selector switch of temperature indicator gently

There is a possibility of getting abrupt result if the supply voltage is fluctuating or if the satisfactory steady state condition is not reached.

Where

Rt = Total thermal resistance of the composite plate

$$\text{Or} \quad R_t = \frac{\Delta T}{q}$$

$$\text{Or} \quad R_t = \frac{T_1 - T_7}{q}$$

$$\text{Or} \quad R_t = \frac{\Delta X}{K_{eff}}$$

$$K_{eff} = \frac{\Delta X}{R_t} = \frac{\Sigma X_1}{R_t}$$

$$K_{eff} = \frac{X_1 + X_2 + X_3}{R_t}$$

Rate of heat supplied (Q)

For calculating the thermal conductivity of composite wall, it is assumed that due to large diameter of the plates heat flowing through central portion is unidirectional i.e. axial flow accordingly temperature sensors are fixed at close to center of the plates.

$$\text{Now } q = \text{Heat flux} = \frac{Q}{A} \quad \text{kCal/Hr. m}^2$$

$$\text{Where } A = \frac{\pi}{4} \times D^2$$

D= Plate diameter

1. Total thermal resistance of composite slab.

$$R_t = \frac{\Delta T}{q} = \frac{TA-TD}{q}$$

2. Thermal conductivity of composite slab

$$K\ \text{composite} = \frac{\Sigma X_i}{R_t}$$

$$= \frac{X_1 + X_2 + X_3}{R_t} = \frac{B}{R_t}$$

B= total thickness of composite slab

Slab Sizes:

1. Cast iron slab : diameter = 150mm = 0.15 m =D
2. Bakelite slab : diameter = 150mm = 0.15 m =D
3. Press Wood slab : diameter = 150mm = 0.15 m =D

Thermal conductivity of:

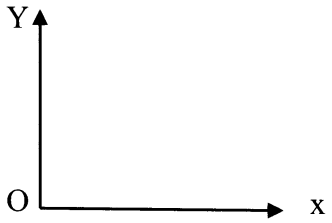
1. Cast Iron : $k_1 = 52 W/m\text{-}^oC$
2. Bakelite : $k_2 = 1.4 W/m\text{-}^oC$
3. Press Wood : $k_3 = 0.12 W/m\text{-}^oC$

Thickness of cast Iron slab $= x_1 = 12.5$ mm = 0.0125 M

Direction of heat flow-→

Thickness of Bakelite Slab $= x_2 = 12.5$ mm = 0.0125 M

Thickness of press Wooden slab $= x_3 = 12.5$ mm = 0.0125 M



$$Q = \frac{40}{2} = 20 \text{ W}$$

$T_1 = 126$, $T_2 = 123$, $T_3 = 82$, $T_4 = 80$, $T_5 = 60$, $T_6 = 59$

$$\Delta T = (T_1 - T_5) = (126-60) = 66$$

$X_1 = 12mm = 0.012m$: $K_1 = 52$ W/m^o-C (Cast iron)

$X_2 = 12mm = 0.012m$: $K_2 = 1.4$ W/m^o-C (Bakelite)

$X_3 = 12mm = 0.012m$: $K_3 = ?$ W/m^o-C (Press Wood)

$$A = \frac{\pi D^2}{4} = \frac{3.17 \times (0.15)^2}{4} = 0.0177 \text{ m}^2$$

$$\text{Heat flux } q = \frac{Q}{A} = \frac{1}{0.0177} = 1130 \text{ w/m}^2$$

Determination of Overall Heat Transfer Coefficient of a Composite Wall Apparatus

Aim:

To determine the overall heat transfer coefficient of a composite wall

Introduction:

Heat transfer through composite wall is the transport of energy between two or more bodies of different thermal conductivity arranged in series or parallel. For example a fastener joining two mediums also acts as one of the layer between these two mediums. Hence thermal conductivity of the fastener is also much necessary in determining the overall heat transfer through the medium.

Apparatus:

The apparatus consists of three slabs of different materials of different thickness clamped in the center using screw rod, at the center of the composite wall a heater is fitted. End losses from the composite wall are minimized by providing thick insulation all round to ensure unidirectional heat flow.

Temperature sensors are fitted at the interface of the plates at different points as to obtain average temperature for each surface. Heat conducted through the composite wall is taken away from atmospheric air.

Procedure:

i. Check for the symmetrical arrangement of plates and ensure the perfect contact between the plates.

ii. Switch ON mains and the console.

iii. The heat input to the heater is fixed for any desired temperature (assume $T_1 = T_i$) of the plates.

iv. After a steady state condition is reached, average temperature of the slabs at the interface is noted.

v. By varying the heat input to the system through a variac different set of readings can be obtained.

Calculations :

(a) Heat flow through composite wall

$$Q = V \times I \text{ (Watts)}$$

$$Q = \frac{K_1 A_1 (T_1' - T_2')}{L_1} = \frac{K_2 A_2 (T_2' - T_3')}{L_2} = \frac{K_3 A_3 (T_3' - T_4')}{L_3}$$

$$K_1 = \frac{QL_1}{A_1 (T_1' - T_2')}, \text{ where } A = \frac{\pi D^2}{4} \quad \text{where } D = 300 \text{ mm.}$$

$$K_2 = \frac{QL_2}{A_2 (T_2' - T_3')}$$

$$K_3 = \frac{QL_3}{A_3 (T_3' - T_4')}$$

Where $\mathbf{A_1 = A_2 = A_3 = A}$.

Note: $T_1'' = (T_1+T_2)/2$.

$T_2'' = (T_3+T_4)/2$.

$T_3'' = (T_5+T_6)/2$.

$T_4'' = (T_7+T_8)/2$.

(b) Overall heat transfer coefficient (U_0)

$$U_0 = \frac{1}{\frac{1}{A}\left(\frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3}\right)}$$

Specification :

1. Mild Steel 25 mm thick of 300 mm dia. 1 No. $K_1 = 25$ w/m ^{0}K
2. Hylam 19mm thick of 300 mm dia 1 No $K_2 = 0.05$ w/m ^{0}K
3. Wooden 12mm thick of 300 mm dia 1 No $K_3 = 0.08$ w /m ^{0}K
4. Mica Heater 300 watts of 300 mm dia 1No
5. Digital temperature indicator 12 channel 1No
6. Digital volt meter 1 No
7. Digital Ammeter 1No
8. Temperature Sensors PT 100 12 Nos

Composite wall:

<table>
<tr><th colspan="2">MILD STEEL</th><th colspan="2">HYLAM</th><th colspan="2">WOOD</th></tr>
<tr><td colspan="2">L_1 = 25 mm
K_1</td><td colspan="2">L_2 = 19 mm
K_2</td><td colspan="2">L_3 = 12 mm
K_3</td></tr>
<tr><td>T_1T_2</td><td>T_3T_4</td><td>T_3 T_4</td><td>T_5T_6</td><td>T_5T_6</td><td>T_7T_8</td></tr>
</table>

TABULER COLUMN:

Sl. No	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	V	I	Remarks

Result: The overall heat transfer coefficient of a composite wall is...........................

Heat Transfer Analysis by Convection

Aim : To Study about convection mode of heat transfer

Convection: Convection is the transfer of heat from one point to another point within a fluid by mixing of hot and cold portion of fluid due to temperature gradient

Newton's law of cooling/ Newton's Rikhman law

$$Q \alpha A (t_s - t_f)$$

$$Q = hA (t_s - t_f)$$

where h = film coefficient or surface heat transfer coefficient or inside film coefficient or individual film heat transfer coefficient.

Heat Transfer Coefficient:

Heat transfer coefficient is the measure of rate of heat transfer for unit temperature difference and unit surface of heat transfer.

or

It is the quantity of heat transferred in unit time through unit area of a temperature difference of degree between surrounding and surface.

Unit is $h = \frac{k\ cal}{hr m^{2\circ} c}$ or $\frac{W}{m^2\ {}^\circ k}$

There are two types of convection:

1] Natural or free convection

2] Forced convection

1] Natural convection:

When circulating current arises from heat transfer process itself is called natural convection ex. flow of air across a heated radiation

2] Forced convection:

When circulating current is produced from external agency such as agitator in a reaction vessel, pump, fan or blower is called forced convection.

ex.- Heat flow to a fluid pumped through a heated pipe.

3. Overall heat transfer coefficient

$$\frac{1}{u} = \frac{1}{hi} + \frac{1}{k/xw} + \frac{1}{ho}$$

Application of dimensional analysis of heat transfer coefficient:

$$\frac{QL}{A\Delta Tk} = \left(\left(\frac{VLe}{u}\right)^a \left(\frac{Cpu}{k}\right)^d \left(\frac{L^3 e^2 \Delta T Bg}{u^2}\right)^f \right)$$

where e = density

$$\frac{hL}{k} = \left(\left(\frac{VLe}{u}\right)^a \left(\frac{Cpu}{k}\right)^d \left(\frac{L^3 e^2 \Delta T Bg}{u^2}\right)^f \right)$$

➤ **Physical significance of the following number and their formulae.**

1) Reynolds Number (N_{Re}):

The ratio of inertia force and viscous force in liquid.

$$N_{Re} = \frac{\text{Inertia force}}{\text{Viscous force}}$$

$$N_{Re} = \frac{Dve}{u}$$

2) Nusselt Number (N_{nu}):

It is the dimension less form of convective heat transfer coefficient i.e. h

Significance of Nusselt No:

- Nusselt No. may be viewed as an enhancement in the rate of heat transfer by convection.
- Nnu = 1, there is not much improvement in the rate of heat transfer due to convection but, when Nnu = 5 then the convective rate of heat transfer is increased by five times.
- $$\text{Nnu} = \frac{\text{Temp. gradient at boundary}}{\text{Temp. gradient across fluid to the boundary}}$$

$$\text{Nnu} = \frac{h\,D}{k}$$

3) Prandit Number (Npr):

Npr describes the thickness of hydrodynamic boundary layer compared with thermal boundary layer

$$\text{Npr} = \frac{\text{Molecular diffusivity of momentum}}{\text{Molecular diffusivity of heat}}$$

$$= \frac{\text{Kinematic viscosity}}{\text{Thermal diffusivity}}$$

$$\text{Npr} = \frac{Cp\,u}{k}$$

If Npr= 1, then thickness of hydrodynamic boundary and thermal boundary layer is equal.

If Npr is less than 1, molecular diffusivity of heat is much larger than momentum, the heat will dissipate much faster.

1) Grashoff Number (N_{GR}):

It is the ratio of buoyancy force to viscous force. This no is also help to predict the type of flow whenever, the type of flow is laminar or turbulent.

$N_{GR} > 10^9$, for fluid flow over vertical plate represent the turbulent flow.

Relation between N_{nu}, N_{Re}, N_{PR} and N_{GR} is given

$Nnu = C [NRe]^{a} [NP_R]^{d} [NG_R]^{F}$

If there is natural convection,

$Nnu = [NP_R] [NG_R]$

In force convection,

$Nnu = [NRe] [NP_R]$

Forced Convection

A) Film Coefficient (h) in pipe:

Laminar Flow

$$Nnu = 1.86 [N_{RE} \times N_{GR} \times N_{PR} \times D/L]^{1/3} \left(\frac{ub}{uw} \right)^{0.14}$$

$$\frac{hd}{k} = 1.86 \left(\left(\frac{Dve}{u} \right) \left(\frac{Cpu}{k} \right) \frac{D}{L} \right)^{1/3} \left(\frac{ub}{uw} \right)^{0.14}$$

Turbulent Flow :

For Turbulent flow of Viscous fluid
For viscous liquid the imperial relationship

$$Nnu = 0.023 [N_{RE}]^{0.8} \times [N_{PR}]^{1/3} \times \left(\frac{ub}{uw} \right)^{0.14}$$

but, water like liquid

$$Nnu = 0.023 [N_{RE}]^{0.8} \times [N_{PR}]^{1/3}$$

This equation known as ' Dittus Bolter equation'

B) Film coefficient for the flow passed over a single sphere

$$Nnu = 2 + 0.60 [N_{RE}]^{0.5} \times [N_{PR}]^{1/3}$$

C) Film coefficient for plane or flat surface (material liquid)

$$Nnu = 0.036[N_{RE}]^{0.8} \times [N_{PR}]^{0.33}$$

when = $Re > 2 \times 10^4$

D) for air over flat surface:

$hc = 5.7 + 3.9\ V$ Where $v < 5m/s^2$

E) Film coefficient for outside the tube such as water chilling or chilling sausages (Channel) For liquid and gases

$Nnu = 0.26[N_{RE}]^{0.6} \times [N_{PR}]^{0.3}$ when $Re > 200$

$Nnu = 0.86[N_{RE}]^{0.43}\ [N_{PR}]^{0.3}$ when $[Re < 200]$

Natural convection:

Empirical relationship for convection heat transfer coefficient is

$Nnu = hD/k = a\,[NR_a]^m$ [where a & m – constant]

NRa→ Rayleigh's no.

Rayleigh's no. is a product of 2 dimensionless no. i.e. $NRa = N_{Gr} \times N_{Pr}$

Sr. No.	Geometry	Characteristic length (l)	Range of N_{Re}	a	m	eq^n (Nnu)
1	Vertical Plate	L	10^4-10^9 10^9-10^{13}	0.59 0.1	0.25 0.333	$Nnu = a\,(N_{Ra})^m$ $Nnu = a\,(N_{Ra})^m$
2	Inclined Plate	L	10^4-10^9 10^9-10^{13}	0.59 0.1	0.25 0.333	$Nnu = a\,(N_{Ra})^m$ $Nnu = a\,(N_{Ra})^m$
3	Horizontal plate Surface area. A, Perimeter P. where upper surface hot plate and lower cold plate	A/P	10^4-10^7 10^7-10^{11}	0.54 0.15	0.25 0.333	$Nnu = a\,(N_{Ra})^m$ $Nnu = a\,(N_{Ra})^m$

4	Horizontal Plate where upper surface cold and lower surface hot	A/P	10^5-10^{11}	0.27	0.25	$Nnu = a (N_{Ra})^m$
5	Vertical cylinder	-	-	-	-	$D \geq \frac{35L}{(N_{GR})^{0.25}}$
6	Horizontal Cylinder	D	10^5-10^{12}	-	-	$Nnu = \left\{0.6 + \frac{0.387 (N_{Ra})^{1/6}}{[1+(0.559/Npr)^{9/16}]^{8/27}}\right\}^2$
7	Sphere	$1/2\ \pi D$	-	-	-	$Nnu = \left\{2 + \frac{0.589 (N_{Ra})^{1/4}}{[1+(0.469/Npr)^{9/16}]^{4/9}}\right\}$ When $NRa \leq 10^{11}$, $Npr \geq 0.7$

Numerical for Rate of Heat Transfer and Heat Transfer Coefficient in Convection

Q.1 Water is flowing at a rate of 0.02kg/sec. which is heated from 20°c to 60°C in a horizontal pipe (inside diameter is 2.5m) inside pipe surface tempt 90°C. Estimate the convective heat transfer coefficient of pipe if the pipe is 1m long.

Solve:

Q.2 Water is flowing at a rate of 0.2 kg/sec which is heated form 20°C to 60°C in horizontal pipe (inside D=2.5m) inside pipe temperature is 90°c. Estimate the convective heat transfer coefficient. if the pipe is 1m long

Solve:

Q.3 Calculate heat transfer coefficient when air at 90°c is passed through a deep bed of green peas. Assume surface tempt. of peas is to be 30°c. The diameter of each pea is (0.5 cm) the velocity of air through the bed is 0.3m/sec.

Solve:

Q.4 Water is flowing at a rate of 0.3m/s across a 7.5 cm sausage at 74°c, if the bulk water tempt is 24°c Estimate the heat transfer coefficient.

Solve:

Q.5 Calculate the surface transfer coefficient to a vegetable puree which is flowing in an estimated velocity of 3m/min over a flat plate of 0.9m long and 0.6m wide if steam is condensing on the other side of the plate and maintaining the surface which is in contact with puree at 104°c

Solve:

Q.6 Estimate the convective heat transfer coefficient for convective heat loss from a horizontal 10 cm diameter steam pipe. (horizontal cylinder type). The surface temp. of insulated pipe is 130°c and the air temp. is 30 °c
(where $N_{Pr} = 0.71$ and $N_{Gr} = 6.109 \times 10^6$)

Solve:

Determination of Heat Transfer Coefficient in a NaturalConvention Flow through a Pipe by Natural Convection apparatus

1.0 Theory :

Heat transfer by convection occurs as a result of the movement of fluid on a macroscopic scale in the form of eddies or circulating currents. If the currents arise from the heat transfer process itself, natural convection occurs. An example of a natural convection process is the heating of a vessel containing liquid by means of a heat source such as a gas flame situated underneath. The liquid at the bottom of vessel becomes heated and expands and arise because its density has become less than that of the remaining liquid. Cold liquid of higher density takes its place and a circulating current is thus sets up. For conditions in which only natural convection occurs the velocity is dependent solely on the buoyancy effects, represented by the GrashoffNumber and the Reynolds group can be omitted.

For natural convection : Nu= f (Gr. Pr) (1)

Where

$$Gr = \frac{\beta g.\Delta t\, l^3\ e^2}{\mu} \qquad \text{where } e = \text{density} \qquad (2)$$

$$\text{And} \quad pr = \frac{Cp\ \mu}{k} \qquad (3)$$

Natural convection over a vertical flat plate is similar to natural convection over vertical tubes. If the tube is heated with an electrical heater the mode of heating is constant heat flux. i.e. the heat flux remain constant throughout the length and the surface temperature of the tube changes to maintain this constant heat flux. This is in constant to steam heating where the surface of heater attains a constant temperature and heat flux along the length of the tube changes. In the present, experiment set –up constant heat flux heating is selected.

The description of free flow along a vertical tube also applies to vertical walls, inclined and horizontal tubes, spheres and other oval shaped bodies. The shape of the body is of secondary importance in the development of free flow. Here is the length of the surface along which the heated air moves that is of great importance.

Local heat transfer coefficient for laminar flow

The local heat transfer coefficient for free laminar flow along a vertical tube can be computed using equation (4).

For constant heat flux heating and $10^3 < Gr_{fx} P_{rf} < 10^9$

$$Nu_x = 0.60\ (Gr_{fx}\ P_{rf})^{0.25}\ (P_{rf}/Pr_w)^{0.25} \qquad (4)$$

Here, the reference temperature is that of the fluid outside the moving layer (Pr_w is selected for the local temperature of the wall) The reference dimension is the co-ordinate along the flow, measured form the point where heat transfer originates.)

The mean heat transfer coefficient (for a length of tube equal to l) can be calculated by the equation. (5)

$$Nu_{fl} = 0.75\ (Gr_{fl}\ Pr_l)^{0.25}\ (Pr_f/Pr_w)^{0.25}$$

Local heat transfer coefficient for turbulent flow

Turbulent flow becomes fully developed at $Gr_f x\ Pr_f > 6 \times 10^{10}$

Following formula is suggested for local heat transfer coefficient with developed turbulent flow.

$$Nufx = 0.15(\ Gr_{fx}\ Pr_f\ )^{1/3}\ (Pr_f/\ Pr_w)^{0.25} \qquad (6)$$

The reference temperature and linear dimension are chosen here as in Eq. (4) The linear dimension is present in both Nusselt and the Grashoff numbers

$$Nufx = \frac{hx}{k} \quad \& \quad Gr_{fx}^{\ 1/3} = \left[\frac{\beta g.\Delta t\ l^3\ e2}{\mu^2}\right]^{1/3}$$

From this it follows that with developed turbulent flow the heat transfer coefficient is independent of the linear dimension. And the local heat transfer coefficient is consequently equal to the mean coefficient of heat transfer.

Heat transfer in natural convection from the outer surface of a vertical tube at transition flow

The experimental results obtained by various investigations indicate that a transition pattern of flow occurs around $10^9 < Gr_{fx}.\ Pr_f < 6 \times 10^{10}$.
The transition pattern of flow is marked by instability of both and heat transfer and consequently by considerable scattering of experimental points.

2.0 OBJECTIVES :

- To experimentally determine the heat transfer coefficient from the outer side of a vertical electrically heated tube in air during natural convection.
- To determine the heat transfer coefficient from the given empirical equation and compare it with the experimental value obtained.

3.0 APPRATUS :

Fig. 1: Draw a Schematic diagram of heating tube

Fig.1 shows the schematic diagram of heating tube. A G.I. tube of 42 mm outer diameter is electrically heated. The surface temperature of the tube is measured at 5 different points using thermocouples welded to its surface. The details of the thermocouple members and its positions are given in table 1. The energy input to the heater is controlled by a variac and is measured by ammeter. The tube is placed vertically.

4.0 SUGGESTED EXPERIMENTAL WORK :

Step 1 : Switch ON the power supply.

Step2 : Manipulate the variac so that the voltmeter reads 30 V.

Step3 : Allow sufficient time for steady state to occur.

Step4 : Note down the thermocouple readings along with voltmeter and ammeter readings.

Step5 : Manipulate the variac to change the voltmeter readings to 35, 40 & 45 V in steps and repeat the steps 3 to 4 each time you change voltmeter reading.

5.0 Results and Discussions:

1. Fill up the data sheet and draw schematic diagram of the experimental set-up
2. Compute the local heat transfer coefficient from the outer side of a vertical heated tube in air during natural convection

   hx = heat flux / (wall temp – ambient temp)
3. Determine the local heat transfer coefficient from the given empirical equation and compare it with the experimental value obtained.

6.0 SAMPLE DATA SHEET:

Name of Experiment : **Free/ natural convection**

Name of the student: Semester Batch Session

material of tube =

Diameter of tube, (m) =

Total length of heater, (m) =

Effective length of heated section of tube, (m) =

Ambient Temp of air, (°c) =

Temp of air, (°c) =

Run no	V	I	W	Temperature °c				
				1	2	3	4	5

7.0 APPENDIX -1: Critical data of experiment

Material of tube	=	G.I
Diameter of tube, m	=	0.042
Total length of heater, m	=	0.91
Effective length of heated section of tube, m	=	0.610
Ambient tempt of air, °c	=	

Table 1: Position of thermocouples on the surface of tube

Thermocouple No	1	2	3	4	5
Distance from Base of tube, mm	10	20	40	80	140

8.0 APPENDIX -2 : Sample Experiment data

Material of tube	=	G.I
Diameter of tube, m	=	0.042
Total length of heater, m	=	0.91
Effective length of heated section of tube, m	=	0.610
Ambient tempt of air, °c	=	20.9

Run no	V	I	W (V x I)	Temperature °C				
				1	2	3	4	5
1	36.3	0.34	12.342	43.4	43.0	42.9	41.9	41.8

9.0 APPENDIX -3 Data Analysis

Heat input = V x I
= 36.3 x 0.34
= 12.342 W

Heat input in the heated section of tube

$$= 12.342 \; \frac{0.610}{0.910}$$

= 8.2732 W

$$\text{Heat Flux} = \frac{\text{Heat input}}{\text{Area of heating tube}}$$

$$\text{Heat flux} = \frac{\text{Heat input}}{\pi d\, l}$$

$$\text{Heat Flux} = \frac{8.2732}{\pi \times 0.042 \times 0.610}$$

$$= 102.79 \text{ W/m}^2$$

Local heat transfer coefficients

$$h_x \text{ at 20mm from bottom} = \frac{102.79}{(43.0 - 20.9)} = 4.65 \; \frac{\text{W}}{\text{m}^2\ {}^{o}\text{K}}$$

Computation of local heat transfer coefficient using empirical equation

Average temperature

$$= \frac{43.0 + 20.9}{2}$$

$$= 31.95^{o}\text{c}$$

The thermal conductivity of air at an average surface temperature of 31.95 °c is 0.0274 W/m°K For a wide range of temperature

$$\frac{\beta g e^2 C_p}{\mu k} = \frac{36.0}{k^4}$$

$$\frac{\beta g e^2 C_p}{\mu k} = \frac{36.0}{(0.0274)^4}$$

$$= 6.387 \times 10^7$$

Gr. Pr at 20mm from bottom

$$Gr.\,Pr = 6.387 \times 10^7 (\Delta t.)\, l^3$$
$$= 6.387 \times 10^7 \times 22.1\,(0.020)^3$$
$$= 11.292 \times 10^3$$

Applying Eq. (4) for computation of local heat transfer coefficient

$$Nux = 0.60\,(Gr^{fx}\,Pr_f)^{0.25}\,(Pr_f/\,Pr_w)^{0.25}$$

$$= 0.60\,(11.292 \times 10^3)^{0.25} \left[\frac{0.701}{0.697}\right]^{0.25} = 6.2$$

Pr_f at 20.9°C = 0.701
Pr_w at 45.2°C = 0.697

$$Nu_x = \frac{hl}{k}$$

$$6.2 = \frac{h\,0.020}{0.0274}$$

$$h_{theo} = 8.5\,\frac{W}{m^2\,{}^oK}$$

Determination of Heat Transfer Coefficient in a Forced Convention Flow through a Pipe

Aim:

To determine the surface heat transfer co-efficient (h)for a horizontal tube loosing heat by forced convection.

Introduction:

Convection is a process of energy transport by the combined action of heat conduction, energy storage and mixing motion. When the mixing motion is induced by some external agency such as pump or a blower the process is called forced convection. The intensity of the mixing motion is generally high in forced convection and consequently the heat transfer coefficients are higher than free convection. By using the dimensional analysis, the experimental results obtained in forced convection heat transfer can be correlated by equation of the form

Rate of heat transfer through convection is given by:

$$Q = hA(T_s - T_{av})$$

Where (h) is the average convective heat transfer coefficient,(A) is the area of heat transfer, T_s is the heated surface temperature and T_{av} is the average fluid temperature.

Description:

The apparatus consists of a blower unit fitted with the test pipe. Nichrome band heater surrounds the test section. Four thermo couples are embedded on the test section and two thermo couples are placed in the air stream at the entrance and exit of the test section to measure the air inlet and outlet temperatures. Test pipe is connected to the delivery side of the blower along with the orifice to measure flow of air through the pipe. Input to heater is given through Dimmer stat and measured by voltmeter and ammeter. Airflow is measured with the help of orifice meter and the manometer fitted on the board.

Procedure:

(1) Put on the supply and adjust the variac to obtain the required heat input.

(2) Switch on the blower unit and adjust the flow of air using gate valve of blower to a desired difference in manometer (4 or 5 cm alternately)

(3) Wait till the steady state is reached.

(4) Take the readings of thermocouples T_1 - T_6.

(5) Note down a) Voltmeter reading V volts.

b) Ammeter reading A amps.

(6) Repeat the same procedure for different heat inputs and also for different flow rates of air & tabulate the values.

Q = heat transfer rate = V x I= watts.

Dia of the tube D= 32 mm

Length of test section L= 610 mm

T_w = avg. Surface temperature.

$$T_w = \frac{(T_2 + T_3 + T_4 + T_5 + T_6)}{5}$$

$$T_a = \frac{(T_1 + T_7)}{2}$$

Volumetric flow rate

$$q_0 = C_d \; a \sqrt{2 g h_a} \quad m^3 / sec.$$

Where, Cd = Co-efficient of discharge of Orifice = 0.62,

a = Area of orifice of air intake = $(\pi d^2 / 4)$ = m^2

d = Diameter of Orifice = 14mm

g = acceleration due to gravity = 9.81 m / sec^2

h_a (in meters of air column) = h water = e water/ e air

ha= hw – ew/ ea

^{h} water = Head in meters of water column = L.H.S. – R.H.S. = (in m).

$^\rho$ water = 1000 Kg / m^3,

ρ_{air} =1.154 Kg / m^3

Velocity of flow through pipe = Vol. flow rate / area of pipe

$$= q/\pi D^2/4 \text{ m/sec}$$

Forced convection specification :

Pipe material : G.I

OD of pipe : 32 mm

ID of pipe : 27 mm

Length of Test section : 610 mm

Distance between two consecutive thermo couple (T1 to T4) : 100 m

Figure: Draw a schematic diagram of Heating tube

Result:

Sr. No.	(h) experimental	Volumetric flow rate	Velocity

Thermocouple Type: Type K (Nickel) & Type J (Iron-Constantan)

Introduction

A thermocouple transducer is formed by a junction of two dissimilar metals. The junction, when heated, will produce a small voltage and associated current flow. The voltage developed is directly proportional to the temperature of the junction.

Objectives

In this experiment we will, Calibrate a K-type & J-type thermocouple .We will measure the time constant of the thermocouple in air and in water.

Apparatus

We will need the following equipment:

Digital multi-meter with 200 mV range setting.

K type & J type thermocouple with metallic sheath.

Mercury-in-glass thermometer.

Kettle and two mugs.

Thermocouple Type: Type K (Nickel):

popular type since it has decent accuracy and a wide temperature range; some instability (drift) over time. If the thermocouple is connecting direct to a voltmeter as shown in figure 1.1, problems will occur. The measured voltage depends not only upon the unknown temperature but room temperature as well. This is undesirable because room temperature can fluctuate, causing apparent fluctuations in the measured temperature. The second problem is that the contacts between metal Cu and the voltmeter and metal C and the voltmeter will both set up small "contact" voltages which will be different from each other because metals Cu and Care different. The differences between these two voltages set up an additional voltage that gives rise to error in the measurement.

Thermocouple Type: Type J (Iron-Constantan):

Cheap because one wire is iron; high sensitivity but also high uncertainty (iron impurities cause inaccuracy) popular type since it has decent accuracy and a wide temperature range; some instability (drift) over time. If the thermocouple is connecting direct to a voltmeter as shown in figure 1.1, problems will occur. The measured voltage depends not only upon the unknown temperature but room temperature as well. This is undesirable because room temperature can fluctuate, causing apparent fluctuations in the measured temperature. The second problem is that the contacts between metal Cu and the voltmeter and metal C and the voltmeter will both set up small "contact" voltages which will be different from each other because metals Cu and Care different. The differences between these two voltages set up an additional voltage that gives rise to error in the measurement.

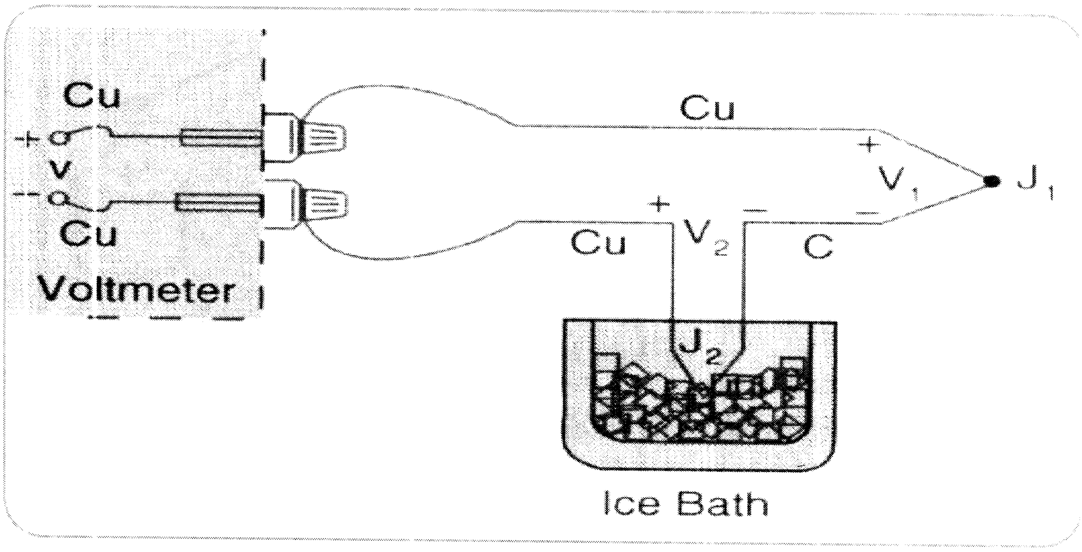
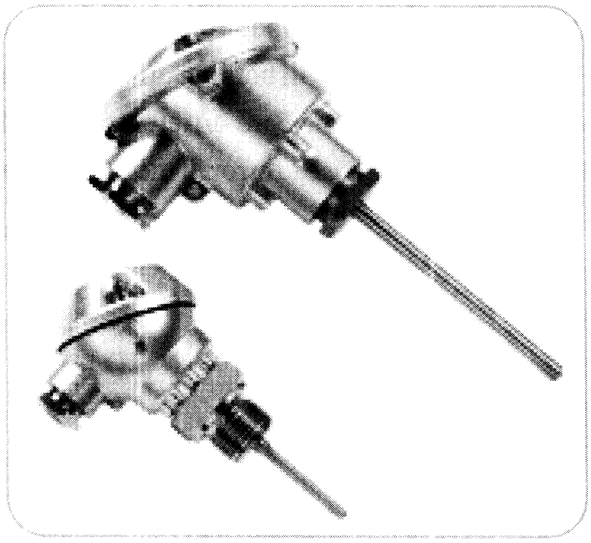


Figure : Thermocouple Equivalent circuit

Procedure : Calibrating the Thermocouple

1) Connect the thermocouple terminals to the digital multi meter.
2) Ensure you connect the positive terminal and negative terminal to the corresponding terminals on the multi meter.
3) Set the multi-meter to the 200 mV range.
4) Prepare a mug of cold water from the tap.
5) Boil the water in the kettle provided.
6) Place thermometer in the water.
7) Place the thermocouple in the water as well.
8) Take a reading of the thermometer and the multi meter voltage and record it in the table below. You need to take as many pairs of readings a possible, covering the temperature range from 80 °C to 20 °C Note: To speed up change in temperature, you can pour some of the cold water into the hot water mug. Wait for 5 seconds for the temperature to settle and take reading.

9) Repeat the last step a number of times until the temperature of the water are near room temperature or until the thermocouple voltage is zero.



Discussion: With this experiment and we can improve the accuracy of these thermocouples readings, the number of digital display point obtained are getting from the multi-meter.

Determination of Thermal conductivity of metal rod Apparatus

Introduction

A thermocouple transducer is formed by a junction of two dissimilar metals. The junction, when heated, will produce a small voltage and associated current flow. The voltage developed is directly proportional to the temperature of the junction.

Aim :

To determine the thermal conductivity of the given metal rod

Introduction :

Thermal conductivity is the physical property of the material. Based on the value of thermal conductivity of material. Thermal conductivity of a material depend on the chemical composition of the substance, the phase(solid, liquid or gas) in which it exists, its crystalline structure if a solid, the temperature and pressure to which it is subjected, and whether or not it is homogeneous material.

Description :

The experimental setup consists of a metal bar, one end of which is heated by an electrical heater while the other end projects inside a cooling water jacket. The middle portion is surrounded by a cylindrical shell filled with insulating powder and five. thermocouple are placed on the bar for temperature measurement. For radial measurement of temperature 4 thermocouples are placed at a sections/radius of 42.5 mm&55mm in the insulating shell. The heater is provided with a dimmerstat for controlling the heat input, water under a constant head is circulated through the jacket and its flow rate and temperature rise are measured using measuring jar and temperature sensors.

Procedure:

(1) Adjust the flow of water to 0.1-0.2 litres / min on Rotameter

(2) Put on the Power supply and adjust the variac to obtain the required Heat input

(3) Wait till the steady state is reached.

(4) Take the readings of thermocouples $T1 - T_{11}$

(5) Repeat experiment for different heat input and water flow rate

Calculations:

Heat carried away by water

$Q_W = m_W \, Cp_W \, \triangle T$

m_W = Mass of flow rate of water in kg/sec

Cp_W = Specific heat of water = 4.178 KJ / Kg

$^0K \; \triangle T = T_{wo} - T_{wi}$

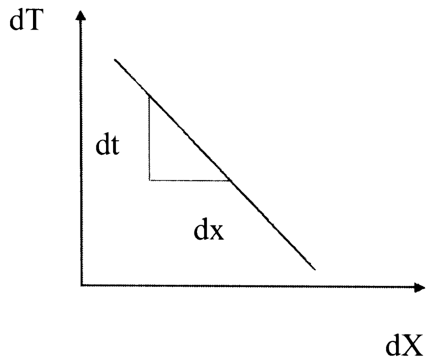
$$q = Q_w + \frac{[(2 \quad 1 \times k\,(T_5 - T_1))}{(\ln(r_o / r_i))]}$$

k = Thermal conductivity of insulating powder

q = Heat flux

Plot the graph of temp. V/s distance [*d*T V/s *dx*]

And find out the temp. Gradient [*d*T / *dx*]



$$Q = Q_w + Q_{\text{conduction}} = Q_w + \frac{2 \quad K.\, l(T_5 - T_1)}{r_o / r_i}$$

k = 0.12w/m k for insulating powder

Also,

$$Q = -KA \quad \frac{dT}{dx}$$

$$K = \quad \frac{-Q}{\frac{dTA.}{dx}}$$

where, A = c/s area of metal rod [$\Pi d^2/4$]

K = is the thermal conductivity of metal rod in (W/ m°k)

Specification:

Thermal conductivity of metal rod:

i. Metal rod: Copper
ii. Total length of the metal bar : 400 mm
iii. Effective length : 320 mm
iv. Diameter of the Metal rod : 35 mm
v. Insulation: Chalk powder
vi. Distance between two consecutive thermocouple : 60 mm(T_1 to T_5)
vii. Radial distance of the thermocouple in the insulating Shell:
viii. Inner radians r_i = 42.5 mm + (35/2)
ix. Outer radians r_o = 55 mm+ (35/2)

Tabular column:

Sl No.	Flow Rate of water		Water Temp.		Temp. of Metal Rod					Temp. in Insulating shall			
	CC/min	Kg/sec	T_{10}	T_{11}	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9

Results (standard):

The thermal conductivity of the given metal rod is

Metal	Thermal Conductivity W/m ^{0}k	State
Pure Copper	330 – 385	at 20^{0}C
Brass	95 – 107	at 20^{0}C
Steel	20 – 45	at 20^{0}C
Stainless Steel	55 – 65	at 20^{0}C

Determination of thermal conductivity of different food products

Introduction:

Thermal conductivity relates the conduction heat transfer rate to the temperature gradient. A food's thermal conductivity depends on factors such as composition, structure, and temperature. where

k = conductivity of mixture

kc = conductivity of continuous phase

kd = conductivity of dispersed phase

a = 3 kcl (2kc + kd)

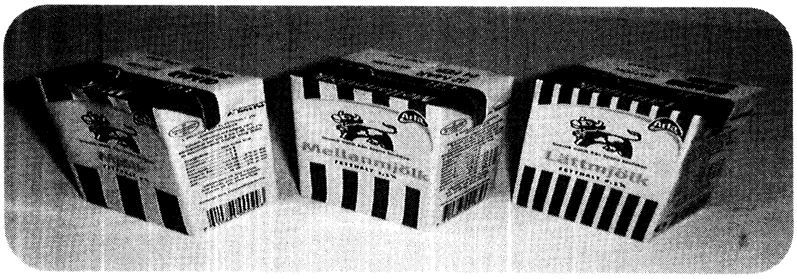
b = V,/(V, + V,)

Vd = volume of dispersed phase

V, = volume of continuous phase

In an effort to account for the different structural features of foods, Kopelman (1966) developed thermal conductivity models for homogeneous and fibrous foods. Differences in thermal conductivity parallel and perpendicular to the food fibers are accounted for in Kopelman's fibrous food thermal conductivity models. Kopelman (1966) developed the expression for thermal conductivity k: where kc is the thermal conductivity of the continuous phase and L3 is the volume fraction of the discontinuous phase. In Equation thermal conductivity of the continuous phase is assumed to be much larger than that of the discontinuous phase., Kopelman (1966) developed two expressions for thermal conductivity. For heat flow parallel to food fibers, thermal conductivity k= is where N2 is the volume fraction of the discontinuous phase. If the heat flow is perpendicular to the food fibers, then thermal conductivity k

In this Application note four different milk products with fat content (given by the manufacturer) <0.1 %, 0.5 %,1.5 % and 3 % were compared in order to investigate if the Hot Disk Thermal Constants Analyzer can be used to determine fat content in dairy products.



The results from the measurements were as follows:

Fat concentration Thermal Conductivity
(%) (Wm-1K-1)

<0.1 0.5634 +/- 0.0003
0.5 0.5563 +/- 0.0008
1.5 0.5485 +/- 0.0007
3 0.5369 +/- 0.0008

Fig. *. The thermal conductivity dependence on fat content in milk is perfectly linear. The deviating point for the skimmed milk sample (<0.1% fat) can possibly be due to even lower fat content.*

Two measurements were made on each milk sample and the probe was moved from one hole to another between the measurements. First the four samples were measured with only a few minutes between each measurement. Later a similar second series of measurements were made After about one hour. The three last concentrations indicate a perfectly linear dependence (Fig. 2.) of the thermal conductivity on the fat concentration. Comparing the change in thermal conductivity (with a Mean deviation of 0.0007 Wm-1K-1 as in these experiments) with the change in fat concentration indicates that it is possible to determine the fat concentration within about 0.09%.

Conclusive remarks

It has been shown that the thermal conductivity of low viscosity liquids can be measured with the Hot Disk thermal constants analyzer and also that the sensitivity of the instrument is sufficient when it comes to determining the fat content of milk. Other examples of applications for low viscosity liquid measurements are for instance water anti freezer mixtures, where the anti-freezer content can be measured.

Study on various types heat exchangers used in food Industry (Plate Heat Exchanger)

Aim:

Study of working principle and construction details of plate heat exchanger.

Introduction:

Heat exchangers are food processing equipment jacketed container vessel made up of material of construction such as Stainless-steel, Alloy –steel, Mild –steel with large capacity in volumes with tall heighted in length and wide in diameter with different shapes and sizes targeted to the efficient transfer of heat and mass operation/process from a hot fluid flow to a cold fluid flow, in most cases through an intermediate metallic wall. Heat exchangers are widely used in process control (by heating or cooling, respectively).

Types of Heat Exchanger :

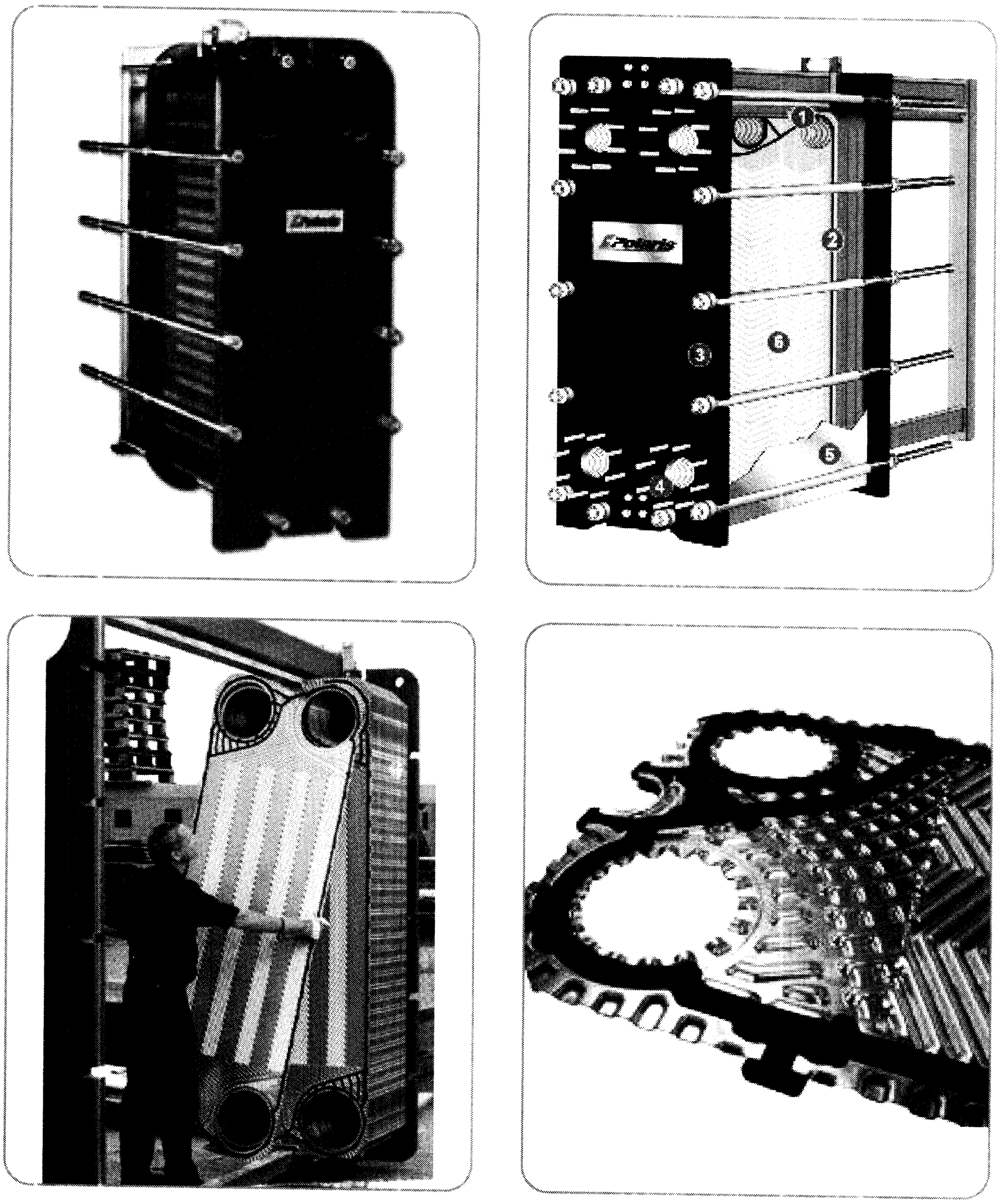
1) Double Pipe Heat Exchanger.
2) Shell & Tube Heat Exchanger.
   a) Fixed Tube Sheet Heat Exchanger.
   b) Floating Head Heat Exchanger.
      I] Internal Floating Head Heat Exchanger.
      II] Outside Packed /External Floating Head Heat Exchanger.
3) U-Tube Heat Exchanger.
4) Re-boiler /Kettle Type Heat Exchanger.
5) Plate & Frame Heat Exchanger.
6) Scrapped Surface Heat Exchanger.
7) Graphite Block Heat Exchanger.
8) Jacketed / Agitated Vessel Heat Exchanger.

Plate And Frame Heat Exchanger

Plate heat exchangers:-

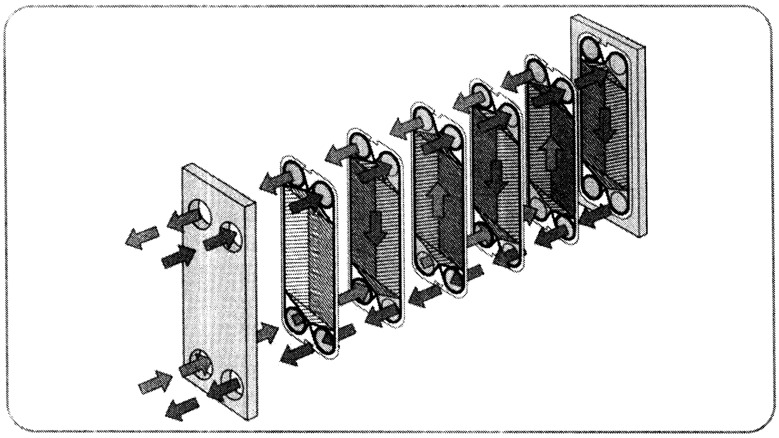
A plate heat exchanger, PHE, is a compact heat exchanger where thin corrugated plates (some 0.5 mm thick, bended 1 or 2 mm) are stacked in contact with each other, and the two fluids made to flow separately along adjacent channels in the corrugation (Fig. 1b). The closure of the staked plates may be by clamped gaskets, brazing (usually copper-brazed stainless steel), or welding (stainless steel, copper, titanium), the most common type being the first, for ease of inspection and cleaning. Additionally, a frame (end-plates and fixing rods) secures together the plate stack and connectors (sometimes PFHE, standing for plate-and-frame heat exchanger, is used instead of PHE). Temperature range (usually limited to 150 °C by the gasket material, although there are designs allowing 400 °C). Typically, plate and frame heat exchangers are used for liquid-liquid exchange at low to medium pressures.

Figure/Diagram



Equipment design-

Plate and frame heat exchangers are made of corrugated plates on a frame. This design creates high turbulence and high wall shear stress, both of which lead to a high heat transfer coefficient and a high fouling resistance. The figure below shows how the fluids travel within the heat exchanger. The two streams flow counter currently. The hot fluid flows down one plate while the cold fluid flows up the neighboring plate. Gaskets ensure that the cold fluid (blue) and the hot fluid (red) don't mix. The diagram below shows the flow in a heat exchanger. The design allows for the two media to flow in alternate directions and not be mixed.



Industrial Application:

Plate and Frame exchangers are especially useful for food and pharmaceutical processing, where high degrees of sanitation are required. Plate and frame heat exchangers are used in the food industry for tomato sauce processing, raw milk cooling, milk pasteurization, and beer brewing.

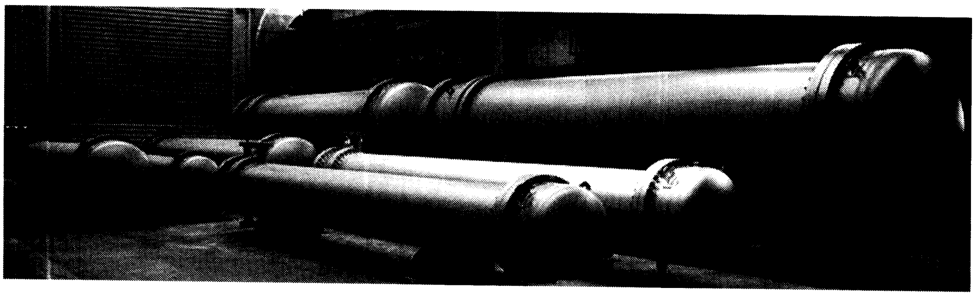
Study of shell and tube heat exchanger

Aim :

Study of working principle and construction details of plate heat exchanger.

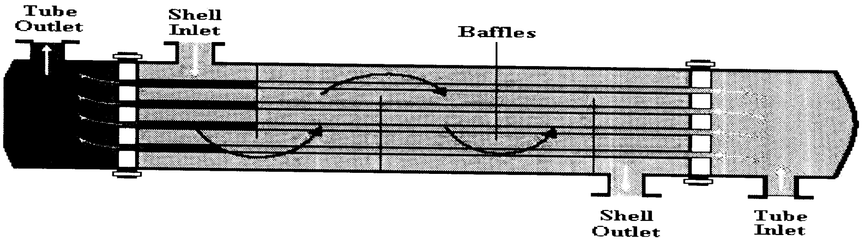
Shell And Tube Heat Exchangers

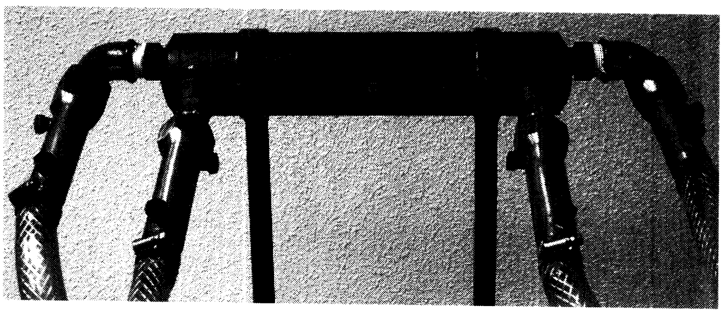
Shell and tube heat exchangers are the most widely used type of heat exchanger. The picture below shows shell and tube heat exchangers in a wide range of sizes.



Construction details:

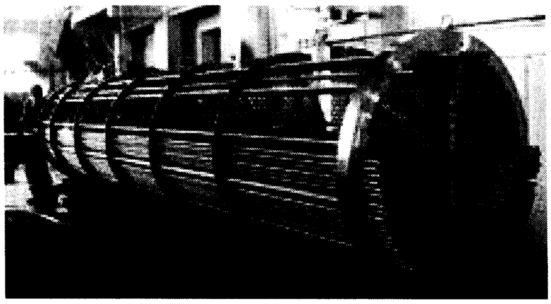
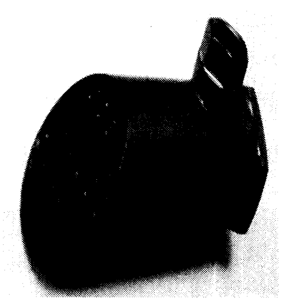
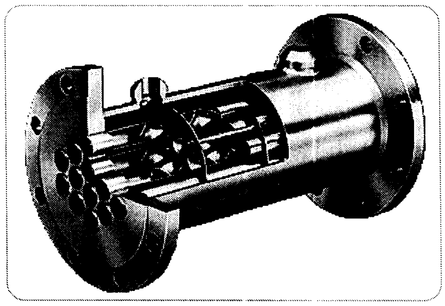
(legend: 1, Tube-fluid exit; 2, Gasket; 3, Shell-fluid entrance; 4, Tubes; 5, Shell; 6, Baffles; 7, Purge; 8, Expansion diaphragm; 9, Tube holding plate; 10, Gasket; 11, Tube-fluid entrance; 12, Head cover; 13, Shell-fluid exit; 14, Drain; 15, Fastener; 16, Tube holding plate; 17, Head cover); e) Construction details with two tube-passes and one shell-pass. As can be seen in Fig. each fluid can flow along several passes. In the tube-side, every set of tubes that the fluid travels through, before it makes a turn, is considered a pass.





General information:

The inside of the exchanger contains many tubes and baffles, as shown in the picture below. These tubes and baffles help direct the two streams flowing through the exchanger. Shown below is a miniature shell and tube heat exchanger. It is used in laboratory and pilot scale plants. These small scale heat exchangers can handle liquid flow rates up to 20 gpm at temperatures of 1000°F and pressures up to 1500 psig.

Determination of Overall Heat Transfer Coefficient of Plate Heat Exchanger (Parallel flow and counter flow)

Introduction

Plate type Heat Exchanger is devices in which heat is transferred from one fluid to another. The necessity for doing this arises in a multitude of industrial applications. Common examples of plate Type heat exchangers are the radiator of a car, the condenser at the back of a domestic refrigerator and steam boiler of a thermal power plant.

plate type Heat Exchangers are classified in three categories.

1. Transfer type
2. Storage Type
3. Direct Contact Type

A transfer type of heat exchanger is one on which both fluids pass simultaneously through the device and heat is transferred through separating walls. In practice most of the heat exchangers used are transfer type one.

i) PARALLEL FLOW in which fluids flow in the same direction

ii) COUNTER FLOW in which they flow in opposite direction and

A simple sample of transfer type of heat exchanger can be in the form of a tube type arrangement in which one of the fluids is flowing through the inner tube and the other through the annulus surroundings. The heat transfer takes place across the walls of the inner tube.

The apparatus consists of a tube type concentric tube heat exchanger. The hot fluid is hot water which is obtained an insulted water bath using a magnetic drive pump and it flow through the inner tube while the cold fluid is cold water flowing through the annuals.

The hot water flows always in one direction and the flow rate of which is controlled by means of a valve. The cold water can be admitted at one of the end enabling the heat exchanger to run as a parallel flow apparatus or a counter flow apparatus. This is done by valve operations.

Thermocouple type sensors measuring the temperature. For flow measurement Rota meters are provided at inlet of cold water and outlet of hot water line. The readings are recorded when steady state is reached.

Specifications :-

i) inner Tube Material : I.D. 15mm

ii) Box : 200 x 600 mm
iii) Temperature Controller : Digital 0-200°C
IV) Temperature Indicator : Digital 0-199.9°C and least count 0.1°C with multichannel switch
vi) Temperature Sensors : Thermocouple (5 Nos.)

Experimental procedure :-

1. Put water in bath and switch on the heaters.
2. Adjust the required temperature of hot water using DTC.
3. Adjust the valve. Allow hot water to recycle in bath through by-pass by switching on the magnetic pump.
4. Start the flow through annulus and run the exchanger either as parallel flow unit
5. Keeping the flow rates same, wait till the steady state conditions are reached.
6. Record the temperature on hot water and cold water side and also the flow rates accurately.
7. Repeat the experiment with a counter flow under identified flow conditions

i) Heat Transfer rate is calculated as

q_h = Heat transfer rate from hot water

= $m_h C_{ph} (T_{hi} - T_{ho})$ Kcal/hr

qc = Heat Transfer rate to the cold water.
$M_c C_{pc} (T_{co} - T_{ci})$ Kcal /hr.

$$q = \frac{(q_h + q_c)}{2} \text{ Kcal/hr}$$

Assume Cph =Cpc =1Kcal/kg°C

ii) LMTD-Logarithmic mean temperature difference which can be calculated as per the following formula:

$$\text{LMTD} = \Delta\text{ Tm} = \frac{\Delta T_1 - \Delta T_o}{\text{In}(\Delta T_1 - \Delta T_o)}$$

Where $\Delta T_1 = T_{hi} - T_{ci}$ (For parallel flow)
$T_{hi} - T_{co}$ (For counter flow)

$\Delta T_1 = T_{ho} - T_{co}$ (For parallel flow)
$T_{ho} - T_{ci}$ (For counter flow)

Note that in a special case of counter flow exchanger exists when the heat capacity rate C_c & C_h are equal. The T_{hi}- T_{co}= $T_{ho} - T_{ci}$ thereby making $T_i = T_o$. In this case LMTD is of the form 0/0 and so unidentified. But it is obvious that since T is constant throughout the exchanger.
Hence

$$\Delta T_m = \Delta T_i = \Delta T_o$$

(acc. To ref Fundamental of Engineering Heat & Mass Transfer by R.C. Sachdeva Pg. 499)

iii) Overall heat transfer coefficient can be calculated by using

$$Q = UA\,\Delta T_m$$

$$U = q/A\,\Delta T_m \text{ Kcal/hr. m}^2\text{- °c}$$

Calculated U_n based on $A_i = \pi d_i L$

U_{ro} based on $Ao = \pi d_o L$

$$U = \frac{U_n + U_{ro}}{2}$$

(iv) Compare the values of T_m and q in the parallel flow and counter flow runs. Note that if experiment is conducted very carefully then the superiority of counter flow arrangement in terms of higher value of T_m and value of q for same flow rates condition can be revealed.

Precautions :-

1. During the complete EXPERIMENTATION open the valves before starting it
2. For parallel flow open the valves V_4 & V_2 and close valve V_3& V_5.
3. For counter flow open the valves V_3 & V_5 and close vlave V_2 & V_4

Calculations :-

Parallel flow

Where

T_{hi} Temperature of Hot Water input		62°C	
T_{ho} Temperature of Hot Water output		48°C	
T_{cl} Temperature of Cold watr input		28°C	
T_{co} Temperature of Cold water output.		40°C	
Inner Tube Material	:	I.D.	15mm
Outer tube Material	:	I.D.	28mm
Length of the Heater Exchanger	:	L=	1.0m

Area of inner Tube $A_i = \pi d_i L = 3.14 \times 0.015 \times 1$ $= 0.0471 m^2$

Area of Box A_o $= 0.2 \times 0.6$ $= 0.12$

m_h Hot water Flow Rate 2.5 LPM = 2.5 x 1000/60 = 41.67

m_c Cold Water Flow Rate 3 LPM = x 1000/60 = 50

Assume $C_{ph} = C_{pc} = 1$ Kcal/kg °c

1. **Heat Transfer rate**

q_h = Heat transfer rate from hot water

= $m_h C_{ph} (T_{hi} - T_{ho})$ Kcal/hr.

= 41.67 x 1 x (62-48) = 583.38 Kcal/hr.

q_c = Heat Transfer rate to the cold water.

$M_c \; C_{pc} (T_{co} - T_{cl})$ Kcal/hr

= 50 x 1 x (40-28) = 600 Kcal/hr.

$$Q = \frac{(q_h + q_c)}{2} \text{ Kcal/hr.} = \frac{583.38 + 600}{2} = 591.70$$

Q = 591.70 Kcal/hr.

2. **LMTD -logarithmic mean temperature difference which can be calculated as per the following formula:**

$$LMTD = \Delta T_m = \frac{\Delta T_i - \Delta T_o}{\ln (\Delta T_i / \Delta T_o)}$$

Where $\Delta T_i = T_{hi} - T_{ci}$ (For parallel flow)

= 62 - 28 = 34

$\Delta T_o = T_{ho} - T_{co}$ (For parallel flow)

= 48-40 = 8

$\Delta T_m = \Delta T_i = \Delta T_o$

3. **Overall heat transfer coefficient can be calculated by using**

$Q = UA \, \Delta T_m$

$U = q/A \, \Delta T_m$ Kcal/hr. m²- °C

Calculated U_{ri} based on A_i = 0.0471

U_{ro} based on A_o = 0.12

$$U_{ri} = \frac{591.70}{0.0471} \times 34 = 427129$$

$$U_{ro} = \frac{600}{0.12} \times 8 = 61146$$

$$U = \frac{U_{ri} + U_{ro}}{2} =$$

$$U = \frac{427129+61146}{2}$$

U = 244138

For Counter Flow

Where	T_{hi}	Temperature of Hot Water input	- 62°C
	T_{ho}	Temperature of Hot Water output	- 44°C
	T_{cl}	Temperature of Cold water input	- 28°C
	T_{co}	Temperature of Cold water output.	- 37°C

Inner Tube Material	:	I.D.	15mm
Outer tube Material	:	I.D.	28mm
Length of the Heater Exchanger	:	L =	1.0m

Area of inner Tube $A_i = \pi d_i L = 3.14 \times 0.015 \times 1$ =0.0471

Area of Outer Tube $A_o = \pi d_i L = 3.14 \times 0.025 \times 1$ = 0.0.785

m_h Hot water Flow Rate 2.5 LPM =2.5 x 1000/60 =41.67

m_c Cold Water Flow Rate 3 LPM = x 1000/60 = 50

Assume $C_{ph} = C_{pc}$ = 1 Kcal/kg °C

1. **Heat Transfer rate**

q_h = Heat transfer rate from hot water

= $m_h C_{ph} (T_{hi} - T_{ho})$ Kcal/hr.

= 41.67 x 1 x (62-44) = 750 Kcal/hr.

q_c = Heat Transfer rate to the cold water.

$M_c \; C_{pc} \; (T_{co} - T_{ci})$ Kcal/hr

= 50 x 1 x (37-28) = 450 Kcal/hr.

$$Q = \frac{(q_h + q_c)}{2} \text{ Kcal/hr.} = \frac{750+450}{2} = 600$$

Q = 600 Kcal/hr.

2. **LMTD -Logarithmic mean temperature difference which can be calculated as per the following formula:**

$$\text{LMTD} = \Delta T_m = \frac{\Delta T_i - \Delta T_o}{\text{In} (\Delta T_i / \Delta T_o)}$$

Where $\Delta T_i = T_{hi} - T_{oo}$ (For Counter Flow)
= 62- 37 = 25

$\Delta T_o = T_{ho} - T_{ci}$ (For Counter flow)
= 44-28 = 16

Δ Tm $= \Delta T_1 = \Delta T_o$

3. **Overall heat transfer coefficient can be calculated by using**

$$Q = UA \, \Delta T_m$$

$$U = q/A \, \Delta T_m \text{ Kcal/hr. m}^2\text{- }^{o}\text{C}$$

Calculated U_{ri} based on A_i = 0.0471

U_{ro} based on A_o =0.078

$$U_{ri} = \frac{591.70}{0.0471} \text{ x } 34 = 427129$$

$$U_{ro} = \frac{600}{0.0785} \times 8 = 61146$$

$$U = \frac{U_{ri} + U_{ro}}{2} =$$

$$U = \frac{427129+61146}{2}$$

$$\mathbf{U = 244138}$$

Numerical on rate of heat transfer in Radiation

Radiation : Radiation is a transfer of heat / energy through space by electromagnetic radiations.

ex. 1. Transfer of heat from sun to earth
2. Heat loss from unlogged steam pipe
3. Baking oven
4. Radiant dryers.

Kirchoff's law : It states that at thermal equilibrium for all bodies the ratio of emissive power to absorptivity is same. This is known as kirchoff's law.

$$\frac{E^1}{a^1} = \frac{E^2}{a^2} = \frac{E^6}{a^6}$$

Emissive Power :

Emissive power means the energy emitted per unit area per unit time.
at thermal equilibrium

Emissivity (e)

Emissivity of any body is defined as the ratio of emissive power to the emissive power of perfectly black body at the same temperature.

i.e. $$e = \frac{E}{Eb}$$

Stephan Boltzman's Law:

It states that total energy emitted by a black body is directly proportional to the fourth power of its absolute temperature.

$$Eb \alpha T^4$$
$$Eb = 6 T^4$$

6→ Stephan's boltzmans constant. [4.88×10^{-8} Kcal / m^2 hr^0 K^4] or (5.73×10^{-8} J/$m^{20}k^4$)

Eb→ emissive Power of black body. for non- black body or real body,

$E = e6\ T^4$ (e-emissivity of real / non black body.

Numerical on Radiation

Q.1 Calculate heat transfer by radiation from unlagged steam pipe 50mm (outside diameter) at 380°k to air at 280°K. Assume emissivity 0.9. $6 = 4.88 \times 10^{-8}$

Solve:

Q.2 Calculate rate of energy emitted by 100 m^2 of a polished iron surface whose emissivity is 0.06 and temp of surface is 37°c. Take $6 = 5.669 . X\ 10^{-8}$

Solve:

Numerical on Rate of Mass Transfer

Mass Transfer: The process in which mass is transferred from one location to another or one phase to another by concentration gradient is called as mass transfer.

Diffusion:

The movement resulting from random molecular motion is called diffusion.

Movement of individual component through a mixture from a region of high concentration to that of law concentration at fixed temperature and pressure without the helop of and external force is called as diffusion

Molecular diffusion:

When the diffusion results from random motion of molecules is called as molecular diffusion

Eddy/ Turbulent diffusion:

Rapid Than molecular diffusion by application of external force

Fick's Law:

Diffusion flux or mass transfer rate is proportional to the concentration gradient per unit volume & inverse the proportional through the distance in the direction of diffusion.

$$\frac{ma}{A} = D\frac{dca}{dx} = D\frac{dc}{dx}$$

Where,

ma = diffusion rate of component per unit time.

A = Are 1 ar to the direction of diffusion (ft2)

d = Constant of diffusion

Ca = Conc. of masses per unit volume (lbm/ft)

x = Distance in the direction of diffusion (ft)

$$\text{Unit:} \frac{ft2}{hr.}$$

depends on temperature pressure & prop. of system.

(1) SHERWOOD NUMBER:- $N_{sh} = \frac{K_m d}{D_{AB}}$

(2) Schmidt Number : $N_{sc} = \frac{u}{e D_{AB}}$ where e = density

(3)Reynolds Number: $N_{Re} = \frac{DVS}{u}$

(4) Levis Number: $N_{Le} = \frac{K}{e c_p D_{AB}}$

If $N_{Re} < 5 \times 10^5$

$$N_{sh} = \frac{K_{mx} \cdot x}{D_{AB}} = 0.332\, N_{Re}^{1/2} \times N_{sc}^{1/3}$$

For laminar flow.

$$N_{sh} = \frac{K_m L}{D_{AB}} = 0.664\, N_{Re}^{1/2} \times N_{sc}^{1/3}$$

Turbulent flow passed over flat plate

$N_{Re} > 5 \times 10^5$

$$N_{sh} = \frac{K_m L}{D_{AB}} = 0.0296 \times N_{Re}^{4/5} \times N_{sc}^{1/3}$$

For laminar flow in pipe NRe < 10000

d= diameter of pipe

$$= \frac{Kmd}{D_{AB}} = 1.86\left(\frac{Nre \times Nsc}{L/D}\right)^{1/3}$$

L = length of pipe

Turbulent flow in a pipe

N_{Re}> 10,000

$$N_{sh} = \frac{Kmd}{D_{AB}} = 0.023 \times (NRe)^{0.8} \; (Nsc)^{1/3}$$

Mass transfer flow over a spherical object

$$N_{sh} = \frac{Km}{D_{AB}} = 2.0 + (0.4\, NRe\, ½ + 0.06\, NRe^{2/3})\, NSC\ 0.4$$

Mass transfer from freely falling liquid droplets.

$$N_{sh} = \frac{Km}{D_{AB}} = 2.0 + 0.6\, NRe\, ½\;\; NSC^{1/3}$$

Numerical : Determine the rate of water evaporated from a full tray of water. Air at a velocity of 2m/l is flowing over the tray. The temperature of water and air is 25°c . The width of tray is 45 cm and length of tray along the direction of air flow is 20 cm. The diffusivity of water vapour in air is D = $0.26 \times 10^{-4} m^2/s$

DATA: V=2m/s

width = 45 cm = 0.45m

length = 20 cm = 0.20m

Diffusivity = $D_{AB} = 0.26 \times 10^{-4} m^2/s$

Kinematic Viscosity = u= 16.14×15^6 m^2/s

Solve: