DRONACHARYA
GROUP OF INSTITUTIONS

LABORATORY MANUAL

HEAT & MASS TRANSFER LAB

SUBJECT CODE: KME-551

B.TECH. (ME) SEMESTER -V

Academic Session: 2023-24, Odd Semester

Dronacharya Group of Institutions
Plot No. 27, Knowledge Park-3, Greater Noida, Uttar Pradesh 201308
Affiliated to

Dr. A P J Abdul Kalam Technical University
Lucknow, Uttar Pradesh 226031

List of Experiments mapped with COs

S. No	Aim of the Experiment	COs
1.	To determine thermal conductivity of conductive material(s).	**CO1**
2.	To determine thermal conductivity of insulating material(s).	**CO2**
3.	To determine the heat transfer Rate and Temperature Distribution for a Pin Fin.	**CO1**
4.	Experiment on Stefan's Law - determination of emissivity, etc.	**CO3**
5.	To find the heat transfer coefficient for Free Convection in a tube.	**CO2**
6.	To compare LMTD and Effectiveness of Parallel and Counter Flow Heat Exchangers.	**CO4**
7.	To conduct experiments on heat pipe.	**CO5**

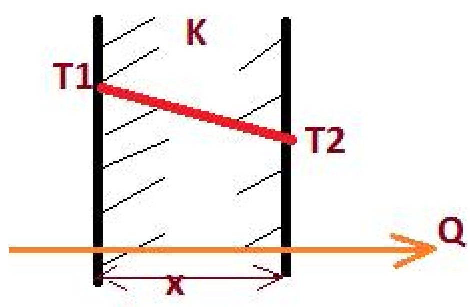
EXPERIMENT NO. 1

OBJECTIVE:

1. To determine thermal conductivity of conductive material(s).
2. For different heat input values measure the temperature drop for each different sections of a composite wall.

THEORY:

Heat transfer through a plane wall of thickness x as shown below can be modelled as :



The rate of heat flow Q over the area A and a small distance dx may be

written as: Q= - k A (dt/d x) (1)

Often known as Fourier Equation, where the –ve sign indicates that the temperature gradient is in the opposite direction to the flow of heat and k is the thermal conductivity of the material. Integrating for a wall of thickness x with boundary temperature T1 and T2 as shown above.

$Q= k A (T_1-T_2)/x$ (2)

The equation (2) can be rewritten

as $Q= A (T_1-T_2) / (x/k)$

Where, (x/k) is known as thermal resistance and k/x is the heat transfer coefficient.

Thermal resistance in Series:

It can be proved that thermal resistances can be added together for the case of heat transfer through a complete section from different media in series.

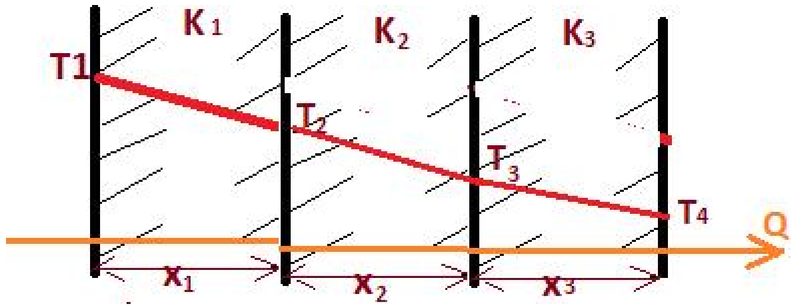


Figure shows a composite wall made up of three materials with thermal conductivity's k_1, k_2, k_3 with thickness as shown and with the temperature T_1, T_2, T_3 and T_4 at the faces.

Applying Eq. (2) to each section in turn and noting that the same quantity of heat Q must pass through each area A

$T_1 – T_2 = x_1 / (k_1\ A).Q$ --- (3)

$T_2 – T_3 = x_2 / (k_2\ A).Q$ --- (4)

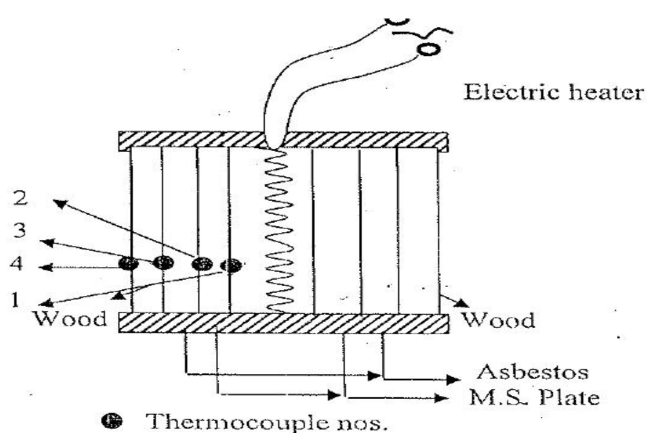
$T_3 – T_4 = x_3 / (k_3\ A).Q$ --- (5)

On addition of above three equations

$T_1 – T_4 = [x_1 / (k_1\ A) + x_2 / (k_2\ A) + x_3 / (k_3\ A)]. Q$

$Q = (T_1 – T_4)/\ \varepsilon\ [x_1 / (k_1\ A)]$ = Total driving force/Total (Thermal resistance/area)

APPARATUS:



The experimental set-up is shown schematically in above fig. It consists of an electrical heater (circular). On both sides of circular heater, there exist two M.S. plates. The M.S plates are accompanied by plates of asbestos and wood. The composite sections are pressed together with the help of clamps.

Thermocouples are placed at the central line of each junction faces to measure its temperature.

EXPERIMENTAL WORK:

1. Draw a neat sketch of the experimental set up giving important dimensions.
2. Switch ON the electric heater and set the voltmeter reading to 30v using the variac. Allow the steady state to achieve .Note down the ammeter reading along with the readings of all thermocouples.
3. Change the voltage to 35v, 40 v and 45v in steps and repeat step 2 each time the voltage is changed.

RESULTS:

1. Filled up the data sheet and drawn the temperature profile along the composite wall.
2. Estimated the temperature drop of each section of composite wall using the equation given. Compared it with experimental values obtained.

SAMPLE DATA SHEET:

Diameter of M.S plate, mm	= 200
Thickness of M.S plate, mm	= 8.0
Diameter of Asbestos plate, mm	= 200
Thickness of Asbestos plate, mm	= 5.8
Diameter of wooden plate, mm	= 200
Thickness of wooden plate, mm	= 12.2

Thermocouple positions are shown in fig.

Thermal conductivity, W/m K

Steel (1%C)	= 45
Asbestos	= 0.21/0.19/0.16

Wood: Sheesham = 0.166

Ambient temp. , °C = 28

S.No	V	I	W	T1	T2	T3	T4

DATA ANALYSIS:

Heat input, Q= V x I

Heat transfer area = Π x $D^2/4$

Temperature drop (dt):

Q=-kA (dt/dx)

Find the temperature drop using above formula for M.S for the different voltages and compare with experimental temperature drop value. Repeat the same for asbestos, wood.

EXPERIMENT NO. 2

OBJECTIVE:

To measure the thermal conductivity of the given insulating material sample by the guarded hot-plate apparatus and compare it with the thermal conductivity of the sample given in the standard reference.

APPARATUS:

It consists of main heater, surrounded by guard heater, cooling plate and insulating material specimen (Bakelite) arranged in the order shown below.

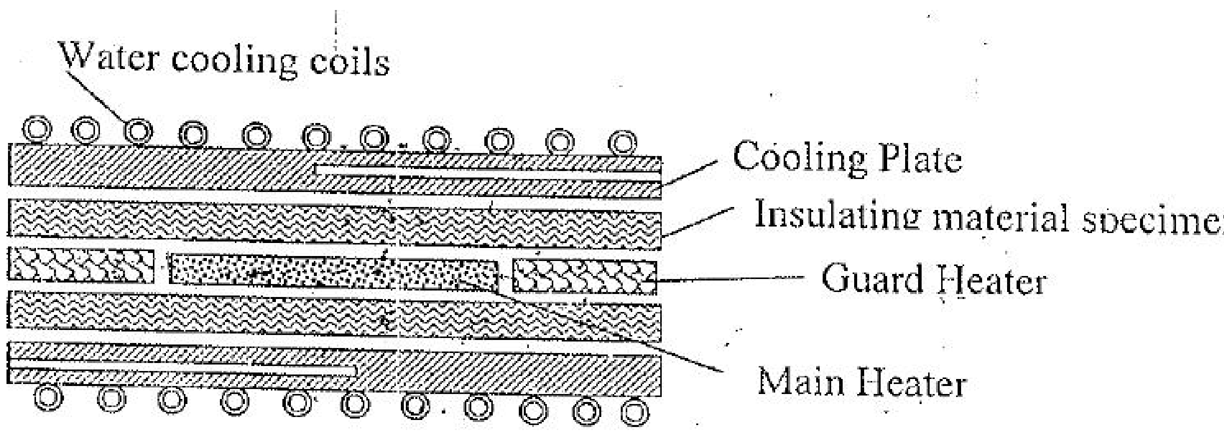


Fig. 1 Schematic diagram of the experimental set-up

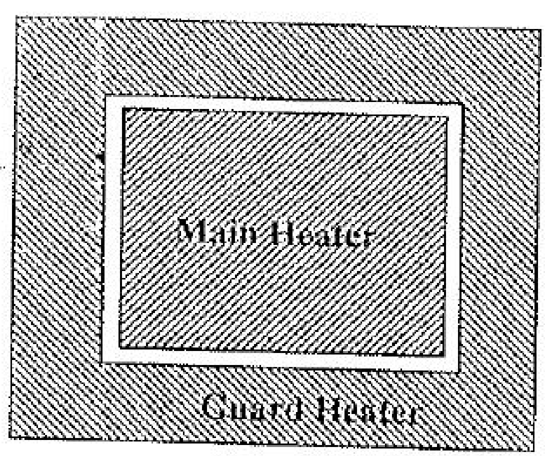


Fig.2 Relative positions of heater

The cooling plate is cooled by flowing water. The guard heater is used to stop the leakage of heat from the edges of the main heater. The apparatus is that is why called guarded hot plate apparatus for determination of thermal conductivity. The apparatus is so designed that its thermal inertia is very less.

THEORY:

The thermal conductivity of insulating materials are determined by passing measured quantity of heat through a known thickness of material layer and monitoring the temperature difference. The thermal conductivity of the material is then computed by equation

$$Q = -K\ A\ \Delta t/x$$

Where Q = the rate of heat transfer,

KJ/s

A= area of heat transfer, m2

Δt= temperature drop across the material layer of thickness,

x, ^{0}c x = thickness of the layer, m

EXPERIMENTAL WORK:

1. Switch ON the cooling water pump and resume the cooling water flow rate to the apparatus.
2. Switch ON the main heater 1 and guard heater 2 .Adjust the voltage of guard heater to 26 V. Measure the temperature of the main heater. Calculate average temperature and adjust the voltage of the guard heater so that its temperature becomes almost equal to the average temperature of the main heater.
3. Give sufficient time for the realization of steady state.
4. Measure the temperature of the main heater, temperature of the guard heater and temperature of the top and bottom cold plates.

RESULTS:

Thermal conductivity of insulating material wool isw/m°C at 30°C and percent difference from a standard value is found.

SAMPLE DATA SHEET:

Thickness of the insulating material, x, m = 0.010

Area of the main heater plate, A, m^2 = 0.103 x 0.103

Run No.	Main heater temp, ^0C	Guard heater temp, ^0C	V	I	Top cold plate temp, ^0C	Bottom cold plate temp, ^0C
	T1	T2			T3	T4

CALCULATION:

Rate of heat transfer Q = V x I

Temperature of main heater, T1, ^0C =

Temperature difference across the sample, ^0C, Δt = T1-T3

Thermal conductivity of slab, K on one side of heater K = (Q. x)/ (2.A. Δt)

% error = $(K_t - K_a)/ K_t$

EXPERIMENT NO. 3

OBJECTIVE:

To measure the temperature profiles of a pin fin heated at its bottom at natural and forced convection. **APPARATUS:**

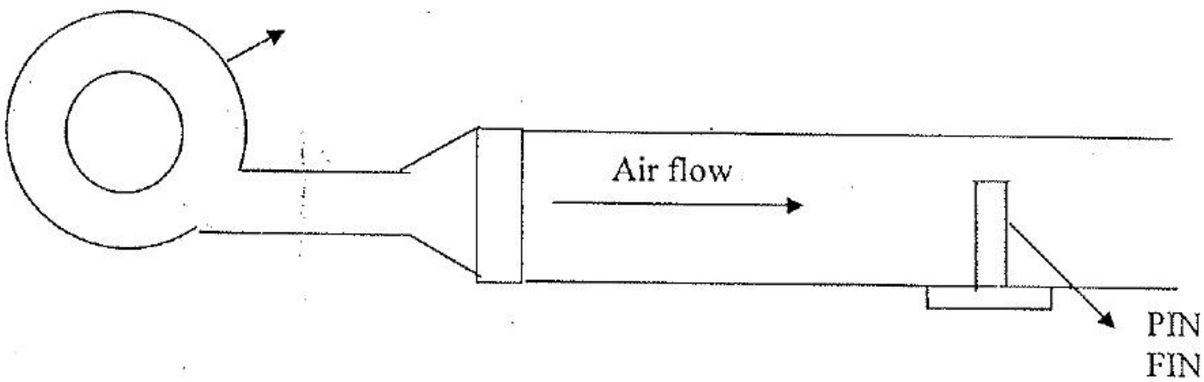


Fig.1: Schematic diagram of apparatus for pin fin in natural and forced convection

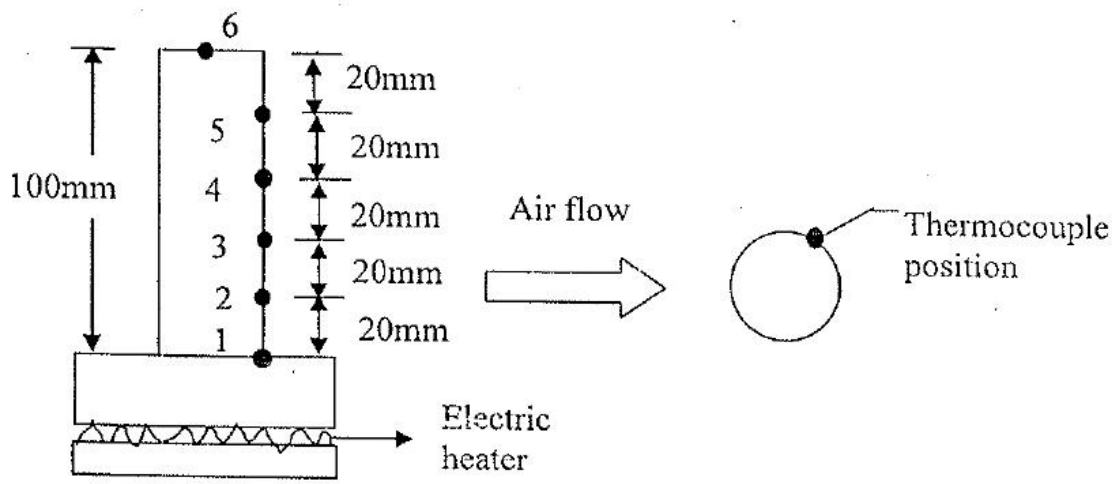


Fig. 2: Details of Pin Fin and thermocouple positions.

It consists of a brass rod of 19.6mm diameter and 100 mm long. At the base of brass rod, a brass flange of 10mm thick and 75mm diameter is welded. The flange is heated by an electrical heater controlled by a variac. Thermocouples were welded on the base, on the length and on the tip of the rod. The whole assembly is put inside a duct. The air flow to the duct is supplied by a blower.

EXPERIMENTAL WORK:

1. Switch ON the air blower and fix a predetermined flow rate of air inside the duct.

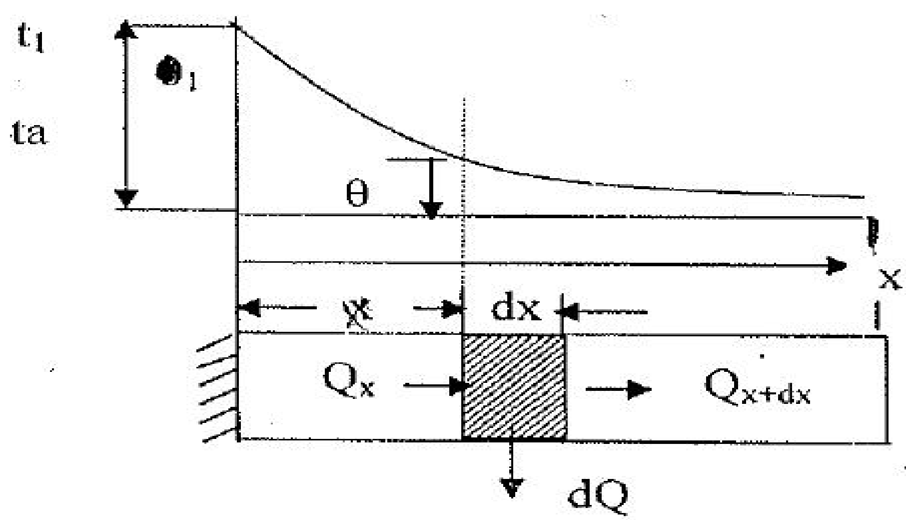
2. Switch ON the electric heater and with help of variac set the voltage to 25V. Allow sufficient time for steady state to occur. Note down the readings of voltmeter, ammeter and thermocouples.

3. Change the energy inputs to the heater by variac and set the voltage to 30, 35, 40 and 45V in stages for each change in voltage repeat above step.

4. Stop the air flow rate and repeat step 2 and step 3 for natural convection.

THEORY:

Fins may be of various cross sections (rectangular, circular, triangular and so on, including irregular geometric forms). Pin fin is a finite rod of circular cross section. Consider the propagation of heat in a straight rod of constant cross section. Let the cross section area be denoted as ‘A’ and its parameter be ‘C’. The rod is placed in a medium of constant temperature ‘t_a’.



Heat Transfer through Pin fin

The coefficient of heat transfer from the surface of the rod to the surrounding is assumed to be constant for the entire surface. Suppose also that the thermal conductivity ‘K’ of the rod material is quite large, and the cross-section of the rod is extremely small in relation to its length. The latter assumption allows us to neglect temperature variations over the cross-sections and to consider that the temperature changes only along the axis of the rod.

$$\theta = t - t_a$$

where, t_a = temperature of the medium

and t = rod temperature.

FORMULA:

$$\theta = \theta_1 \frac{\cosh[m(l-x)]}{\cosh(ml)}$$

$$Q_a = \theta_1 \sqrt{hCkA} \quad \tanh(ml)$$

EXPERIMENTAL DATA:

Diameter of pin fin, mm D = 19.6

Length of pin fin, mm L = 100.0

Material of construction = Brass

Ambient air temperature, °C, Ta = 35.6

Orientation = Vertical

FREE/NATURAL CONVECTION:

Run No.	V	I	W	Thermocouple No. Temperature, °C					
				1	2	3	4	5	6

FORCED CONVECTION:

Run No.	V	I	W	Thermocouple No. Temperature, °C					
				1	2	3	4	5	6

Computation of temperature along the length of PIN FIN during Natural Convection:

Average surface temperature along the length of Pin Fin = (T1+T2+T3+T4+T5+T6)/6

= °C

Thermal conductivity of air, k =0.029 W/m K

Base temperature, T1 =

For a wide range of temperature, $k^4 (\beta g \rho^2 C)/(\mu k) = 36$ for air

$$(\beta g \rho^2 C)/(\mu k) = 36 / k^4$$

$$= 36/(0.029^4)$$

$$= 5.1 \times 10^7$$

Determination of heat transfer coefficient during Natural

Convection: Gr. Pr = $(\beta g \rho^2 C)/(\mu k)$ (T1-Ta) (L^3)

$= 5.1 \times 10^7 \times (T1-35.6)(0.1^3)$

=

$h = C''. (T1-Ta)^n L^{3n-1}$

(For above cases based on the value of Gr.Pr, C'' =1.37 & n=0.25)

$h = 1.37 \times (T1-35.6)^{0.25}(0.1)^{3x0.25-1}$

= W/m^2K

$C/k.A = (\prod.D)/(k.\prod/4.D^2) = 4/(k.D) = 4/(111x19.6x10^{-3}) = 1.887$ (since k_{brass} =111 w/mc) $m = \sqrt{(h.C/k.A)}$

$= \sqrt{(h\ x1.887)} =$

Computation of temperature at a distance of 20 mm from the base.

$$\theta = \theta_1 \frac{\text{Cosh}\,[m(l-x)]}{\text{Cosh}\,(ml)}$$

Assuming no heat loss from pin fin tip.

(T-Ta) = (T1-Ta) .Cosh[m(l-x)]/Coshml

T-35.6 = (T1-35.6) .Cosh[m(0.1-.02)]/Cosh(mx0.1)

Substitute the values of m and T1 in above equation.

T_{th} =

T_{exp} =

% Error =

Computation of temperature along the length of PIN FIN during Forced convection:

For finding h:

Q= h A (T1-Ta)

V x I = h x (π.D.L). (T1-Ta)

Substituting the values from given data and table

gives h h =

C/k.A = (∏.D)/ (k.∏/4.D^2) = 4/ (k.D) =4/(111x19.6x10^{-3}) =1.887 (since k_{brass} = 111 w/m°C)

m = √(h.C/k.A)

= √ (h x1.887) =

Computation of temperature at a distance of 20 mm from the base.

$$\theta = \theta_1 \frac{\text{Cosh}\,[m(l-x)]}{\text{Cosh}\,(ml)}$$

Assuming no heat loss from pin fin tip.

(T-Ta) = (T1-Ta) Cosh[m(l-x)]/Coshml

T-35.6 = (T1-35.6) Cosh[m(0.1-.02)]/Cosh(mx0.1)

Substitute the values of m and T1 in above

equation. T_{the}=

T_{exp}=

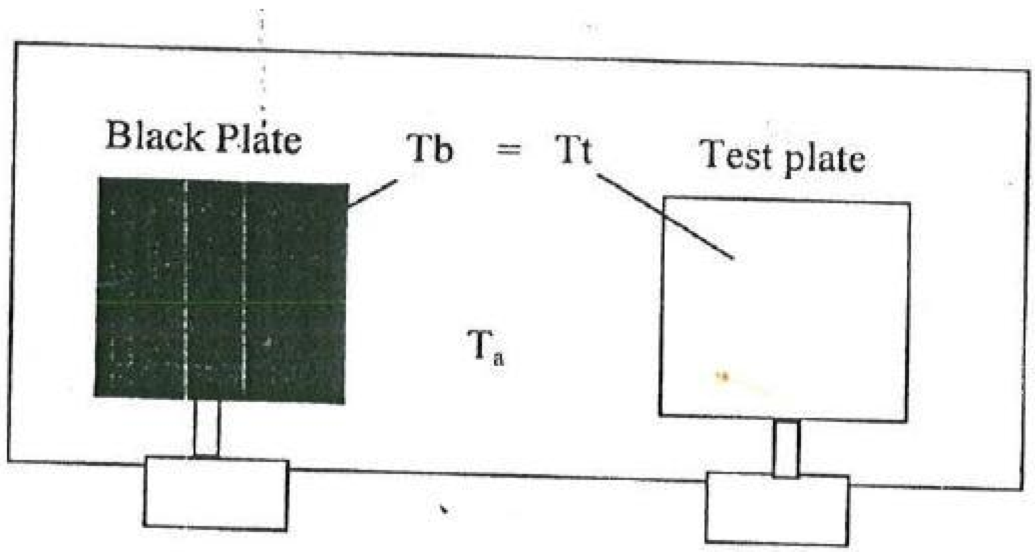
EXPERIMENT NO. 4

OBJECTIVE:

To determine the mean emissivity of a copper plate at different temperature.

APPARATUS:

The experimental set-up is shown below. It primarily consists of two square plates, one coated black and other has a rough surface. Both the plates are heated from the backside using electric heater. The plates are placed inside an enclosure to decrease convective losses and provide equal losses from both the plates.



The heat input to both the plates are controlled using two separate variacs and are measured by digital volt and ammeter. The temperature of the plates are measured by thermocouples. The ambient temperature is also measured by thermocouple placed inside the chamber.

The heat inputs to the plates are dissipated through conduction, convection and radiation modes of heat transfer. The experimental set-up is designed in such a fashion that at steady state the losses due to convection and conduction are same from both the plates. When both the plates are at same temperatures the difference in heat input to these plates are primarily because of their radiation characteristics arising out of their different emissivities.

THEORY:

In the study of radiation exchange phenomena, emissivity of a surface plays an important role. The emissivity of a surface varies with its temperature, its roughness, and if metal its degree of oxidation. However the average value can be determined by a simple experiment if the temperature of the two surfaces and the heat flux by radiation are known.

The total amount of radiant energy equation emitted by a Gray body at an absolute temperature T is given by Stephan-Boltzman law is:

$$E_q = \varepsilon \sigma T^4$$

Where ε = emissivity of the body and

σ = Stephan-Boltzman constant = 5.67x 10^{-8} W/m^2 K^4

The net heat transfer takes place by all the modes of heat transfer combined i.e conduction, convection and radiation.

The experimental set up employs two plates one-test plate and other black plate of same dimension heated by electric heaters from the backside of the plate.

Let W_b = Heat input to the black plate (black body),

W W_t = Heat input to test plate (non-black), W

T_b = Temperature of the black plate, K

T_t = Temperature of test plate, K (for the present experiment T_t is kept equal to T_b)

T_a = Ambient temperature, K

ε_b = Emissivity of the black plate (black body) = 1

ε = Emissivity of the test plate (non- black body)

A = Area of the plate (length x breadth), m^2

σ = Stephan-Boltzman constant = 5.67x 10^{-8} W/m^2 K^4

Then using the Stefan Boltzman law, the emissivity of the test plate can be calculated as follows:

$$(W_b - W_t) = (\varepsilon_b - \varepsilon) \sigma A (T_b^4 - T_a^4)$$

From the above equation the emissivity of the test plate can be computed as all other parameters are known. It should be noted that the emissivity is a surface property and depends on the nature of the surface and temperature.

EXPERIMENTAL WORK:

1. Switch ON the power supply to the apparatus [illegible] plate and fix the voltage 15V to 16V. [illegible]
2. [illegible]
3. [illegible]
4. [illegible]
5. [illegible]
6. [illegible] black and test plates. Keep the voltage of black plate to 24
7. and 27 for additional sets of readings.

RESULT:

The mean emissivity of copper plate is

SAMPLE DATA SHEET:

Test plate diameter = 150mm

Black plate diameter = 150mm

Area of the Black plate = 0.018m^2

Area of Test Plate = $0.018 m^2$

ε_b = 1

OBSERVATION TABLE:

S.No	Heat input to Black plate		T_b (^{0}C)	Heat input to Test Plate		T_t (^{0}C)	T_a (^{0}C)
	V	I		V	I		

DATA ANALYSIS/CALCULATION:

For different values of V & I identify the value of emissivity by substituting in the equation given below.

W_b =VxI

W_t =VxI

T_b = (K)
T_a = (K)

$$(W_b - W_t) = (\varepsilon_b - \varepsilon)\, \sigma\, A\, (T_b^4 - T_a^4)$$

Then, find the average of the emissivity for 3 readings: $\varepsilon_{final} = (\varepsilon_1 + \varepsilon_2 + \varepsilon_3)/3$

EXPERIMENT NO. 5

OBJECTIVE:

1. To experimentally determine the heat transfer coefficient from the outer side of a vertical electrically heated tube in air during natural convection.

2. To determine the heat transfer coefficient from the given empirical equation and compare it with the experimental value obtained.

APPARATUS:

A G.I tube of 42mm 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. The energy input to the heater is controlled by a variac and is measured by ammeter and voltmeter. The tube is placed vertically.

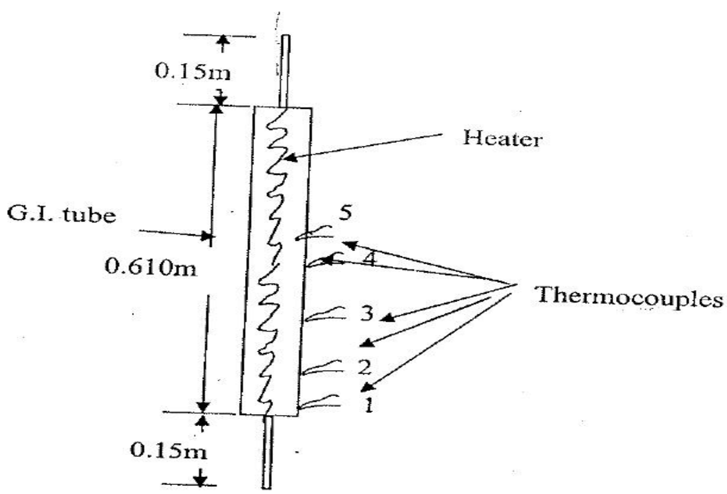


Fig.1: Schematic diagram of heating tube

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 the vessel becomes heated and expands and rises because its density takes place and a circulating current is thus sets up.

For the conditions in which only natural convection occurs the velocity is dependent solely on the buoyancy effects, represented by the Grashof Number and the Reynolds group can be omitted.

For natural convection:

$Nu = f(Gr, Pr)$

$Gr = \beta . g . \Delta t . l^3 . \rho^2 /$

μ^2 $Pr = C_p \, \mu / K$

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 given below.

For constant heat flux heating and $10^3 < Gr_{fx} . Pr_f$

$< 10^9$ $Nu_x = 0.60 \, (Gr_{fx} . Pr_f)^{0.25} . (Pr_f / Pr_w)^{0.25}$

The mean heat transfer coefficient (for a length of tube equal to 1) can be calculated by the equation given below

$Nu_x = 0.75 \, (Gr_{fx} . Pr_f)^{0.25} . (Pr_f / Pr_w)^{0.25}$

Local heat transfer coefficient for turbulent flow:

Turbulent flow becomes fully developed at $Gr_{fx} . Pr_f > 6 \times 10^{10}$

Local heat transfer coefficient is found by: $Nu_{fx} = 0.15 \, (Gr_{fx} . Pr_f)^{1/3} . (Pr_f$

$/ Pr_w)^{0.25}$ $Nu_{fx} = h.x/k$ & $Gr_{fx} = [\, \beta g . \Delta t . l^3 . \rho^2 / \mu^2]^{1/3}$

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.

The experimental results obtained by various investigators indicate that a transition pattern of flow occurs around $10^9 < Gr_{fx} . Pr_f < 6 \times 10^{10}$

EXPERIMENTAL WORK:

1. Switch ON the power supply.
2. Manipulate the variac so that the voltmeter reads 30V
3. Allow sufficient time for steady state to occur.
4. Note down the thermocouple readings along with voltmeter and ammeter readings.
5. Manipulate the variac to change the voltmeter readings to 35, 40 & 45V in steps and repeat the

steps 3 to 4 each time you change voltmeter reading.

RESULTS:

The local heat transfer coefficient from the given empirical equation is determined and compared with experimental value obtained.

OBSERVATION TABLE:

Run No.	V	I	W	Temp, ^0C			
				1	2	3	4

DATA ANALYSIS:

Material of tube = G.I

Diameter of tube, in m, d = 0.042

Total length of heater, m = 0.91

Effective length of heated section of tube, in m, l =

0.610 Ambient temperature of air, in °C, T_a = 20.9

Heat input = V x I

=

Heat input in the heated section of tube = Heat input x Effective length of heated section of tube/ Total length of heater

Heat flux = Heat input/Area of heating tube

= Heat input/ (πdl)

=

Local heat transfer coefficients:

h_x at 20mm from bottom = Heat flux/(T_{wall} – Ta)

=

Computation of local heat transfer coefficient using empirical equation

Average temperature = $(T_2+Ta)/2$

=

The thermal conductivity of air at an average surface temperature is 0.0274

w/mk For a wide range of temperature

$\beta.g.\ \Delta t.\rho^2\ C_p / (\mu\ k) = 36.0/k^4$

Gr.Pr at 20 mm from bottom

$Gr.Pr = \beta g.\ \Delta t.\rho^2\ C_p / (\mu\ k).\ \Delta t.l^3$

Applying the below for computation of local heat transfer

coefficient. $Nu_x = 0.60\ (Gr_{fx} .Pr_f)^{0.25}.(Pr_f / Pr_w)^{0.25}$

=

Pr_f at 20.9°C = 0.701

Pr_w at 45.2°C = 0.697

$Nu_x = h\ l/K$

h_{theo}=

EXPERIMENT NO. 6

OBJECTIVE:

1. To determine the LMTD and overall heat transfer coefficient of the heat exchanger during parallel and counter current flow configuration.
2. To estimate the effectiveness of the heat exchanger under parallel and counter current flow conditions.

APPARATUS:

Hot water is generated in the hot water tank using an electric heater. The hot water is then pumped to the inner tube using a centrifugal pump and is metered using rotameter. Hot water flow rate is controlled by valve V1. Cooling water (cw) is taken from water supply line. The flow rate of cooling water is controlled by the valve V2 and is metered by a rotameter before it is fed to the outer tube of the heat exchanger.
Valves V3, V4, V5 & v6 are used to direct the water flow in parallel and counter current directions. Four RTDs (Resistance Temperature Detector) are used to measure the inlet and outlet temperatures of cooling as well as hot water streams.

THEORY:

For parallel and counter flow:

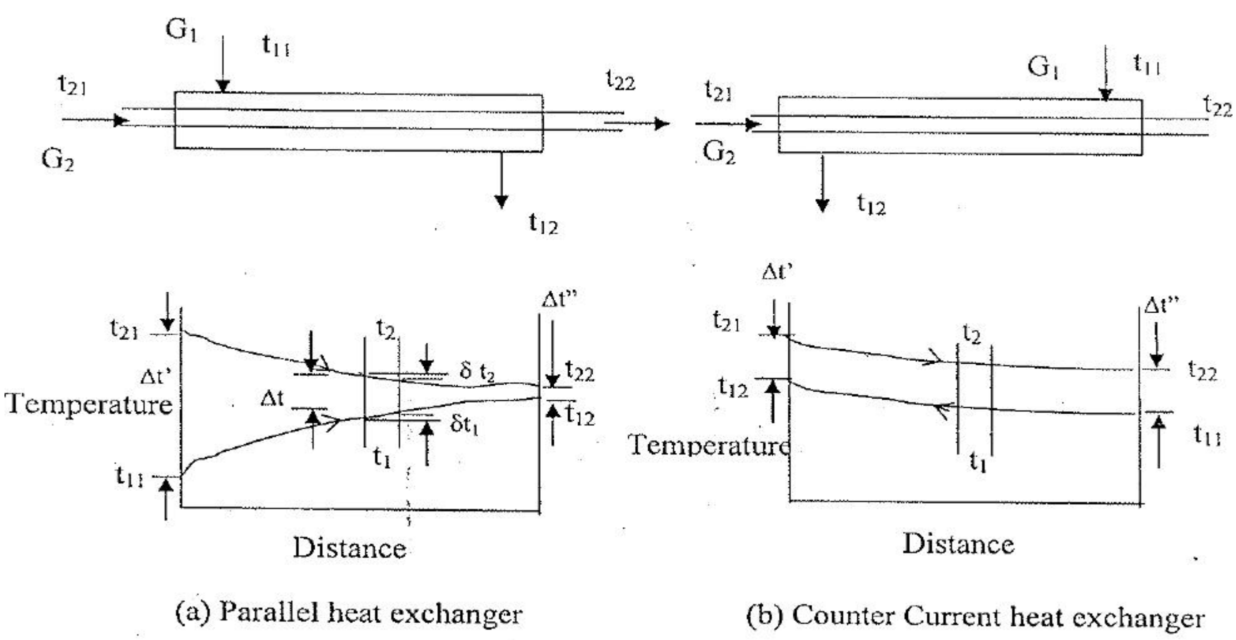


Fig. 1: Flow arrangements and temperature profiles of parallel and counter current heat exchangers

Log mean temperature difference (LMTD):

$$LMTD = (\Delta t)_{ln} = \frac{\Delta t' - \Delta t''}{\ln \frac{\Delta t'}{\Delta t''}} = \frac{\theta_1 - \theta_2}{\ln \frac{\theta_1}{\theta_2}}$$

Number of transfer unit, NTU = $U.A/C_{min}$ = U.A/

$(G.C_P)_{min}$ Effectiveness of Heat Exchanger, $\eta = Q/Q_{max}$

EXPERIMENTAL WORK:

1. Fill the hot water tank with distilled water(or good quality water)
2. Start the electric heater.
3. Adjust cooling water flow in counter-current model by opening the valves V4 and V6 and closing valves V3 and V5.
4. Adjust the flow rate of hot water in the inner tube using valve V1.
5. Allow sufficient time for steady state to occur.
6. At steady state note down the flow rates of cooling as well as hot water along with its inlet and outlet temperatures.
7. Close valve V4 and V6 and open valve V3 and V5. Now the flow becomes parallel. Repeat steps 5 &6.
8. Change hot water flow rate by manipulating valve V1 and repeat steps 3,5 & 6 without altering the flow rate of cooling water. Repeat steps 7,5 and 6.
9. Repeat step 8 for several values of hot water flow rate.
10. The whole exercise i.e. steps 3 to 9 can be repeated for different values of cooling water flow rates.

RESULTS:

FOR PARALLEL FLOW:

LMTD,ΔT_{ln} =

Heat transferred, Q =

Overall heat transfer coefficient, U =

Number of transfer units, NTU =

Effectiveness, $\eta_{parallel}$ =

FOR COUNTER FLOW:

LMTD, ΔT_{ln} =

Heat transferred, Q =

Overall heat transfer coefficient, U =

Number of transfer units, NTU =

Effectiveness, $\eta_{counterflow}$ =

SAMPLE DATA SHEET:

Tube Material = Brass

Length of tube ,mm = 1000 x 2

Inside diameter of inner tube, mm = 6.3

Outside diameter of inner tube, mm = 8.0

Run No.	Counter-Current flow temperatures, ^{0}c						Parallel flow temperatures, ^{0}c					
	t 11	t 12	t 21	t 22	q1(lpm)	q2(lpm)	t 11	t 12	t 21	t 22	q1(lpm)	q2(lpm)

DATA ANALYSIS:

For Parallel Flow:

Computation of LMTD, ΔT_{ln}

$\Delta T_{ln} = ((t_{21} - t_{11}) - (t_{22} - t_{12}))/ (\ln((t_{21} - t_{11})/(t_{22} - t_{12})))$

Computation of Q:

The heat transferred is computed based on the hot stream as it is surrounded by cold stream and there are less chances of picking up heat from environment

C_P =4.189 x 10^3 J/kg.k

Q=Volumetric flow rate x density x Specific heat x temperature difference

= q_2 / 60 x density at $(t_{21} + t_{22})/2$ x C_P x $(t_{21} – t_{22})$

= W

Computation of U:

A = πDL = π x 0.008 x 1 = 0.050256

m^2 Q = UA ΔT_{ln}

U= Q/ (A. ΔT_{ln})

= W/m^2 K

Computation of Number of transfer units & Effectiveness:

G = mass flow rate = Volumetric flow rate x density = q_2 / 60 x density at $(t_{21}$ +

$t_{22})/2$ NTU =N= U.A/ $(G.C_P)_{min}$

=

Effectiveness, $\eta_{parallel}$ =1/2 x [1- e^{-2N}]

=

For Counter-Current Flow:

Computation of LMTD, ΔT_{ln}

ΔT_{ln} = $((t_{21} – t_{12}) – (t_{22} – t_{11}))/ (\ln ((t_{21} – t_{12})/ (t_{22} – t_{11})))$

Computation of Q:

The heat transferred is computed based on the hot stream as it is surrounded by cold stream and there are less chances of picking up heat from environment

C_P =4.189 x 10^3 J/kg.k

Q=Volumetric flow rate x density x Specific heat x temperature difference

= q_2 / 60 x density at $(t_{21} + t_{22})/2$ x C_P x $(t_{21} – t_{22})$

= W

Computation of U:

A = πDL = π x 0.008 x 1 = 0.050256

m^2 Q = UA ΔT_{ln}

U= Q/ (A. ΔT_{ln})

= w/m^2 k

Computation of Number of transfer units &

Effectiveness: G=mass flow rate

= Volumetric flow rate x density

= q_2 / 60 x density at $(t_{21} + t_{22})/2$

NTU = N = U.A/ $(G.C_P)_{min}$

=

Effectiveness, $\eta_{counter\ flow}$ =N/ (1+N)

EXPERIMENT NO. 7

OBJECTIVE:

1. To determine the boiling heat transfer coefficient experimentally by measuring Q, A,t_s and t_w

2. To determine the boiling heat transfer coefficient theoretically using equation 4 and to compare it with experimentally determined heat transfer coefficient.

APPARATUS:

It mainly consists of a cylindrical vessel, which houses a heating tube. The tube is electrically heated by an electric heater. The power to electrical heater is controlled by a variac and is measured using a voltmeter and an ammeter. The vapour generated due to boiling is condensed and returned back to main liquid pool using a helical tube condenser fitted inside a vessel. A brass cock is provided to remove air from the vessel. Thermocouple holes are drilled on the wall of the heating tube to measure its wall temperature.

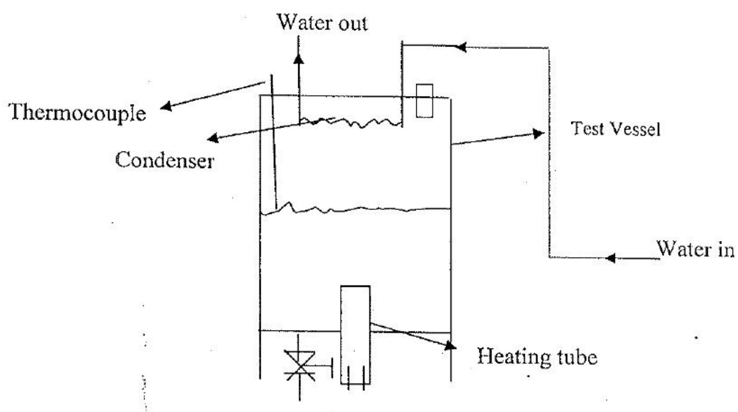


Fig.1: Schematic diagram of apparatus for two phase heat transfer

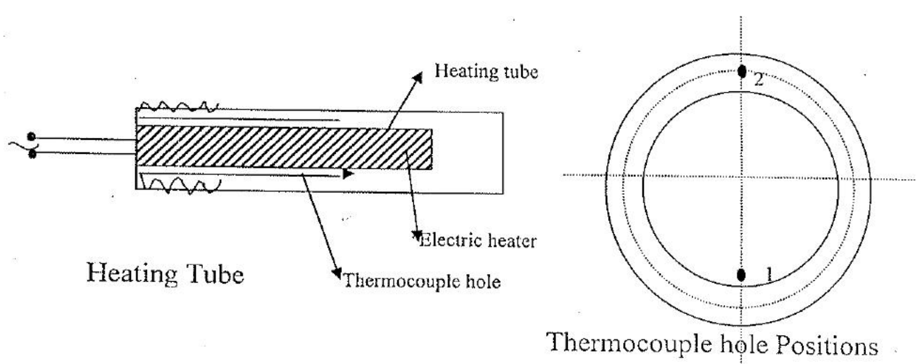


Fig.2: Details of heating tube and thermocouple position

THEORY:

Boiling is a two phase heat transfer phenomena as it involves both liquid and vapour phase. Boiling is defined as the process of intensive vaporization in the entire volume of a liquid at the saturation temperature or somewhat superheated with respect to saturation temperature, accompanied by the formation of vapour bubbles.

Stephan and Abdefsalam , in order to establish correlations for nuclear boiling with wide applications. For each group of substances they employed a different set of dimensionless numbers because, while certain dimensionless numbers are important for one group of substances, the same may not be so for another group.

These correlations are as follows:

(a) For water

$$Nu = 0.246 \times 10^7 X_1^{0.673} X_4^{-1.58} X_3^{1.26} X_{13}^{5.22} \quad (1)$$

$10^{-4} < (P/Pc) < 0.886$ and contact angle θ is 45^0

(b) For hydrocarbons

$$Nu = 0.0546 (X_5 X_1)^{0.67} X_{13}^{-4.33} X_4^{0.248} \quad (2)$$

$5.7 \times 10^{-3} < (P/Pc) < 0.9$ contact angle θ is 35^0

(c) For Cryogenic fluids

$$Nu = 4.82 X_{10}^{0.624} X_9^{0.117} X_5^{0.257} X_3^{0.374} X_4^{-0.329} \quad (3)$$

$4 \times 10^{-3} < (P/Pc) < 0.97.$ contact angle θ is 1^0

Where $Nu = \left(\frac{hd_b}{k_l}\right)$; $d_b = 0.0146 \beta \left(\frac{2\sigma}{g(\rho_l - \rho_v)}\right)^{0.5}$

$$X_1 = \frac{Q\, d_b}{h_{fg} T_s} \; ; \; X_3 = \frac{C_p T_s d_b^2}{a^2}$$

$$X_4 = \frac{h_{fg} d_b^2}{a^2} \qquad X_5 = \frac{\rho_l}{\rho_v} \qquad X_{10} = \nu_l/a$$

$$X_9 = (h_{fg} \rho C_p)_w / (h_{fg} \rho C_p)_l \qquad X_{13} = \frac{(\rho_l - \rho_v)}{\rho_l}$$

Where,

h_{fg} - latent heat of vaporation , J/kg
h_b - diameter of bubble, m
T_s - Saturated temperature of liquid, K
θ - Contact angle, degree
q - heat flux, W/m^2
C_p - Specific heat, J/kgK
ρ_l - density of liquid, kg/m^3
ρ_v - density of vapour, kg/m^3
ν - Kinematic Viscosity, m^2/s
a - Thermal diffusivity, m^2/s

Suffix w stands for wall, v for vapour and l for liquid.

For computation of boiling heat transfer coefficient MOSTINSKI had given following correlation

$$h = 0.104 \times P_c^{0.69} q^{0.7} \left[1.8 \left[\frac{P}{Pc}\right]^{0.17} + 4 \left[\frac{P}{Pc}\right]^{1.2} + 10 \left[\frac{P}{Pc}\right]^{10} \right] \qquad (4)$$

Where,

h = is in W/m^2K
P = pressure in bar
Pc = Critical pressure in bar
q = heat flux in W/m^2

This is much simpler correlation and gives reliable results. This equation is valid for single component fluid.

Experimentally the boiling heat transfer coefficient can be determined from the equation

given below. $h = (Q/A) / (t_s - t_w)$ ---(5)

Where Q is the rate of heat transferred by the electric

heater, A is the heat transfer area,

t_s is the saturation temperature of liquid

t_w is outer wall temperature of the heating tube on which boiling is taking place.

EXPERIMENTAL WORK:

1. Start the cooling water flow inside the helical condenser.
2. Switch ON the electric heater and adjust the voltmeter reading to 80V by variac and open the brass cock. The liquid inside the vessel will get heated up and vapour will be generated. The vapour will push the air accumulated inside the vessel through the bubbler. Now the vessel is free from air.
3. Now close the brass cock.
4. The liquid will now start boiling. Bubbles will come out from the surface of the heating tube. Allow steady state to achieve and then note down the wall temperatures, liquid temperature, voltmeter and ammeter readings.
5. Now increase the heat input to the heater by increasing the voltage to 85V in steps and repeat step4.

RESULTS:

1. Estimated the heat transfer coefficient by measuring Q, A,t_s and t_w using equation 5 for different values of heat flux(Q/A)

2. Estimated the boiling heat transfer coefficient theoretically using equation 4 and to compared it with experimentally determined heat transfer coefficient.

CRITICAL DATA:

O.D of heating tube , mm = 25.0

P.C.D of thermocouple holes, mm = 21.0

Length of heating section of tube, mm = 140

Diameter of vessel, mm = 94

Height of vessel, mm = 300

Material of heating tube = Copper

Orientation = Vertical

Run No.	V	I	W = Q	Q/A	Liquid Temp t_s, ^0C,3	Wall Temp. ^0C	
						1	2

DATA ANALYSIS:

Heat input, W = Vx I

Average value of measured wall temperature $t_w = (t1 + t2)/2$

=

Area of heating tube = π dl

=

Rate of heat transferred per area, q = Heat input/Area of heating tube

=

Let t_w = t1 =

Corrected wall temperature of tube, t2:

$$Q = 2\,\pi\,.k.l\,(t1 - t2)/\ln\left(\frac{r2}{r1}\right)$$

= 2 x 386 x 0.140 x (tw – t2) /ln (25.0/21.0)

t2 =

(tw)corrected =

Computation of heat transfer coefficient using equation 5

h_{exp} = q/ ((tw)corrected - ts)

=

Computation of heat transfer coefficient using MOSTINSKI equation:

Pc for water =225.5bar

P = 1 bar

P/Pc = 0.00443

$$h = 0.104 \times P_c^{0.69} q^{0.7} \left[1.8 \left[\frac{P}{Pc}\right]^{0.17} + 4 \left[\frac{P}{Pc}\right]^{1.2} + 10 \left[\frac{P}{Pc}\right]^{10} \right]$$

h_{theo} = $0.104 \times (225.5)^{0.69} \cdot (q)^{0.7} \cdot (0.7164 + 0.00599 + 2.91 \times 10^{-23})$

Ms. Krati Hardya
Lab IN-charge

Dr. Shailesh Kumar Singh
Head of Department (ME)

Prof. (Dr.) Seema Shukla

Director