DATE:

EXPERIMENT NO. 1

Title: DETERMINATION OF THERMAL CONDUCTIVITY OF INSULATING POWDER (ASBESTOS)

Aim: To determine thermal conductivity of insulating powder (asbestos)

Apparatus: Two concentric spheres with insulating powder in between annular space, ammeter, voltmeter, temperature indicator and thermocouple.

Specifications:
1) Voltmeter range = 0 – 300 V
2) Ammeter range = 0 – 5 A
3) Diameter of inner sphere= 0.1m
4) Diameter of outer sphere= 0.2m
5) Temperature indicator= 0- 999^o c (digital)

Theory:
Introduction:
Insulating material of different types such as asbestos, glass wool etc is used in engineering practice to prevent the leakages of heat. These materials offer resistance to heat flow and are useful in saving the energy. These materials posses a relatively small value of thermal conductivity. Table 1 gives the list of commonly used insulating materials and their thermal conductivity values. Mechanical engineer should know these values and method to determine these values.

Table 1 commonly used insulating materials and their thermal conductivity values

Material	Thermal conductivity (K) (W/mk)	State
Asbestos	0.23	20^0 c
Plastic	0.58	20^0 c
Wood	0.17	20^0 c
Brick	0.23	20^0 c
Concrete	1.279	20^0 c
Fire brick	0.14	20^0 c
Mineral wool	0.047	20^0 c
Plaster	0.779	20^0 c
Rubber	0.163	20^0 c
Cork sheet	0.042	20^0 c
Glass	0.744	20^0 c

Modes of heat transfer:

Heat always flow from high temperature region to low temperature region. The heat transfer takes place by three distinct modes as Conduction, Convection and Radiation.

1) **Conduction**: It is an exchange of energy through a substance by direct interaction between its molecules. It is the mode of heat transfer accomplished via two mechanisms.
a) By molecular interaction where by energy exchange takes place by kinetic motion of direct impact of molecules. This type of energy transfer always exists as long as there is a temperature gradient in a system comprising of solid, liquid and gas.
b) By direct motion of free electrons as in the case of metallic solids while moving from one location to other. These electrons carry some amount of energy along with them. The metallic alloys have a different concentration of free electrons and their ability to conduct heat is directly proportional to the conduction of free electrons in them. Pure direction is found only in solids.

2) **Convection**: It is possible only in presence of a fluid medium. The transport of heat energy is directly linked with transport of fluid medium itself. Hence convection is a combination of conduction, fluid flow and mixing.

3) **Radiation**: It is electromagnetic wave phenomenon and no medium is required for its propagation. Energy transfer by radiation depends only on temperature and optical properties of emitter.

Fourier’s law of Heat Conduction:

A physical law for heat transfer by conduction was given by Fourier (1955). It states that, the rate of flow of heat flux due to conduction in any direction is directly proportional to temperature gradient present in that direction.
According to the Fourier’s law,

$$Q/A= dt/dx$$

Where Q= rate of flow of energy in x- direction (watt)
A= area normal to the direction of heat flow (m^2)
dt/dx= temperature gradient in x- direction ($^0C/m$)
Q/A= heat flux (w/m^2)
Introducing constant of proportionality in above equation, we get

$$Q= -KA(dt/dx)$$

‘K’ is called as thermal conductivity which is physical property of the substance and is defined as the ability of a substance to conduct heat. Its S.I. unit is w/mk. The negative sign in the above equation is account for fact that, heats always flow in the direction of decreasing temperature. Hence temperature gradient in the direction of heat flow is negative.

Heat Conduction through hallow sphere:

Consider a hallow sphere as shown in figure
Let, r_1= Inner radius of sphere
r_2= Outer radius of sphere
T_1= Temperature of inner sphere
T_2= Temperature of outer sphere
K= Thermal conductivity of material of sphere.

Now , according to Fouriers law

$$Q= -KA(dt/dr)$$

Where dt/dr= temperature gradient in radial direction.

For sphere, $A= 4\pi r^2$ .... (at radius r)

$$Q= -K(4\pi r^2)* dt/dr$$

$$Q*dr/(4\pi r^2)= -K.dt$$

Boundary conditions are

1) at $r=r_1$, $T=T_1$ 2) at $r=r_2$, $T=T_2$

Therefore integrating above equation between boundary conditions

$$\int_{r1}^{r2} \frac{Q*dr}{4\pi r2} = -\int_{T1}^{T2} K.dt$$

$$\frac{dr}{r2} = ¿ \int_{T1}^{T2} K.dt$$

$$\frac{Q}{4\pi} \int_{r1}^{r2} ¿$$

r_2

$$Q/4\pi * [-1/r] = K (T_1- T_2)$$

r_1

Therefore $Q= 4\pi Kr_1 r_2 (T_1- T_2)/ (r_2- r_1)$

Experimental setup:

It consists of two thin concentric copper spheres. The insulating powder (asbestos) is filled between two spheres. The electric heater is placed at centre of sphere. Four thermocouples are placed on inner sphere and four thermocouples are outer sphere. The whole panel consist of voltmeter, ammeter, dimmer set and digital temperature indicator.

Procedure :

1. Put switch on
2. Predetermine voltage to heater.
3. Wait for steady state condition.
4. Note down steady state temperature readings.
5. Calculate thermal conductivity of insulating powder using formula.

$$Q= 4\pi K r_1 r_2 (T_1- T_2)/ (r_2- r_1)$$

Where Q= Heat transfer rate (watt)

r_1= Radius of inner sphere (meter)

r_2= Radius of outer sphere (meter)

T_1= Temperature of inner sphere (^{0}C)

T_2= Temperature of outer sphere (^{0}C)

K= Thermal conductivity (w/mk)

Precautions:

1. Do not exceed input beyond 150 watt.
2. Do not touch any electrical connections.
3. Do not lift sphere.

Observation Table:

Sr. No.	V (volt)	A (amp)	Temperature of inner sphere ^0C				Temperature of outer sphere ^0C			
			T1	T2	T3	T4	T5	T6	T7	T8

Calculation steps:

$K= Q^* (r_2- r_1)/ 4\pi Kr_1 r_2 (T_i- T_o)$

T_i= ....^0C
T_o= .... ^0C
Now
Q= V.I. cos (Ø)
Q= .... (watt)

Now K= ....w/mk

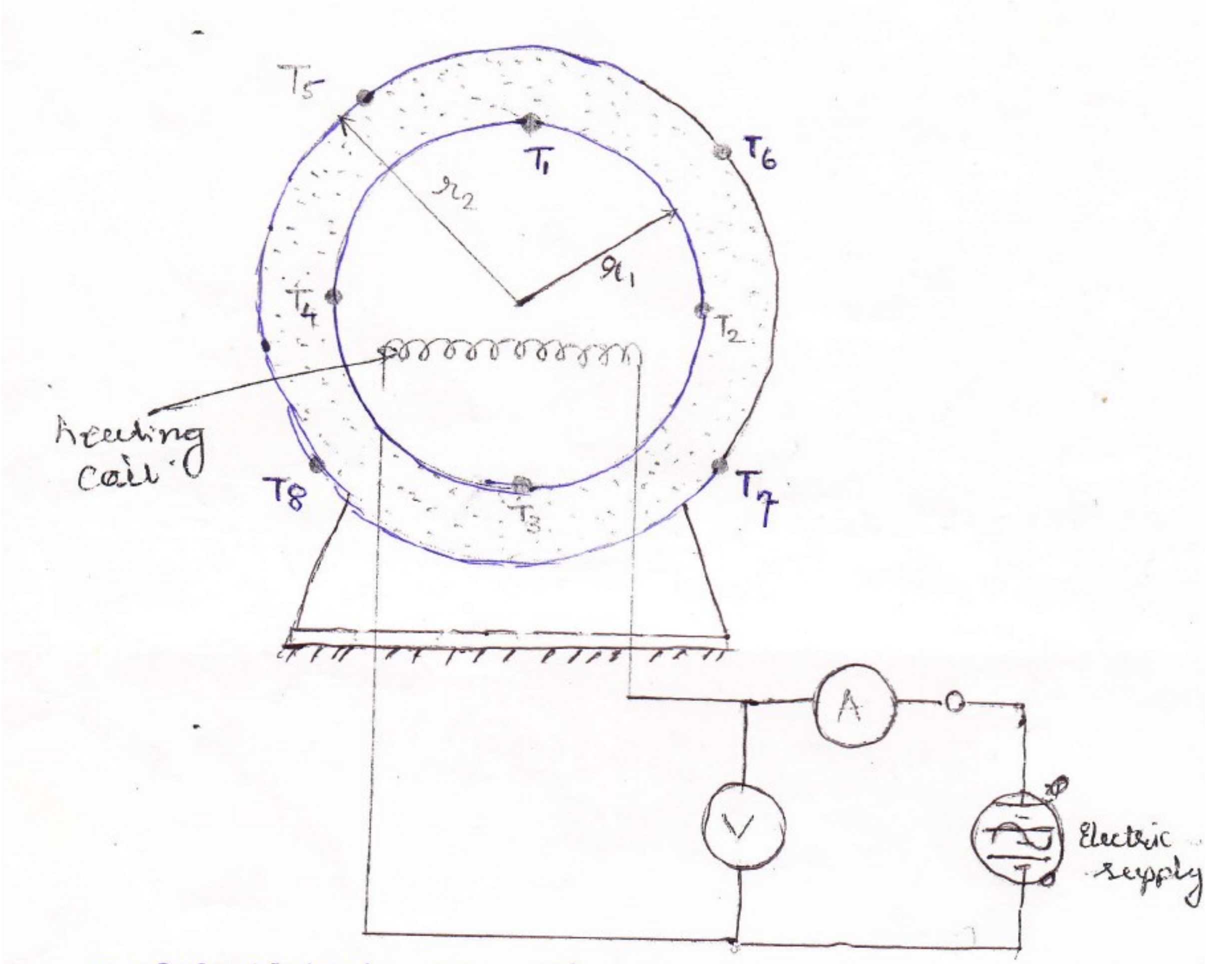
Result:
Thermal conductivity of the given insulating powder, K= .... w/mk

Conclusion:
The value of thermal conductivity obtained from the experiment is greater than actual value of thermal conductivity.

Justification:
The difference in actual and experimental value of thermal conductivity is because of
1. Powder may not be packed properly. Due to this air is insulator may get trapped between two spheres.
2. Thermal resistance of wall material is neglected.

Exercise:

1) Define thermal conductivity?
2) Explain the experiment setup?
3) Explain the Fourier law of heat conduction?
4) Which materials are called as insulating material? Name any five.
5) What is the use of voltmeter and ammeter in the experimental setup?



* EXPERIMENTAL SET UP *

DATE:

EXPERIMENT NO. 2

Title:- TEMPRATURE DISTRIBUTION THROUGH A COMPOSITE WALL.

Aim :- To determine thermal conductivity of different materials in composite wall/slab.

Appratus :- Composite circular slab (made up of mild steel, plaster of Paris and wood) heating coil between two steel plates, eight thermocouples, ammeter, voltmeter dimmerstat, digital temperature indicator.

Specification:-

1)Thickness of mild steel slab = 12 mm
2)Thickness of plaster of paris slab = 15 mm
3)Thickness of wood slab = 17mm
4)Diameter of slab = 250mm
5)Voltmeter range = 0-300 V.
6)Ammeter range = 0-3A.

Theory:-

Fourier's law of heat conduction:-

According to Fourier's law of heat conduction, the rate of flow of heat flux due to conduction in any direction is directly proportional to the temperature gradient present in that direction.

$$q = Q/A= -k dt/dx$$

q = Heat flux in watt/m^2
A = Area normal to the direction of heat flow.

Heat flow through infinite slab:-

Consider an infinite slab of thickness 'b'. Let the faces of the slab be maintained at temperature T1 and T2 respectively.

As the length and width of the slab the infinite, the temperature gradient along those directions can be neglected. Therefore temperature is a function of x-direction only.

Hence,

$\delta T / \delta x = dt/dx$

Therefore fourier equation becomes.

$Q/A= -k dt/dx$

$Q/A \, dx = -k dt$

Integrating between the boundary condition

At $x = 0$, $T = T_1$

& $x = b$, $T = T_2$

Therefore

$$\int_0^b Q/A \, dx = -k \int_{T1}^{T2} Dt$$

$$Q/A(x)_o^b = k (T)_{T2}^{T1}$$

$Q = KA (T1-T2)/b$

Electrical analogy of heat conduction:-

The process of flow of energy can be proved to be analogous with the process of flow of electrons through the conductor.

According to ohm's law, the flow of current is proportional to the potential difference.

$$I \alpha \Delta E$$

The relationship is given by

$$I = \Delta E/R$$

Similarly, for the conduction process, we can write

$$Q = \Delta T/R_{th}$$

This shows that the process of heat flow is analogues with the process of flow of current. In above thermal equation the term $R_{th}$is called as thermal resistance. This thermal resistance is analogous to the electrical resistance.

For an infinite slab the thermal resistance is given by,

$R_{th} = b/KA.$

Composite Slab (Slab in Series):-

The problem of heat transfer through the composite system can be solved by the application of thermal resistance concept. Then heat flow can be given by the formula,

$Q = (T1-T4) / \sum R_{th}$

Where ,

T1 = Temperature of inside wall.

T4 = Temperature of outside wall.

$\sum R_{th} =$ Equivalent resistance of the system.

The value of $\sum R_{th}$can be given as,

$$\sum R_{th} = R_1+R_2+R_3$$
$$= (b_1/K_1A) +(b_2/K_2A)+ (b_3/K_3A)$$

Experimental Setup:-

The composite slab consists of three layers of different materials as mild steel, plaster of Paris and wood. The slabs are circular in cross section. The heating element is also circular in shape. In order to ensure equal rate of heat flow both sides of the heating element is sandwiched between two identical seats of composite slabs. Thermocouples are fixed at the interfaces.

Control panel consist of dimmerstat, voltmeter, ammeter, and digital temperature indicator with a selector switch.

Procedure:-

i) Put the main switch on & adjust the dimmest to supply a particular voltage to the heating element.

ii) Wait for the steady state condition.

iii) Note the steady state temperature readings.

iv)Calculate the thermal conductivity of each slab using the formula,

$$Q = KA(T_a-T_b)/b$$

Where Q = Heat input (watt)

A = Cross section area of slab (m^2)

b = Thickness of slab (m)

T_a&T_b = Mean temperature at the interface.

Precaution:-

i) Provide sufficient insulation, so as to reduce the relative & connective losses taking place from lateral surfaces.

ii) Do not touch any electrical connection.

iii) Tighten the screw properly so that uniform heat transfer takes places.

Observation Table:-

"V" Volt	"I" Amp	Temperature of upper slab (^{0}C)				Temperature of lower slab (^{0}C)			
		T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8

Calculation Steps:-

i) Calculate the cross sectional area of circular slab = $(\pi/4)*d^2$…….m^2

ii) Input power to heating coil (Q), Q = V.I. Cos Ø……..watt.

iii)Calculate thermal conductivity of mild steel (K_1)by using following relation.

Heat transfer through 1st slab (mild steel) in axial direction

$$Q/2 = [(K_1*A)/b_1]*\{[(T_1+T_5)/2)]-[(T_2+T_6)/2)]\}$$

K_1=……………..W/m^{o}c.

iv) Calculate thermal conductivity of plaster of paris (K_2)by using following relation.

Heat transfer through 2nd slab (POP) in axial direction

$$Q/2 = [(K_2*A)/b_2]*\{[(T_2+T_6)/2)]-[(T_3+T_7)/2)]\}$$

K_2=……………..W/m^{o}c.

v) Calculate thermal conductivity of wood (K_3)by using following relation.

Heat transfer through 3rd slab (wood) in axial direction

$$Q/2 = [(K_3*A)/b_3]*\{[(T_3+T_7)/2)]-[(T_4+T_8)/2)]\}$$

K_3=……………..W/m^{o}c.

vi) To find equivalent thermal conductivity K_{eq} use following equation.

$$Q/2 =(K_{eq}*A)/(b_1+b_2+b_3)*[((T_1+T_5)/2))-((T_4+T_8)/2))]$$

K_{eq} = …………….. W/m^{o}c.

Result:-

Thus following are the values of thermal conductivities in (W/m^{o}c)obtained from the experiment.

i) Thermal conductivity of mild steel (K_1) =

ii) Thermal conductivity of plaster of paris (K_2) =

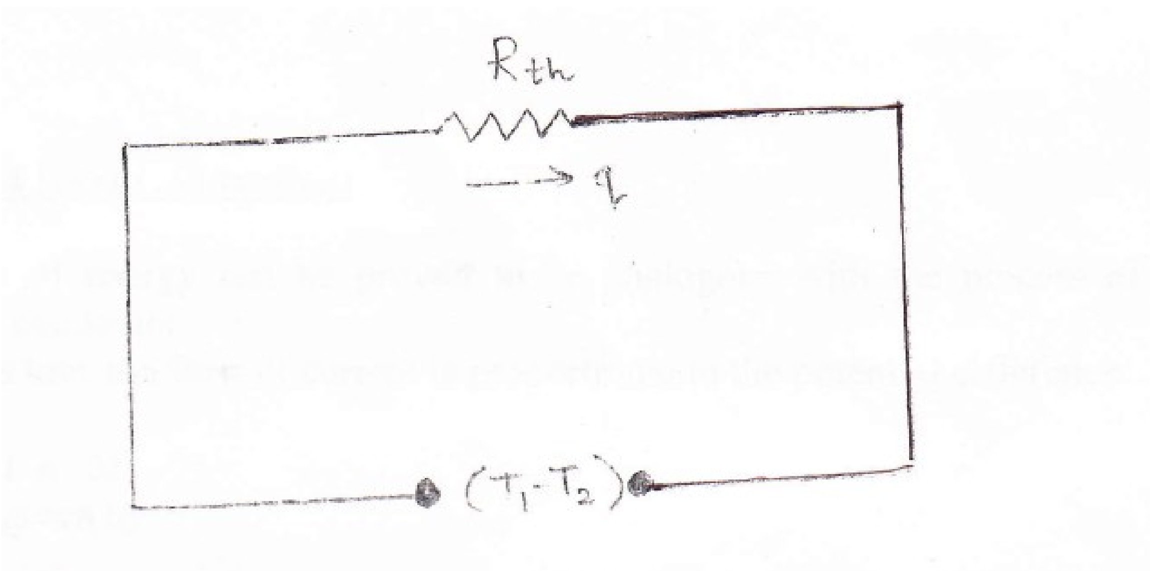
iii) Thermal conductivity of wood (K_3) =

iv) Thermal conductivity of equivalent slab (K_{eq}) =

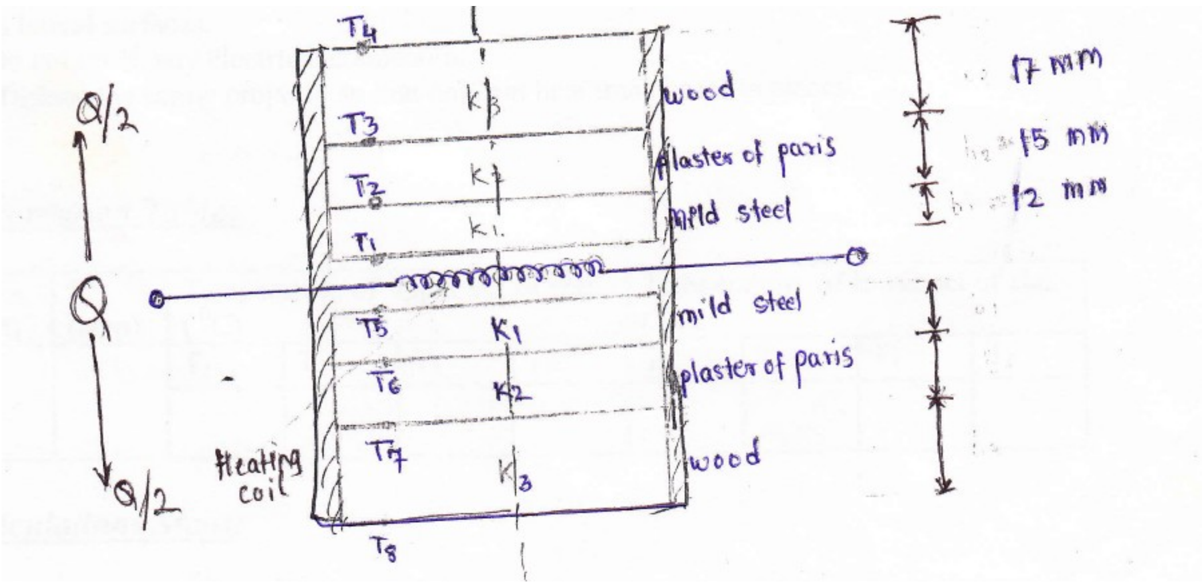
Conclusion:-

Exercise:

1. What does mean by composite wall?
2. Why the heating coil is located at the centre?
3. Explain the experimental setup?
4. Why the insulation is provided along periphery of the slabs?
5. What does mean by equivalent thermal conductivity?



Equivalent electrical circuit



Experimental setup

DATE:

EXPERIMENT NO. 3

Title: DETERMINATION OF STEFAN-BOLTZMANN CONSTANT.

Aim: To determine Stefan Boltzmann constant.

Apparatus: Cooper hemisphere, small copper disc, water tank, thermocouples, digital temperature indicator, stop watch.

Specifications:
1. Mass of copper disc= 3.048 gm
2. Diameter of disc= 30mm
3. Specific heat of copper (C_p) = 385 J/kgK

Theory:

Radiation: Radiation is the transmission of thermal energy without physical contact between the bodies involved. Radiation mode of heat transfer can be affected through vacuums and it does not necessarily affect the medium between the heat sources and receive. Thermal energy transfer is in the form of electromagnetic waves.

Stefan Boltzmann Law: This law states that the emissive power of a black body is directly proportional to fourth power of its absolute temperature.

$$e_b \propto T^4$$
$$e_b = \sigma T^4$$

Where σ is Stefan Boltzmann constant
For black surfaces we get

$$e_b = \int_0^\infty e\, b\lambda * d\lambda$$

Where $e_{b\lambda}$ is given by Planks equation

$$e_b = 5.67*10^{-8}\ T^4$$

Therefore $\sigma = 5.67*10^{-8}\ W/m^2K^4$

Shape factor:
It is defined as a fraction of energy emitted by one surface and directly intercepted by the other surface. The value of shape factor depends only on the geometrical configuration of the system. Hence, also known as geometrical factor or configuration factor.
Shape factor depends on following parameters,
1. Shape and size of the surface.
2. Orientation of the surfaces with respect to each other.
3. The distance between the surfaces.

Experimental setup:

It consists of metallic tank. Bottom of this tank is hemispherical shape and is made of copper. This outer surface of tank is of non conducting type. This is done by converting outer surface of tank by an insulating material. Hot water is poured from top into tank and its hemispherical shaped bottom serves the purpose of radiating body.

Four thermocouples are fixed on the bottom surface at which thermal radiation is being emitted by it. Tank is mounted on a base plate.

Procedure:

1. Remove copper disc from hemispherical shell.
2. Supply hot water from geyser.
3. Observe steady temperature recorded by various thermocouple on hemisphere.
4. When the temperature of hemispherical shell becomes constant, insert the disc at the bottom of hemispherical shell.
5. Note down the initial temperature of Cu disc.
6. Note down the temperature after every 30 seconds.
7. Plot the graph between temperature of disc and time. Find (dT/dt).
8. Calculate the Stefan Boltzmann constant using formula.

$$\sigma = mC_p(dT/dt)_{t=0}/A(T_{avg}^4 - T_a^4)$$

Precautions:

1. Don’t touch any electrical connection.
2. Maintain constant flow of the water.

Observation table:

Temperature of hemispherical surface:

$T_1\,^0C$	$T_2\,^0C$	$T_3\,^0C$	$T_4\,^0C$

Temperature of Cu disc with respect to time:

Time (sec)	Temperature (^0C)
0	

Calculation steps:

1. Find average temperature of hemispherical shell $T_{avg} = (T_1 + T_2 + T_3 + T_4)/4$
2. Plot the graph between temperature of copper disc and time
3. From graph calculate dT/dt.

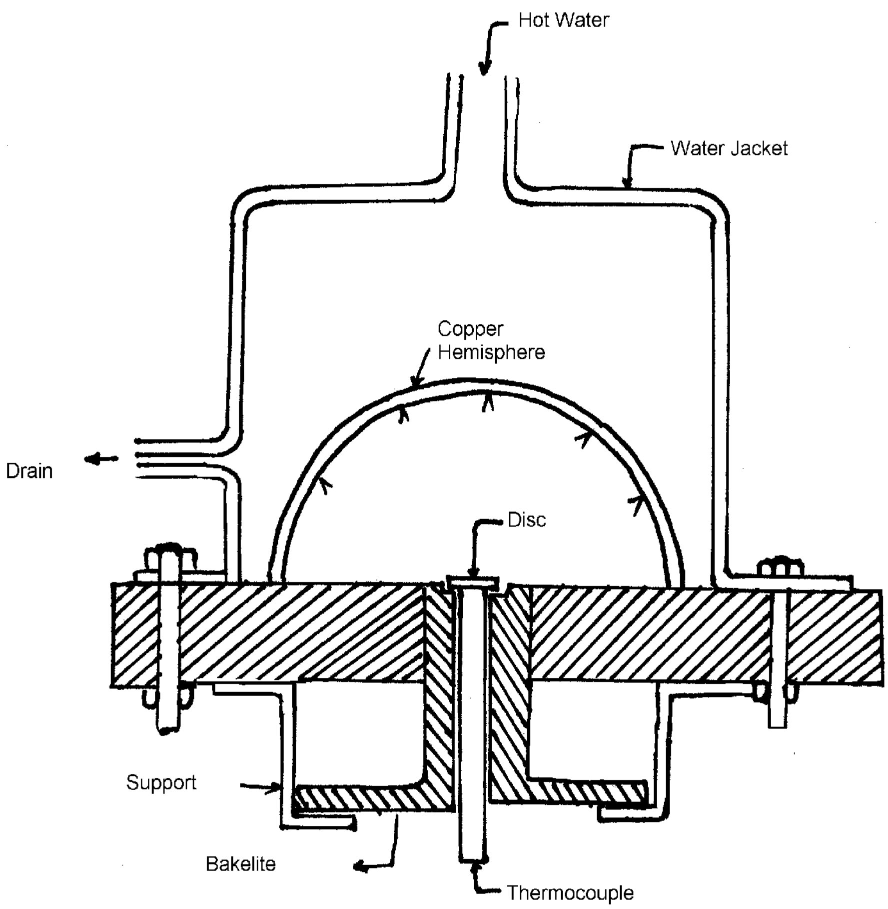
4. Calculate the surface area of copper disc.
5. Calculate $\sigma = mC_p(dT/dt)_{t=0}/A(T_{avg}^4 - T_a^4)$

Result:
The experimental value of Stefan Boltzmann constant = ... W/m^2K^4

Conclusion:

Exercise:

1. What is statement of Stefan Boltzmann law?
2. What is the value of Stephen Boltzmann constant?
3. Explain experimental setup?
4. Why the hemispherical bowl shape is selected in experiment?
5. What is procedure of conducting the experiment?



Stefen Boltzman Apparatus

DATE:

EXPERIMENT NO. 4

Title: DETERMINATION OF EMISSIVITY OF A METAL SURFACE

Aim: To determine emissivity of a test surface.

Apparatus: Circular disc of gray and black body, eleven thermocouples, Voltmeter, Ammeter, two separate dimmerstats, Digital temperature indicator.

Specifications:

1. Voltmeter range 0-300V
2. Ammeter range 0-5A
3. Dimmerstat range 0-2A / 230V
4. Temperature indicator range 0-999^{0}C
5. Diameter of specimen= 150 mm
6. Diameter of black body= 150 mm

Theory:

Black body: Black body is the body that absorbs all incident radiant energy and reflect none.

Gray body: Gray body is the body with surface for which monochromatic properties are constant over all wavelengths. It is an idealized body.

Emissivity: Emissivity of a surface is defined as "the ratio of emissive power of a given or test surface (e) to emissive power of a perfectly black surface (e_b), both surfaces are maintained at same temperatures.

$$E= e/e_b$$

Emissivity of perfect black surface is 1 and emissivity of a perfect white surface is 0. All the practical surfaces are having emissivity between 0 to 1.

Emissive power: Emissive power of a surface is the total energy emitted by surface per unit area per unit time. Its unit is w/m^2.

Experimental setup:

1. It consist of two circular copper plates, one is with black surface and other test specimen. The plates are made up of similar size and heat loss by conduction and convection is same for both the plates.
2. Each plate is provided by heating coil at the bottom. The heat supplied to each plate is varied by dimmerstat and is measured with the help of voltmeter and ammeter.
3. To measure the surface temperature each plate is provided with five thermocouple. Thermocouple number 1 to 5 is mounted on test surface and 6 to 10 are fixed on black body. Both the plates are placed in same glass enclosure.

4. The thermocouple number 11 is left open in the enclosure for measuring surrounding temperature.

Procedure:
1. Put the main switch on.
2. Adjust voltage supply (Give more input to black body)
3. Wait for steady state condition.
4. Take temperature, voltmeter and ammeter readings.
5. Calculate the emissivity of the test surface using formula

$$\varepsilon_s = 1 - [(Q_b - Q_s) / \sigma A(T_s^4 - T_a^4)]$$

where
ε_s= emissivity of test surface
Q_b= heat input to black surface
Q_s= heat input to specimen
A= surface area of the specimen= $(\pi/4)*d^2$
T_s= temperature of specimen
T_a= temperature of surrounding air to black and specimen surface
σ= Stefan Boltzmann constant= $5.67*10^{-8}$ w/m^2K^4
d= diameter of black surface plate= diameter of specimen plate.

Precautions:
1. All electrical connection must properly made.
2. Temperature of both bodies is kept as close as possible.
3. The heat input to black body must be kept slightly higher than that of specimen.
4. Take the reading when steady state condition is reached.
5. Whole set up must be enclosed in glass container.
6. Do not exceed input power beyond 150 W.
7. Do not touch any electrical connections.

Observation table:

Test surface			Black surface			Temperature of test surface (^{0}C)					Temperature of black surface (^{0}C)					Surrounding air temperature (^{0}C)
V Volt	I Amp	Q (W)	V volt	I Amp	Q (W)	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_a

Calculation steps:
1. Calculate the average surface temperature of test specimen as
   $T_s = T_1 + T_2 + T_3 + T_4 + T_5 / 5$
2. Calculate average surface temperature of black surface
   $T_b = T_6 + T_7 + T_8 + T_9 + T_{10} / 5$
3. Calculate surface area of test specimen
   $A = (\pi/4)*d^2$
4. Calculate the heat input to test specimen and black body

$Q_b = (VI)_b$ and $Q_s = (VI)_s$

5. Calculate the emissivity of test specimen

$\varepsilon_s = 1 - [(Q_b - Q_s)/ \sigma A(T_s^4 - T_a^4)]$

Result:

Emissivity of test specimen is =

Conclusion:

Exercise:

1. Define emissivity?
2. On which factors emmisivity value depends?
3. Explain experimental setup?
4. Why two metal plates are used in experiment?
5. Emmisivity of surface depends on which factors?

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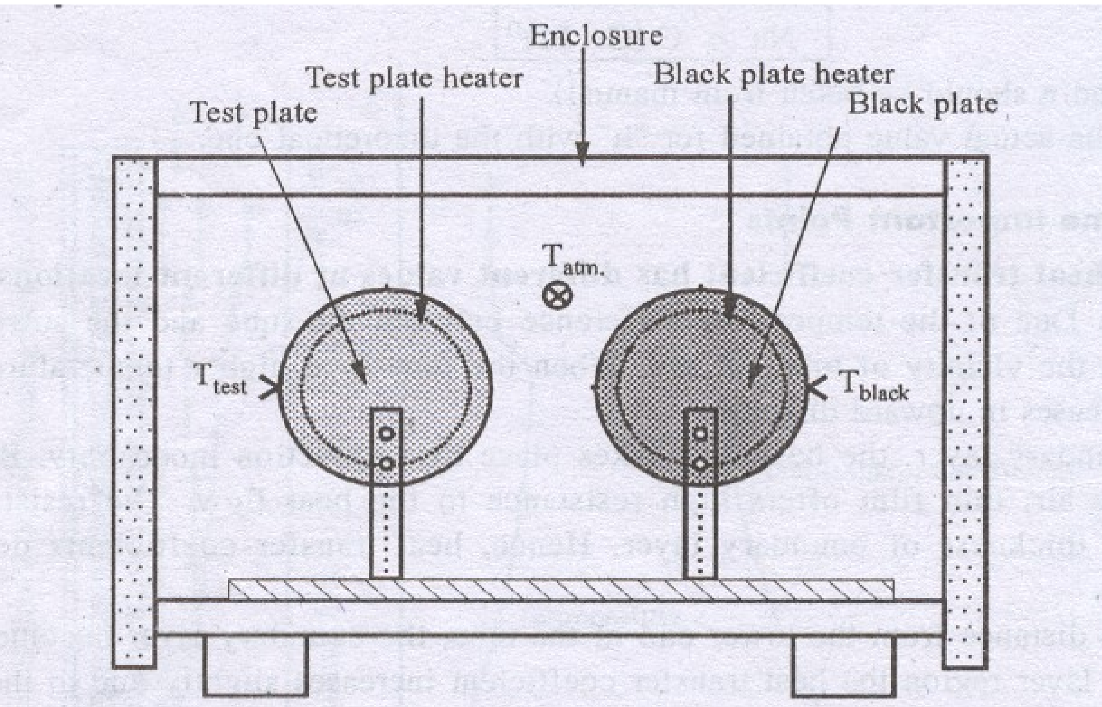

Schematic Diagram for emissivity measurement apparatus

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EXPERIMENT NO. 5

Title: NATURAL CONVECTION HEAT TRANSFER FROM A HEATED VERTICAL CYLINDER

Aim: To determine the film heat transfer coefficient from a hollow vertical tube heated from inside.

Apparatus:A hallow vertical tube, thermocouple, heating coil, voltmeter, ammeter, dimmer stat, temperature indicator, a glass cover.

Specifications:
1. Length of tube= 0.5m
2. Diameter of tube= 0.043m
3. Voltmeter range: 0-300 volt
4. Ammeter range: 0-5 amp.

Theory:

Natural convection:
When a hot body is kept in a cold surrounding, heat is transferred to the surrounding fluid by natural convection. The fluid layer in contact with the body gets heated and the hot fluid due to decrease in density rises up and the cold fluid rushes in from the bottom side. The process is continuous and the cold fluid rushes in from the bottom side. The process is continuous and the heat transfer takes place due to the relative motion of hot and cold fluid particles.
Convection process of heat transfer is observed in practice even in absence of any external element as fan or blower is termed as natural convection.
In quenching process the object gets cooled in a batch, a hot or cold surface kept is still air approaches thermal equilibrium with air. In contrast to forced convection, natural convection phenomenon is due to the temperature difference between the surface and the fluid and is not created by any external agency. The fluid particle makes contact with solid and exchange heat due to the temperature difference as per Newton's law of cooling or heating.

Newton's Law of Cooling:
Newton's law of cooling states that rate of heat flux by mode of convection is directly proportional to temperature difference between surfaces and surrounding. Mathematically we can represent the Newton's law as

$$q \propto (T_s - T_a)$$

whereq....(Q/A_s) heat flux (w/m^2)
A_s.... surface area (m^2)
T_s....average surface temperature
T_a....ambient temperature
Therefore $Q= h A_s (T_s-T_a)$
Where h is proportionality constant called as heat transfer coefficient (w/m^{2}K)

Dimensionless numbers:

Prandtl number (Pr): It is the ratio of kinematic viscosity to thermal diffusivity.

Pr = Molecular diffusivity of momentum/ Molecular diffusivity of heat

Nusselt number (Nu): It is the ratio of rate of heat transfer by convection to rate of heat transfer by conduction.

Nu= $Q_{convection}$/ $Q_{conduction}$ = hL/K or hd/K

Grashoff number (Gr)= It is related only with natural convection heat transfer. It is defined as the product of inertia force and buoyancy force to square of viscous force. Its value indicates whether fluid flow in natural convection is laminar or turbulent.

Experimental setup:

1. Experimental set up consists of a hollow copper tube which is fixed vertically and it is surrounded by gas plates.
2. For the sake of heating of the tube a heating coil is provided placed inside it.
3. To have indication of heating at different places a number of thermocouples are fitted on the surface of the tube along its length.
4. One of these thermocouples is used to record the ambient temperature.
5. The record panel consists of a digital temperature indicator with a selector switch and dimmer stat to control energy supplied to the heater.

Procedure:

1. Make the connections and put switch on.
2. After steady state is reached, note down temperature along the length of the tube.
3. Note down ambient temperature, voltage and current.
4. Calculate heat transfer coefficient by using formula.

$$h= Q/ A (T_s - T_a)$$

where Q= Heat input = VI cos(Ø) (watt)

A= Surface area (m^2)

$(T_s - T_a)$= Temperature difference (^{0}C)

Precautions:

1. Heat transfer from tube surface by natural convection should be ensured by switching off the fans.
2. Reading should be taken after steady state is reached.
3. Do not touch any electric connection.

Observation Table:

Voltage 'V' (volt)	Current 'I' (amp)	Cylinder surface temperature (^{0}C)							Ambient temp
		T1	T2	T3	T4	T5	T6	T7	Ta

Calculation steps:

I) Theoretical heat transfer coefficient

1. Calculate average surface temperature of cylinder

$T_s = T1+T2+T3+T4+T5+T6+T7 / 7$
2. Calculate the mean temperature of film, $T_m = (T_s + T_a)/2$
3. Note down properties of air corresponding to Tm such as density, dynamic viscosity, kinematic viscosity, specific heat, thermal conductivity and Prandtl number.
4. Find Grashoff number, $Gr = (g\ \beta\ \Delta T\ d^3)/\ \nu^2$
5. Find Nusselt number, for Free Cinvection use following relations

$$Nu = 1.1\ (Gr.Pr)^{1/5} \ldots\ldots\ldots\ldots\ldots\ 10 < Gr.Pr < 10^4$$
$$Nu = 0.53\ (Gr.Pr)^{1/4} \ldots\ldots\ldots\ldots\ldots\ 10^4 < Gr.Pr < 10^9$$
$$Nu = 0.13\ (Gr.Pr)^{1/3} \ldots\ldots\ldots\ldots\ldots\ 10^9 < Gr.Pr < 10^{12}$$

6. Find theoretical convective heat transfer coefficient, h form Nusselt number

$$h = (Nu*K)/L \quad (w/m^2K)$$

II) Experimental heat transfer coefficient

1. Calculate heat input to heating coil, $Q = VI\cos(\text{Ø})$
2. Calculate surface area for cylinder, $A = \pi dL$
3. Calculate temperature difference between average cylinder surface and surrounding temperature (Ts- Ta)
4. Calculate Experimental heat transfer coefficient

$$h = Q/\ A\ (T_s - T_a) \quad (w/m^2K)$$

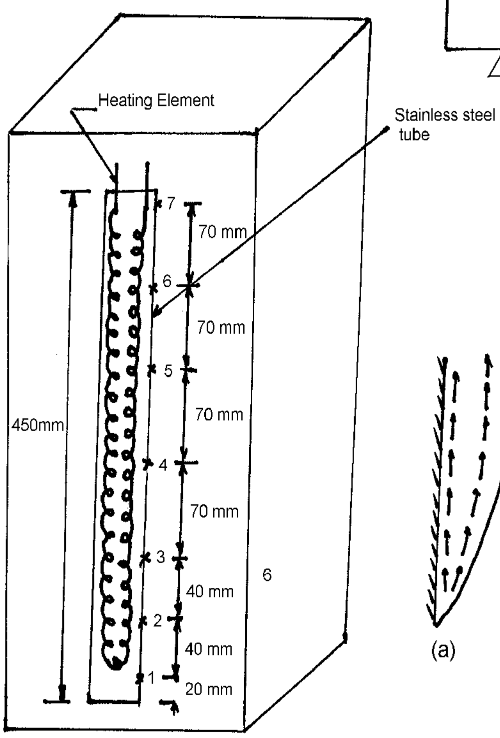
Result:
1. Theoretical heat transfer coefficient=

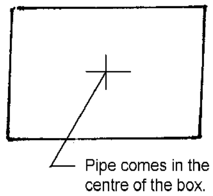
2. Experimental heat transfer coefficient=

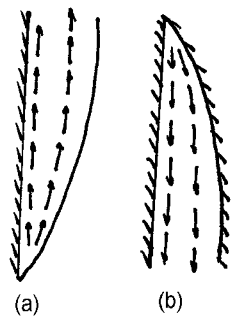
Conclusion:

Exercise:

1. What is the meaning of natural convection?
2. What does mean by convective heat transfer coefficient?
3. Explain experimental setup?
4. Which dimensionless numbers are used for calculation of h?
5. Explain significance of prandtl number?







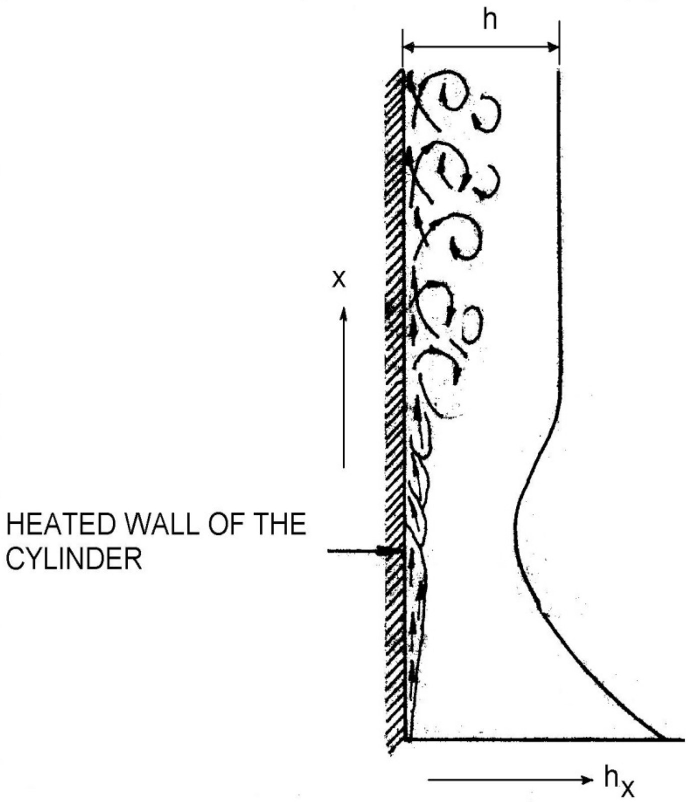
I. D. of pipe ϕ 39 mm

O. D. of pipe ϕ 45 mm

Schematic Test Cylinder

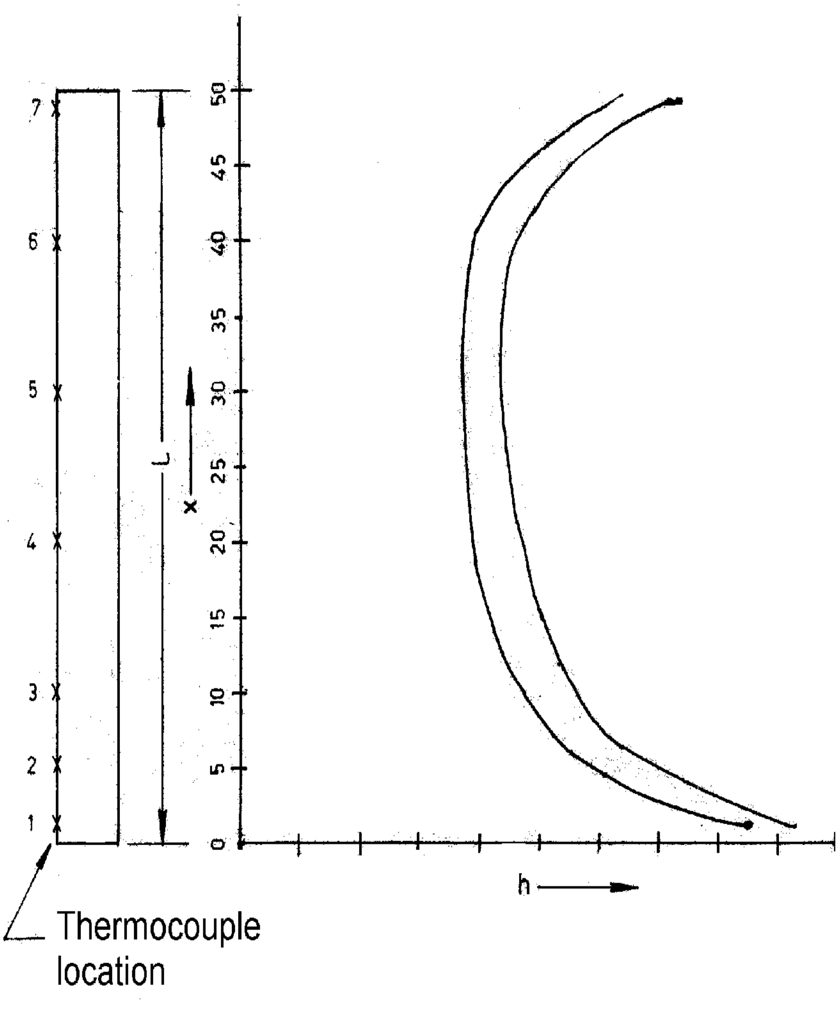
(a) Heated vertical plate

(b) Cooled vertical plate



Variation of the heat transfer
co-efficientalong the heightof the tubein
free air flow and dependance of this
variation on the nature of the flow

DATE:



Variation of local heat transfer

EXPERIMENT NO. 6

Title: HEAT TRANSFER IN FORCED CONVECTION FOR A PIPE LOSING HEAT TO AIR FLOWING THROUGH IT.

Aim: To determine forced convection heat transfer coefficient

Apparatus: Blower along with pipe, dimmer stat, thermocouples, heater, digital temperature indicator, voltmeter, ammeter

Specifications:
1. Voltmeter range= 0- 300 volt
2. Ammeter range= 0 -4 amp
3. Diameter of pipe= 42mm
4. Length of test section pipe= 400mm
5. Orifice diameter= 20mm

Theory:

Forced Convection:
In forced convection fluid are forced to move over surface with the help of some external agent or elements like fan, pump, and blower etc. Obviously in this type we can get higher rates of heat transfer. Following are the examples of forced convection
1) Use of pump to obtain the flow of water through tubes of boiler.
2) Cooling of IC engine cylinder with the help of water pump.

Reynolds number (Re): It is defined as the ratio of inertia force to viscous force.

Re= Inertia force/ Viscous force = $(\rho V D / \mu)$

The Reynolds number indicates that whether the flow of fluid through the pipe is laminar or turbulent.

Experimental setup:
The experimental setup consists of a blower for supply of air through a 42 mm inner diameter pipe, an air heater and the test section. The power to the heater is controlled by a dimmer stat. Temperature of the air at inlet T1 and outlet T8 of the test section are measured by thermocouples located in the air stream. Test section wall surface temperatures (T2 to T7) are measured by thermocouples embedded in the surface at different locations from the entrance. A gate valve is provided in the passage to control the rate of air flow through the system. An orifice plate 20 mm diameter is also fitted near the test section to measure the flow rate. A U tube water manometer is mounted on the panel board which is also having an ammeter, voltmeter, temperature indicator, thermocouple selector switch and dimmer stat on it.

Procedure:
1. Check electrical connections and switch on the heater.
2. Start the blower by keeping the valve fully open.
3. Wait till steady state is reached.

4. Note down the steady state temperature, voltmeter and ammeter readings and also pressure drop across the orifice.
5. Calculate heat transfer coefficient.

Precautions:
1. Do not touch any electrical connection.
2. Make sure that control valve is open.
3. Take carefully reading when steady state is reached.

Observation table:

<table>
<tr><td rowspan="3">V volt</td><td rowspan="3">I amp</td><td colspan="6">Temperature along length of test section (^{0}C)</td><td colspan="2">Temperature of air (^{0}C)</td><td rowspan="3">Manometer reading difference (cm)</td></tr>
<tr><td>T2</td><td>T3</td><td>T4</td><td>T5</td><td>T6</td><td>T7</td><td>At inlet of test section T1</td><td>At outlet of test section T8</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Calculation steps:

I) Theoretical heat transfer coefficient

1. Calculate average surface temperature of test section of pipe

$$Ts= (T2+ T3+ T4+ T5+ T6+ T7) / 6$$

2. Calculate the average temperature of air at test section

$$Ta= (T1+ T8) / 2$$

3. Calculate the mean temperature of film, Tm = (Ts + Ta) /2
4. Calculate the discharge of air through the pipe

Discharge (Qair)= cross section area * velocity of air
Cross section area= $(\pi/4)*(d_0*d_0)$
Velocity of air at orifice= $C_d * \sqrt{\{2 g \Delta h_w (\rho_w / \rho_a)\}}$
Where
d_0... diameter of orifice
C_d... Coefficient of discharge of orifice
Δh_w ... difference in manometer height of water
ρ_w ... density of water
ρ_a ... density of air

5. Calculate velocity of air at test section (V_{TS})

V_{TS} = (discharge of air) / (cross section of pipe at test section)
$= Q_{air}/ \{(\pi/4)*(d_p*d_p)\}$
Where d_p... diameter of pipe at test section

6. Calculate the Reynolds number, $Re= \rho V_{TS} d_p / \mu$
8. Find Nusselt number, $Nu= 0.023 \{(Re)^{0.8} * (Pr)^{0.3} \}$
9. Find the convective heat transfer coefficient form Nusselt number as, $h = (Nu*K)/ d_p$

II) Experimental heat transfer coefficient
1. Calculate heat input to heating coil, Q= VI cos(Ø)....watt
2. Calculate surface area for test section of pipe, A= πdL.....m^2
3. Calculate the temperature difference between average surface temperature of test section and average temperature of air (Ts – Ta).....^{0}C
4. Calculate experimental heat transfer coefficient as,
h= Q/ A(Ts-Ta)......w/m^2K

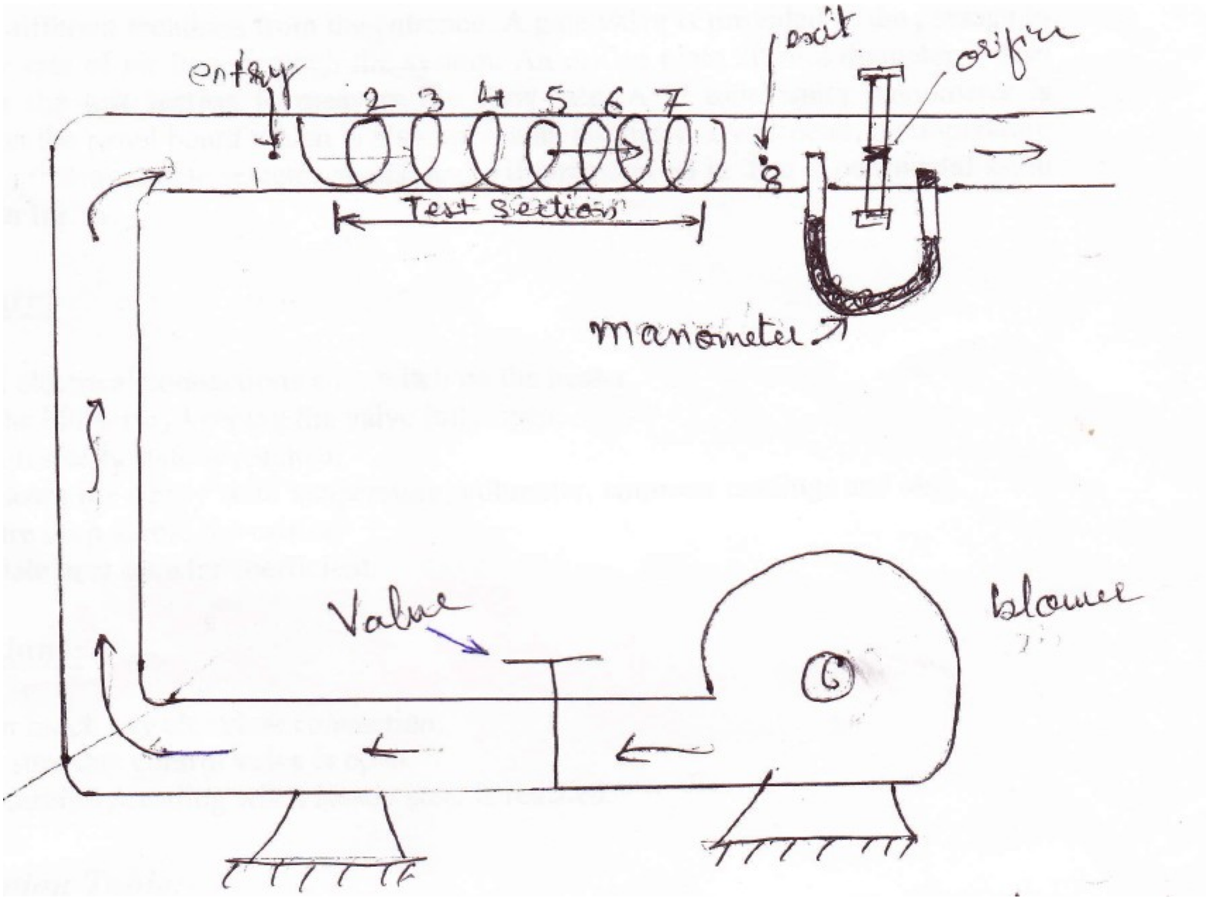
Result:
1. Theoretical heat transfer coefficient=

2. Experimental heat transfer coefficient=

Conclusion:

Exercise:

1. What does mean of Reynolds number?
2. Explain the purpose of orifice meter?
3. Explain experimental set up?
4. What is the range of values of convective heat transfer coefficient for forced convection for air?
5. On what factors value of h depends?



Experimental setup

DATE:

EXPERIMENT NO. 7

Title: - TEMPRATURE DISTRIBUTION ALONG THE LENGTH OF A FIN AND DETERMINATION OF FIN EFFECTIVENESS AND FIN EFFICIENCY.

Aim: -To study temperature distribution on a fin surface and to determine effectiveness & efficiency pin fin.

Apparatus: - Long square duct, blower, pin fin 9of brass) of circular cross section, electric heater, dimmerstat, digital temperature indicator, thermocouples, orifice and u- tube manometer

Specification:-

1. Duct dimensions: - (0.14 x 0.14) m^2
2. Orifice diameter: - 8 mm
3. Pin fin length: - 125 mm
4. Fin diameter: - 12 mm
5. Coefficient of discharge: - 0.62
6. Thermal conductivity of brass: - 111 W/mk
7. Voltmeter Range: - 0-300 Volt.
8. Ammeter Range: - 0.54 Amp.

Therory :-

Introduction:-

In many engineering applications large quantities of heat have to be dissipated from small areas. Heat transfer by convection between a surface & the fluid surrounding can be increased by attaching to the surface this strip of metal called as fins. Fins increase the effective area of the heat transfer surface there by increasing the heat transfer by convection.

Efficiency of fins:-

It is defined as the actual rate of heat flow obtained from the pin fin to maximum possible rate of heat flow that can be obtained from the same fin as shown in fig.4.1 the maximum heat transfer would occur if temperature of the extended surface were equal to the base temperature at all points.

$$\eta_{fin} = \frac{Q_{act}}{Q_{max}}$$

Effectiveness of fins:-

The effectiveness of fins gives the percentile increase in heat transfer rate from the fins provided. This helps in deciding whether fins should be used or not. The effectiveness is defined as the ratio of rate of heat transfer obtained with fins to that obtained without fins.

$\varepsilon = Q_f / Q_b$

Where, Q_f= Rate of heat transfer with fins.

Q_b= Heat transfer from base surface when exposed to the fluid without fins.

We can include that;

1) If **ε < 1:-** It shows that fins reduce the rate of heat flow from the surface. Hence fins should not be provided.

2) If **ε =1:-** It indicates that fins provided do not give any additional rate of heat transfer, from economical consideration, there is no point in providing fins.

3) If **ε> 1:-** Here, fins increases the rate of heat flow, hence fins should be provided but in practice the effectiveness value should be more than two.

Pin Fin:-

When temperature gradient across any cross section of fin can be neglected then the fin is known as a pin fin. This assumption eliminates the complications in analysis of fin. The temperature gradient can be neglected when fin has its cross section area very small relative to it's length & it's thermal conductivity is sufficiently high.

Types of fins:-

Fins with insulated end: - If temperature gradient at the end of any fin is almost equal to zero, we approximate the fin to have it's end insulated. Following equations can be used for fins with insulated end.

i) $(T-T_\infty) / (T_0-T_\infty) = \cos h\ [(m(1-x)] / \cos (m1)$

ii) $Q = (\sqrt{hpKA}) * \tan h(m1)$

iii) $\eta_{fin} = \tan h(m1) / m1$

iv) **ε =** $\tan h(m1) / (\sqrt{hpKA})$

Infinitely long fin:-When we get the temperature at the end of fin almost equal to the surrounding fluid temperature, we approximate the fin to be infinitely long fin. Following equations can be used for infinitely long fin.

i) $(T-T_\infty) / (T_0- T_\infty) = e^{-mx}$

ii) $Q = (\sqrt{hpKA})* (T_0- T_\infty)$

iii) $\eta_{fin} = 1/m1$

Fins with convection of its end:- When at the end of a fin, neither the temperature gradient nor the temperature difference between fin & surrounding fluid is zero, the fin is said to be fins with convection of its end type and following equations can be used for this of fin.

i)$(T-T_\infty) / (T_0- T_\infty) = \{ \cos[m(1-x)]+(h/mk) \sin h [m(1-x)]\}/\{\cos(m1)+[(h/mk) \sin h (m1)]\}$

ii) $Q = (\sqrt{hpKA})* (T_0- T_\infty)*\{[\tan h(m1)+(h1/mK)] / [(h/mk) \tan h(m1)]\}$

Experimental Setup:-

It consists of a long square duct open to atmosphere at one end, while a blower is fixed to the other end. A pin fin is fitted to duct wall. Electric heater is provided to heat the pin fin at it's base as shown in fig.4.3. Control panel consist of dimmerstat which controls the power input to the heater. Five thermocouples are fitted along the length of fin. One thermocouple is used to measure the temperature of air. Digital temperature indicator is used to measure the temperature at different point sensed by thermocouples.

Procedure:-

1. Switch on the heater

2. For natural convection mode open the lid on the upper surface of duct.

3. Note down the temperature after steady state is reached.

4. For forced convection close the lid, switch on the blower and adjust the manometer difference 8-10 cm. of water column and note down the steady temperature.

5. Calculate the effectiveness and efficiency for each case using formulae as given below.

i)$\boldsymbol{\varepsilon} = (\sqrt{pK/hA})* \tan h\{m[1+(d/4)]\}$

ii) $\eta_{fin} = \{\tan\{m[1+(d/4)]\} / \{m[1+(d/4)]\}$

Where, p = Perimeter of fin

K = Thermal conductivity of fin

A = Cross sectional area of fin

h = Convectional heat transfer coefficient.

l = Length of fin

$m = (\sqrt{hp/KA})$

d = Diameter of fin

Precautions:-

1. Do not exceed heat input beyond 150 watt.

2. Do not touch any electrical connection.

Observation Table:-

Convection Mode	Temprature (^{o}c)						Manometer Height(cm)
	Tempature of pin fin (^{o}c)					Atmospheric air temp. Ta (^{o}c)	
	T_1	T_2	T_3	T_4	T_5		
Natural							-------------
Forced							

Calculation Steps:-

(I) For Natural convection mode:-

1. Calculate average surface temperature of fin

$$T_S = (T_1+T_2+T_3+T_4+T_5)/5$$

2. Calculate the mean temperature of fluid.

$$Tm = (Ts+ Ta) /2$$

3. Note down properties of air corresponding to Tm such as μ, ρ, γ, Cp, K and also note down Prandtl number.

4. Find Grashoff number.

$$Gr = (g\ \beta \Delta T\ d^3) / \gamma^2$$

5. FindNusselt number, for free convection condition use following relations.

$$Nu = 1.1\ (Gr.Pr)^{1/5} \text{ ---------------- } 10 < Gr\ Pr < 10^4$$

$$Nu = 0.53\ (Gr.Pr)^{1/4} \text{ ---------------- } 10^4 < Gr\ Pr < 10^9$$

$$Nu = 0.13(Gr.Pr)^{1/3} \text{ ---------------- } 10^9 < Gr\ Pr < 10^{12}$$

6. Find convective heat transfer coefficient, h from nusselt number.

$$h = (Nu*K) / d$$

7. Calculate $m = (\sqrt{hp/K_bA})$

8. Calculateefficiency $\eta_{fin} = \{\tan\{m[1+(d/4)]\} / \{m[1+(d/4)]\}*100$

9. Calculate Effectiveness **ε** $= (\sqrt{pK_b/hA})* \tan h\{m[1+(d/4)]\}$

10. Calculate heat flow rate $Q = (\sqrt{hpK_bA})*(T_s-T_\infty)* \tan h\{m[1+(d/4)]\}$

(II) For Forced convection mode:-

1. Calculate average surface temperature of fin

$$T_S = (T_1+T_2+T_3+T_4+T_5)/5$$

2. Calculate the mean temperature of fluid.

$$Tm = (Ts+ Ta) /2$$

3. Calculate the discharge of air through the air duct.

Discharge (Qair) = cross sectional area x velocity of air.

Cross sectional area = $(\pi/4)(do*do)$

Velocity of air at orifice = $Cd*\sqrt{\{2g\Delta hw(\rho w/\rho a)\}}$

Where, do = Diameter of orifice

Cd = Coefficient of discharge of orifice

Δhw = Difference in manometer height of water

ρw = Density of water

ρa = Density of air.

4.Calculate the Reynolds number

$$Re = \rho\ Vd\ De / \mu$$

Where,

De…..is equivalent diameter of duct = (4* cross section area of duct)/(wetted perimeter)

$De = \{4*(0.14)^2] / \{ 2*(2*0.4)\} = 0.14$ m

Vd….. Velocity of air at pin fin through duct.

$Vd = Qair / \{(\pi/4)(De*De)\}$

5. CalculatePrandtlNimber, $Pr = \{(\mu\ Cp) / Kair\}$

6. FindNusselt Number, $Nu = 0.615\{(Re)^{0.466}*Pr^{1/3}\}$

7. Find convection heat transfer coefficient, h from nusselt number, $h = (Nu*K) /d$

8. Calculate m, $m = (\sqrt{hpK_bA})$

9. Calculate Efficiency. $\eta_{fin} = \{\tan\{m[1+(d/4)]\} / \{m[1+(d/4)]\}*100$

10. Calculate Effectiveness. $\boldsymbol{\varepsilon} = (\sqrt{pK_b/hA})* \tan h\{m[1+(d/4)]\}$

11. Calculate heat flow rate $Q = (\sqrt{hpK_bA})*(T_s-T_\infty)* \tan h\{m[1+(d/4)]\}$

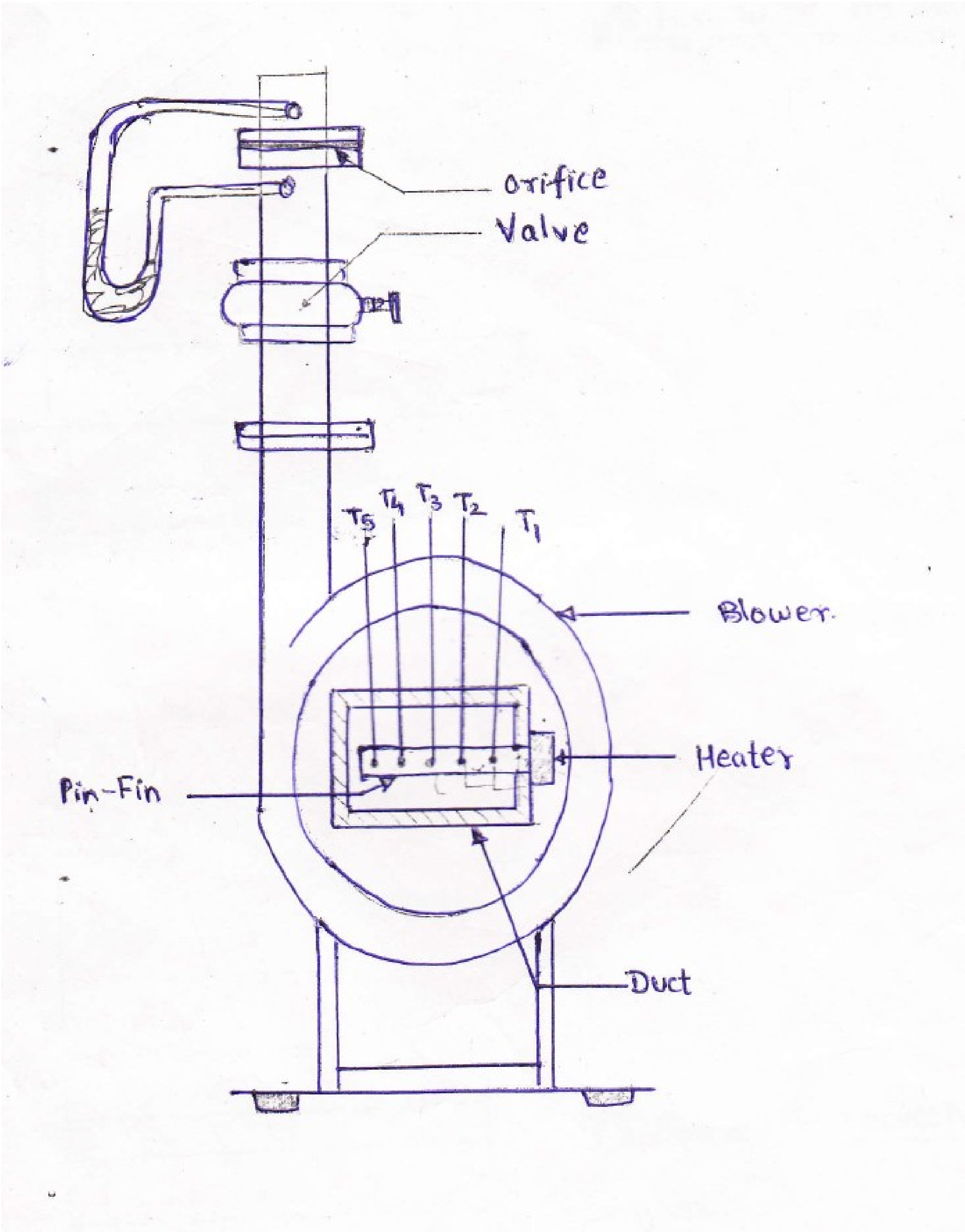
Result:-

Sr.No	Convection Mode	Efficiency	Effectiveness	Heat Flow,Q (Watt)
1.	Natural			
2.	Forced			

Conclusion:-

Exercise:

1. What does mean by pin fin?
2. Explain the experimental setup?
3. Explain effectiveness and efficiency of pin fin?
4. What does effectiveness 10 indicates?
5. Explain relation of heat transfer coefficient with effectiveness?



Experimental setup

DATE:

EXPERIMENT NO. 8

Title: PERFORMANCE OF A PARALLEL FLOW AND COUNTER FLOW HEAT EXCHANGER

Aim: To find effectiveness, overall heat transfer coefficient in parallel and counter flow heat exchanger.

Apparatus: Heating coil, voltmeter, ammeter, thermocouple, stop watch, measuring flask.

Specifications:
Inner tube
i) Inner diameter, di= 16.5 mm
ii) Outer diameter, do= 21.5 mm
Outer tube
i) Inner diameter, Di= 27.5 mm
ii) Outer diameter, Do= 33.5 mm

Length= 1.5 m, K(copper)= 386 w/mk

Theory:

Introduction:
Heat exchanger is a device in which the exchange of energy between two fluids at different temperatures takes place. The fluid which gives the energy is known as hot fluid while one which receives the energy is cold fluid. The heat may be in the form of latent heat or sensible heat. Heat exchangers form a major part of any process industry and hence it is one of the application of heat transfer which draws the maximum attention of a process engineer.

Classification of heat exchanger:
Heat exchangers are device in which heat is transferred from one fluid to another. The necessity for doing this arises in a wide variety of applications including a space heating and cooling, thermal power production and chemical process equipments. By considering the transfer process occurring in them, heat exchangers may generally be classified as Direct transfer type, storage (or regenerated) type and direct contact type.
A Direct transfer type of heat exchanger is one in which the cold and hot fluid flows simultaneously through the device and heat is transformed through the wall separating the fluids. This type of heat exchanger is most widely used in practice. This heat exchanger has concentric tube arrangement. One fluid flows through the inner tube while other flows through annular space between the two tubes. The heat transfer takes place across the walls of the inner tube, although simultaneous flows of both fluids occur in heat exchanger. There is no mixing of two fluids. There are also no moving parts.
A storage type heat exchanger (or Regenerator) is one in which heat transfer from the hot fluid to cold fluid occurs through a coupling medium in the form of porous solid materials. The hot and cold fluid flow alternately through the matrix.The hot fluid storing heat in it and

the cold fluid attracting heat from it. In many applications a continues flow has to be maintained on both hot and cold sides. In such cases it is common to use rotating type matrix.
Unlike the two previous types direct contact type heat exchanger is one in which the two fluids are not separated. If heat is to be transferred between gas and fluid, gas is either bubbled through the liquid or the liquid is separated in the form of droplets in the gas. For heat exchanger between two liquids one liquid is sprayed through the other, the only restriction is that the liquid have to be immiscible. Very often in direct contact heat exchanger the process of heat transfer is also accompanied by mass transfer. Cooling towers and scrubbers are example of such equipment.
The direct transfer type heat exchanger is generally used in most applications. The most serious defect from which it suffers is the fact that with the passage of time, scale and direction tend to accumulates on heat exchanger surface. This accumulation (called foulling) increases the thermal resistance to heat flow, so that the performance of the heat transfer type slowly deteriorates.
In contrast the storage type heat exchanger because of periodic flow reversal tends to the self cleaning. The major disadvantage of storage type is that some mixing of hot and cold fluid is irreversible and that scaling the hot side from the cool side in the rotary design presents considerable difficulty.

Classification according to the flow arrangement:

These are classified as

1. Parallel flow,
2. Counter flow
3. Cross flow heat exchangers.

In the parallel flow heat exchanger, the two fluid streams enter at one end, flow through in the same direction and leaves at the other end. In counter flow, they flow in opposite direction. In cross flow heat exchangers, one fluid moves through the heat exchanger at right angles to the flow path of other fluids.

Experimental setup:
Experimental setup consists of a tube in tube type heat exchanger. Hot water flows through the annular space between inner and outer tubes. A pipe and wall arrangement is provided to select the direction of cold water. Four thermocouples are provided at both inlets and both outlets to measure temperature. Mass flow rate is measured by measuring flask and stop watch.

Procedure:
1. For parallel flow open valves V1 and V4, switch on the heater and adjust the flow.
2. Note down the temperature and mass flow rate of hot and cold fluids at steady state.
3. for counter flow open valves V2 and V3.
4. After adjusting flow rate, note down the temperature and flow rates of both hot and cold fluids.
5. Calculate overall heat transfer coefficient and effectiveness for each case by using the respective formulae.

Precautions:

1. Take thermometer reading correctly.
2. Make sure the heater is properly earthed.
3. Adjust and check the valve positions.

Observation table:

Sr.no.	Type of flow	Volume of hot water collected in 60 sec (ml)	Hot water inlet temp Thi (^{0}C)	Hot water outlet temp Tho (^{0}C)	Volume of cold water collected in 60 sec (ml)	Cold water inlet temp Tci (^{0}C)	Cold water outlet temp Tco (^{0}C)
1	Parallel						
2	Counter						

Calculation step:

- ❖ PARALLEL FLOW

For hot water side

1. Calculate average temperature of water and note down the properties of hot water from properties of water chart required as μ, ρ, Cp, K, Pr etc.
2. Calculate mass flow rate of hot water
   Mass flow rate= discharge*density
3. Find velocity of water
   Velocity= discharge/ cross section area
4. Find out Reynolds number
   Reynolds number= ρ*V*D/μ
5. Find Nusselt number Nu
   Nusselt number= $0.023*Re^{0.8}*Pr^{0.3}$
6. Find out hi as hi= Nu*K/di

For cold water side

7. Calculate average temperature of water and note down the properties of cold water from properties of water chart required as μ, ρ, Cp, K, Pr etc.
8. Calculate mass flow rate of hot water
   Mass flow rate= discharge*density
9. Find velocity of water
   Velocity= discharge/ cross section area
10. Find out Reynolds number
    Reynolds number= ρ*V*D/μ

11. Find Nusselt number Nu
    Nusselt number= $0.023*Re^{0.8}*Pr^{0.3}$
12. Find out ho as ho= Nu*K/do

For both hot and cold water (combined)

13. Find out overall heat transfer coefficient (Ui)
    1/Ui= (1/hi) + (ri/Kcu)*ln(ro/ri) + (ri/Ri)*(1/hi)

14. Find out LMTD

    LMTD= (Thi-Tci) - (Tho-Tco) / ln [(Thi-Tci) / (Tho-Tco)]

15. Find out heat transfer rate

    Q= Ui*(π di L)* LMTD

16. Find out effectiveness

    $\varepsilon = m_h*Cph*(Thi - Tho) / (mCp)_{min}* (Thi - Tci)$

- COUNTER FLOW

For hot water side

1. Calculate average temperature of water and note down the properties of hot water from properties of water chart required as μ, ρ, Cp, K, Pr etc.
2. Calculate mass flow rate of hot water
   Mass flow rate= discharge*density
3. Find velocity of water
   Velocity= discharge/ cross section area
4. Find out Reynolds number
   Reynolds number= ρ*V*D/μ
5. Find Nusselt number Nu
   Nusselt number= $0.023*Re^{0.8}*Pr^{0.3}$
6. Find out hi as hi= Nu*K/di

For cold water side

7. Calculate average temperature of water and note down the properties of cold water from properties of water chart required as μ, ρ, Cp, K, Pr etc.
8. Calculate mass flow rate of hot water
   Mass flow rate= discharge*density
9. Find velocity of water
   Velocity= discharge/ cross section area
10. Find out Reynolds number
    Reynolds number= ρ*V*D/μ
11. Find Nusselt number Nu
    Nusselt number= $0.023*Re^{0.8}*Pr^{0.3}$

12. Find out ho as ho= Nu*K/do

For both hot and cold water (combined)

13. Find out overall heat transfer coefficient (Ui)

    $1/U_i = (1/h_i) + (r_i/K_{cu})*\ln(r_o/r_i) + (r_i/R_i)*(1/h_o)$

14. Find out LMTD

    $LMTD = (T_{hi}-T_{co}) - (T_{ho}-T_{ci}) / \ln[(T_{hi}-T_{co}) / (T_{ho}-T_{ci})]$

15. Find out heat transfer rate

    $Q = U_i*(\pi\, d_i\, L)* LMTD$

16. Find out effectiveness

    $\varepsilon = m_h*C_{ph}*(T_{hi} - T_{ho}) / (mC_p)_{min}* (T_{hi} - T_{ci})$

Result:

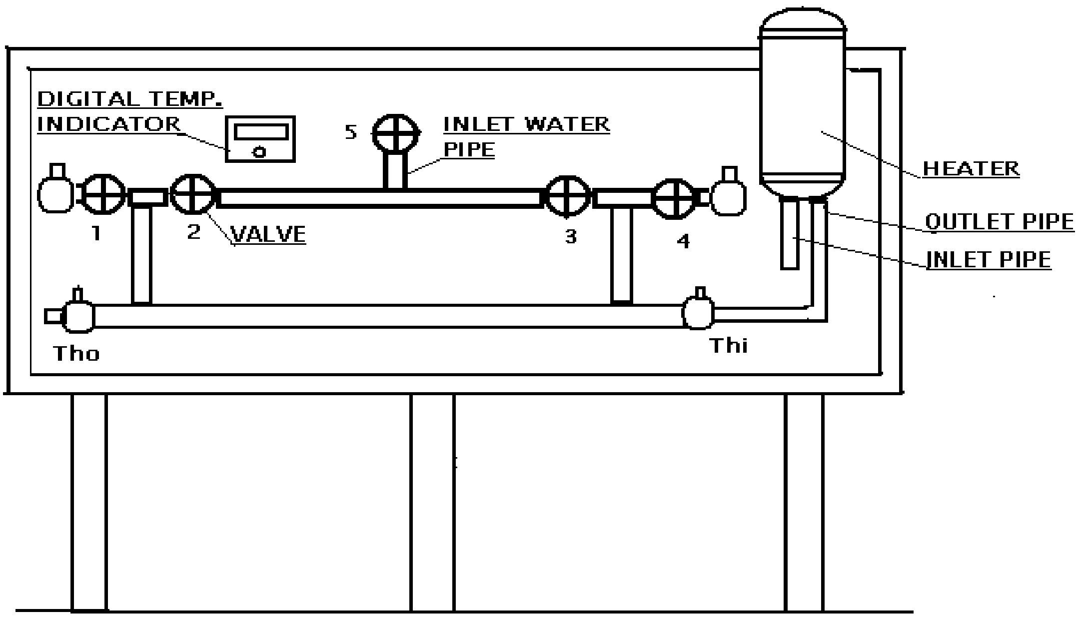
Sr. No.	Type of flow	LMTD (^{0}C)	Heat of flow (w)	Effectiveness
1	Parallel			
2	Counter			

Conclusion:

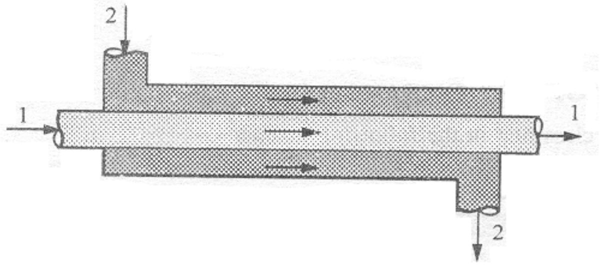
Exercise:

1. What is the meaning of effectiveness of heat exchanger?
2. What are different types of heat exchanger?
3. Explain the experimental setup?
4. Explain procedure of conducting experiment?

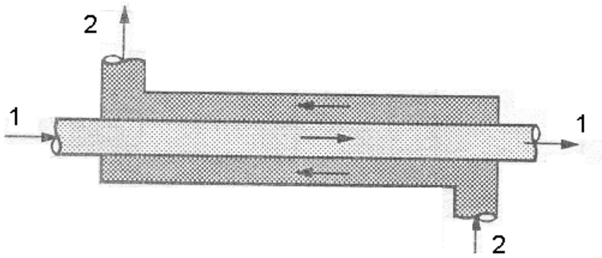
5. What is the meaning of LMTD?



HEAT EXCHANGER APPARATUS

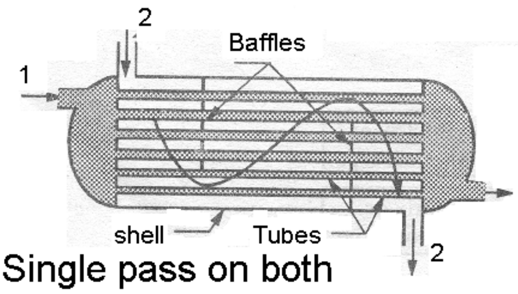


Parallel flow Heat Exchanger

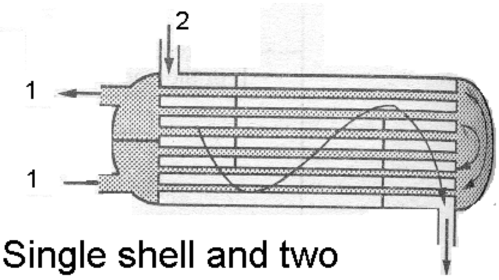


Counter flow Heat Exchanger

Shell and Tube type



Single pass on both sides

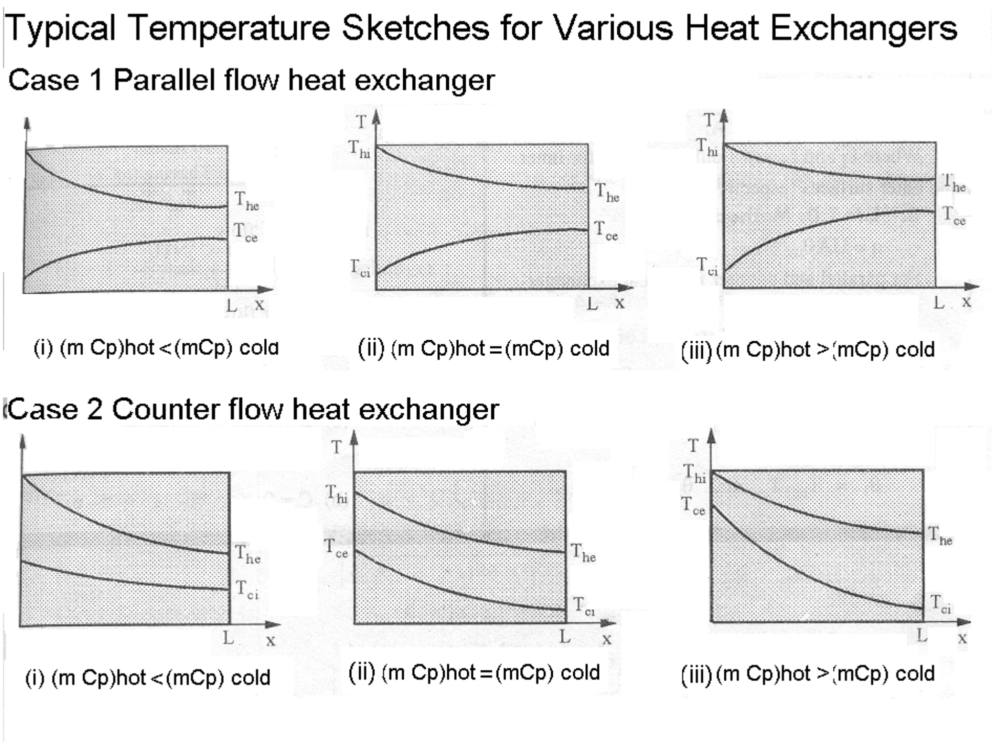


Single shell and two tube passes

DATE:

EXPERIMENT NO. 9

Title:



DETERMINATION OF CRITICAL HEAT FLUX IN POOL BOILING.

Aim: To determine critical heat flux of given metal (Nichrome) wire.

Apparatus: metal wire, glass container, dimmer stat, voltmeter, heater, ammeter, thermometer, nichrome wire

Specifications:

1. Wire diameter= 0.029 mm
2. Wire length= 0.1 m
3. Ammeter range= 0-5 amp
4. Thermocouple range= 0-200 ^{0}C
5. Voltmeter range= 0-120 V

Theory:

Boiling:

When a substance undergoes a change of phase from liquid to vapour while extracting heat from the surface which is at a temperature higher than the saturation temperature of liquid, the phenomenon is known as boiling.
Heat transformed from the solid surface to the liquid is given by

$$Q= h\,(T_s – T_{sat}) = h\Delta T_e$$

Where ΔT_e = excess temperature

Types of Boiling:

1. Pool Boiling: If heat is added to liquid from submerged solid surface, the boiling process is known as pool boiling. In this process the vapour produced may form bubbles, which grow and subsequent ally detach from the surface, rising to the free surface due to buoyancy effects Ex. Boiling of water in a kettle on a stove.

2. Flow or forced convection boiling: This type of boiling occurs in a flowing stream and boiling surface may itself be a portion of the flow passage. A necessary condition for the occurrence of pool boiling is that the temperature of the heated surface exceeds the saturation temperature of the liquid.

3. Sub cooled or local boiling: If the temperature of the liquid is below the saturation temperature the process is called sub cooled or local boiling. In this the bubbles formed at the surface eventually condense in the liquid.

4. Saturated or bulk boiling: If the liquid is maintained at saturation temperature (or higher), the process is called as saturated or bulk boiling. The boiling process depends on the nature of the surface, thermo chemical properties of the liquid and vapour bubble dynamics. Depending upon the different manner it can be explained with the help of graph of Heat flux from the surface vs temperature difference. This graph is known as typical pool boiling curve. The different zones of this curve are Natural convection region, Nucleate boiling region and Film boiling region.

Natural convection region: In this region heat flux increases gradually with increase in temperature difference. This zone is obtained where the difference is very small ($\Delta T \leq 5\ ^0C$). The heat transfer takes place just similar to that natural convection. On this region vapour is produced at the free surface of fluid by evaporation hence it is also known as interface evaporation.

Nucleate boiling region: This is obtained where the temperature difference in the range from 5 to 30 ^0C approximately. The heat flux increases rapidly with temperature difference reaches peak value at the end region. Due to high temperature difference vaporization takes place on the hot surface it self and bubbles of vapour are formed. Due to loss of heat to the fluid, the vapour get condensed and hence bubbles collapse either on the surface of somewhere on its way to the free surface. Because of this no bubbles reach the interface as the bubbles leaves the metal surface almost immediately, the surface is always available for heat transfer and hence in the region the heat transfer rate increases continuously, till it attains a maximum value. The maximum value of heat flux is known as critical heat flux.

Film boiling region: When temperature difference increases further, the rate of bubble formation becomes vary high. The bubble form a blanket over the metal surface with increasing temperature difference, the film gets stabilized and then offers more resistance to heat flow. The point where the surface is completely covered by a vapour blanket is known as Liedenfrost point. It gives the minimum rate of heat flux because the heat transfer from the surface to the liquid occurs by conduction through the vapour.

Critical heat flux: At the end of nucleate boiling region the heat flux attains a maximum value known as critical heat flux.

Significance of critical heat flux: While designing boilers, evaporators the major criteria is to obtain the highest rate of heat flow from the minimum possible areas. This is obtained by achieving maximum rate of heat flux. It can be done by increasing temperature difference. But pool boiling curve shows that with further increase in temperature difference the heat flux reduces.

If one takes the design heat flux value which is more than the critical heat flux value, the graph shows that the corresponding temperature difference required for that is much more. At this layer temperature difference may exceed the melting point of the solid and the failure of the system may occur. Hence one may want to operate the heat transfer surface close to the critical heat flux value, but rarely would want to exceed it.

Experimental setup:

It consists of a water bath with an immersed heating coil in it. Two electrodes are fixed to the lid of water bath while the ends of these protrude in to the water. A thin nichrome wire is connected between the ends of the mains through a dimmer stat. A voltmeter and an ammeter are provided to measure the voltage and an ammeter is provided to measure the voltage and current supplied to the electrodes.

Procedure:

1. Switch on heater and wait until water attains required temperature.
2. Increase voltage supplied to nichrome wire using dimmer stat.
3. Observe voltmeter and ammeter readings at the instant when nichrome wire brakes.
4. Observe different types of boiling occurring during experiments and calculate the heat flux, as

$q = Q/A = VI \cos(\text{Ø}) / \pi dL$.......................$w/mm^2$

where

q= heat flux in .w/mm^2

V= voltage in volt

I= current in ampere

d= diameter in m

L= length in m

Precautions:

1. Do not touch any electrical connections.
2. Switch of the heater for next reading.

Observation table:

Sr. No.	Bulk temperature of water (^0C)	Voltage V (volt)	Current I (amp)

Calculation steps:

1. Find surface area of the wire in sq. mm as, A= πdL.
2. Calculate input power to heating coil in watt as, Q= VI
3. Calculate critical heat flux in w/mm^2

Result table:

Sr.no.	Bulk temperature of water (^{0}C)	Critical heat flux (w/mm^2)

Conclusion:

Exercise:

1. What is the meaning of critical heat flux?
2. Explain the pool boiling curve?
3. What is the procedure of for conducting the experiment?
4. Explain the experimental setup?
5. What is the use of critical heat flux value?

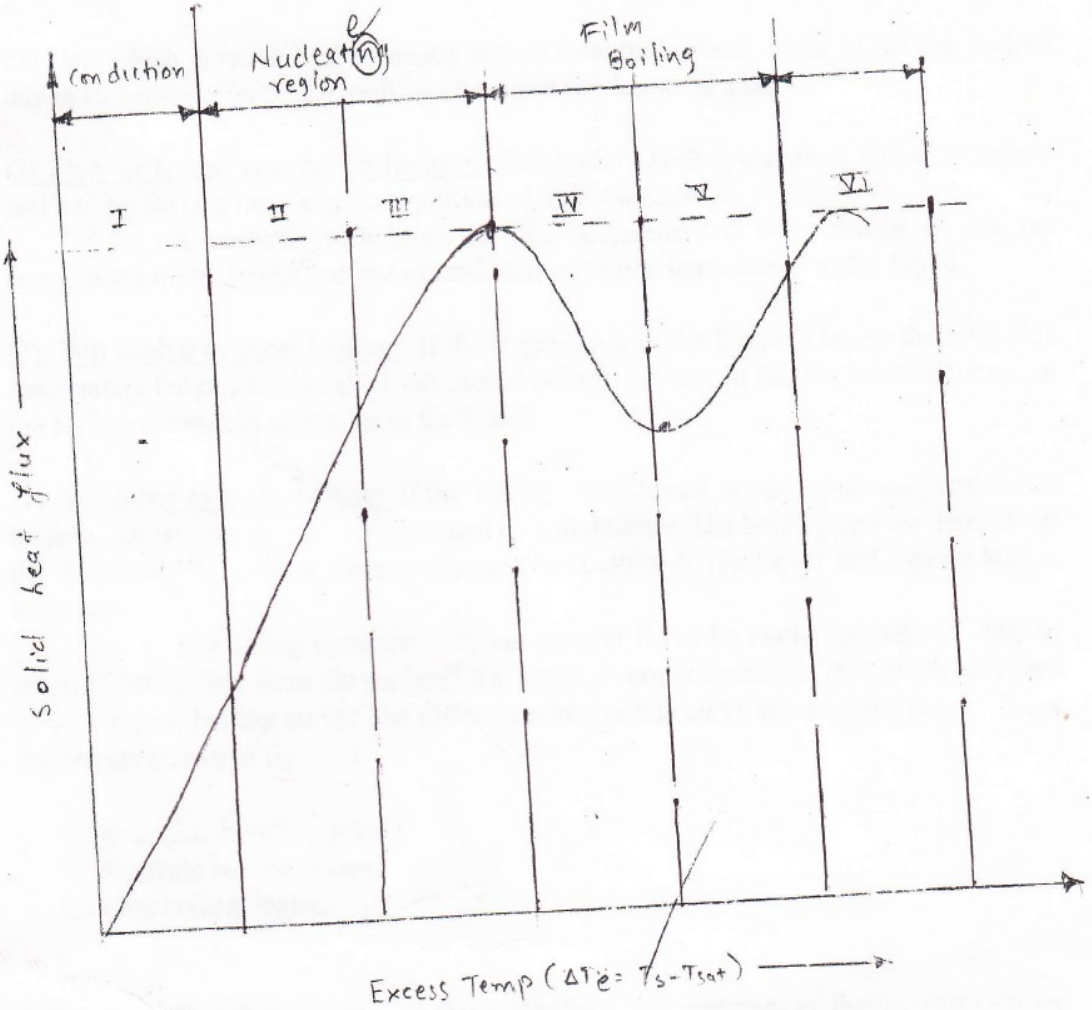


Fig: 9.) pool boiling curve.

I → Heat transfer by super heating liquid rising to liquid vapour interface where evaporation takes place.

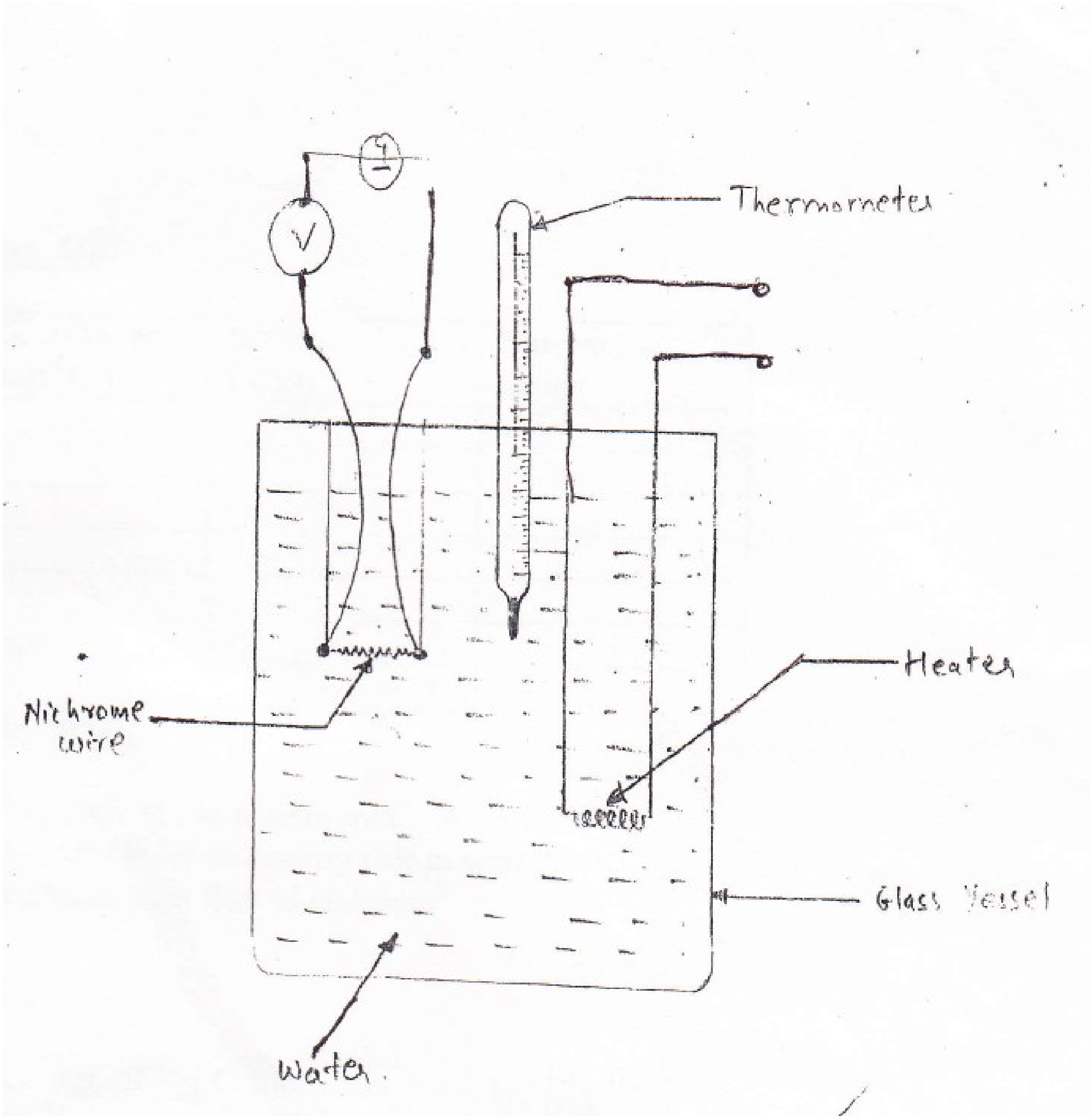
II → Bubble condenses in superheated liquid.

III → Bubble rise to surface

IV → Unstable film

V → Stable film

VI → Reduction through vapour predominant.



Experimental setup

DATE:

ASSIGNMENT NO. 1

DATE:

ASSIGNMENT NO. 2

THERMOPHYSICAL PROPERTIES OF AIR AT ATMOSPHERIC PRESSURE

T (K)	ρ (kg/m^3)	c_p ($kJ/kg \cdot K$)	$\mu \cdot 10^7$ ($N \cdot s/m^2$)	$\nu \cdot 10^6$ (m^2/s)	$k \cdot 10^3$ ($W/m \cdot K$)	$\alpha \cdot 10^6$ (m^2/s)	Pr
Air							
100	3.5562	1.032	71.1	2.00	9.34	2.54	0.786
150	2.3364	1.012	103.4	4.426	13.8	5.84	0.758
200	1.7458	1.007	132.5	7.590	18.1	10.3	0.737
250	1.3947	1.006	159.6	11.44	22.3	15.9	0.720
300	1.1614	1.007	184.6	15.89	26.3	22.5	0.707
350	0.9950	1.009	208.2	20.92	30.0	29.9	0.700
400	0.8711	1.014	230.1	26.41	33.8	38.3	0.690
450	0.7740	1.021	250.7	32.39	37.3	47.2	0.686
500	0.6964	1.030	270.1	38.79	40.7	56.7	0.684
550	0.6329	1.040	288.4	45.57	43.9	66.7	0.683
600	0.5804	1.051	305.8	52.69	46.9	76.9	0.685
650	0.5356	1.063	322.5	60.21	49.7	87.3	0.690
700	0.4975	1.075	338.8	68.10	52.4	98.0	0.695
750	0.4643	1.087	354.6	76.37	54.9	109	0.702
800	0.4354	1.099	369.8	84.93	57.3	120	0.709
850	0.4097	1.110	384.3	93.80	59.6	131	0.716
900	0.3868	1.121	398.1	102.9	62.0	143	0.720
950	0.3666	1.131	411.3	112.2	64.3	155	0.723
1000	0.3482	1.141	424.4	121.9	66.7	168	0.726
1100	0.3166	1.159	449.0	141.8	71.5	195	0.728
1200	0.2902	1.175	473.0	162.9	76.3	224	0.728
1300	0.2679	1.189	496.0	185.1	82	238	0.719
1400	0.2488	1.207	530	213	91	303	0.703
1500	0.2322	1.230	557	240	100	350	0.685
1600	0.2177	1.248	584	268	106	390	0.688
1700	0.2049	1.267	611	298	113	435	0.685
1800	0.1935	1.286	637	329	120	482	0.683
1900	0.1833	1.307	663	362	128	534	0.677
2000	0.1741	1.337	689	396	137	589	0.672
2100	0.1658	1.372	715	431	147	646	0.667
2200	0.1582	1.417	740	468	160	714	0.655
2300	0.1513	1.478	766	506	175	783	0.647
2400	0.1448	1.558	792	547	196	869	0.630
2500	0.1389	1.665	818	589	222	960	0.613
3000	0.1135	2.726	955	841	486	1570	0.536