Thermal Engineering lab

Department of Mechanical Engineering

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(Affliated to Osmania University,Hyderabad)

King koti Road,Abids,Hyderabad

Department of Mechanical Engineering

THERMAL ENGINEERING LABORATORY MANUAL

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CONTENTS

GENERAL INSTRUCTIONS TO STUDENTS

1. Keep the variance to zero voltage position before starting the experiments.
2. Increase voltage slowly.
3. Do not increase voltage above 150 V.
4. Keep all the assembly undisturbed.
5. Operate selector switch of temperature indicator slowly.
6. Operate all the switches and controls gently.
7. Always ensure that the equipment is earthed properly before switching on the supply.
8. Ensure steady state heat transfer before noting down the readings.

COURSE OUTCOMES

1)HEAT TRANSFER THROUGH COMPOSITE WALL

Aim:-

1. **To determine total thermal resistance and thermal conductivity of composite wall.**
2. **To plot temperature gradient along composite wall structure.**

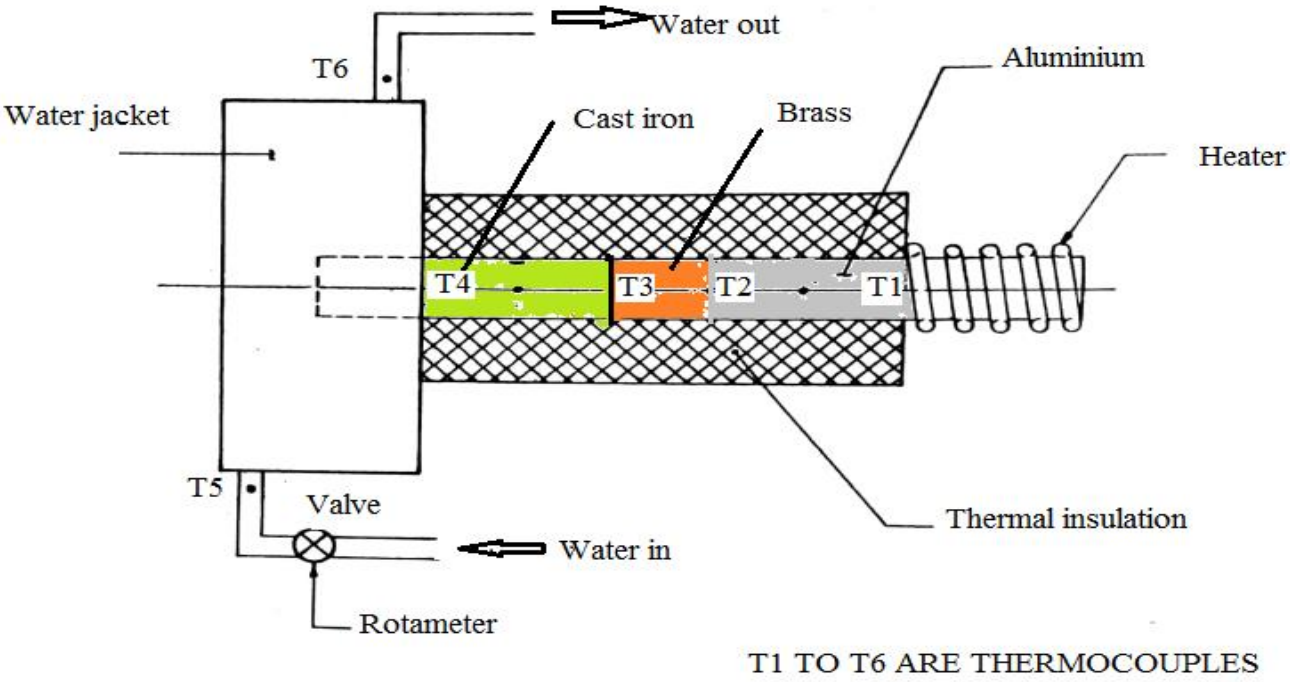
Theory::
The apparatus consists of a cylindrical composite slab made of Aluminium, Brass, Copper . A Nichrome band heater is wraped around the periphery of the slab at one end to heat the composite slab. A Cooling water jacket is provided on other end of a composite structure. The rods are covered with asbestos rope to prevent heat loss. Rotameter is provided to measure flow rate of water across the water jacket A dimmerstat is provided for varying the input to the heater and measurement of input is carried out by a voltmeter and ammeter. Thermocouples are embedded between interfaces of the slabs, to read the temperature. The experiments can be conducted at various values of input and calculation can be made accordingly.

Specifications:
1.Heater: Band heater capacity 400 watt maximum.
2.Heater Control Unit: 0-230V. Ammeter 0-2Amps. Single phase dimmerstat (1No.).
3.Voltmeter 0- 200V. Ammeter 0-2Amps.
4.Temperature Indicator (digital type): 0-200^{o}C. Service required – A. C. single phase 230 V. earthed electric supply.
5.Rota meter 0.2 to 2 LPM
6.Length of Aluminium (L_A) =100mm
7.Length of Brass (L_B) = 20mm
8.Length of Cast iron(L_C) = 50mm
9. Slab Radius = 25 mm.

Procedure:

1. Start the supply of heater by varying the dimmerstat adjust the input at the desired value.

2. Take readings of all the thermocouples at an interval of 10 minutes until fairly steady temperatures are achieved and rate of rise is negligible.
3. Note down the reading in observation table.



Tabularcolumn

S.NO	V	I	Q=V*I Watts	T_1 ^0C	T_2 ^0C	T_3 ^0C	T_4 ^0C	T_5 ^0C Water inlet	T_6 ^0C Water out let	Overall Thermal conductivity (K_O) $\frac{W}{mk}$
1										
2										
3										
4										

Temperature difference Readings: $\Delta T_A = T_1 - T_2$

$\Delta T_B = T_2 - T_3$

$\Delta T_C = T_3 - T_4$

Calculations:

Read the Heat supplied Q = V * I Watts

$$\text{Heat flux}(q) = \frac{Q}{A} \quad \frac{W}{M^2}$$

Where

$$A = \pi r^2$$

r = Radius of Slab =25mm

1. Total thermal resistance of composite slab

$$R_{\text{TOTAL}} = \frac{\Delta T_A - \Delta T_C}{A * (T_1 - T_4)} \quad {}^0\text{C/Watt}$$

2.Thermal conductivity of composite slab.

$$K_{\text{COMPOSITE}} = \frac{Q * L}{A * (T_1 - T_4)} \quad \frac{w}{mk}$$

L = Total thickness of composite slab.=170 mm

3Thermal conductivity of Aluminium ,Brass, Cast iron

$$K_{AL} = \frac{Q * L_A}{A * (T_1 - T_2)} \quad \frac{w}{mk}$$

$$K_{BR} = \frac{Q * L_B}{A * (T_2 - T_3)} \quad \frac{W}{mk}$$

$$K_{CI} = \frac{Q * L_C}{A * (T_3 - T_4)} \quad \frac{w}{mk}$$

2. To plot thickness of slab material against temperature gradient.

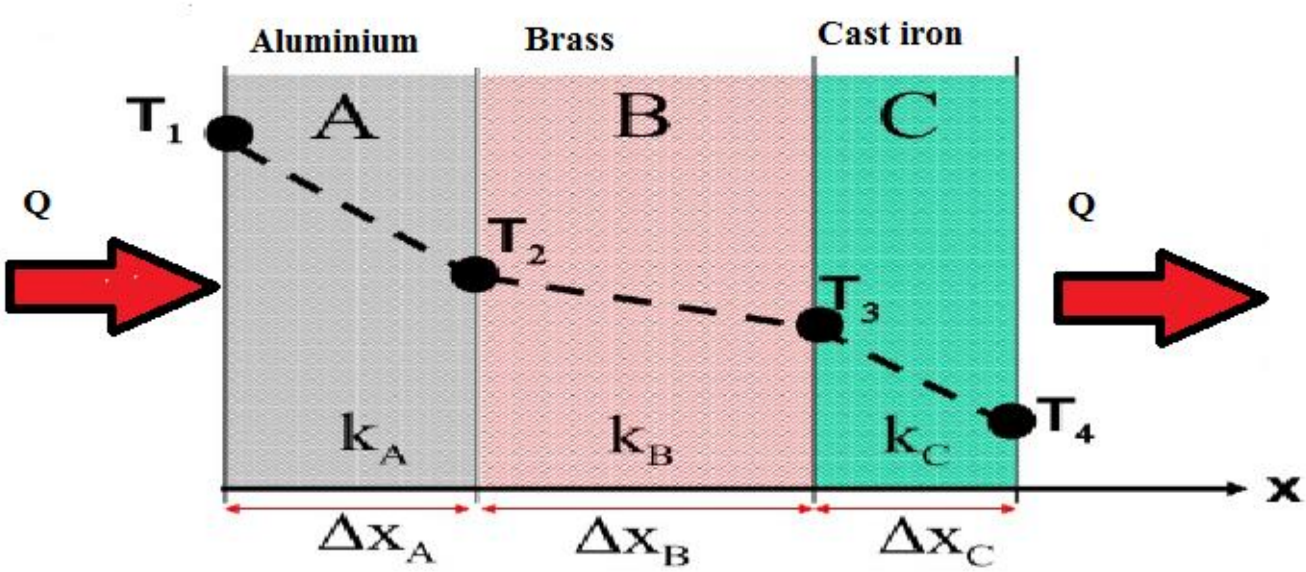


FIG:CONDUCTION THROUGH COMPSITE WALL

RESULT

Thermal conductivity of aluminium = $\frac{w}{mk}$

Thermal conductivity of Brass = $\frac{w}{mk}$

Thermal conductivity of Cast iron = $\frac{w}{mk}$

Overall Thermal conductivity = $\frac{w}{mk}$

CALCULATIONS

VIVA QUESTIONS

1. Define thermal conductivity?
2. For which material thermal conductivity is highest?
3. Why negative sign in Fourier's Law?
4. What are the units of thermal conductivity?
5. What is the first law of thermodynamics?
6. What is the second law of thermodynamics?
7. How is thermal conductivity measured practically?
8. Why are diamonds sinks used in cooling electronic components?
9. What is the physical mechanism of conduction in solids, liquids and gases?
10. What do you mean by "ρc_p"?
11. What is the physical significance of thermal diffusivity?
12. Is heat transfer a scalar or vector quantity?
13. What do you mean by steady heat transfer and how does it differ from transient heat transfer?
14. What is lumped system? How does heat transfer in a lumped system differ from steady heat transfer?
15. How are ordinary and partial differential equations used in heat transfer analysis?
16. What is a boundary condition? Explain.

2.THERMAL CONDUCTIVITY OF METAL ROD

Aim :- **To determine thermal conductivity of metal rod**.

Theory :

Thermal conductivity is the physical property of the material denoting the ease with a particular substance can accomplish the transmission of thermal energy by molecular motion.

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

Mechanism of Thermal Energy Conduction In Metals:

Thermal energy may be conducted in solids by two modes :

1. Lattice Vibration.
2. Transport by free electrons.

In good electrical conductors a rather large number of free electrons move about in the lattice structure of the material. Just as these electrons may transport electric charge, they may also carry thermal energy from a high temperature region to a low temperature region. In fact, these electrons are frequently referred as the electron gas. Energy may also be transmitted as vibrational energy in the lattice structure of the material. In general, however, this latter mode of energy transfer is not as large as the electrons transport and it is for this reason that good electrical conductors are almost always good heat conductor viz. Copper, Aluminium and silver. With increase in the temperature, however the increased lattice vibrations come in the way of the transport by free electrons for most of the pure metals the thermal conductivity decreases with increase in the temperature.

The experimental set up consists of the metal bar, one end of which is heated by an electric heater while the other end of the bar projects inside the cooling water jacket. The middle portion of the bar is surrounded by a cylindrical asbestos rope .

The temperature of the bar is measured at four different sections. The heater is provided with a dimmerstat for controlling the heat input. Water is circulated through the jacket and its flow rate and temperature rise are noted.

Specification:

1. Length of the metal bar (total) : 210 mm
2. Size of the metal bar (diameter) : 38 mm
3. No. of thermocouples : 6
4. Heater coil (Band type) : Nichrome.
5. Water jacket diameter : 80mm
6. Temperature indicator.
7. Dimmerstat for heater coil : 2A / 230 V.
8. Voltmeter 0 to 300 volts.
9. Ammeter 0 to 2 Amps.
10. Rotameter for water flow rate

The heater will heat the bar at its end and heat will be conducted through the bar to other end.
After attaining the steady state.
Heat flowing out of bar = Heat gained by water

$Q_w = M_f * Cp_w * (T_6 – T_5) = K * A * (\Delta T / \Delta T_X)$

Where, M_f : Mass flow rate of the cooling water In Kg / Sec

Cp_w : Specific Heat of water =4.197Kj/Kg K

Heat conducted through the bar (K)

$$Q = K *A* [\Delta T / \Delta T_X]$$

Where, : ΔT = Change in temperature. $(T_1 – T_4)$

ΔT_X : Length.=210 mm

Area of the bar = $A = \frac{\pi}{4} * d^2$

$\frac{\Delta T}{\Delta T_x}$ is obtained from graph

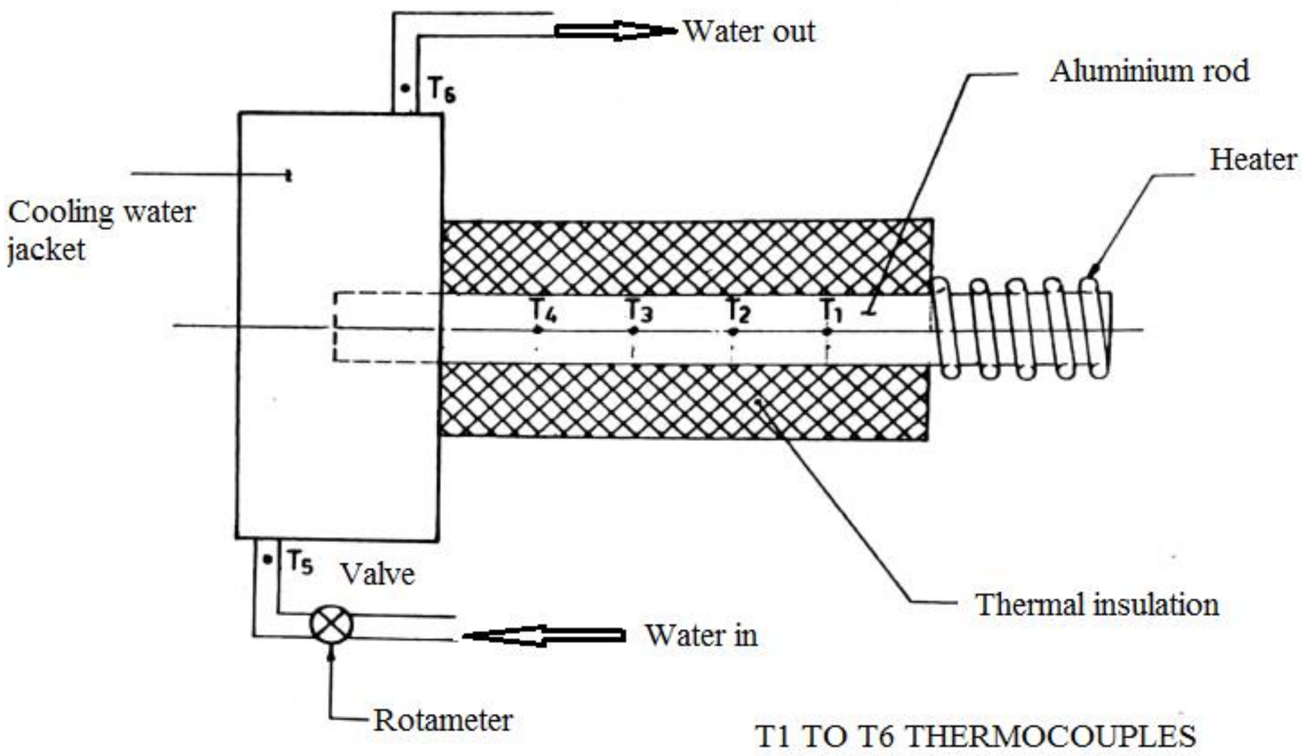


FIG: THERMAL CONDUCTIVITY OF METAL ROD

T_1 , T_2, T_3, &T_4 Thermocouples are kept at a distance of 50 mm

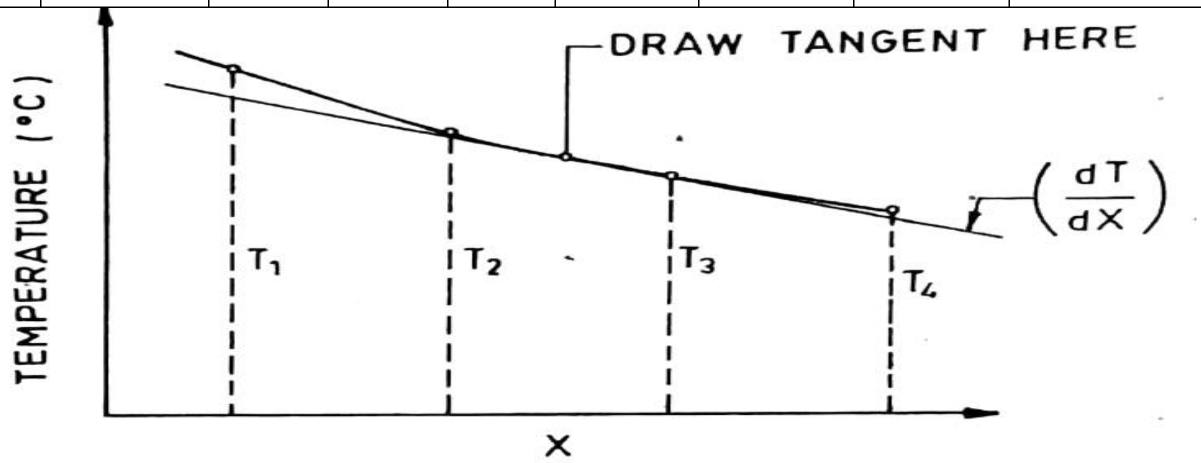
Procedure:

Start the electric supply.

1. Adjust the temperature in the temperature indicator by means of rotating the knob for compensation of temperature equal to room temperature. (Normally this is per adjusted)
2. Give input to the heater by slowly rotating the dimmerstat and adjust it to voltage equal to 80 V, 120 V etc.
3. Start the cooling water supply through the jacket
4. Go on checking the temperature at some specified time interval say 5 minute and continue this till a satisfactory steady state condition is reached.
5. Note the temperature readings
6. Note the mass flow rate of water in Kg/Sec and temperature rise in it.

Tabular column :

S.NO	Mass Flow rate of water Kg/sec (M_f)	T_1 ^0C	T_2 ^0C	T_3 ^0C	T_4 ^0C	T_5 ^0C Water inlet	T_6 ^0C Water out let	Thermal conductivity (K) $\frac{W}{mk}$
1								
2								
3								
4								



GRAPH: TEMPERATURE Vs LENGTH

Calculations:

1. Heat flowing out of bar. = Qw

   Qw = M_f * Cp * (ΔTw) Watts

   Where, M_f : Mass flow rate of the cooling water In Kg/Sec

   Cp :Specific Heat of water =4.197KJ/Kg K

   $\Delta Tw = (T_5 - T_6)$

2. Thermal conductivity of Bar (K)

$$K = \frac{M_f * C_p * \Delta Tw}{\left(\frac{\Delta T}{\Delta Tx}\right) * A} \; W/M\ ^oC$$

Where, dt : Change in temperature. ($T_1 – T_4$)

dx : Length Across temperature. =210 mm =0.21m

A : Area of the bar (π /4 x d^2).

RESULT

Thermal conductivity of metal rod is found out to be K= ------------ $\frac{w}{mk}$

CALCULATIONS

VIVA QUESTIONS

1. Define thermal conductivity.

2. For which material thermal conductivity is highest?

3. Why negative sign in Fourier's Law?

4. What are the units of thermal conductivity?

5. What is the first law of thermodynamics?

6. What is the second law of thermodynamics?

7. How is thermal conductivity measured practically?

8. Why are diamonds sinks used in cooling electronic components?

9. What is the physical mechanism of conduction in solids, liquids and gases?

10. What do you mean by "ρcp"?

11. What is the physical significance of thermal diffusivity?

12. Is heat transfer a scalar or vector quantity?

13. What do you mean by steady heat transfer and how does it differ from transient heat transfer?

14. What is lumped system? How does heat transfer in a lumped system differ from steady heat transfer?

15. From heat transfer point of view, what is the difference between isotopic and un isotopic materials? 16. What is heat generation in a solid?

17. How are ordinary and partial differential equations used in heat transfer analysis?

18. What is a boundary condition? Explain.

19. What is the material for which thermal conductivity is to be found in thermal conductivity of solids experiment

3)HEAT TRANSFER FROM A PIN-FIN APPARATUS

Aim: 1)To draw the variation of temperature along the length of the pin fin under forced convection.
2)To determine the value of heat transfer coefficient under forced convection to find
a)Theoritical values of temperature along the length of the fin
b)Effectiveness and Efficiency of pi fin

Theory:

The heat transfer from a heated surface to the ambient is given by the relation q=hAΔT. In this relation h is the heat transfer coefficient , ΔT is the temperature difference and A is area of heat transfer. To increase q, h may be increased or surface area may be increased. In some cases it is not possible to increase the value of heat transfer coefficient and the temperature difference ΔT and thus the only alternative is to increase the surface area of heat transfer. The surface area is increased by attaching extra material in the form of rod (circular or rectangular) on the surface where we have to increase the transfer rate. "This extra material attached is called the extended surface or fins".

The fins may be attached on a plane surface, then they are called plane surface fins. If the fins are attached on the cylindrical surface, they are called as circumferential fins. The cross section of fin may be circular, rectangular or parabolic.

Temperature distribution and heat transfer from fins from end insulated condition:

Temperature distribution along the length of the fin is

$$\frac{\theta}{\theta 0} = \frac{T-T\infty}{T0-T\infty} = \frac{\cosh m\,(L-x)}{\cosh mL}$$

Where T= Temperature at any distance X from the fin
T_0= Temperature at X=0
T_∞= Ambient Temperature
L= Length of the fin
m= $\sqrt{\frac{hp}{KA}}$ h_c= Convective heat transfer coefficient
p= perimeter of the fin

A= area of the fin

K= thermal conductivity of the fin

Heat flow $q= \theta_0 \tanh mL \sqrt{h * p * k * A}$

Effectiveness Of Fins:

Effectiveness of a fin is defined as the ratio of the heat transfer with fin to the heat transfer from the surface without fins.

For end insulated condition:

$$\varepsilon = \sqrt{\frac{P\,K}{h\,A}}\ \text{Tanh mL}$$

The efficiency of fin is defined as the ratio of the actual heat transferred by the fin to the maximum heat transferred by the fin area were at base temperatures.

$$\eta = \frac{\tanh mL}{mL}$$

An aluminium fin of circular cross section in fitted across a long rectangular duct. The other end of the duct is connected to the suction side of a blower and the air flows past the fin perpendicular to the axis. One end of the fin projects outside the duct and is heated by a heater. Temperature at five points along the length of the fin. The air flow rate is measured by an orifice meter fitted on the delivery side of the blower.

Specifications:

1)Diameter of the fin =15 mm

2)Length of the fin= 170 mm

3)Duct size = 100 mm inner dia

4)Blower = axial flow fan type

5)No: of thermo couples: 3 on the surface of the fin and

2 for air temperature

6)Multichannel Digital Temperature Indicator

7)Voltmeter 0 to 300 volts.

8)Ammeter 0 to 2 Amps.

Thermal conductivity of aluminium, k=232.56 $\frac{w}{mk}$

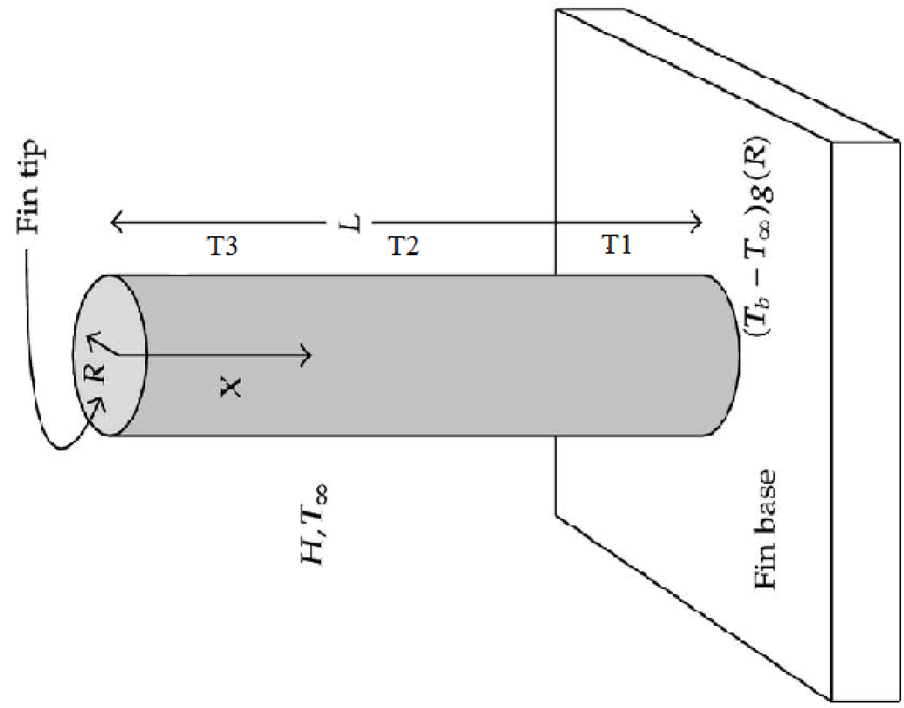


FIG:PIN FIN SETUP

Experimental Procedure:

To study the temperature distribution along the length of a pin fin under natural and forced convection, the procedure is as under

Natural Convection:

1.Start heating the fin by switching ON the heater element and adjust the voltage on dimmerstat to say 50 volt

2.Note down the thermocouple reading.T_1 to T_5

3.When steady state is reached, record the final readings 1 to 5 .

4.Repeat the same experiment with voltage 70volts and 90 volts.

Forced Convection:

1.Start heating the fin by switching ON the heater and adjust dimmerstat voltage.

2.Start the blower and adjust the air flow rate to a particular velocity by operating the blower control knob.

3.Note down the thermocouple readings T_1 to T_5

4.When the steady state is reached, record the final reading

Tabular column :

Natural Convection:

Sr. No.	V Volts	I Amps	Q=V*I Watts	Temperatures				
				T_1 (⁰C)	T_2 (⁰C)	T_3 (⁰C)	T_4 (⁰C)	T_5 (⁰C)
1								
2								
3								
4								

Forced convection:

Sr. No	V Volts	I Amps	Q=V*I Watts	Anemometer reading m/s	Temperatures				
					T_1 (⁰C)	T_2 (⁰C)	T_2 (⁰C)	T_4 (⁰C)	T_5 (⁰C)
1									
2									
3									
4									

Calculations:

1. V_a = Velocity of air in the duct =4.2 m/sec from Aneometer

.Average Surface Temperature of Fin is given by,

$$T_S = \text{Surface temperature} = \frac{T_2 + T_3 + T_4}{3}$$

$$T_\infty = \text{Ambient temperature} = \frac{T_1 + T_5}{2}$$

$$T_M = \text{Mean temperature} = \frac{T_S + T_\infty}{2}$$

From Dry air atmospheric pressure table take the following values from data book

ν= ----------m^2/sec , P_r= -----, K= ----------W/m k , d_f=0.015 m

$$RE = \text{Reynolds number} = \frac{V_a * d_f}{\gamma}$$

The relation for Nu is

2) $Nu = C * R_e^{n} * P_r^{1/3}$

The value of C, and n from standard table

R_e=0.4 to 4.0	C=0.989, n=0.33
R_e=4 to 40	C=0.911, n=0.385
R_e=40 to 4000	C=0.683, n=0.466
R_e=4000 to 40000	C=0.293, n=0.618
R_e=40000 to 400000	C=0.27, n=0.805

$$h_c = \frac{N_u * K}{d_f}$$

Where K Thermal conductivity of air at Mean temperature = ------------ W/m°k

3) $m = \sqrt{\frac{hp}{KA}}$ where P= perimeter= π d_f

A= Area= π/4 * d_f^2

K=Thermal conductivity of Aluminium material=232.56 $\frac{w}{mk}$

4) Temperature distribution is given by

$$\frac{T - T\infty}{T0 - T\infty} = \frac{\cosh m\,(L - x)}{\cosh mL}$$

$$T = T_\infty + (T0 - T\infty)\frac{\cosh m(L-x)}{\cosh mL}$$

Where X is the thermocouple distance at different positions.
$X = X_1, X_2, X_3,$

Where T=Temperatures at above points
$T = T_1, T_2, T_3,$

Given thermocouple distance X_1=30 mm= 0.03 m
X_2= 50 mm= 0.05 m
X_3= 80 mm= 0.08 m

$$T = T_\infty + (T0 - T\infty)\frac{\cosh m(L-x)}{\cosh mL}$$

$T=T_1$ at $X=X_1$, $T=T_2$ at $X=X_2$, $T=T_3$ at $X=X_3$

Distance X in mts	Temperature from experiment in deg. c	Temperature from calculation in deg. c

Effectiveness of pin fin $= \varepsilon = \sqrt{\frac{PK}{hA}}$ Tanh mL

Efficiency of pin fin $= \eta = \frac{\text{Tanh mL}}{\text{mL}}$

Plot a graph of temperature distribution along the length of the pin fin from observed readings. Also draw the graph of calculated temperature readings along the length of the fin

Precautions:

1. See that the dimmerstat is at zero position before switching ON the heater.
2. Operate the changeover switch of temperature indicator, gently.
3. Be sure that the steady state is reached before taking the final reading.

Results :

Heat transfer coefficient for the fin for natural convection is = W/m² K

Heat transfer coefficient for the fin for forced convection is = W/m² K

Effectiveness of the pin fin is = ε=

Efficiency of the pin fin is = η =

CALCULATIONS

CALCULATIONS

VIVA QUESTIONS

1. What is convection?
2. Classify convection.
3. What is forced convection & natural convection?
4. Explain difference between forced convection and natural convection?
5. Force convection in a liquid bath is caused by----
6. Explain Newton's law of cooling?
7. Give the relation between 'Fluid velocity' and 'Heat transfer'?
8. On which properties does convection heat transfer strongly depend?
9. Define convection heat transfer coefficient with dimensions.
10. Define Nussult number.
11. Develop velocity boundary layer for flow over a flat plate?
12. Explain Prandtl number.
13. Fluid properties are evaluated at what temperature?
14. The Prandtl number will be lowest for------
15. What is significance of Nussult's number in convection?
16. The hydro dynamic and thermal boundary layers are identical at Prandtl number equal to-----
17. The temperature gradient in the fluid flow over a heated plate will be------
18. The ratio of heat transfer by convection to that by conduction is called-----
19. Define buoyancy force and discuss significance of the buoyancy force in Natural convection?
20. Define volume expansion coefficient and discuss significance in Natural convection?
21. Define Grashoff number and discuss significance of Grashoff number?
22. What is significance of Rayleigh's number?
23. The free convection heat transfer is significantly affected by----
25. What is significance of Stanton number?
26. The convective heat transfer coefficient from a hot cylindrical surface exposed to still air varies in accordance with------
27. For Laminar conditions, the thickness of thermal boundary layer increases with the distance from the leading edge in proportion to------
28. What is the material used in pin fin experiment?

4.HEAT TRANSFER IN NATURAL CONVECTION

Aim:- To determine the heat transfer coefficient for the surface of the tube in both vertical and horizontal position by natural convection.

Theory:-

When a hot body is kept in still atmosphere, heat is transferred to the surrounding fluid by natural convection. The fluid layer in contact with the hot body gets heated; rise up due to the decrease in its density and the cold fluid rushes in to take place. The process is continuous and the heat transfer takes place due to the relative motion of hot cold fluid particles.

The heat transfer coefficient is given by

$$h = \frac{q - q_1}{A_s * (T_S - T_A)}$$

If heat loss by radiation is neglected

$$h = \frac{q}{A_s * (T_S - T_A)}$$

Where, h = Average surface heat transfer coefficient (W/ m^2 ^{0}C)

q = Heat transfer rate (Watts)

As = Area of heat transferring surface = π. d. l (m^2)

T_s = Average surface temperature = $\frac{T_1+T_2+T_3+T_4}{4}$ ^{0}C

Ta = Ambient temperature = T_5 ^{0}C

q1 = Heat loss by radiation = $\sigma * A * \varepsilon * (T_S^4 - T_A^4)$

Where, σ = Stefan Boltzmann constant = 5.667 $\times 10^{-8}$ W/m^2.K^4

A = Surface area of pipe = (0.05966) m^2 = π D L

ε = Emissive of pipe material = 0.6

T_s and T_a Surface and ambient temperatures in ^{0}K respectively

The surface heat transfer coefficient, of a system transferring heat by natural convection depends on the shape, dimensions and orientation of the fluid and the temperature difference between heat transferring surface and the fluid. The dependence of 'h' on all the above-mentioned parameters is generally expressed in terms on non-dimensional groups as follow

$$\frac{h*l}{k} = A*\left[\frac{g*L^3*\beta*\Delta T}{\vartheta^2}*\frac{C_P*\mu}{K}\right]^n$$

Where,

$\frac{h*l}{k}$ is called the Nusselt number,

$\frac{g*L^3*\beta*\Delta T}{\vartheta^2}$ is called to Grashof Number and

$\frac{C_P*\mu}{K}$ is the Prandtl Number

A and n are constants depending on the shape and orientation of the heat transferring surface.
Where,
L = A characteristic dimension of the surface.

K = Thermal conductivity of fluid.

v = Kinematics Viscosity of fluid.

μ = Dynamic Viscosity of fluid.

Cp = Specific heat of fluid.

β = Coefficient of volumetric expansion for the fluid.

g = Acceleration due to gravity.

ΔT = [Ts – Ta]

For gases,

$$\beta = \frac{1}{T_f + 273} \quad {}^{o}k$$

$$T_f = \frac{T_s + T_a}{2} \quad {}^{o}k$$

Where T_f film temperature

For a vertical cylinder losing heat by natural convection, the constant A and n of equation(2) have been determined and the following empirical correlation obtained.

For horizontal position

$$\frac{h * l}{k} = 0.54 * (Gr * Pr)^{0.25} \quad \text{for} 10^4 < Gr * Pr < 10^8$$

$$\frac{h * l}{k} = 0.13 * (Gr * Pr)^{0.333} \quad \text{for} 10^8 < Gr * Pr < 10^{12}$$

For Vertical position

$$\frac{h * l}{k} = 0.59 * (Gr * Pr)^{0.25} \quad \text{for} 10^4 < Gr * Pr < 10^8$$

$$\frac{h * l}{k} = 0.13 * (Gr * Pr)^{0.333} \quad \text{for} 10^8 < Gr * Pr < 10^{12}$$

L = Length of the cylinder.=500mm

All the properties are determined at the mean film temperature (T_f). from Data book

Specification:

1. Diameter of the tube (d) = 38 mm
2. Length of tube (L) = 500 mm
3. Multichannel Digital Temperature Indicator.
4. Ammeter 0 – 2 Amp.
5. Voltmeter 0 – 200 Volts.
6. Dimmerstat 2 Amp. 240 Volts.
7. Heater :400watts
8. Thermocouples : 5

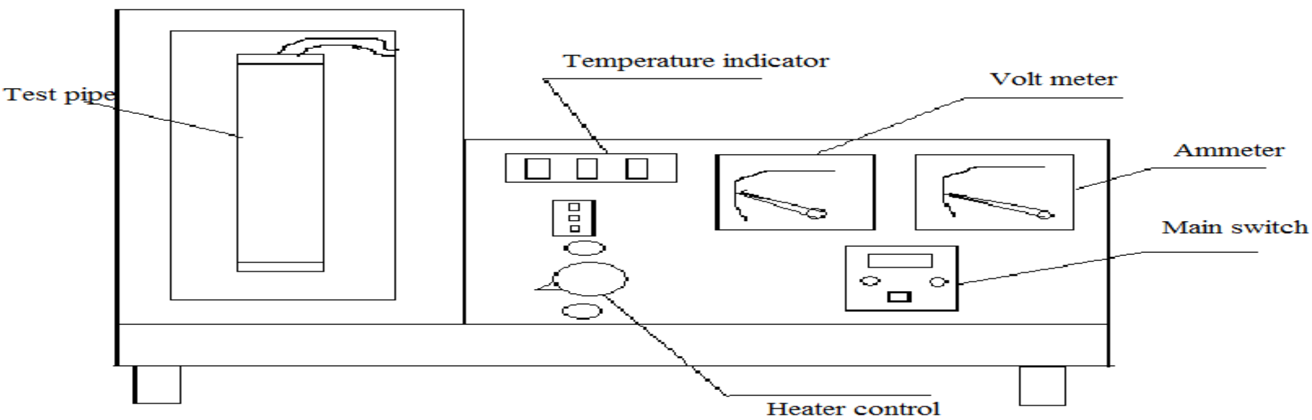


FIG: NATURAL CONVECTION APPARATUS

Procedure:

1. Put ON the supply and adjust the dimmerstat to obtain the required heat input – (Say 40W, 60W, 70W etc)
2. Wait till the steady state is reached, which is confirmed from temperature reading- (T_1 to T_7)
3. Measure surface temperature at the various point i.e. T_1 to T_7.
4. Note the ambient temperature i.e. T_8.
5. Repeat the experiment at different heat inputs (Do not exceed 80w).

Observations

1. O. D. Cylinder = 38mm.
2. Length of cylinder = 500mm.
3. Input to heater Q= V x I Watts.

Tabular column :

S.NO	V	I	Q=V*I	T1	T2	T3	T4	T5	h theory	h Expt
1										
2										
3										
4										

Calculations:

1) Calculate the value of average surface heat transfer coefficient, for vertical and horizontal positions

$$h = \frac{q}{A_s * (T_S - T_A)}$$

2) Compare the experimentally obtained value with the prediction of the correlation equations .

Note – The heat loss due to radiation and conduction is not considered, but they are present, which give different between actual and theoretical values.

RESULTS :-

Heat Transfer coefficient for a vertical tube losing heat by natural convection is found out to be

1)Experimentally h=----------------------$\frac{w}{m^2 k}$

2)Theoritically h=-----------------------$\frac{w}{m^2 k}$

Heat Transfer coefficient for a Horizontal tube losing heat by natural convection is found out to be

1)Experimentally h=---------------------- $\frac{w}{m^2 k}$

2)Theoritically h=----------------------- $\frac{w}{m^2 k}$

CALCULATIONS

CALCULATIONS

VIVA QUESTIONS

1. What is convection?
2. Classify convection.
3. What is forced convection & natural convection?
4. Explain difference between forced convection and natural convection?
5. On which properties does convection heat transfer strongly depend?
6. Define convection heat transfer coefficient with dimensions.
7. Define Nussult number.
8. Develop velocity boundary layer for flow over a flat plate?
9. The Prandtl number will be lowest for------
10. What is significance of Nussult's number in convection?
11. The hydro dynamic and thermal boundary layers are identical at Prandtl number equal to-----
12. The temperature gradient in the fluid flow over a heated plate will be------
13. The ratio of heat transfer by convection to that by conduction is called-----
14. Define buoyancy force and discuss significance of the buoyancy force in Natural convection?
15. Define volume expansion coefficient and discuss significance in Natural convection?
16. Define Grashoff number and discuss significance of Grashoff number?
17. The free convection heat transfer is significantly affected by----
18. The convective heat transfer coefficient from a hot cylindrical surface exposed to still air varies in accordance with------
19. For Laminar conditions, the thickness of thermal boundary layer increases with the distance from the leading edge in proportion to------

5.HEAT TRANSFER IN FORCED CONVECTION

Aim: To determine the heat transfer coefficient in forced convection.

Theory:

In many practical situations and equipments, we invariably deal with flow of fluids in tubes e.g. boiler, super heaters and condensers of a power plant, automobile radiators, water and air heaters or coolers etc. the knowledge and evolution of forced convection heat transfer coefficient for fluid flow in tubes is essentially a prerequisite for an optional design of all thermal system

Convection is the transfer of heat within a fluid by mixing of one portion of fluid with the other. Convection is possible only in a fluid medium and is directly linked with the transport of medium itself.

In forced convection, fluid motion is principally produced by some superimposed velocity field like a fan, blower or a pump, the energy transport is said due to forced convection.

The apparatus consists of a blower unit fitted with the test pipe. The test section is surrounded by a Nichrome band heater. Three thermocouples are embedded on the test section and two thermocouples are placed in the air stream at the entrance and exit of the test section to measure the air temperature. Test pipe is connected to the delivery side of the blower along with the orifice to measure flow of air through the pipe. Input to the heater is given through a dimmerstat.

It is to be noted that only a part of the total heat supplied is utilized in heating the air. A temperature indicator is provided to measure temperatures of pipe wall at various points in the test section. Airflow is measured with the help of orifice meter and the water manometer fitted on the board.

Specification:

Pipe diameter (D_o)	:	38 mm
Length of test section (L)	:	500 mm
Orifice Diameter (d)	:	10 mm

Dimmer stat : 0 to 2 amp, 230 volt, AC

Diameter of the pipe (D_o) = 38 mm

Length of the test section (L) = 500 mm

Diameter of the orifice (d) = 10 mm

Temperature indicator : Digital type and range 0 - 200 °c

Voltmeter :0 -100 /200v

Ammeter : 0 – 2 amp

Heater : Nichrome wire heater wound on Test Pipe (Band Type) 500 watt

T1:- Air Inlet Temperature

T5:- Air Outlet Temperature

T2 ,T3&- T4:- Pipe Wall Temperature

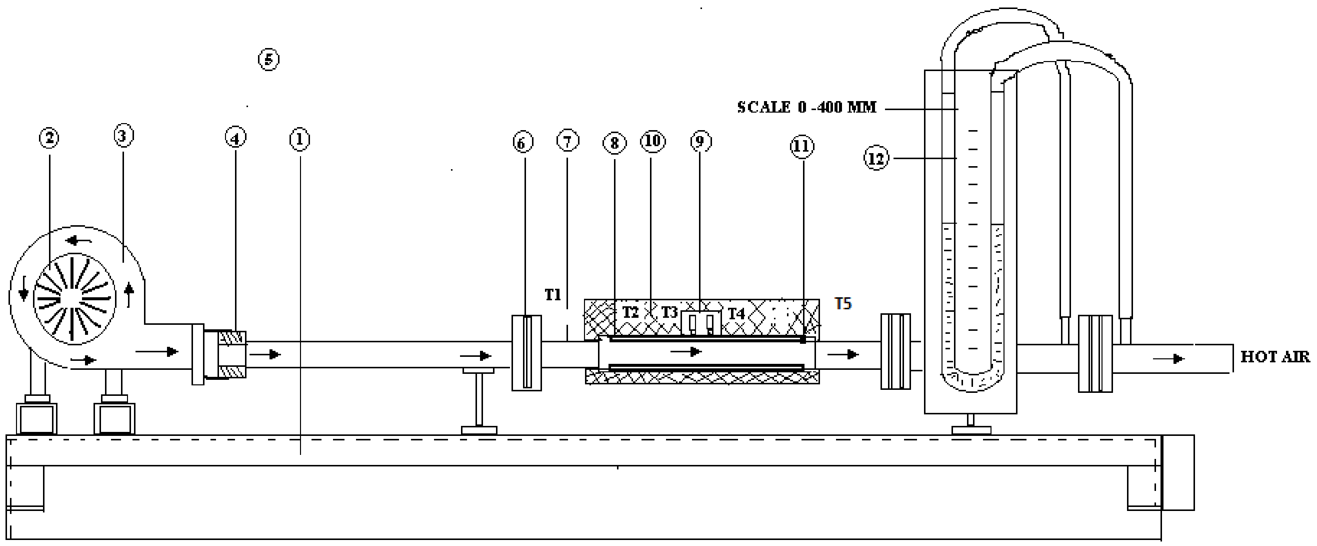


FIG: FORCED CONVECTION APPARATUS

1)Table 2) Motor 3) Blower 4) Adapter 6) Orifice 7) Air Inlet Temperature

8) Mica Covered Heater 9) Heater Socket 10) Foam Packing 11) Stainless Still Cladding 12)Monometer

Procedure:

1. Switch ON the mains system
2. Switch ON blower.
3. Switch ON heater
4. Start the heating of the test section with the help of dimmerstat and adjust desired heat input with the help of Voltmeter and Ammeter. Say 60volts ,70volts etc
5. Take readings of all the six thermocouples at an interval of 10 min until the steady state is reached.

Precaution

1. Keep the dimmer stat at zero position before switching ON the power supply.
2. Increase the voltmeter gradually.
3. Do not stop the blower in between the testing period.
4. Do not disturb thermocouples while testing. Operate selector switch of the thermocouple gently. Don't exceed 200 watts
5. Operate selector switch of the temperature indicator gently.

Tabular column:

S. NO	V (Volts)	I (Amps)	Q=V*I Watts	Temperature in °c					Manometer reading of water H in meter	
				T_1°C	T_2°C	T_3°C	T_4°C	T_5°C	H_1	H_2
1										
2										
3										
4										

Calculation:

1) Ao = Area of Cross Section Orifice in m^2

$$A_o = \frac{\pi}{4} D^2$$

d=dia of orfice=10mm

2) Q = Volume flow rate in m^3 / sec

$$Q = C_d * A_o * \sqrt{2 * g * h * \frac{\rho_w}{\rho_a}}$$

Where,

Cd = Coefficient of discharge of orifice = 0.68

Ao = area of cross section of orifice in m^2

ρ_w = Density of water = 1000 Kg/m^3

ρ_a = density of air at ambient temp. = 1.03 Kg/m^3

H = manometer reading in meter = H_1- H_2

3) Ma = mass flow rate of air in Kg / sec

Ma = Q * ρ_a

Where

ρ_a = Density of air at Ambt. temp. = 1.03 Kg/m^3

4) Δ_T = Temperature rise in air in ^{0}C or ^{0}K

Δ_T = (T_5 – T_1)

5) Q_a = Heat carried away by Air in kJ / sec or Watts

Q_a = m_a * Cp * ΔT

Where,

C_p = specific heat of air= 1.005 KJ / Kg °K

6) Ta = Average Temperature of Air in ^{0}C

$$T_a = \frac{T_1+T_5}{2}$$

7) Ts = Average Surface Temperature in ^{0}C

$$T_S = \frac{T_2+T_3+T_4}{3}$$

8) A = Test Section Surface Area in m^2

A = π * D_i * L

Where,

D_i = Inner diameter of the test pipe in meter

L = Length of the test section in meter

9)h = Heat Transfer Coefficient in $\frac{w}{m^2 k}$

$$h = \frac{Q}{A * (T_S - T_A)} \ \frac{w}{m^2 k}$$

Theoritical calculations:

1)Ac = Cross Test Section Area in m^2

$$A_C = \frac{\pi}{4} {D_i}^2$$

2)V = Mean Velocity of Flow through tube in $\frac{m}{sec}$

$$V = \frac{Q}{A_c}$$

3)Re = Reynold's Number

$$Re = \frac{V\,D}{\vartheta}$$

Where,

υ = Kinematic Viscosity in (m^2/ s) at bulk mean Temp. i.e.

$$\frac{T_1 + T_5}{2}$$

Pr = Prandtle Number

4)Pr = 0.7 at Avg. Temperature

5)Nu = Nusselt Number

$Nu = 0.023 * Re^{0.8} * Pr^{0.3}$

h = heat transfer coefficient calculated by using the correlations

$Nu = 0.26\ Re^{0.6}\ Pr^{0.33}$ ………… For Re <2300 (Laminar flow)

$Nu = 0.023\ Re^{0.8}\ Pr^{0.33}$ ………… For Re >2300 (turbulent flow)

$$NU = \frac{hD}{K}$$

Where,
K = thermal conductivity of air at avg. temp. in --------

RESULTS:-

Heat transfer coefficient in forced convection of air in a tube is found out to be experimentally ------------ $\frac{w}{m^2 k}$

Heat transfer coefficient in forced convection of air in a tube is found out to be Theotitically ------------ $\frac{w}{m^2 k}$

CALCULATIONS

CALCULATIONS

VIVA QUESTIONS

1.What is convection?

2. Classify convection.

3. What is forced convection & natural convection?

4. Explain difference between forced convection and natural convection?

5. Force convection in a liquid bath is caused by----

6. Explain Newton's law of cooling?

7. Give the relation between 'Fluid velocity' and 'Heat transfer'?

8. On which properties does convection heat transfer strongly depend?

9. Define convection heat transfer coefficient with dimensions.

10. Define Nussult number.

11. Develop velocity boundary layer for flow over a flat plate?

12. What is drag force?

13. Define friction coefficient (or) drag coefficient?

14. Explain Reynolds number?

15. What is critical Reynolds number?

16. Explain Prandtl number.

17. Fluid properties are evaluated at what temperature?

18. For forced convection, Nussult number is a function of---------

19. The Prandtl number will be lowest for------

20. What is significance of Nussult's number in convection?

21. The hydro dynamic and thermal boundary layers are identical at Prandtl number equal to-----

22. The temperature gradient in the fluid flow over a heated plate will be------

23. The ratio of heat transfer by convection to that by conduction is called-----

24. What is significance of Stanton number?

25. The convective heat transfer coefficient from a hot cylindrical surface exposed to still air varies in accordance with------

26. For Laminar conditions, the thickness of thermal boundary layer increases with the distance from the leading edge in proportion to------

27. Which dimensionless number has a significant role in forced convection?

6) EMISSIVITY MEASUREMENT APPARATUS

Aim: To determine Emissivity of radiating test plate surface.

Theory-

All substances at all temperatures emit thermal radiation. Thermal radiation is an electromagnetic wave and does not require any material medium for propagation. All bodies can emit radiation and have also the capacity to absorb all or a part of the radiation coming from the surrounding towards it. An idealized black surface is one, which absorbs all the incident radiation with reflectivity and transmissivity equal to zero. The radiant energy per unit time per unit area from the surface of the body is called, as the emissivity of the surface is the ratio of the emissive power of the surface to the emissive power of a black surface at the same temperature. It is noted by E. For black body absorptivity = 1 and by the knowledge of Kirchoff's Law emissivity of the black body becomes unity. Emissivity being a property of the surface depends on the nature of the surface and temperature. It is obvious from the Stefan Boltzmann's Law that the prediction of emissive power of a surface requires knowledge about the values of its emissivity and therefore much experimental research in radiation has been concentrated on measuring the values of emissivity as function of surface temperature. The present experimental set up is designed and fabricated to measure the property of emissivity of the test plate surface at various temperatures

Under steady state conditions:

W_1 = Heater input black plate.

Watts = $V_1 * I_1$

W_2 = Heater input to test plate.

Watts = $V_2 * I_2$

Area of plates = $A = \frac{\pi}{4} D^2$

d = Diam. Of plate = 2000mm

T_1 = Temperature of black body ^0K

T_3 = Inside temperature of enclosure ^0K

T_2 = Temperature of grey body ^0K

E_b = Emissivity of black plate.

(To be assumed equal to unity.)

E = Emissivity of test plate

σ = Stefan Boltzmann constant

$5.67 \times 10^{-8} \frac{W}{M^2K^4}$

By using the Stefan Boltzmann Law:

$$W_1 - W_2 = \frac{(E_b - E) * \sigma * A * (T_1^4 - T_2^4)}{0.86}$$

Specifications:

1. Test plate made of circular aluminium plate with polished surface, mounted on asbestos cement sheet,diameter:200mm
2. Black body made of circular aluminium plate with surface black Teflon coated, mounted on asbestos cement sheet,diameter:200mm
3. Heaters for Nichrome strip wound on mica sheet and sandwiched between two mica sheets capacity of heater = 200 watts each approx.
4. Digital voltmeter and ammeter.
5. Enclosure size 580mm x 300mm x 300mm approximately with one side Perspex and bottom fitted on cement sheet.
6. Thermocouples – Choromel Alumel – (3Nos).
7. Channel selector and digital temper display.
8. Regulator to vary input power to heaters independently.

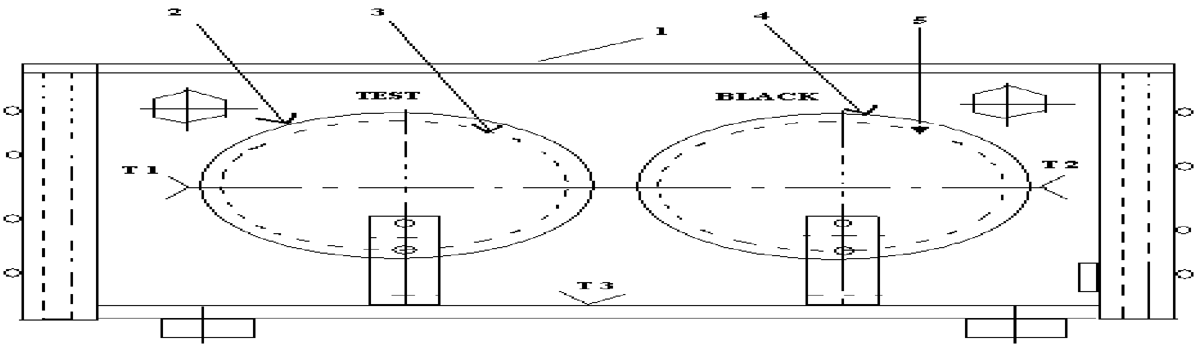


FIG: EMISSIVITY MEASUREMENT APPARATUS

(1) Enclosure (2) Test Plate (3) Test Plate Heater (4) Black body

(5) Black body Heater T 1 to T 3 Thermocouple Position

Procedure:

1. Gradually increase the input to the heater to black plate and adjust it to some value viz. 30, 50, 75 watts and adjust the heater input to test plate slightly less than the black plate 27, 35, 55 watts etc.
2. Check the temperature of the two plates with small time intervals and adjust the input of test plate only, by the dimmerstat so that the two plates will be maintained at the same temperature.
3. This will required some trial and error and one has to wait sufficiently (more than one hour or so) to obtain the steady state condition.
4. After attaining the steady state condition record the temperatures. Voltmeter and Ammeter readings for both the plates.
5. The same procedure is repeated for various surface temperatures in increasing order.

Tabular column:

Sr. No.	BLACK BODY				TEST PLATE				ENCLOSURE TEMP.	Emissivity E
	V_1	I_1	$W_1=V_1 * I_1$ Watts	T_1	V_2	I_2	$W_2=V_2 * I_2$ Watts	T_2	T_3 ^0C	
1										
2										
3										
4										

Calculations:

$$W_1 - W_2 = \frac{(E_b - E) * \sigma * A * (T_1^4 - T_2^4)}{0.86}$$

$\sigma = 5.67 \times 10^{-8} \frac{W}{M^2 K^4}$

E = Emissivity of Test plate to be determined

This fact could be verified by performing the experiments at various values of T_2 and E can be plotted in a graph

$$E = 1 - \left\{ \frac{0.86 * (W_1 - W_2)}{\sigma * A * (T_1^4 - T_2^4)} \right\}$$

Result :
Emissivity of radiating test plate surface is found out to be E = --------------

CALCULATIONS

VIVA QUESTIONS

1. Explain Radiation.
2. Heat energy transfers in radiation in which form?
3. What is a Block body?
4. Explain Stefan – Boltzman's law? What is value of the Stefan – Boltzman contant?
5. Explain spectral blackbody emissive power?
6. Discuss Planck's distribution law.
7. Define emissivity.
8. Explain obsorptivity, reflectivity and transmissivity.
9. Define irradiation.
10. Explain Kirchoff's law.
11. Radiation between two surfaces mainly depends on-----
12. Define Shape factor (or) view factor (or) configure factor (or) angle factor
13. Explain Radiosity?
14. Explain Radiation Heat transfer between two surfaces?
15. What is network representation and what is its algebra?
16. Define Radiation shields?
17. Thermal radiation occur in the portion of electro magnetic spectrum between the wavelengths ----- 18. For infinite parallel plates with emissivities $\varepsilon 1$ and $\varepsilon 2$ shape factor for radiation from surface 1 to surface 2 is ------

7.Stefan Boltzmann Apparatus

AIM

To determine the Stefan- Boltzmann's constant in the radiation heat transfer.

Theory:

All the substances emit thermal radiation. When heat radiation is incident over a body, part of radiation is absorbed, transmitted through and reflected by the body. A surface which absorbs all thermal radiation incidents over it is called black surface. For black surface, transmissivity and reflectivity are zero and absorptivity is unity. Stefan Boltzmann Law states that emissivity of a surface is proportional to fourth power of absolute surface temperature i.e.

$E \alpha T^4$

Then heat transfer rate $Q = \sigma * A * (T_H^4 - T_C^4)$

Where

E = emissive power of surface, W / m2 T = absolute temperature

σ = Stefan Boltzmann constant

σ = 5.667 x 10-8 W / m^2 K^4

T_H = Temperature of hot body

T_C = Temperature of cold body

The Apparatus consists of a water-heated jacket of hemispherical shape. A copper test disc is fitted at the center of jacket. The hot water is obtained from a hot water tank, fitted to the panel, in which water is heated by an electric immersion heater. The hot water is taken around the hemisphere, so that hemisphere temperature rises. The test disc is then inserted at the center. Thermocouples are fitted inside hemisphere to average out hemisphere temperature. Another thermocouple fitted at the center of test disc measures the temperature of test disc. A timer with a small buzzer is provided to note down the disc temperatures at the time intervals of 25 seconds.

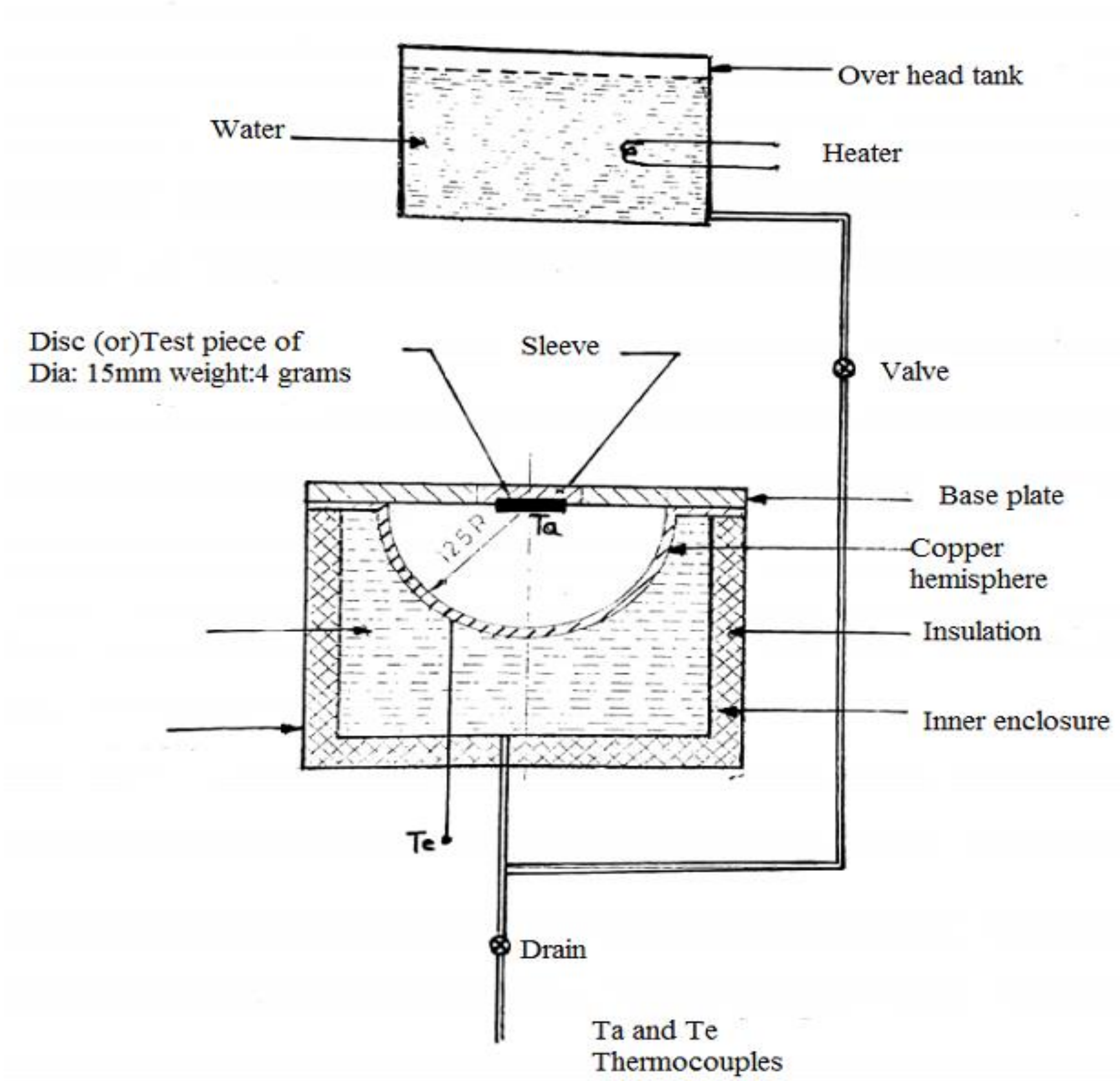


FIG:STEFAN BOLTZMANNS CONSTANT APPARATUS

PROCEDURE

1.Switch on the mains and the console

2.Put 'ON' the heater.

3.Remove the disc (D) or test piece

4.After water attains the maximum temperature open the valve and dump the water to the enclosure jacket

5.Note down the hemisphere temperatures

6.Note down the test disc temperature

7.Start the timer. At the start of timer cycle, insert test disc into the hole of hemisphere.

8.Note down the temperatures of disc for every 25 seconds

Tabular column:

T_1=Enclosure Temperature (^{O}C)=

T_2=Temperature of disc (^{O}C)=

Time In Seconds	Temperature Of Disc ^{O}C
0	
25	
50	
75	
100	
125	
150	
175	
200	
225	
250	
275	
300	

CALCULATIONS

1) Area of test disc, $A = (\pi/4)*d^2$ = d=15 mm

2) mass of test disc, m = 4 grams =0 .004 kg.

3) Initial Test disc temperature(T_D)

T_D =

As area of hemisphere is very large as compared to that disc, we can put

$$Q = \sigma * A * (T_1^4 - T_2^4) \text{ ---------(1)}$$

Where Q = heat gained by disc/sec.

$$Q = m * C_p * \frac{dT}{dt} \text{-----------(2)}$$

Equating equation 1 and 2

$$\sigma * A * (T_1^4 - T_2^4) = m * C_p * \frac{dT}{dt}$$

$$4)\sigma = \frac{m * C_p * \frac{dT}{dt}}{A * (T_1^4 - T_2^4)} \quad \frac{W}{M^2 K^4}$$

dT = Change in temperature of the disc

dt= Change in time=300sec

C_P= Specific heat of copper disc = 410 J/Kg $_0$ C

Theoretical value of σ = 5.667x 10^{-8} $\frac{W}{M^2 K^4}$

In the experiment this value may deviate due to reasons like convection, temperature drop of hemisphere, heat losses etc.

PRECAUTIONS

1.Never put 'ON" the heater before putting water in the tank.

2.Put 'OFF' the heater before draining the water from heater tank.

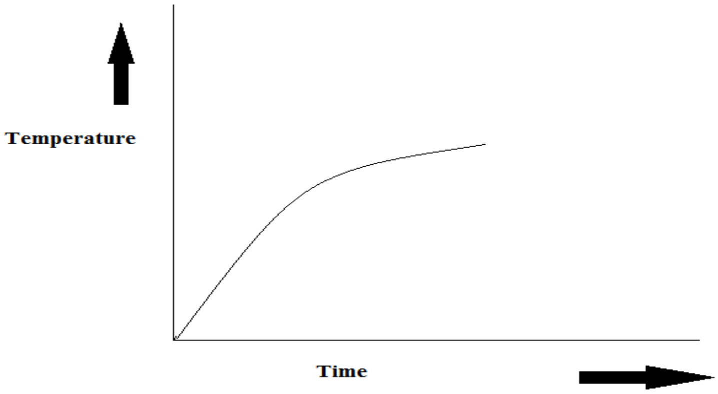
3.Drain the water after completion of experiment.

4.Operate all the switches and controls gently

RESULT

Stefan – Boltzmann's constant, σ = ________ $\frac{W}{M^2 K^4}$

Plot the graph for temperature of the absorber Vs time



GRAPH : TEMPERATURE Vs TIME

CALCULATIONS

VIVA QUESTIONS

1. Explain Radiation.

2. Heat energy transfers in radiation in which form?

3. What is a Block body?

4. Explain Stefan-Boltzmann's law? What is value of the Stefan– Boltzmann constant?

5. Explain spectral blackbody emissive power?

6. Discuss Planck's distribution law.

7. Define emissivity.

8. Explain absorptivity, reflectivity and transmissivity.

9. Define irradiation.

10. Explain Kirchhoff's law.

11. Radiation between two surfaces mainly depends on-----

12. Define Shape factor (or) view factor (or) configure factor (or) angle factor

13. Explain Radiosity?

14. Explain Radiation Heat transfer between two surfaces?

15. What is network representation and what is its algebra?

16. Define Radiation shields?

17. Thermal radiation occur in the portion of electro magnetic spectrum between the wavelengths -----

18. For infinite parallel plates with emissivity's $\varepsilon 1$ and $\varepsilon 2$ shape factor for radiation from surface 1 to surface 2 is ------

8.PARALLEL FLOW / COUNTER FLOW HEAT EXCHANGER

Aim:-

To determine heat transfer rate and overall heat transfer coefficient of Parallel flow and counter flow heat exchanger.

To determine NTU, Effectiveness and Efficiency of Parallel flow and counter flow heat exchanger.

Theory:

Heat exchanger is a device used for affecting the process of heat exchange between two fluids that are at different temperatures. It is useful in many engineering processes like those in Refrigeration and Air conditioning system, power system, food processing systems, chemical reactor and space or aeronautical applications. The necessity for doing this arises in multitude of industrial applications. Common examples of best exchangers are the radiator of a car, the condenser at the back of the domestic refrigerator, and the steam boiler of a thermal power plant.

The simple example of transfer type of heat exchanger can be in the form of a tube in tube type arrangement . Hot fluid flowing through the inner tube and the Cold through the annulus surroundings it. The heat transfer takes place across the walls of the inner tube. The experiments are conducted by keeping the identical flow rates [approx] while running the unit as a parallel flow heat exchanger and counter flow exchanger.

The temperatures are measured with the help of the temperature sensor. The readings are recorded when steady state is reached. The outer tube is provided with adequate insulation to minimize the heat losses.

The PF & CF heat exchanger consist of following components

1. Main Frame
2. Heat Exchanger
3. Temperature Indicator
4. Hot water Generator
5. Rota meter for hot & cold water flow rate measurement
6. Temperature Sensors

The total assembly is supported on a main frame. The apparatus consists of a 'tube in tube' type concentric tube heat exchanger. The hot fluid is water, which is obtained from the hot water generator it is attached at the top of assembly to supply the hot fluid Different valves are provided in the system to regulate the flow of fluid to the system. The hot water & cold water admitted at the same end & the opposite end, named parallel & counter flow heat exchanger accordingly, is done by valve operation.

The concentric type heat exchanger is connected in system, which transfers thermal energy between two fluids at different temperature.

Specification:

Inner Tube Material : copper
Outer Diameter (do) : 19 mm
Thickness : 1.2mm
Outer Tube Material : Stainless steel
Inner Diameter (D_i) : 50 mm
Length of the heat (L)
Exchanger : 1000 mm
Heater : 1kw x 01 No.
Thermostat : 1 (Range10-110^{0}C)
Temperature Indicator : 6 Channel (0 to 200 ^{0}C), 0.1 ^{0}C Resolution
MCB : 16 Amp for Heater,

Type of Heat Exchangers:

Heat exchangers are classified in three categories.

1. Transfer Type

According to flow arrangement

2. Parallel flow
3. Counter flow

Storage Type

1. Direct Transfer Type
2. Shell and tube heat Exchanger

A Transfer type heat exchanger is the one in which both fluids pass simultaneously flow through the device and heat is transferred through separating walls. In practice most of the heat exchangers used are transfer type ones. The transfer type heat exchangers are further classified according to flow arrangements as

Parallel Flow, in which fluids flow in the same direction.

Counter flow, in which they flow in opposite direction.

Procedure:

1. Operate the valve system to make water flow either in parallel or counter flow direction.
2. Allow the water to circulate in the inner copper tube by opening flow control valve of the rotameter, to monitor the flow rate.
3. Switch on the water heater to heat the water.
4. Once the temperature of hot water is reached steady state start the flow of water through hot and cold water side and adjust it as per requirement.
5. For Parallel flow the flow of hot & cold water should be on same side & for counter flow the flow of both the fluids should be on opposite side. Make this adjustment with the help of valves
6. Wait to stabilized the temperature on the indicator.
7. As the temperature get stabilized take down the readings for different four channels by using switch on the panel.
8. Readings for the flow rates can be taken from the rotameter attached at the front of the instrument.
9. Take down the readings by varying the flow rates.
10. Observe flow rate of hot water to be less than flow rate of cold water
11. Once the experiment is completed drain the water remains in concentric tube. By opening the cocks given at side & below the shell.

Precautions:

1. Do not put on heater unless water flow is continuous.

2. Once the flow is fixed, do not change it until note down the readings for that flow.
3. The thermocouples should keep in pockets
4. There should make the oil well in pockets of thermocouple.
5. Equipment should be earthed prop
6. Once the experiment is completed drain out the water remain in both the tubes.

Observation:

Inner Tube

Inner tube material = Copper (COLD WATER FLOWS)

Diameter (do) = 19 mm = 0.019 m

Thickness =1.2mm

Outer Tube

Outer tube Material = STAINLESS STEEL. (HOT WATER FLOWS)

Diameter (D) = 50 mm = 0.055 m

Length of the heat Exchanger = 1000 mm = 1.0 m

Constants:

1. C_{pc} = Specific heat of cold water = 4.174 KJ / KG k
2. C_{ph} = Specific heat of hot water = 4.174 KJ / KG k

Tabular column – I:

Parallel Flow Run:

S. NO.	HOT WATER SIDE			COLD WATER SIDE		
	Flow rate m_h. (Kg/hr)	Inlet Temp. Thi (°C)	Outlet Temp. Tho (°C)	Flow rate m_c. (Kg/hr)	Inlet Temp. Tci (°C)	Outlet Temp. Tco (°C)
1						
2						
3						
4						

<u>**Note**</u>: Tci in parallel is becoming Tco in counter Flow while making necessary Correction.

Calculation for Parallel Flow:

1) Q_h = Heat transfer rate from hot water in KJ / sec

$$Q_h = M_h * C_{ph} * (T_{hi} - T_{ho})$$

2)Qc = Heat transfer rate from cold water in KJ /sec

$$Q_c = M_c * C_{pc} * (T_{co} - T_{ci})$$

Q = Total heat transfer rate in KJ /sec

$$3)Q = \frac{Q_h + Q_C}{2}$$

4) Δ_{Tm} = Logarithmic mean temperature difference in ^{0}K

$$\Delta_{Tm} = \frac{T_{in} - T_{out}}{\ln \frac{T_{in}}{T_{out}}}$$

Where

$$T_{in} = T_{hi} - T_{ci}$$

$$T_{out} = T_{ho} - T_{co}$$

5) U_o = Overall heat transfer coefficient based on outer area in W / m^2 K

$$U_o = \frac{Q_c}{A_o * \Delta_{Tm}}$$

A_o = Area of outer side tube in m^2

Ao = π * do * L

do = diameter of outer tube =0.055m

6) U_i = Overall heat transfer coefficient based on inner area in W / m^2 K

$$U_i = \frac{Q_h}{A_i * \Delta_{Tm}}$$

A_i = Area of inner side tube in m^2

$A_i = \pi * d_i * L$

d_i = diameter of inner tube =0.019m , L=1m

7)C = Capacity ratio

$$C = \frac{C_{min}}{C_{max}}$$

Where,

$$C_{min} = M_h * C_{ph}$$

$$C_{max} = M_c * C_{pc}$$

8) ε = Effectiveness of heat exchanger

$$\varepsilon = \frac{M_c * C_{pc} * (T_{co} - T_{ci})}{Mcp_{min} * (T_{hi} - T_{ci})} = \varepsilon = \frac{M_h * C_{ph} * (T_{hi} - T_{ho})}{Mcp_{min} * (T_{hi} - T_{ci})}$$

$$Mcp_{min} = M_h * C_{ph} < M_c * C_{pc} \qquad \varepsilon = \frac{T_{hi} - T_{ho}}{T_{hi} - T_{ci}}$$

$$Mcp_{min} = M_c * C_{pc} < M_h * C_{ph} \qquad \varepsilon = \frac{T_{co} - T_{ci}}{T_{hi} - T_{ci}}$$

9)NTU_i = No. of transfer unit for inner surface

$$NTU_i = \frac{U_i * A_i}{C_{min}}$$

10)NTU_o = No. of transfer unit for outer surface

$$NTU_o = \frac{U_o * A_o}{C_{min}}$$

Tabular column – II:

Counter Flow Run :

SR. NO.	Hot Water Side			Cold Water Side		
	Flow rate m_h. (Kg/hr)	Inlet Temp. Thi (°C)	Outlet Temp. Tho (°C)	Flow rate m_c. (Kg/hr)	Inlet Temp. Tci (°C)	Outlet Temp. Tco (°C)
1						
2						
3						
4						

Note: Tci in parallel is becoming Tco in counter Flow while making necessary Correction.

Calculation For Counter Flow:

1)Qh = Heat transfer rate from hot water in KJ / sec

$$Q_h = M_h * C_{ph} * (T_{hi} - T_{ho})$$

2)Qc = Heat transfer rate from cold water in KJ /sec

$$Q_c = M_c * C_{pc} * (T_{co} - T_{ci})$$

3)Q = Total heat transfer rate in KJ /sec

$$Q = \frac{Q_h + Q_C}{2}$$

4)Δ_{Tm} = Logarithmic mean temperature difference in ^0K

$$\Delta_{Tm} = \frac{T_{in} - T_{out}}{\ln \frac{T_{in}}{T_{out}}}$$

Where,

$T_{in} = T_{hi} - T_{co}$

$T_{out} = T_{ho} - T_{ci}$

5)Uo = Overall heat transfer coefficient based on outer area in W / m^2 K

$U_O = \frac{Q_c}{A_o * \Delta_{Tm}}$

Ao = Area of outer side tube in m^2

Ao = π * do * L do = diameter of outer tube =0.055m ,L =1m

6)Ui = Overall heat transfer coefficient based on inner area in W / m^2 K

$U_i = \frac{Q_h}{A_i * \Delta_{Tm}}$

Ai = Area of inner side tube in m^2

Ai = π * di *L d_i = diameter of inner tube =0.019m , L=1m

7)ε = Effectiveness of heat exchanger

$\varepsilon = \frac{M_c * M_{pc} * (T_{co} - T_{ci})}{M_h * M_{ph} * (T_{hi} - T_{ci})}$ With $M_h < M_c$

8)C = Capacity ratio

$C = \frac{C_{min}}{C_{max}}$

Where,

$C_{min} = M_h * C_{ph}$

$C_{max} = M_c * C_{pc}$

9)NTU_i = No. of transfer unit for inner surface

$$NTU_i = \frac{U_i * A_i}{C_{min}}$$

10) NTU_o = No. of transfer unit for outer surface

$$NTU_o = \frac{U_o * A_o}{C_{min}}$$

RESULTS

TYPE OF FLOW	Over All Heat Transfer (U)		Effectiveness	Capacity Ratio	NTU	
	U_O	U_I	ε	C	NTU_i	NTU_o
Parallel flow						
Counter flow						

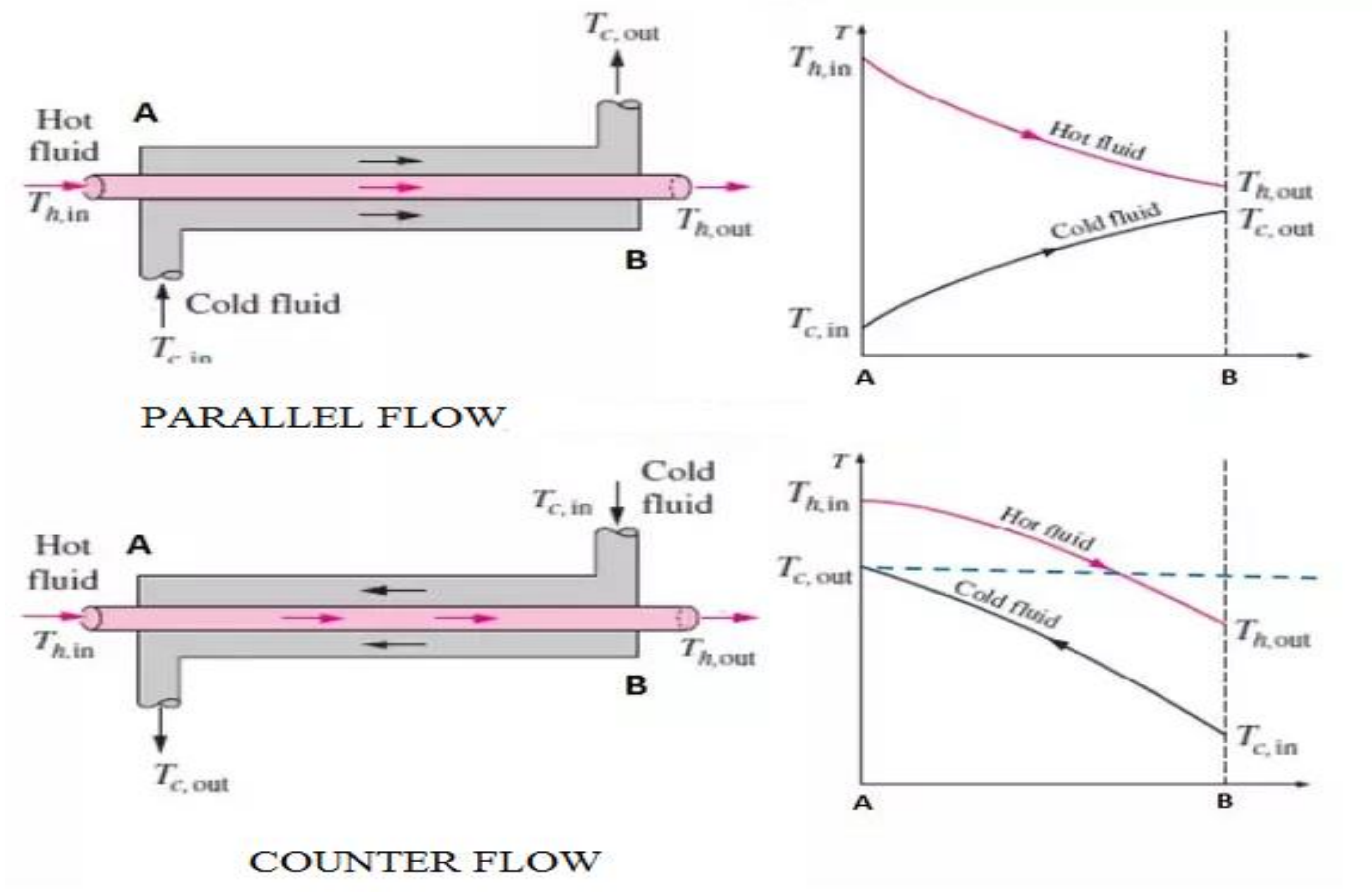


FIG: PARALLELFLOW AND COUNTERFLOW SET UP

CALCULATIONS

CALCULATIONS

CALCULATIONS

VIVA QUESTIONS

1. Classify convection.
2. What is forced convection & natural convection?
3. Explain difference between forced convection and natural convection?
4. Force convection in a liquid bath is caused by----
5. Explain Newton's law of cooling?
6. Give the relation between 'Fluid velocity' and 'Heat transfer'?
7. On which properties does convection heat transfer strongly depend?
8. Define convection heat transfer coefficient with dimensions.
9. Define Nussult number.
10. Develop velocity boundary layer for flow over a flat plate?
11. What is drag force?
12. Define friction coefficient (or) drag coefficient?
13. Explain Reynolds number?
14. What is critical Reynolds number?
15. Explain Prandtl number.
16. Fluid properties are evaluated at what temperature?
17. For forced convection, Nussult number is a function of---------
18. The Prandtl number will be lowest for------
19. What is significance of Nussult's number in convection?
20. The hydro dynamic and thermal boundary layers are identical at Prandtl number equal to-----
21. The temperature gradient in the fluid flow over a heated plate will be------
22. The ratio of heat transfer by convection to that by conduction is called-----
23. Define buoyancy force and discuss significance of the buoyancy force in Natural convection?
24. Define volume expansion coefficient and discuss significance in Natural convection?
25. Define Grashoff number and discuss significance of Grashoff number?
26. What is significance of Rayleigh's number?
27. The free convection heat transfer is significantly affected by----

28. The dimension less parameter ( ) 3 3 3 g l t μ β ρ Δ is called as----
29. What is significance of Stanton number?
30. The convective heat transfer coefficient from a hot cylindrical surface exposed to still air varies in accordance with------
31. For Laminar conditions, the thickness of thermal boundary layer increases with the distance from the leading edge in proportion to------
32. Which dimensionless number has a significant role in forced convection?
33. Explain about a heat exchanger.
34. Classify heat exchangers.
35. Which type of heat transfer takes place in heat exchangers?
36. What is fouling?
37. Classify fouling?
38. What is the relation between fouling and overall heat transfer coefficient?
39. Define heat capacity ratio?
40. Explain different methods to design heat exchangers?
41. Define LMTD
42. Explain LMTD for parallel flow
43. Explain LMTD counter flow
44. What is correction factor?
45. What is effectiveness?
46. Explain effectiveness in parallel and counter flow?
47. Expand NTU
48. The normal automobile radiator is a heat exchanger of which type?
49. The Condenser in a thermal power plant is an exchanger of which type?
50. The effectiveness of heat exchanger is given by-------

9. PERFORMANCE TEST ON VAPOR COMPRESSION REFRIGERATION TEST RIG

Aim
To find the COP of the refrigeration System

Theory:
The ideal thermodynamic cycle on which the refrigerator works is the vapor compression cycle shown in the following figure, on both T – s and p – h coordinates

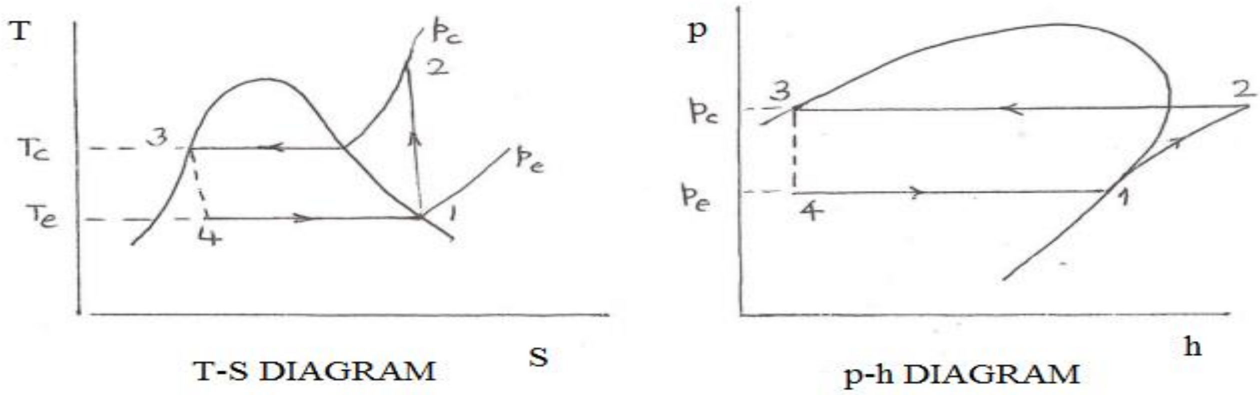


FIG: VAPOURCOMPRESSION CYCLE

The cycle consists of four processes:

Process 1-2 :
The refrigerant vapor leaving the evaporator is compressed isentropically from state 1 to 2 . In the ideal cycle state 1 corresponds to the saturated vapor state for the evaporator temperature . At state 2 the pressure is equal to the condenser pressure and entropy = entropy at state 1.Work of compression ,per kg refrigerant, Wc is given by:

$Wc = (H_2 – H_1)$

Process 2-3:-
During the constant pressure process 2-3 the compressed vapor at state 2 is cooled to the saturation temperature tc, also called the condensing temperature , and then condensed to saturated liquid at state 3 The magnitude of rejected heat by the condenser Qc is given by :$Qc = (H_2 – H_3)$

Process3 – 4 :
The high pressure liquid at state 3, at the condenser pressure, is throttled during 3-4 to evaporator pressure at 4 by passing it through either an expansion valve or a capalliary. During throttling process there is no change in enthalpy.

Process 4 – 1 :
This is the process during which cooling is realized .Liquid entering the evaporator at state 4 , picks up heat from the refrigerator at the evaporator temperature (te) and leaves the evaporator at state 1 as saturated vapor. The cooling produced per kg refrigerant, Q_1 is given by: $Q_1 = (H_1 – H_4)$

The COP of the refrigerator is given by:

$$COP = \frac{Q_1}{W_C} = \frac{H_1 - H_4}{H_2 - H_1}$$

The experimental set up is an actual vapor compression refrigeration system with provisions to measure pressures and temperature at various locations . Both options ,capillary tube and an expansion valve, are available in the system to expand the refrigerant between the condenser and the evaporator, The COP can be computed, with the help of the experimental observations the refrigerant used in the system is
R 134 a.

Procedure:
1. . Switch "on" the Mains and the console
2. Select the type of expansion by operating the switch to respective position.
i.e capillary open/Expansion valve open
3. Switch "on" the compressor and the fan
4. Now cooling takes place at the selected expansion device
5. Wait for 30 minutes
6. Record the following readings:
a) Pressures P_1 and P_2 as indicated on the compound and pressure gauges respectively.
b) Temperatures at locations T_1, T_2, T_3, T_4, T_5, .

T_1=Temperature at compressor inlet

T_2= Temperature at compressor out let

T_3= Temperature at Condenser outlet

T_4= Temperature after throttling

T_5= Temperature in side Freezer

P_1=Suction Pressure of compressor ,PSI

P_2= Discharge Pressure of compressor ,PSI

7. The experimental is to be conducted on both the expansion devices which are capillary & thermo static expansion valve individually

Tabular column:

Expansion devices	Power input to compressor	T_1	T_2	T_3	T_4	T_5	P_1 PSI	P_2 PSI
Capalliary open								
Expansion valve open								

Calculations:

In VCR cycle the steady state heat balance is given by

$Q_1 + W = Q_2$ ----------------(1)

Where Q_1 = Heat removed by the evaporator from the refrigerated system

Heat gained by the refrigerant in the evaporator

1) $Q_1 = H_1 - H_4$ Per kg of refrigerant

Q_2 = Heat transferred from the refrigerant in the condenser

2) $Q_2 = H_2 - H_3$ Per kg of refrigerant

W= Work done by the compressor on the refrigerant

3) $W = H_2 - H_1$ Per kg of refrigerant

H_1=Enthalpy of refrigerant at exit of the evaporator

H_2=Enthalpy of refrigerant at exit of the compressor

H_3=Enthalpy of refrigerant at exit of the condensor

H_4=Enthalpy of refrigerant at exit of the throttle valve

The values of enthalpies of the refrigerant at different states can be obtained from tables/charts using the measured values of pressure and temperatures. The work done by the compressor can be directly obtained from the panel .The coefficient of performance (COP) of refrigerant system is given by

4) $COP = \frac{Q_1}{W_C} = \frac{H_1 - H_4}{H_2 - H_1}$

$$\text{Ton of refrigeration} = \frac{HP}{COP}$$

Results

Expansion device	Experimental COP	Ton of refrigeration	Relative COP
Capalliary valve			
Expansion valve			

CALCULATIONS

10.AXIAL FLOW FAN TEST RIG.

Aim

The experiment is conducted at various pressures to
Determine the Overall efficiency.
Determine the Isothermal efficiency.

Theory:

Axial compressors are rotating, airfoil based compressors in which the working fluid principally flows parallel to the axis of rotation. This is in contrast with other rotating compressors such as centrifugal, axi-centrifugal and mixed-flow compressors where the air may enter axially but will have a significant radial component on exit. Axial flow compressors produce a continuous flow of compressed gas, and have the benefits of high efficiencies and large mass flow capacity, particularly in relation to their cross-section. They do, however, require several rows of airfoils to achieve large pressure rises making them complex and expensive relative to other designs (e.g. centrifugal compressor). Axial compressors are widely used in gas turbines, such as jet engines, high speed ship engines, and small scale power stations. They are also used in industrial applications such as large volume air separation plants, blast furnace air, fluid catalytic cracking air, and propane dehydrogenation. Axial compressors, known as superchargers, have also been used to boost the power of automotive reciprocating engines by compressing the intake air, though these are very rare. However, elsewhere the total design and capacities have been discussed in standard textbooks, here, the equipment is designed according to the standards and to the very minimum capacity as because these are designed in large stages and capacities which may vary in the range of several horsepower to 'n' number of stages. In this equipment an attempt has been made to design the equipment for the purpose of the academic purpose hence, certain main streams have been neglected due to complexities in manufacturing the educational versions of smaller units, however, the key features have been maintained to the maximum extent

The apparatus consists of Single Stage Compressor according to the standard design.

The compressor is directly coupled to a A.C motor of 5hp capacity by means of Flange coupling.

The motor is controlled by means of AC Drive of same capacity to conduct the experiment at different speeds. Pressure Tapings are provided at inlet, stages and outlet, with manometer for measuring. Multi Tube Manometers are made of clear Acrylic with vinyl sticker scale to for better readings. Starter for the motor and Energy meter for power measurement are provided in the control panel with other necessary instruments. Compressor assembly with motor is mounted on the separate frame made of C – channel. This makes the complete assembly sturdy.

Specifications:

Axial Fan : a)Aero foil type with provisions to change the blade angle. Mounted on shaft and housed in circular duct 400mm dia

b)Speed:0-2900RPM

Motor : 5HP A.C Motor,3ph,440v,15A

Drive: VFD drive for AC motor speed control(0-2900)

Electrical input: 3ph,415V,20A,AC supply with neutral and earth

Measurements:

Speed: By digital meter

Static head rise: Measured at up stream of impeller on surface of duct connected to u- tube manometer in terms of height of water coloumn

Flow: Measured by pitot tube connected to u- tube manometer in terms of height of water coloumn across the duct at center

Duct: 400mmdia x 2000mmlong,ms circular duct for air flow

Head/flow control: baffle/butterfly type of control valve with marking of gate opening

Power input to motor: measured by energy meter connected to ac supply to the motor.

PROCEDURE:

1.Connect the input power for console to 3ph AC supply with neutral and earth.

2.Keep the speed control knob at off

3.Switch on the mains and observe the light indicators are on

4.Keep the inlet valve open fully, set the pitot tube at center of duct,See the pitot tube should face in the direction of flow of air

5.Switch on the green button of ac drive and slowly rotate the speed control knob so that the motor axial fan speed builds up

6.Set the speed of fan to test speed using speed control knob

7Note down the readings namely ,axial fan speed, flow static head(velocity head),energy meter eading for full opening of valves as per the table of readings.

8Slowly close the valve in steps and note down the readings as mentioned above.

9.After the readings are taken reduce the speed by bring back the speed control knob to zero and press red button and switch off the electrical mains

10.Tabulate the readings and prepare table of calculations using the formulae.

Calcultions:

ρ_w =Density of water =1000kg/m3

ρ_a= Density of air at room temperature =1.29kg/m3

g = Acceleration due to gravity=9.81m/sec2

A = Area of duct = $(\pi/4) \times D^2$ D=0.4m

E.M Constant= Energy meter constant=1600 Imp/KWH

1. **Electrical input to AC motor as read on energy meter(Input power)**

$$\text{Input power} = \frac{n * 3600}{1600 * t}$$

n = No of revolutions (or) impulse of energy meter

t= Time taken for ‘n’ revolutions (or) impulse of energy meter

2. **Static head developed due to air in the duct**

$$Hsta = \frac{h\ sta}{1000} * \left[\frac{\rho_w}{\rho_a} - 1\right] \quad \text{meter of air column}$$

H_{sta} = 0.744 * h_{sta}

Where h_{sta} is the static head developed in mm of water to be read from manometer

3.Volume flow rate

Q = Area of duct x Velocity of air = A x V

Where A = 0.074m^2 V = $\sqrt{2 * g * Hv}$

$$Hv = \frac{h\,v}{1000} * \left[\frac{\rho_w}{\rho_a} - 1\right]$$

h_v is the velocity head developed in mm of water to read on U tube manometer

4.Air power calculated from out put of fan (Break power)

$$BP = \frac{\rho_a * g * Q * Hsta}{1000}$$

5.Efficiency of the Axial fan

$$\eta = \frac{BP}{IP} * 100$$

6.Iso thermal efficiency

$$\eta_{\text{Isothermal}} = \frac{\eta_{\text{Overall}}}{\text{Input power}} * 100$$

Overall efficiency =η_o = $\frac{H_{a\,inlet}}{H_{a\,outlet}} * 100$

$$H_{a\,inlet} = \left[\frac{\rho_w}{\rho_a}\right] * h\ intlet$$

$$H_{a\,outlet} = \left[\frac{\rho_w}{\rho_a}\right] * h\ outlet$$

$$\text{Input power} = \frac{n * 3600}{1600 * t}$$

Tabular column:

Blower speed in RPM	Energy meter readings		Static head rise in mm of water ‘ h_{sta}’ in mm	Velocity head in mm of water’h_v’ in mm
	n	t		

Table of calculations

Axial fan speed in RPM ‘N’	Electrical input in KW	Static pressure rise Meter of air column H_{sta}	Volume flow rate (Q) in M^3/sec	Axial fan out put (BP) in KW	Axial fan efficiency %η	Isothermal efficiency η_{iso}

CALCULATIONS