Department of Mechanical Engineering

Lab Manual

HEAT TRANSFER AND FLUID MECHANICS LAB
(MEC 210)

Laboratory Location: **Ground Floor, Room No-001&003**

Indian Institute of Technology (Indian School of Mines) Dhanbad-826004

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Safety in the Lab

- You are only allowed in the laboratory when there is a 'responsible person' present such as a demonstrator or the laboratory staff.
- Do not touch any equipment or machines kept in the lab unless you are asked to do so.
- A tidy laboratory is generally safer than an untidy one, so make sure that you do not have a confused tangle of electrical cables. Electrical equipment is legally required to be regularly checked, which means it should be safe and reasonably reliable: do not tamper or attempt to repair any electrical equipment (in particular, do not rewire a mains plug or change a fuse - ask one of the laboratory staff to do it). Never switch off the mains using the master switches mounted on the walls. Please make yourself aware of the fire exits when you first come into the lab. When the alarm sounds please leave whatever you are doing and make your way quickly, calmly and quietly out of the lab. You must always follow instructions from your demonstrators and the laboratory staff.
- You must keep walkways clear at all times and in particular coats and bags must be stowed away safely and must not pose a trip hazard.
- It is important that you make a point of reading the "Risk Assessment" sheet included in the manuscript of each experiment before you start work on the experiment.
- Please take notice of any safety information given in your scripts. If an experiment or project requires you to wear PPE (personal protective equipment) such as gloves and safety glasses, then wear them.
- Always enter the lab wearing your shoes. It is strictly prohibited to enter the lab without shoes.
- There must be NO smoking, eating, drinking, use of mobile phones or using personal headphones in the laboratory. This last point is not because we dislike your choice of music but because you must remain aware of all activity around you and be able to hear people trying to warn you of problems.
- Keep the lab neat and clean

Title:

- Provide a title that is a description of your lab followed by a lab number.
- The title should clearly identify the experiment's variables (independent & dependent)

Objective/Purpose/Problem:

- This is the place to explain what you are trying to find out or what you are going to do in the lab.
- Include information about the variables involved.

Hypothesis: "If………then………because………"

- This is a cause/effect statement.
- This is a prediction of what the expected outcome of the lab will be.
- Relate the hypothesis to the purpose/problem of the lab.
- Try to focus your hypothesis on the information/research you collected.

Materials:

- List all items in a column.
- Make sure to record the exact size and amount of each item required.

Procedures:

- List and number each step.
- Use complete sentences (begin with a capital letter and use end punctuation).
- Should be clear enough for someone else to use as instructions for repeating your experiment.

Observations/Data:

- Be sure to accurately record your observations/data in a chart or table.
- Create a graph to provide a visual of your data.
- Provide a verbal description of your data.
- List all quantitative (numbers) and qualitative (words) data.
- List all variables and explain what your control was.

Conclusion: "When……………then…   "

- Match your conclusion to the purpose or the problem.
- Base your conclusion on your analysis of your observations and any data that has been collected.
- **Explain:** (The following are just suggestions and DO require elaboration.)
    - What you did in the experiment
    - What you observed (trends/patterns in your data that supported or did not

support your hypothesis)

- What you learned from the lab
- If you think it was a fair test (i.e. – was there anything that may have impacted the accuracy of your results)
- Questions for further research and investigation

➢ **Application:** Can you think of an analogous situation that applies to real life?

<u>List of Experiments</u>

EXPERIMENT NO. 1

Determination of Thermal conductivity of metal rod and insulating powder

Experiment No. 1a

Name of the Experiment: Determination of thermal conductivity of insulating powder (asbestos powder)

Aim: To find the thermal conductivity of asbestos powder at different heat flow condition

INTRODUCTION

Conduction is the transport of energy in a medium due to a temperature gradient, and the physical mechanism is one of random atomic or molecular activity. Conduction heat transfer is governed by *Fourier's law [1]*.

Insulation Systems: Thermal insulations consist of low thermal conductivity materials combined to achieve an even lower system thermal conductivity. In conventional *fiber*, *Powder,* and *flake* -type insulations, the solid material is finely dispersed throughout an air
space. Such systems are characterized by an *effective thermal conductivity [1].* In order to determine the appropriate thickness of insulation, knowledge of thermal conductivity of material is essential. The unit enables to determine the thermal conductivity of insulating powders, using 'sphere in sphere' method.

Theory: The basic theory is based on Fourier's Law of heat conduction as given below in spherical coordinates for one d heat conduction in the radial direction

$$Q = -k(4\pi r^2)\frac{dT}{dr}$$

The above equation is written at distance ***r*** from the centre of the concentric sphere for thickness ***dr,*** as shown in Fig. 1.

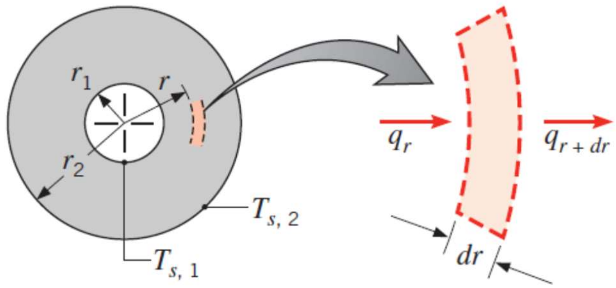


Fig. 1 One-D heat Conduction in a spherical shell at radius r with elemental thickness dr [1]

The final expression for heat transfer is based on the following assumptions.

1. Steady-state heat conduction
2. Uni-directional heat conduction
3. Thickness of the inner and outer wall of the concentric sphere is negligible

The formula used for finding thermal conductivity of asbestos powder is given below using the electrical network diagram shown in Fig. 2

$$Q = \frac{(T_i - T_o)}{R_1 + R_2 + R_3}$$

Where $R_1 = (r_1 - r_i)/4\pi k_b r_1 r_i$,

$R_2 = (r_2 - r_1)/4\pi k_{ins} r_2 r_1$,

$R_3 = (r_O - r_2)/4\pi k_b r_2 r_0$

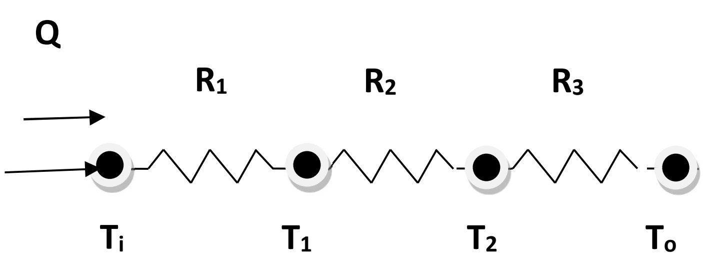


Fig. 2 Electrical resistance network of a concentric sphere having asbestos powder packing between the inner and outer sphere

If the thickness of the brass sphere is small, then $r_1 \sim r_i$, and the value of k_b is large, $R_1 = 0$,

Similarly, $r_2 \sim r_o$, and the value of k_b is large, $R_3 = 0$,

$$\text{Finally} \quad Q = \frac{4\pi k r_i r_0 (T_i - T_o)}{(r_0 - r_i)}$$

$$and\ k_{ins} = \frac{Q(r_0 - r_i)}{4\pi r_i r_0 (T_i - T_o)}$$

Where T_i is the average inner wall temperature, and T_o is the average outer wall temperature.

The above formula can also be derived by solving the 1-D heat conduction equation in spherical coordinates as given below.

$$\frac{d^2T}{dr^2} + \frac{2}{r}\frac{dT}{dr} = 0$$

Apparatus Used: There are two spherical shells. The insulating powder (asbestos) whose conductivity is to be calculated, is packed between these two shells. An electric heater is provided in the inner shell. The power is supplied from outside through auto-transformer for heating purpose. Four thermocouples are placed on the outer surface of the inner sphere, and six are fixed on the inner surface of the outer sphere. These thermocouples will be used for finding the average temperatures on inner and outer sphere surfaces. The schematic of the set-up and The actual photograph of the set-up are shown in Fig. 3 and Fig. 4, respectively.

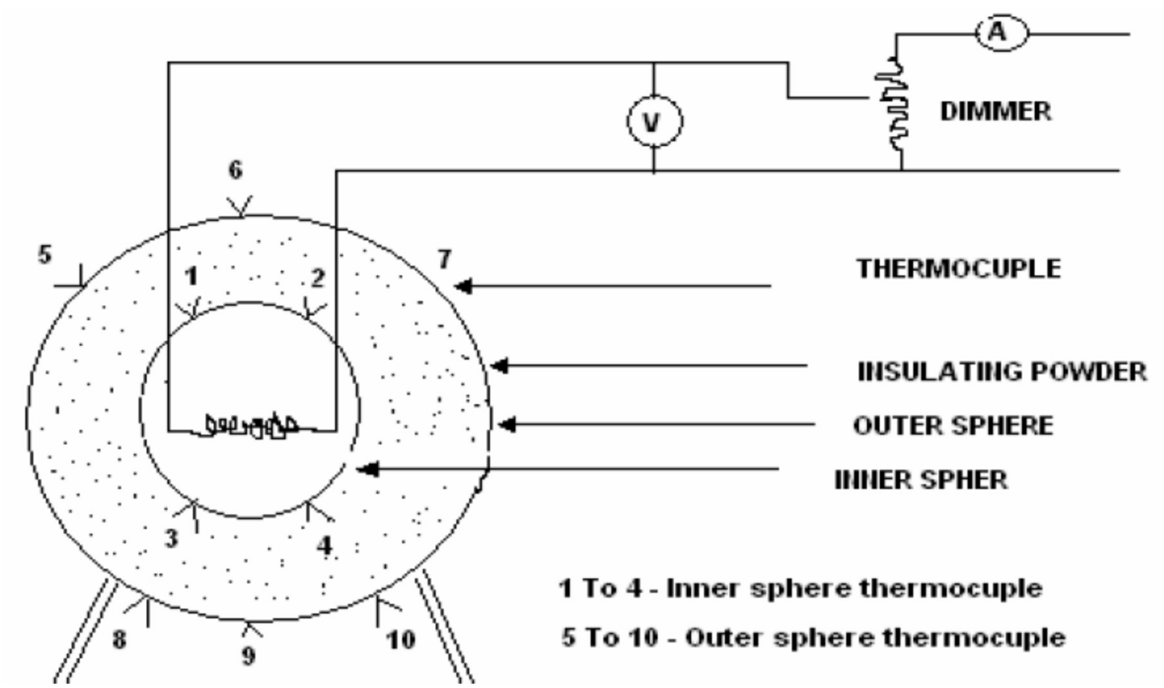


Fig. 3. Schematic of the set-up

Fig. 3 Actual photograph of set-up

Experimental Procedure:

1. Keep the dimmerstat knob at zero position and switch on the experiment.
2. Slowly rotate the dimmerstat knob, so that voltage is applied across the heater and fix it at some suitable value.
3. Wait until steady state is reached.
4. Note down all temperatures and input of the heater in terms of volts and current.
5. Repeat the procedure for different heat inputs.

Specifications: Inner sphere: ID = 100 mm

Outer diameter, OD = 200 mm

Observation Table:

Sr, no	Temperature readings, °C										Heater input	
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	V	I

Calculations:

$$k_{ins} = \frac{Q(r_0 - r_i)}{4\pi r_i r_0 (T_i - T_o)}$$

Where Q is heater input and can be calculated as, $Q = V \times I$

$$and\ T_i = \frac{T_1 + T_2 + T_3 + T_4}{4}$$

$$T_0 = \frac{T_5 + T_6 + T_7 + T_8 + T_9 + T_{10}}{6}$$

Results and Discussion: Comments on thermal conductivity obtained from the experiment and compare with the theoretical value.

Precautions:

1. Operate all the switches and control gently
2. Earthing is essential for the unit.

Questions:

1. What is the effect of medium grain structure on thermal conductivity?
2. Application of insulating material.
3. How does temperature influence the thermal conductivity of insulating material?
4. Solve 1-D steady-state heat conduction equation in the hollow sphere for finding heat transfer.

References:

1. F. Incropera, and D. J. Dewitt, Fundamentals of heat and mass transfer –Wiley & Sons Inc., 7th Edition, 2011.

Experiment No. 1b

Name of the Experiment: Thermal Conductivity of metal rod

Objective: To determine the thermal conductivity, k (W/m-K) of a metal rod made of copper and compare the same with the known value.

Apparatus required: Metal rod apparatus. Measuring flask, Stop watch

Theory: Thermal conductivity is an important transport property which decides how fast a medium transmits heat when a temperature gradient is created. From Fourier's law of heat conduction thermal conductivity associated with conduction in x direction is defined as:

$$q_x'' = -k_x \frac{\partial T}{\partial x} \Rightarrow k_x = -\frac{q_x''}{(\partial T/\partial x)} \quad (1)$$

From the above equation it is clear that thermal conductivity is having the directional characteristic. However, for a homogeneous and isotropic material thermal conductivity is same in all direction at all points of a material body. The values of *k* for a substance depends on the chemical composition, the physical state and texture, and the temperature and pressure. As conduction is the transportation of the heat energy due to microscopic motion (atomic or molecular activity) the thermal conductivity of solid is generally higher than that of liquid, which is higher than that of gas. The mechanism of heat conduction in case of solid may be due to lattice vibration and movement of the free electrons. For metallic solid the contribution of movement of free electron is dominating. In the present experiment an attempt has been made to determine the thermal conductivity of a metal rod by measuring the heat rate and the temperature gradient along the metal rod.

Experimental Setup:

The experimental set up consists of a copper rod (as shown in Fig. 1a and 1b), one end of which is heated by a heater while the other end is inserted in to a cooling water jacket. The central portion of the rod is surrounded by a cylindrical shell filled the asbestos powder (an insulator; k_{ins}=0.15 W/m-K). The sole aim of providing this insulation to keep the heat transfer in the metal rod one dimensional (along the length) from the heater end to the cooling water with minimum heat loss in the radial direction. In order to measure the temperature at different sections of the metal rod, seven thermocouples are inserted along the length at equal intervals as shown in the schematic. Two more thermocouples are inserted in the water jacket to indicate the water inlet and exit temperature. With the help of the dimmer stat the heat input to the metal rod can be varied by controlling the power input to the heater. The cooling water at a constant flowrate is circulated through the jacket.

Specifications:

1. Length of the metal rod = 450 mm.
2. Diameter of metal rod, d = 25 mm
3. Effective length = 231 mm
4. Inner radius of insulating shell (r_i) = 25 mm.
5. Outer radius of insulating shell (r_o) = 80 mm.
6. No of thermocouples mounted of the rod = 7

7. No of thermocouples mounted in water jacket =2
8. Measuring flask capacity= 0 to 1000 ml

Experimental Procedure:

1. Connect the cold water supply to the inlet of the cooling chamber
2. Connect outlet of the cooling chamber to drain.
3. Ensure that all ON/OFF switches given on the panel are at OFF position.
4. Ensure that variac knob is at zero position.
5. Start water supply at constant flow rate.
6. Now switch on the main power supply.
7. Switch on the panel with the help of Mains ON/OFF Switch given on the panel.
8. Fix the power input to the heater with the help of variac.
9. After half an hour, start recording the temperature of various points at each five minutes interval.
10. If the temperature readings are same for at least three times, assume that steady state is achieved.
11. Record the final steady state temperature
12. Record flow rate of cooling water by collecting the water coming from the water jacket in the measuring flask and recording the corresponding time of collection from the stop watch.
13. Process 8-12 are repeated for different heat inputs.

Observation Table

S. No	Mass flow rate of water (kg/s)	Heater input		*Thermocouple readings in ^oC*								
		V	I	1	2	3	4	5	6	7	8	9
1												
2												
3												

Thermocouple positioning along the length of the rod

Thermocouple numbers along the axis of the rod	1	2	3	4	5	6	7
Distance from heating end of the rod, mm	33	66	99	132	165	198	231

Calculations: From energy balance the heat lost at the end of the metal rod inserted into water jacket is equal to heat taken by the circulating cooling water. Mathematically

$$-kA_C\left(\frac{dT}{dx}\right)_{x=L} = \dot{m}c(T_{w,out} - T_{w,in}) = \dot{m}c(T_9 - T_8) \qquad (2)$$

Hence the thermal conductivity of the metal rod in terms of other measured quantities is given by:

$$k = -\frac{\dot{m}c(T_{w,out} - T_{w,in})}{A_C\left(\frac{dT}{dx}\right)_{x=L}} = -\frac{\dot{m}c(T_9 - T_8)}{A_C\left(\frac{dT}{dx}\right)_{x=L}} \qquad (3)$$

Where,

k = thermal conductivity of the metal rod, W/m-K

$\dot{m}$ =Mass flow rate of cooling water, kg/s

c = Specific heat of water, J/kg-K

$T_{w,out}$ = water out let temperature

$T_{w,in}$ = water inlet temperature

A_C = Cross sectional area of the metal rod and is given by: $A_C = \frac{\pi}{4}d^2$

$\left(\frac{dT}{dx}\right)_{x=L}$ = the temperature gradient in the metal rod at x=L (the end which is inserted in to the cooling water jacket)

Once the steady state temperatures at different location of the metal rod is recorded the temperature variation T vs. x is plotted. The slope of the curve at x=L i.e. $\left(\frac{dT}{dx}\right)_{x=L}$ is calculated from the plot.

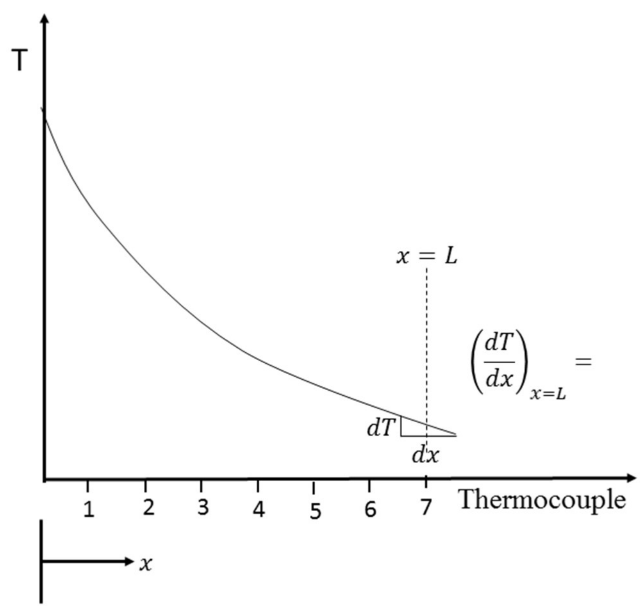


Fig.2 Temperature distribution along the length of the bar

The above formula is only valid when radial loss is negligible.
The negative sign is introduced in the equations 2 and 3, because heat flows in the direction of decreasing temperature and serves to make the heat flux positive in the positive direction.

Result and discussion:
The following should be presented:

1. The temperature variation along the length of the metal rod should be presented.
2. Sample calculation for the thermal conductivity should be done atleast for two different heat inputs.
3. Thermal conductivity of two sections can be calculated and its variation with temperature can be studied.
4. Discussion of results and sources of errors.

Precautions:

1. Operate all the switches and control gently.
2. Wait till perfect steady state is reached.
3. Handle the changeover switch of temperature gently.
4. Keep the water flow rate low so that appreciable temperature rise in cooling water can be observed.
5. Power fluctuation during the experiment must be avoided.

Questions:

1. What is thermal conductivity of pure copper at room temperature?
2. Why insulation is provided over the copper rod?
3. Write the heat balance equation at different location of the rod.
4. What is the difference between the power input to the heater and heat taken by the cooling water? State the reason behind this difference.
5. What is the need of steady state in this experiment?
6. Under what condition the temperature profile along the length of the rod will be straight line

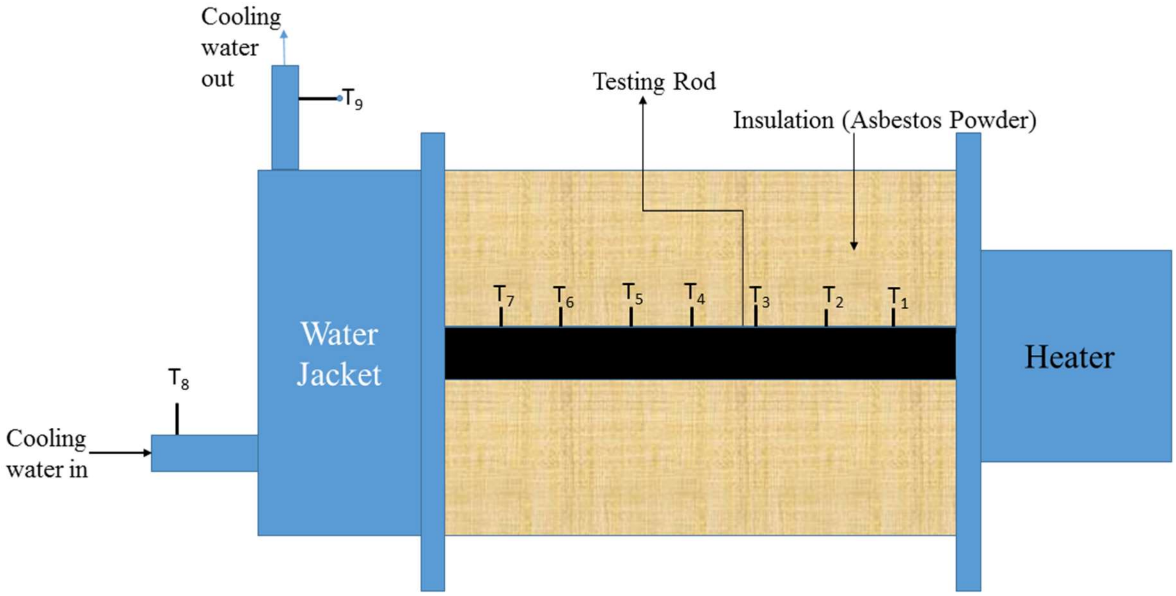


Fig. 1a Schematic diagram of metal rod apparatus

Fig. 1b Metal rod apparatus

Experiment No. 2

Determination of Thermal conductivity of composite wall

Name of the Experiment: Composite wall apparatus
OBJECTIVE: To determine equivalent thermal resistance and thermal conductivity of Composite walls.
Apparatus required: Composite wall with all instrumentation

DESCRIPTION

Many practical situation in engineering practice involve heat transfer through a medium comprising two or more material of different thermal conductivity,e.g.the walls of building, refrigerator,cold storage plants, hot water tanks etc. The apparatus shown in Fig. 1 consists of a central heater sandwiched between two sheets.Three types of slabs are provided on both side of heater, which forms a composite structure. A small hand press frame is provided to ensure the perfect contact between the slabs. A dimmerstat is provided for varying the input to the heater and measurement of input to the heater and measurement of input is carried out by a voltmeter,ammeter.Thermocouples are embedded between interaces of the slabs,to read the temperature at the surface.

The experiments can be conducted at various values of input and calculation can be more accordingly.

Theory: Fourier's Law of heat conduction

$$Q = -k\,A\,\frac{dT}{dx}$$

SPECIFICATIONS

Assembly :Slabs assembly arranged symmetrically on both sides of heater.

COMPOSITE SLABS: 1] Wall thickness**:**

Mild steel = 0.01m

Bakelite = 0.01m

Press wood = 0.01m

2] Slab diameter = 0.3 m

Experimental procedure:

1. Switch on mains from control panel box
2. Switch on heater after ensuring dimmerstat at zero position
3. Adjust the heating rate(50-110 V) through the dimmerstat to a suitable level(V.I)
4. Wait for steady state condition and then record the reading of all temperatures from digital temperature indicator Voltmeter and Ammeter.
5. Repeat the same procedure for different heat rate.

OBSERVATION TABLE

READING	**SET-1**	**SET-2**	**SET-3**
V= Voltmeter (Volt)			
I= Ammeter (Amp)			
Q= Heat supplied (W/mK)			

SR NO.	THERMOCOUPLE READING IN °C
1	T_1
2	T_2
3	T_3
4	T_4
5	T_5
6	T_6
7	T_7
8	T_8

CALCULATION: For calculating the thermal conductivity of composite walls, it is assumed that due to large diameter of the plates heat flowing through central area, where uni directional flow is assumed, is considered. Accordingly thermocouples are fixed at close to center of the plates.

1) q = Heat flux in W/m^2

$q = Q/A \ W/m^2$

2) Q = the Rate of heat supplied in Watt.

$Q = V \times I$ Watt

Where V = Voltage on Volt

I = Current in Ampere.

3) A=Area of plates in m^2

$A = \pi/4 \ d^2$

Where d = half diameter of plates in m.

4) Refer Figs. 2, 3(a) and 3(b) for thermal conductivity of individual material and equivalent thermal conductivity of the composite walls

$$T_A = \frac{T1 + T2}{2}$$

$$T_B = \frac{T3 + T4}{2}$$

$$T_c = \frac{T5 + T6}{2}$$

$$T_D = \frac{T7 + T8}{2}$$

$$Q = \frac{TA - TB}{R1} = \frac{TB - TC}{R2} = \frac{TC - TD}{R3}$$

Where $R1 = \frac{L1}{k1A}$, $R1 = \frac{L2}{k2A}$, $R3 = \frac{L3}{k3A}$

From the above relations, k_1, k_2 and k_3 may be found out.

Equivalent thermal conductivity is determined by the following formula

$$\frac{Le}{keA} = \frac{L1}{K1A} + \frac{L2}{k2A} + \frac{L3}{k3A}$$

Where Le = L1+L2+L3 = 3L (L1= L2 = L3)

Results and discussion: Plot graph (average temperature along thickness of the wall)

Comments on thermal conductivity obtained from the experiment

Questions:

1. Why composite wall is used?
2. How to find equivalent of thermal conductivity of the composite wall?
3. Why the composite wall is symmetric about the heater?

Appendix

Fig. 1 Composite wall apparatus

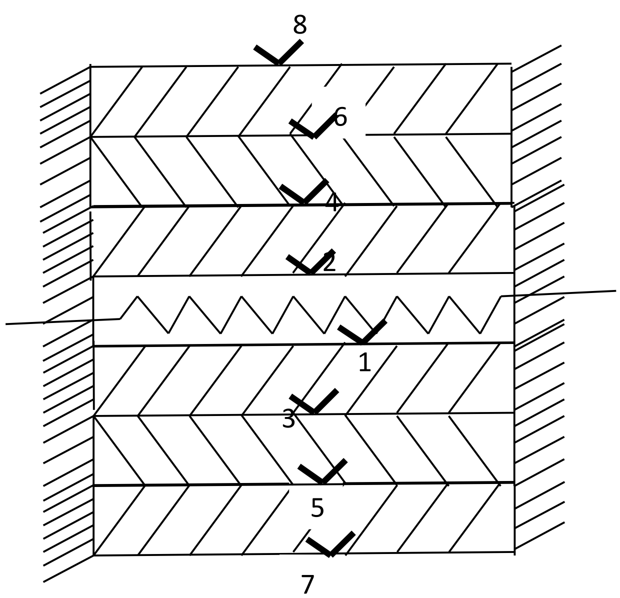


Fig. 2 Sectional view of the experimental set up showing thermocouples point and heater

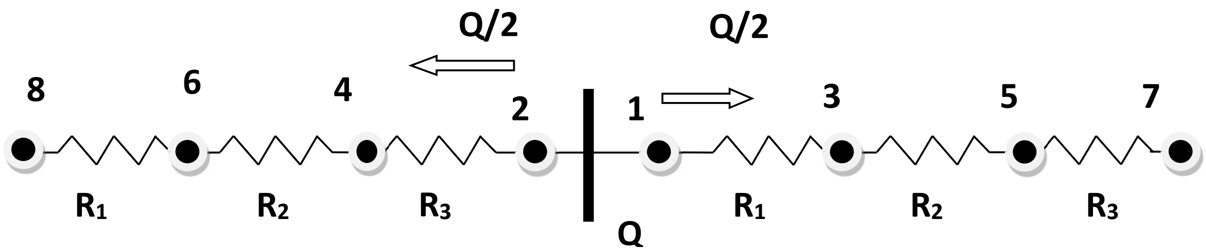


Fig. 3(a) Electrical resistance net work of the composite wall showing all the resistances, temperature nodal points and heat distribution.

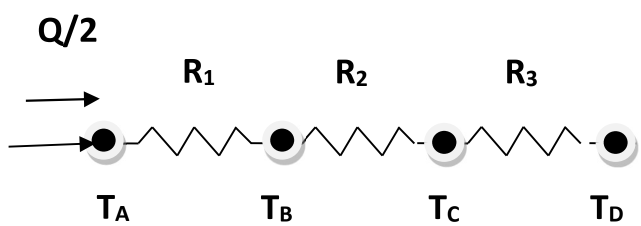


Fig. 3(b) Equivalent electrical resistance net work of the composite wall showing the resistances, average temperature nodal points and heat distribution

Experiment No. 3
Performance study of pin-fin

Name of the experiment: Pin-fin apparatus

Objective: To find temperature distribution along the length of fin in natural convection
To find efficiency and effectiveness of the Pin-fin

Introduction: Extended surface or fins are used to increase the heat transfer rates from a surface to the surrounding fluid when it is not possible to increase the value of the surface heat transfer coefficient and temperature difference between the surface and the fluid. Fins are fabricated in variety of forms. Cooling of small engines by fins is the common example of its applications.

Theory: All three fins shown in Fig 1 act as pin-fins as its end cross-section is very small. The amount of heat transfer through tip of the fin is very small with compared to lateral surface. Hence, the fins act as insulated end fin.

Let Ac = cross section area of the fin, m^2

P = circumference of the fin, m.

L = length of the fin = 0.102 m.

T_1 = Base temperature of the fin.

T_f = Duct fluid temperature (channel No.6 of temperature indicator)

Ø =Temperature difference of fin and fluid temperature

$= T - T_f$

h = heat transfer coefficient, w / m^2 °C.

k_f = Thermal conductivity of fin material.

= 110 W/m K for brass

= 46 W/ m K for mild steel.

= 232 W/ m K for aluminium.

Heat is conducted along the length of fin and also lost to surroundings. Applying heat balance equation for a differential element of length dx along the length of fin at a distance x from base,

$\frac{d^2Ø}{dx^2} - \frac{hP}{k_f.A}Ø = 0$ ---1

$Ø = (C_1.e^{mx}) + (C_2.e^{-m})$----------------------------2

Where, $m = \sqrt{\frac{h.P}{k_f.Ac}}$ -- -(3)

With the boundary conditions of $Ø = Ø_1$ at x= 0.

$Ø_1 = T_1 - T_f$, assuming tip to be insulated.

$\frac{dØ}{dx} = 0 \; at \; x = L$ results in obtaining equation (2) in the form.

Temperature distribution equation

$$\frac{T - T\infty}{T1 - T\infty} = \frac{\cos h[m(L - x)]}{\cos h(mL)} \quad (4)$$

Efficiency and effectiveness of fin

$$\eta = \frac{\tan h(mL)}{mL} \quad (5)$$

$$E = \frac{\tan h(mL)}{\sqrt{\frac{hA_C}{k_f\,P}}} \quad (6)$$

Heat transfer coefficient, h may be found from empirical correlations in free convection condition as given below.

$Nu = 1.10(Gr.\,Pr)^{1/6}$ for $10^{-1} < Gr.Pr < 10^4$ (7)

$Nu = 0.53(Gr.\,Pr)^{1/4}$ for $10^4 < Gr.Pr < 10^9$ (8)

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

Where $Gr = \frac{g\beta\Delta TLc^3}{\upsilon^2}$, $Pr = \upsilon/\alpha$

Specifications: Diameter of pin-fin = 12 mm

Length of fin = 102 mm

Experimental procedure: Same as experiment no 4(A)

Observations:

Sr. no	Heat input		Fin surface temperature					Ambient temperature
	V	I	T1/T6/T11	T2/T7/12	T3/T8/13	T4/T9/T14	T5/T10/T15	T16
Aluminium								
Brass								
Mild steel								

Calculations:

Based on geometric condition and flow condition, find heat transfer coefficient, h in free convection using suitable empirical correlations as given in (7), (8) and (9).

Putting the h value in equations (4), (5) and (6) find the temperature distribution, efficiency and effectiveness of the fins.

Comments and Conclusions: Plot temperature distribution along the length of the fins theoretically and experimentally. The location of thermocouple positions are shown in Fig. 2.

Questions:

1. What is fin parameter? Find the expression for the same.
2. Solve the ordinary differential equation for fin and find the expression for temperature distribution of fin.
3. How fin parameter influences the temperature distribution?
4. What is pin-fin?

Fig. 1 Experimental setup of Pin-fin apparatus

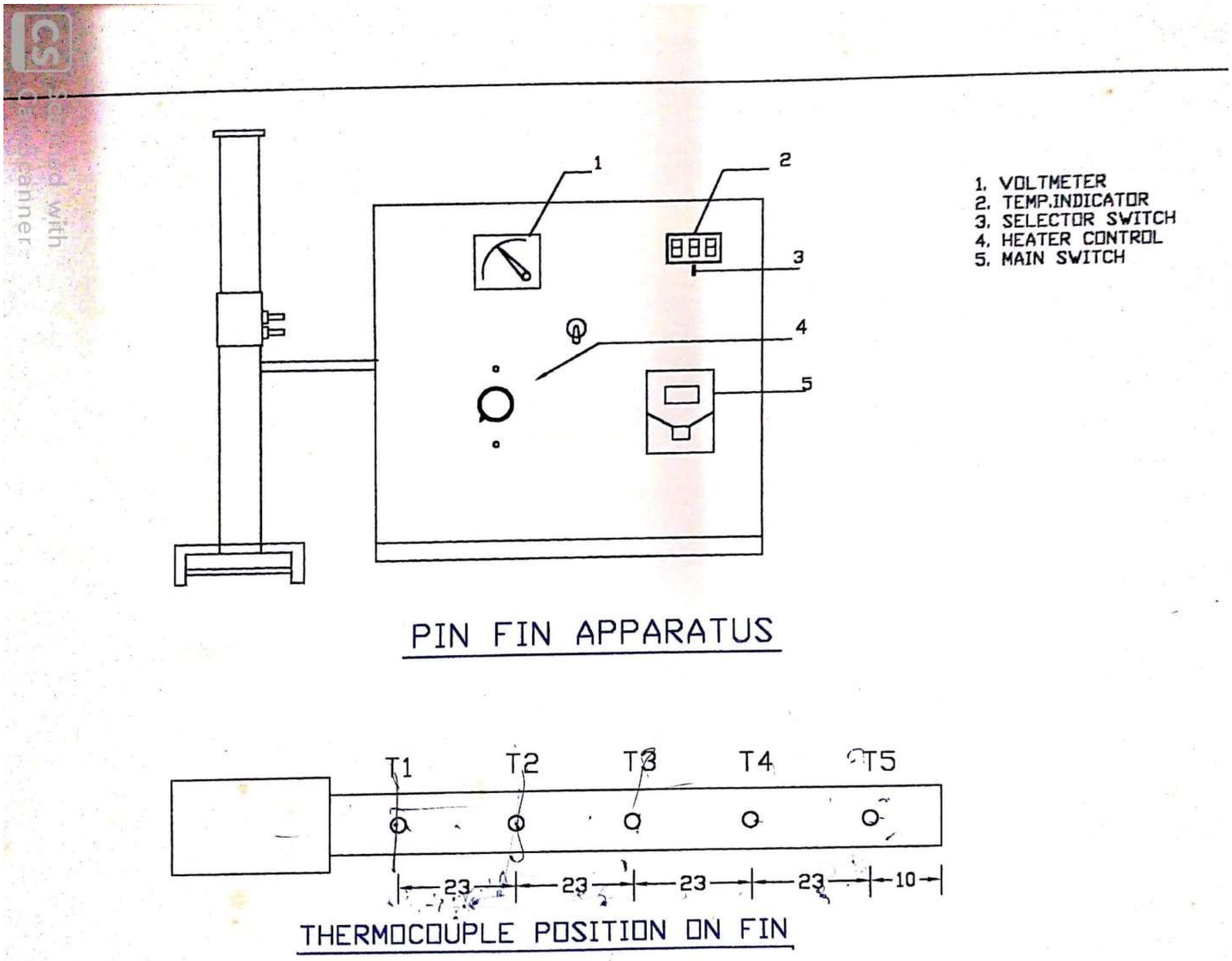


Fig 2 Thermocouple positions along the length of the fin

EXPERIMENT NO. 4

Determination of Heat transfer coefficient of air under free and forced convection

EXPERIMENT NO. 4a

FORCED CONVECTION APPARATUS

AIM: Average surface heat transfer coefficient for a pipe losing heat by forced convection to air flowing, Reynold's Number, Nusselt Number and heat flow rate for different air flow.

THEORY:

The apparatus consists of a blower unit fitted with the test pipe. The test section is surrounded by a Nichrome band heater. Four 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 and measured by meters. It is to be noted that only a part of the total heat supplied is utilized in heating the air. A temperature indicator with cold junction compensation is provided to measure temperature of pipe wall at various points in the test section. A flow is measured with the help of orifice-meter and the water manometer fitted on the board. Details of the test pipe are given in the figure. Schematic diagram of the set up is shown in figure.

SPECIFICATIONS:

1. Pipe Diameter = (D_0) = 33mm
2. Pipe Diameter = (D_i) = 28mm
3. Length of test section (L) = 400mm
4. Blower 1/2 FHP motor
5. Orifice Diameter = (d) = 14mm connected to water manometer
6. Dimmerstat: 0 to 2 amp, 260 volt, AC
7. Temperature indicator: range 0 to 300 °C
8. Voltmeter: 0 to 100/200V, Ammeter 0 to 2 amp
9. Heater: Nichrome wire heater wound on test pipe (Band Type) 400watt

Experimental procedure:

1. Start the blower and adjust the mass flow rate.
2. Adjust the heater input by adjusting the dimmerstat position
3. Report all the observations after reaching the steady state condition.
4. Check the steady state temperature by temperature readings from T1-T7 at the interval of 10 minutes.
5. Take at least minimum four sets of reading.

OBSERVATION TABLE:

S.NO.	Voltage &current setting		Temperature in °C						Manometer reading of water H in water
	V (volt)	I (Amp)	T_1°C	T_2°C	T_3°C	T_4°C	T_5°C	T_6°C	

CALCULATIONS:

1. The rate at which air is getting heated is calculated as

$q_a = m.c_p.\Delta T$ Kcal/hr (in MKS units)

kJ/hr (in SI units)

Where,

m = mass flow rate of air ...... Kg/hr

C_p = specific heat of air ...... Kcal/ºC kg (in MKS units)

...... KJ/ºK kg (in SI units)

$\Delta T = (T_6 - T_1)$ Temperature rise in air .... ºC (in MKS units)

.... ºK (in SI units)

m = Q.ρ where ρ is the density of air to be evaluated at $(T_1 + T_6)/2$ ......Kg/hr

Q = Volume flow rate

$$= C_d * \frac{\pi}{4} * d^2 * \sqrt{2 * g * H * \frac{\rho w}{\rho a}} \quad m^3/hr$$

$h_a = q_a / A (T_s - T_a)$ Kcal/hr.m^2. ºC (in MKS units) & W/m^2. ºK (in SI units)

Where,

q_a = the rate at which the air is getting heated.

A = the test section area (heat transferring area)

= πD_iL .... m^2

T_a = Average temperature of air $(T_1 + T_6)/2$ ºC

T_s = Average surface temperature

= $(T_2+T_3+T_4+T_5)/4$ °C

Where,

C_d = Coefficient of discharge =0.64

H = difference of water level in manometer, in meter

ρ_w = Density of water (1000 Kg/m^3)

ρ_a = Density of air (1.03 Kg/m^3)

d = Density of orifice (0.014 meter)

Using this procedure obtain the value of h_a for different flow rates.

2. Reynold's Number (Re) :

$$Re = \frac{VD_i}{\upsilon}$$

Where,

V = velocity of air

$= \frac{Q}{\pi (D_i)^2/4}$

υ = Kinematic viscosity (in SI unit m^2/s) to be evaluated at average of bulk mean temperature = $(T_1 + T_6)/2$

Nu = Nusselt Number = $h_a D_i/K$

K = Thermal conductivity of air at $(T_1 + T_6)/2$ .... W/m.ºK (in SI units)

3. Prandtl Number (Pr) :

$$Pr = \frac{\mu C_p}{k}$$

The appropriate correlation for turbulent flow through closed conduits is the Dittus-Boelter correlation.

$Nu = 0.023 (Re)^{0.8}.(Pr)^{0.4}$

C_p = specific heat of the fluid ...... Kcal/ºC kg (in MKS units)

...... KJ/ºK kg (in SI units)

u = velocity of the fluid (m/s)

k = Thermal conductivity of fluid ...... W/m ºK (in SI units)

...... Kcal/hr. m ºC (in MKS units)

RESULTS:

CONCLUSIONS:

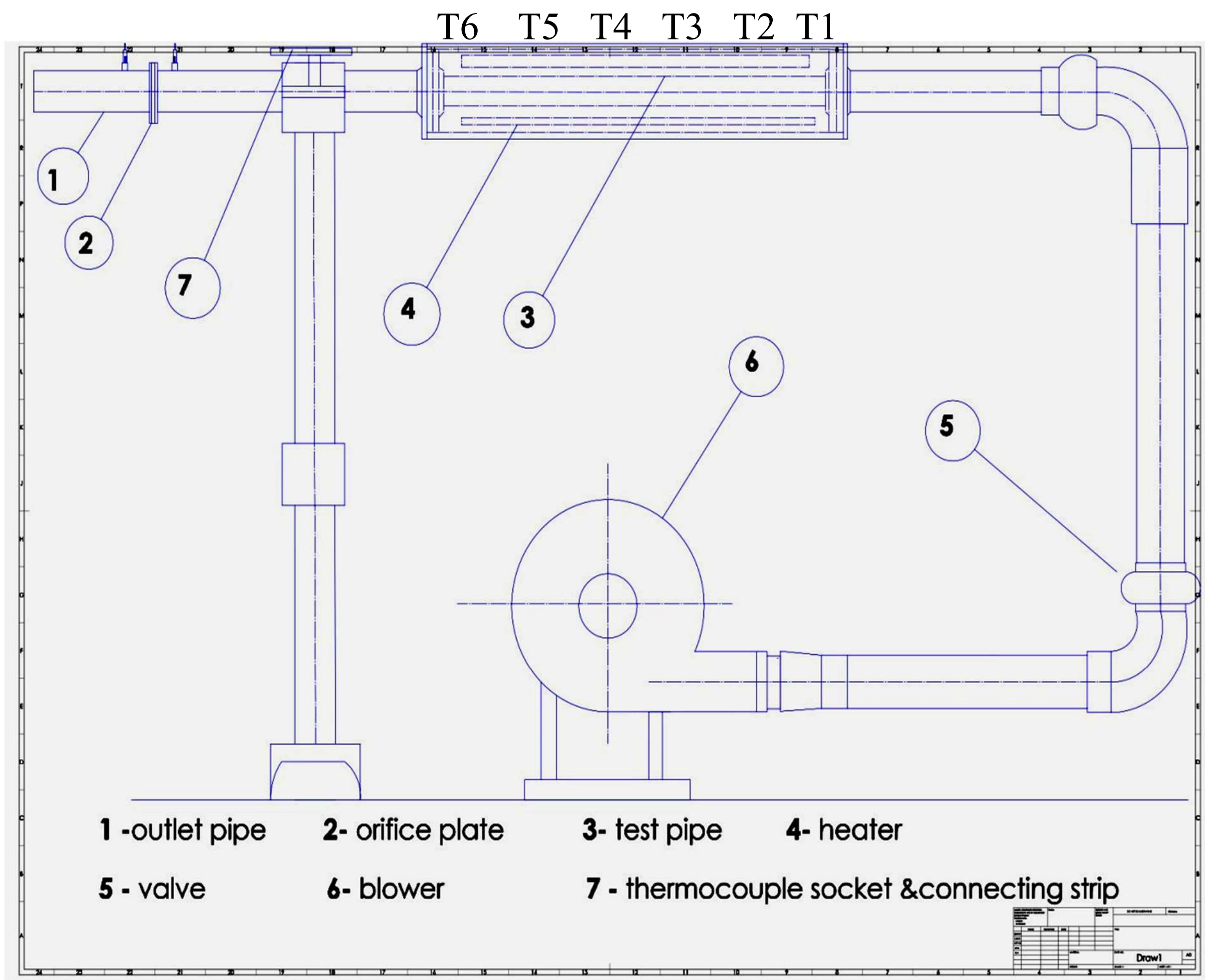
Questions:

1. What is the typical value of heat transfer coefficient of air for forced convection heat transfer?

2. What is the orifice meter?
3. Write down functional group of Nusselt no.

APPENDIX:

EXPERIMENTAL SETUP:



Experiment No. 4b

Title of the experiment: Free convection heat transfer from a heated vertical cylinder to its surrounding air

Objective:

1. To determine the average heat transfer coefficient both experimentally and theoretically.
2. To compare the experimental and theoretical values of the heat transfer coefficient.
3. To determine the local heat transfer coefficient experimentally and show the variation along the height of the cylinder.

Theory: Convection is the mode of heat transfer due to bulk fluid motion. It can be from a solid surface to a moving fluid or between two fluid mediums at different temperatures having relative motion. It is a well-known fact that convection is not a fundamental mode of heat transfer. It is always associated with conduction. The bulk fluid motion known as advection, always tries to increase the temperature gradient and accelerates the conduction rate. In case of forced convection the bulk fluid motion is caused by an external agent such as fan, blower, pump etc. However, in case of natural convection the fluid motion is due to the buoyancy forces within the fluid. Buoyancy is due to the combined presence of fluid density gradient and a body force proportional to the density. The body force proportional to the fluid density may be the gravity, centrifugal force or Coriolis force etc. The density gradient may be due to temperature gradient or may be due to concentration gradient. However, in this course the focus is on the natural convection in which gravity is the body force and temperature gradient is the sole cause of density gradient. When a hot surface is kept in a quiescent fluid, the fluid layer in touch with the solid surface get heated and become lighter which is surrounded by far stream dense fluid, there by subjected to net upward force resulting a natural convection loop as shown in the Fig. a. It is noteworthy to mention here that temperature gradient is not a sufficient condition for natural convection to occur. Irrespective of the mode of convection the heat transfer from the solid surface to the adjoining fluid layer is purely by conduction due to no slip condition. Applying Fourier's law and Newton's law of cooling at solid liquid interface, from the interface energy balance the convective heat transfer coefficient can be defined as:

$$q'' = -k_f\left(\frac{\partial T}{\partial y}\right)_{y=0} = h(T_s - T_\infty)$$

$$\Rightarrow h = \frac{q''}{(T_s - T_\infty)} = \frac{-k_f\left(\frac{\partial T}{\partial y}\right)_{y=0}}{(T_s - T_\infty)}$$

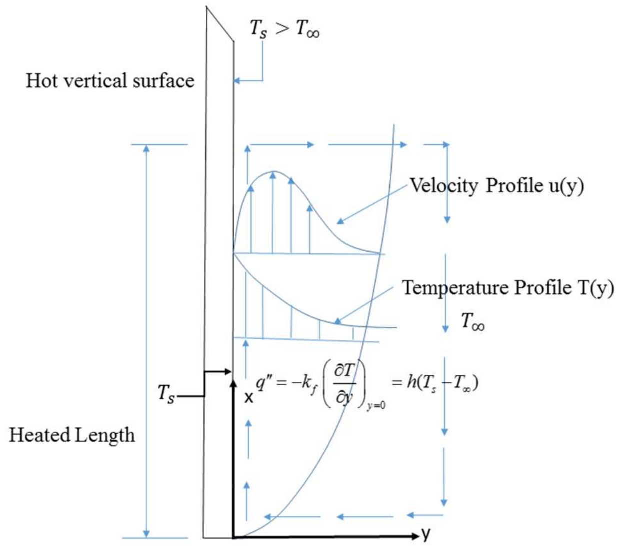


Fig. a. Schematic of natural convection from hot vertical surface

Where q'' is the heat flux, $\left(\frac{\partial T}{\partial y}\right)_{y=0}$ is the temperature gradient in the fluid adjacent to solid wall, k_f is the thermal conductivity of the fluid, T_s is the average surface temperature, T_∞ is the free stream temperature far away from the solid wall and h is the convective heat transfer coefficient. Although this equation looks very simple in case of natural convection the convective heat transfer coefficient depends on many parameters such as fluid properties $(k, \rho, c_p, \beta, \mu)$, temperature difference $(T_s - T_\infty)$, the geometry and orientation of the heat transfer surface. Out of the three important forces such as inertia, viscus and body force in case of natural convection the viscus force and the body force due to buoyant effect is important and their relative magnitude is expressed in terms of a non-dimensional number called Grashof number. Natural convection flow patterns for some commonly observed situations are shown in Fig.2 The present experimental set up is designed and fabricated to study the natural convection phenomenon from a hot vertical cylinder to the surrounding air in terms of the variation of local heat transfer coefficient along the axis of the cylinder and the comparison of average heat transfer coefficient obtained experimentally with the value obtained by using an appropriate correction.

Experimental Setup: The experimental setup consists of a brass tube fitted vertically in a rectangular duct shown in Fig. 5. The duct is open at the top and bottom and forms an enclosure and serves the purpose of undisturbed surrounding. One side of the duct is made of Perspex, for visualization. An electric heating element is kept in the vertical tube, to heat the tube surface. The tube surface is polished to minimize the radiation loss. Hence the heat is lost from the tube to the surrounding air by natural convection only. The temperature of the vertical tube is measured at seven axial locations using thermocouples. Another thermocouple is used to measure the air temperature inside the enclosure. The heat input to the heater is measured by an ammeter and a voltmeter and is varied by a dimmer stat. The vertical cylinder with the thermocouple positions is shown in the Fig.2, while the possible flow pattern and also the expected variation of local heat transfer coefficient is shown in Figs. 1, 3 and 4.

Experimental procedure:

1. Put on the supply and adjust the dimmerstat to obtain the required heater input. Adjust the power input with the help of the voltmeter and ammeter to a value between 40 W and 70 W
2. Wait till the fairly steady state is reached, which is confirmed from temperature reading (T_1-T_7).
3. After ensuring steady state note down the surface temperature at the seven thermocouple locations of the vertical cylinder. (**Note: Keep the power input fixed; otherwise, steady state will not be reached.**)
4. Note down the ambient temperature, T_8.
5. Repeat the experiment for at least three different heat input.

Specifications:

1. Outer diameter of the cylinder (O.D.), D = 38 mm
2. Length of the cylinder, L = 510 mm
3. Vertical distance of the thermocouple1 from the leading edge =1cm
4. Vertical distance between thermocouples 1 and 2 = 4 cm
5. Vertical distance between thermocouples 2 and 3 = 5 cm
6. Vertical distance between thermocouples 3 and 4 = 10 cm
7. Vertical distance between thermocouples 4 and 5 = 10 cm
8. Vertical distance between thermocouples 5 and 5 = 10 cm
9. Vertical distance between thermocouples 6 and 7 = 9 cm
10. Gap between the thermocouples 7 and top of the cylinder =2 cm

Observation Table:

Run No.	Voltage (Volt)	Current (amp)	T_1 (^OC)	T_2 (^OC)	T_3 (^OC)	T_4 (^OC)	T_5 (^OC)	T_6 (^OC)	T_7 (^OC)	T_8 (^OC)
1										
2										
3										

Calculation:

Heat Transfer Rate

$\dot{Q} = VI$

Heat Transfer Area

$A_s = \pi D L$

Heat Flux

$q'' = \dot{Q}/A_s$

Average surface temperature

$$T_s = \frac{T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7}{7}$$

Ambient temperature of the air in the enclosure

$$T_a = T_8$$

Film temperature

$$T_f = \left(T_s + T_a\right)/2$$

Local heat transfer coefficient at 7 axial locations

$$h_j = q''/(T_j - T_a),\ j = 1, 2, \ldots\ldots 7$$

Average heat transfer Coefficient

$$h_{av} = q''/(T_s - T_a)$$

Average Nusselt Number

$Nu_{av} = h_{av} L/k$, k is the thermal conductivity of air at T_f

Gravitational acceleration

$g = 9.8\ m/s^2$

The volume coefficient of expansion

$\beta = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)$, for air which is assumed to be an ideal gas $\beta = \frac{1}{T_f}$, T_f in K.

Grashof Number

$Gr = \frac{g\beta(T_s - T_a)L^3}{\nu^2}$, ν is the kinematic viscosity of air at T_f

Rayleigh number

$Ra = GrPr$, Pr = Prandtl number of air at T_f

Standard empirical correlation for natural convection (for comparison)

$$Nu=\begin{cases} .56Ra^{1/4}, 10^4 < Ra < 10^9 \\ .13Ra^{1/3}, 10^9 < Ra < 10^{12} \end{cases}$$

Note: For all thermophysical property of air the attached chart may be referred.

Results and discussion:

The following should be presented:

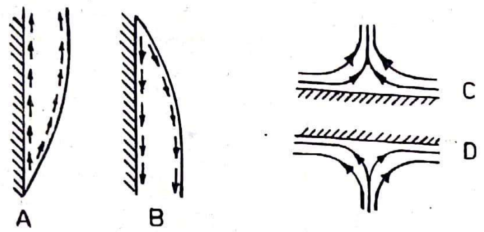
1. A sample calculation.
2. A table summarizing the calculations (e.g. with Nu_{av} and Ra for each run.)
3. A plot of log (Nu_{av}) vs log (Ra) obtained from your calculated values & plot of standard empirical correlation on the same set of axes.
4. Determination of correlation for average Nusselt number.
5. Calculate and plot the variation of local heat transfer coefficient along the length of the tube.
6. Compare the experimentally obtained value with the predictions of the correlation
7. Discussion of results and sources of errors.

Questions:

1. What is the typical range of heat transfer coefficient of air in free convection heat transfer?
2. Why the heat transfer coefficient in natural convection is less than that of forced convection?
3. Why heat transfer coefficient increases towards the end of trailing edge of the vertical cylinder?
4. How heat transfer coefficient is influenced by properties of fluid and other conditions?
5. Give the physical significance of Grashof Number?
6. Draw the expected velocity and temperature profiles at a particular distance from the bottom of the pipe.
7. Explain the reason behind the variation of heat transfer coefficient along the length of the cylinder

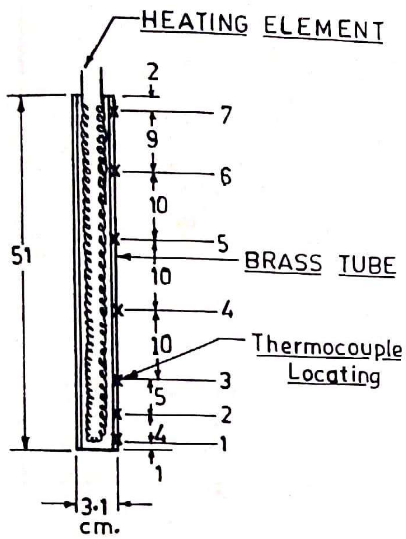
Precautions:

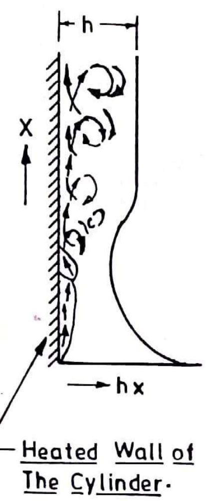
1. Keep the dimmerstat at zero position before switching on power supply.
2. Do not exceed 80 Watts.
3. Handle the change-over switch of temperature indicator gently when changing from one position to another.



A – HEATED VERTICAL PLATE.
B – COOLED VERTICAL PLATE.
C – UPPER SURFACE OF A HEATED HORIZONTAL PLATE.
D – LOWER SURFACE OF A HEATED HORIZONTAL PLATE.

Fig. 1 NATURAL CONVECTION FLOW PATTERNS.





VARIATION OF THE HEAT-TRANSFER COEFFICIENT ALONG THE HEIGHT OF THE TUBE IN FREE AIR FLOW AND DEPENDENCE OF THIS VARIATION ON THE NATURE OF FLOW.

Fig. 2 SCHEMATIC TEST CYLINDER.

Fig. 3

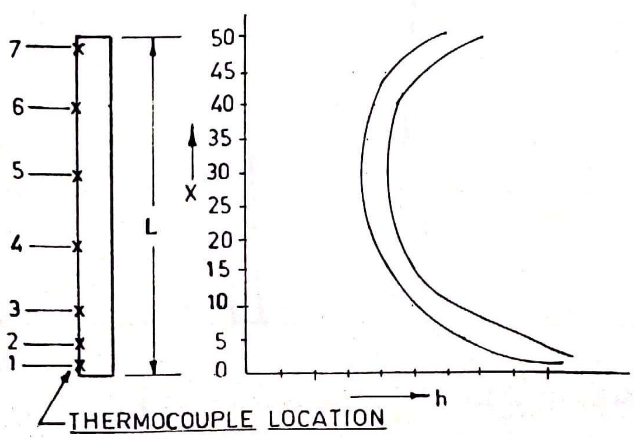


Fig. 4 VARIATION OF LOCAL HEAT TRANSFER COEFFICIENT.

Fig. 5. Experimental setup of Natural convection apparatus

EXPERIMENT NO: 5

Determination of Stefan Boltzmann constant of a black disc

Title of the experiment: To determine the Stefan Boltzmann constant

Objectives:

1. To experimentally determine the Stefan Boltzmann constant for thermal radiation

Theory:

Radiation is the energy emitted by matter in the form of *electro-magnetic waves* (or *photons*) as a result of the changes in the electronic configurations of the atoms or molecules. All bodies at a temperature above absolute zero emit thermal radiation. Unlike conduction and convection, the transfer of energy by radiation does not require the presence of an *intervening medium.* In fact, energy transfer by radiation is fastest (at the speed of light) and it suffers no attenuation in a vacuum. This is how the energy of the sun reaches the earth.

The maximum rate of radiation that can be emitted from a surface at an absolute temperature *Ts* (in K, Kelvin) is given by the **Stefan–Boltzmann law** as: $\boldsymbol{E_b = \sigma T_s^4}$

where $\sigma = 5.67 \times 10^{-8}$ W/m^2·K^4 is the *Stefan–Boltzmann constant.*

The idealized surface that emits radiation at this maximum rate is called a **blackbody,** and the radiation emitted by a blackbody is called **blackbody radiation**. The radiation emitted by all real surfaces is less than the radiation emitted by a blackbody at the same temperature, and is expressed as: $\boldsymbol{E = \varepsilon E_b = \varepsilon \sigma T_s^4}$

where ε is the **emissivity** of the surface. The property emissivity, whose value is in the range $0 \leq \varepsilon \leq 1$, is a measure of how closely a surface approximates a blackbody for which $\varepsilon = 1$.

On the other hand, when radiation is incident over a surface of a body, part of this incident radiation (irradiation) is absorbed, transmitted through and reflected by the body. The fraction of irradiation that is absorbed by the surface is known as **absorptivity α.** Like emissivity, it is also a property of the surface and its value is in the range $0 \leq \alpha \leq 1$. A blackbody absorbs the entire radiation incident on it. That is, a blackbody is a perfect absorber ($\alpha = 1$) as it is a perfect emitter.

Description of the Apparatus

The experimental apparatus consists of a water heated jacket of hemispherical shape. There is a circular opening at the centre of the hemisphere where a blackened copper test disc can be fitted, when desired . The water is heated by an electric immersion heater in the hot water tank. The hot water is taken around the hemisphere, so that hemisphere temperature rises and comes to a steady value. The test disc is then inserted at the center and the temperature rise of the disc is measured.

Thermocouples are fitted inside hemisphere to get the average temperature of the hemisphere. 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 interval of 5 seconds.

Experimental Procedure

1. Check that water inlet cock of water jacket is closed and fill up sufficient water in the heater tank.
2. Put ON the heater.
3. Blacken the test disc with the help of black & let it cool.
4. Put the thermometer and check water temperature.
5. Boil the water and switch OFF the heater.
6. Check that drain cock of water jacket is closed and open water inlet cock.
7. Check that there is sufficient water above the top of hemisphere (A piezometer tube is fitted to indicate water level)
8. Note down the hemisphere temperatures (i.e. upto channel 1 to 4)
9. Note down the test disc temperature (i.e channel No.5)
10. Start the timer. Buzzer will start ringing. At the start of timer cycle, insert test disc into the hole at the bottom of hemisphere.
11. Note down the temperature of disc, every time the buzzer rings. Take at least 4 – 5 readings.

Principle:

When a surface of emissivity ε and surface area *A,* is at an *absolute temperature Ts* is *completely enclosed* by a much larger surface at absolute temperature T_{surr} separated by a gas (such as air) that does not intervene with radiation, the net rate of radiation heat transfer between these two surfaces is given by: $$\boldsymbol{q_{rad} = \epsilon\sigma A(T_s^4 - T_{surr}^4)}$$
In this special case, the emissivity and the surface area of the surrounding surface do not have any effect on the net radiation heat transfer.

In the present experiment, heat received by the blackened disc form the hemispherical surface by radiation: $$\boldsymbol{q = \epsilon\sigma A(T_{surr}^4 - T_s^4) = \epsilon\sigma A\left(T_H^4 - T_D^4\right) = \sigma A\left(T_H^4 - T_D^4\right)}$$

where, T_H is the absolute temperature of the hemispherical surface (in K) and T_D is the absolute temperature of the disc (in K) at any point of time. **Here, it is assumed that the blackened disc is perfectly black with emissivity (ε) = absorptivity (α) = 1**

Now, if T_D is the initial temperature of the disc before it is inserted into the circular opening and brought in radiation contact with the hemisphere, then the rate of heat transfer to disc at time, t = 0, is $$\boldsymbol{q = \sigma A\left(T_H^4 - T_D^4\right)} \qquad \textbf{(1)}$$

We can also calculate the rate of heat received by the disc from its temperature gradient (i.e. rate of change of temperature with time) as follows: $$\boldsymbol{q = m.c_p\left(\frac{dT}{dt}\right)_{t=0}} \qquad \textbf{(2)}$$
where, $\left(\frac{dT}{dt}\right)_{t=0}$ is the time rate of change of temperature of the disc at time t = 0,
m and c_p are the mass and specific heat of the disc, respectively.

Now, from Equations (1) and (2), Stefan-Boltzman constant can be obtained as:

$$\boldsymbol{\sigma = \frac{m.c_p\left(\frac{dT}{dt}\right)_{t=0}}{A\left(T_H^4 - T_D^4\right)}} \qquad (3)$$

Observation Table:

misphere Temperature (°C)	me (Sec)	interval	st disc Temp-erature (°C) (T5)

Calculations

1) Area of test disc, A = $(\pi/4) \times d^2$ m^2 (use, d =20 mm)
2) Weight of test disc, m = 0.0052 kg.
3) Specific heat of copper (disc material), cp = 381 J/kg-°C
4) Plot a graph of temperature rise of test disc with time as base.
5) Determine the slope of the line at time t = 0, i.e., $\left(\frac{dT}{dt}\right)_{t=0}$ (K/s)
6) Find the average temperature of the hemispherical surface:

$$T_H = \frac{T1 + T2 + T3 + T4}{4} + 273.15\ K$$

7) Calculate, Stefan-Boltzman constant (σ) using Equation (3)
8) Compare the value obtained with the theoretical value of Stefan-Boltzman constant (σ).
9) Calculate the Stefan-Boltzman constant (σ) at other time (5, 10, 15 sec) by using T_D = temperature at 5, 10, 15 sec and the slope of temperature curve at the corresponding time.

Discussion:

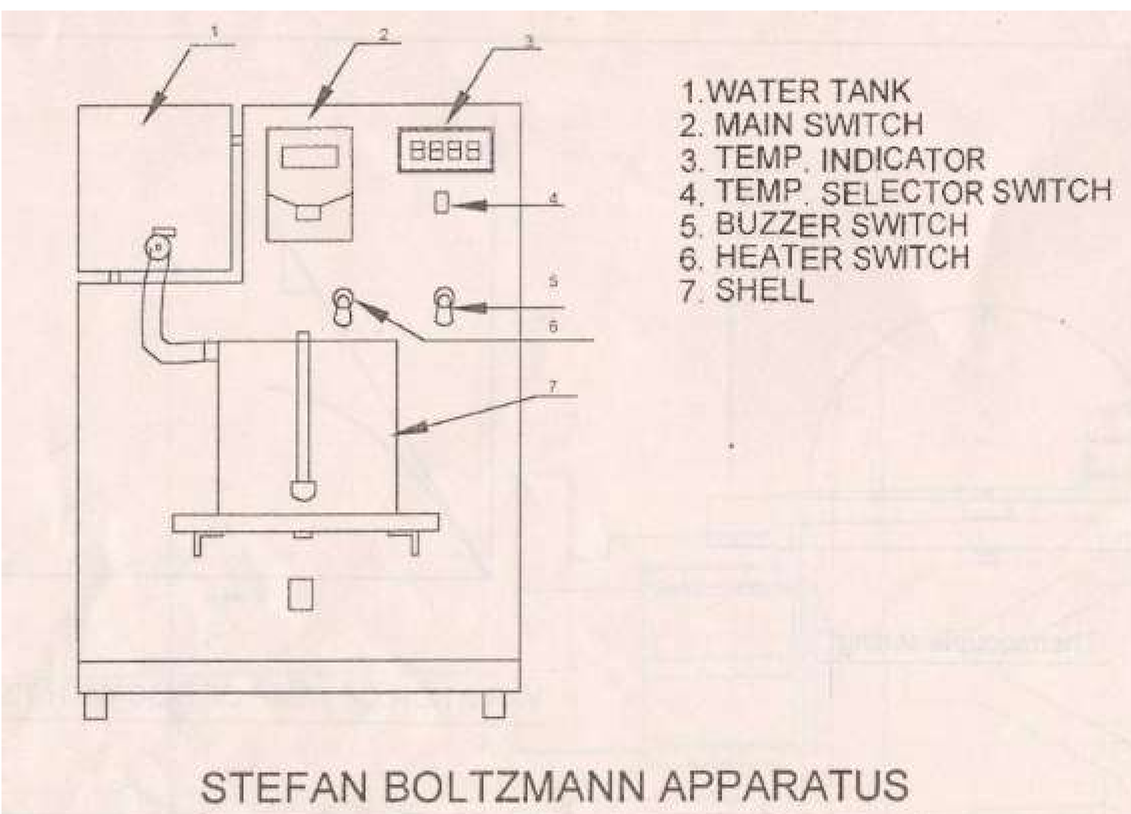
In the experiment, the obtained value of Stefan-Boltzman constant (σ) may deviate from the theoretical value due to reasons like convection, temperature drop of hemisphere, heat losses, etc.

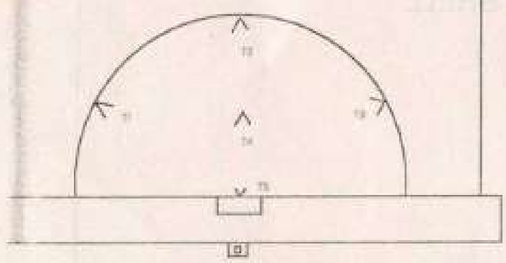
Precautions

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.

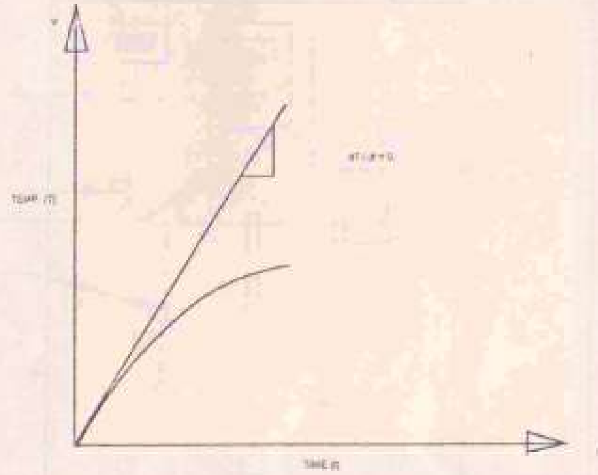
Questions:

1. Why temperature slope is determined at t = 0
2. Write down the properties of the shape factor,
3. What is the black body.





Thermocuple setting



VARIATION OF TEMP.OF DISC WITH TIME

Experiment No. 6

Determination of emissivity of a test surface

AIM: To determine the emissivity of a highly polished surface

INTRODUCTION

All substances at all temperatures emit radiations. Thermal radiation is an electromagnetic wave and does not require any physical medium for propagation. All bodies can emit radiation and also have 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 emissive power and is denoted by 'e'.The emissivity of the surface is the ratio of the emissive power of the surface to the emissive power of the black surface at the same temperature. It is denoted by 'E'

$$E = \frac{e}{e_b}$$

Absorptivity of a black body is 1, and by the knowledge of Kirchhoff's law, the 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 Boltzman's law that the prediction of emissive power of the 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.

Table 1 gives approximate values of emissivity for some common materials for reference.

Material		Temperature	Emissivity
	Polished copper steel, Stainless steel Nickel.	20 °C	0.15, increases with temperature
	Aluminium (oxidized)	90-540°C	0.20 to 0.35
Metals			
Non-Metals	Brick, Wood, Marble,	20-100 °C	0.80 to 1

Water

APPERATUS:

This experimental setup consists of t plates of aluminum, one of them is used as black surface and other as text plate as shown in Fig. 1. Both the plates are heated by separate heating element and kept in a closed box which makes undisturbed natural convection surroundings. Power supply to each plate is varied by using dimmer stat and measured by a voltmeter and ammeter product. Temperature of plates measured by means of two thermocouples and temperature of ambient is measured by third thermocouple. One plate is blackened by a thick layer of lamp black (a black pigment made from soot) to form idealized black surface while other is used as test plate whose emissivity has to be measured. The experimental set up is designed in such a way that under steady-state conditions, the heat dissipation by convection is same for both the plates with the same surface temperatures. The difference in the heater input readings is because of the difference in the radiation characteristics owing to their different emissivities' values.

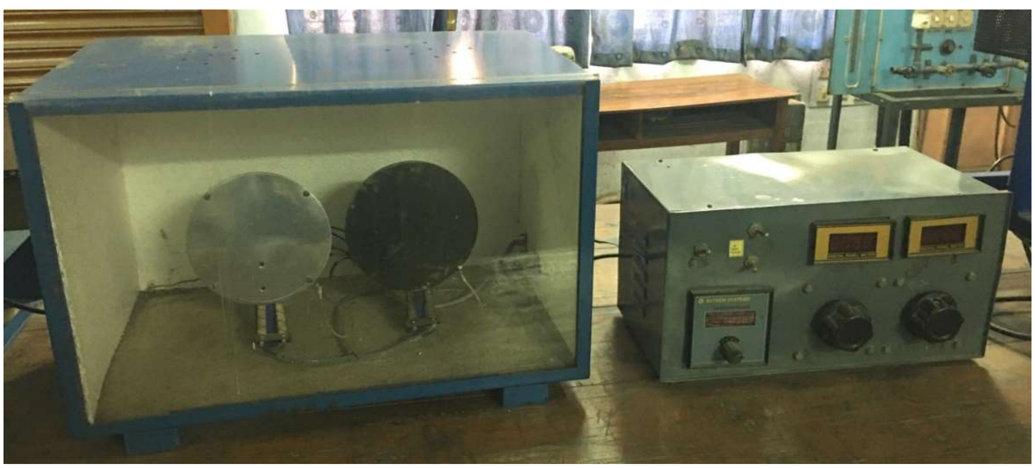


Fig. 1 Photograph of actual set-up

THEORY:

Under steady-state conditions:

Let W_1=heater input to black plate watts =V_1I_1

W_2= heater input to test plate watts =V_2I_2

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

d=Diameter of plates =160 mm

T_s=Temperature of plates = K

T_D=Ambient temperature = K

ε_b=emissivity of black plate =assumed to be unity

ε= emissivity of non-black test plate

σ=Stefan Boltzmann constant.

In SI unit=5.67×10^{-8}w/m^{2}K^4

Also Black plate W_1= Heat loss by radiation (Stefab Boltzman's law) +Heat loss by convection (Newton's law of cooling)

$W_1 = \varepsilon_b \sigma A\left(T_s{}^4 - T_D{}^4\right) + hA\,(T_s - T_D)$---------------------------------(1)

Where *h* is convection heat transfer coeficiant

For test plate, W_2= Heat loss by radiation (Stefab Boltzman's law) +Heat loss by convection (Newton's law of cooling)

$W_2 = \varepsilon \sigma A\left(T_s{}^4 - T_D{}^4\right) + hA\,(T_s - T_D)$------------------------------------(2)

By equation 1-equation 2, and for the same surface temperature of both plates,

$W_1 - W_2 = (\varepsilon_b - \varepsilon)\sigma A\left(T_s{}^4 - T_D{}^4\right)$--(3)

Here the emmisivity of black body can be taken as one.

From eqn 3

$$\varepsilon = 1 - \frac{W_1 - W_2}{\sigma A\left(T_s{}^4 - T_D{}^4\right)}$$

PROCEDURE

1. Gradually increase the input to the heater to the black plate and adjust it to some value viz 30, 50, 75 watts. 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 require 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.

PRECAUTIONS:

1. Use stabilized AC single phase supply (preferably).
2. Always keep the dimmerstat at zero position before start.
3. Use the proper voltage range on voltmeter.
4. Gradually increase the heater inputs.
5. See that the black plate is having the layer of lamp black uniformly.

There is a possibility of getting absurd results if the supply voltage is fluctuating or if the input voltage is not adjusted until the satisfactory steady state condition is reached.

SPECIFICATIONS:

1. Test plate (Aluminium) =160 mm diameter
2. Black plate (Aluminium) =160 mm diameter
3. Heater for one Nichrome strip wound on mica sheet and sandwiched between two mica sheets.
4. Heater for (2) as above capacity for heater=200 watt each.
5. Dimmer state for 1 =0-2 A,0-260V
6. Dimmer state for 2 =0-2 A,0-260V
7. Voltmeter 0-100-200 V, Ammeter 0-2 amp
8. Enclosure size 580mm ×300mm×300 mm approx.
9. Thermocouples-chromel Alumel -3 nos.
10. Temperature indicator 0-300 °C.
11. DPDT switch

OBSERVATION TABLE:

No	BLACK PLATE	ST PLATE	NCLOSURE TEMPERATURE T_D °C

CALCULATION:

$W_1 = V_1 \times I_1$

$W_2 = V_2 \times I_2$

And

$$\varepsilon = 1 - \frac{W_1 - W_2}{\sigma A\left({T_s}^4 - {T_D}^4\right)}$$

Where

W_1 is the heat input to disc coated with lamp black

And W_2 is the heat input to test disc

A=Area of disc (m^2)

T_s =Surface temperatures of discs K

T_D =Ambient temperature of enclosure K

ε =Emissivity of specimen to be determined.

The emissivity of test plate can be calculated at various surface temperature of the plates.

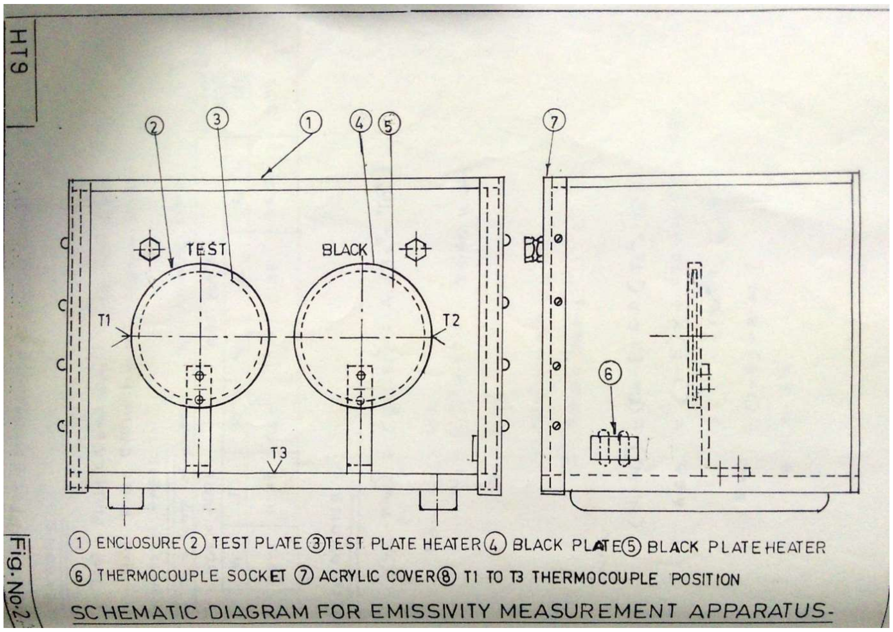
RESULTS:

CONCLUSIONS:

Questions:

1. What is emissivity?

2.How emissivity is influenced by different factors?



SCHEMATIC DIAGRAM FOR EMISSIVITY MEASUREMENT APPARATUS-

EXPERIMENT NO. 7

Concentric study of concentric tube Heat exchanger

Title of the experiment: Performance study of concentric heat exchangers..

Objectives:

1. To determine and compare the rate of heat transfers in two heat exchangers
2. To determine and compare the overall heat transfer coefficients in two heat exchangers.

Theory:

The process of heat exchange between two fluids that are at different temperatures and separated by a solid wall occurs in many engineering applications. The device used to implement this exchange is termed a heat exchanger, and specific applications may be found in space heating and air-conditioning, power production, waste heat recovery, and chemical processing.

Heat exchangers are typically classified according to flow arrangement and type of construction. The simplest heat exchanger is one for which the hot and cold fluids move in the same or opposite directions in a concentric tube (or double-pipe) construction. In the parallel-flow arrangement of Figure 1(a), the hot and cold fluids enter at the same end, flow in the same direction, and leave at the same end. In the counterflow arrangement of Figure 1(b), the fluids enter at opposite ends, flow in opposite directions, and leave at opposite ends. Figure 2 shows the variation of temperatures of hot and cold fluids during their flow through the parallel flow and counter-flow heat exchangers.

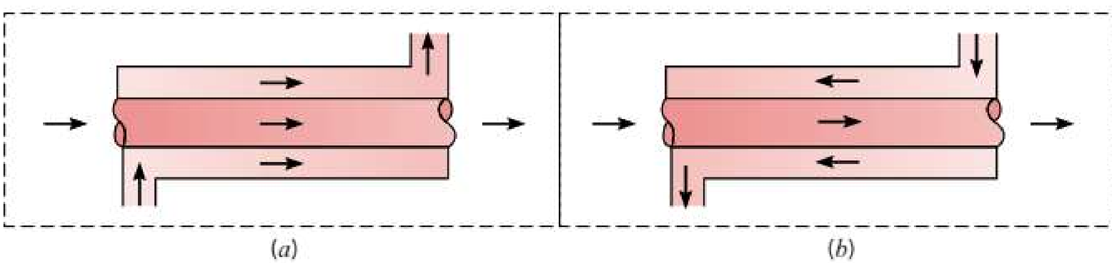


Figure 1: Concentric tube heat exchangers. (a) Parallel flow. (b) Counterflow.

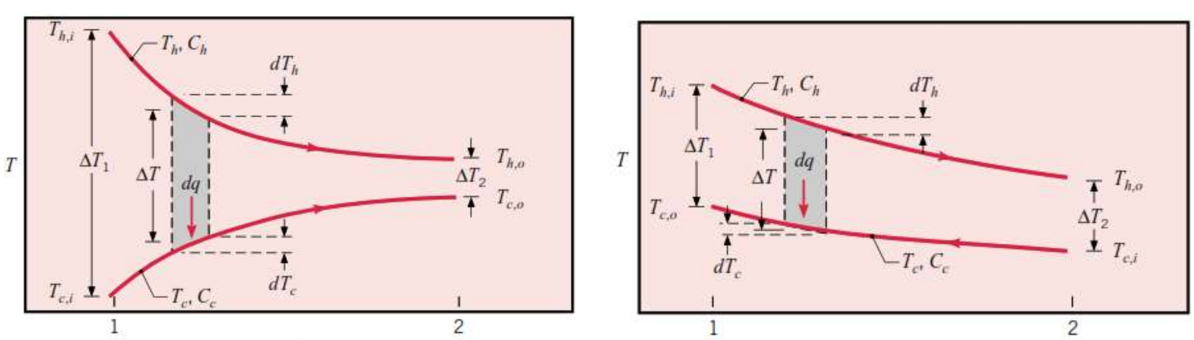


Figure 2: Temperature distributions for a parallel-flow and a counterflow heat exchanger.

Heat transfer through either of the heat exchangers can be estimated as:

$$q = UA\Delta T_{LM} \qquad (1)$$

where, ‘U’ is known as the overall heat transfer coefficient, which is defined in terms of the total thermal resistance to heat transfer between two fluids. The overall heat transfer coefficient is determined by accounting for conduction and convection resistances between fluids separated by composite plane and cylindrical walls, respectively.

‘A’ is the heat transfer surface area, depending on whether cold side or hot side surface area is considered for heat transfer, we may write:

$$UA = U_c A_c = U_h A_h$$

where, c and h refer to the cold side or hot side of the heat exchanger.

ΔT_{LM} is known as Log Mean Temperature Difference (LMTD) which is defined as

$$\Delta T_{LM} = \frac{\Delta T_2 - \Delta T_1}{\ln(\Delta T_2/\Delta T_1)}$$

Note that, for parallel-flow heat exchanger:

$$\Delta T_1 = T_{h,i} - T_{c,i} \qquad and \qquad \Delta T_2 = T_{h,o} - T_{c,o}$$

while for counter-flow heat exchanger:

$$\Delta T_1 = T_{h,i} - T_{c,o} \qquad and \qquad \Delta T_2 = T_{h,o} - T_{c,i}$$

For a special case in counter flow heat exchanger, if $\Delta T_1 = \Delta T_2$, then $\Delta T_{LM} = \Delta T_1 = \Delta T_2$
In these equations, $T_{h,i}$, $T_{h,o}$ are inlet and outlet temperatures of hot fluid, respectively, and $T_{c,i}$, $T_{c,o}$ are inlet and outlet temperatures of cold fluid, respectively.

Fins are often added to surfaces exposed to either or both fluids and that, by increasing the surface area, they reduce the resistance to convection heat transfer. When fluids used on either sides of a heat exchangers are a liquid and a gas, then fins are normally provided on the gas side, since the convection heat transfer coefficients of gases are much lower than that for liquids.

Experimental Procedure:

1. Connect 440 V with neutral and earth, 15A per phase supply to the equipment in your laboratory.
2. Close the drain valve V1. fill the water tank with clean tap water. Ensure that water level should be maintained in water tank throughout the experiment.
3. Fill water in manometers such that the two limbs are filled half way.
4. Provide arrangement to drain the water at the outlet of both the heat exchangers i.e. one for heat exchanger with fins and other one for heat exchanger without fins.
5. Ensure that valve V8 and V9 are fully open.
6. Ensure that valve V7 is fully open, at the same time V6 is fully closed. Refer to the Figure 3.
7. Ensure that valve V11 is fully open, at the same time V10 is fully closed.

8. Switch on the Mains supply of the trainer.
9. Switch on the pump using the switch provided on the panel.
10. Observe the water flow rate on rotameter.
11. Switch ON all the three geysers, by using switch provided on the control panel. Wait for 3 to 5 min. Observe that the temperature T_2 increases.
12. Ensure that damper of the blower is fully open. Start the blower by using DOL starter. Ensure that direction of rotation of blower is as per marked direction.
13. Observe the water level difference in the manometer 1. Note the readings as per observation table.
14. Read the temperatures T1, T2, T3 and T7 on temperature indicator by using rotary knob.
15. Note that air temperature T3 starts increasing. Wait till the temperature T3 becomes steady.
16. Note the reading in observation table.

Now we will take the readings for Heat exchanger without fins under the same conditions.

17. Without switching off blower, pump or geyser, open the valves V8 and V9 fully.
18. Open the valve V6 fully and close the valve V7 fully.
19. Open the valve V10 fully and close the valve V11 fully.
20. Observe the water flow rate in rotameter. It should be same as it was at the time of experiment of heat exchanger with fins.
21. Observe the water level difference in the "manometer 2". Note the readings as per observation table.
22. Read the temperature T4, T5, T6 and T7 on temperature indicator by using rotary knob.
23. Observe that air temperature T3 starts increasing. Wait till the temperature T3 becomes steady. Note the readings in observation table.
24. By using bypass valve i.e. valve V2, vary the water flow rate and follow the procedure from step 13-23 for another set of readings.
25. Switch OFF the blower and he geysers.
26. Wait for 2 min.Switch off Pump and Mains.
27. Disconnect the 440 V,15 A per phase with neutral supply.

Note: You can adjust the water flow rate by operating glob valve i.e.V8 and V9.

OBSERVATION TABLE

Water flow rate	Heat exchanger with Fins			Manometer readings		Heat exchanger without Fins			Manometer readings		Ambient Temp.
LPH	T1 (°C)	T2 (°C)	T3 (°C)	H1 (mm)	H2 (mm)	T4 (°C)	T5 (°C)	T6 (°C)	H3 (mm)	H4 (mm)	T7 (°C)

Parameters required for Calculations

Parameter	Value
Density of water	1000 kg/m^3
Density of air	1.178 kg/m^3
No of Fins	6
Thickness of Fin	2.6 mm
Height of fin	15 mm
Coefficient of discharge	0.6
Orifice Diameter	0.015 m
Specific heat for air	1.005 kJ/kg.K
Copper Tube ID	8.9 mm
Copper Tube OD	16 mm
Heat transfer Area with fins	0.14024 sq .m
Heat transfer Area without fins	0.05024 sq .m

Result Table 1

ΔH		ΔT		\ir Velocity (m/s)		Mass of Air (kg/s)	
ith Fins 1 – H2)	ithout Fins (H3 – H4)	ith Fins 3 – T7)	ithout Fins 6 – T7)	ith Fins	ithout Fins	ith Fins	ithout Fins

Result Table 2

No. of obsn.	Heat transfer rates (W)	Heat transfer rates (W) (without fins)	Effectiveness	Overall heat transfer coefficient (W/m^2-K)

(with fins)

Q_{water}	Q_{air}	Q_1	Q_{water}	Q_{air}	Q_2	$\varepsilon = Q_1/Q_2$	With fins	Without fins

Calculations:

Volume flow rate of air:

$\dot{V} = C_d \times \frac{\pi}{4} \times (d^2) \times \sqrt{\frac{2 \times g \times \rho_1 \times \Delta H}{\rho_2}}$ m³/sec

Where, C_d = Coefficient of Discharge

ρ_1 = water density in kg/m³

ρ_2 = Air density in kg/m³

ΔH = manometer difference = $H_1 - H_2$ (for heat exchanger with fins)

= $H_3 - H_4$ (for heat exchanger without fins)

Mass flow rate of Air (kg/s): $\dot{m} = \dot{V} \times \rho_2$

Rate of heat loss of water: $Q_{water} = m_w\, 3C_{p,w}3\Delta T_w$

$C_{p,w}$ = Specific heat for water =4.187 kJ/kg.K

ΔT_w = Temperature drop of water = $T_1 - T_2$ (for heat Exchanger with fin)

= $T_4 - T_5$ (for heat Exchanger without fin)

Rate of heat gain by air: $Q_{air} = \dot{m} \times C_p \times \Delta T$

C_p = Specific heat for air =1.005 kJ/kg.K

ΔT = Temperature rise of air = $T_3 - T_7$ (for heat Exchanger with fin)

= $T_6 - T_7$ (for heat Exchanger without fin)

(Ideally, if there is no heat loss to the surroundings, Q_{air} should be equal to Q_{water})

Rate of heat transfer: $Q_1 = (Q_{water} + Q_{air})/2$ (for heat Exchanger with fin)

$Q_2 = (Q_{water} + Q_{air})/2$ (for heat Exchanger without fin)

Fin effectiveness: Effectiveness of a fin system is defined as the ratio of the heat transfer with fin to the rate of heat transfer from the surface without fins. Thus, $\varepsilon = \frac{Q_1}{Q_2}$

Log mean Temperature Difference LMTD

$$\Delta T_{LM} = \frac{\Delta T_2 - \Delta T_1}{\ln(\Delta T_2/\Delta T_1)}$$

where, $\Delta T_1 = T_1 - T_3$ *and* $\Delta T_2 = T_2 - T_7$ (for heat exchanger with fins) and $\Delta T_1 = T_4 - T_6 \quad and \quad \Delta T_2 = T_5 - T_7$ (for heat exchanger without fins)

Overall heat transfer coefficient (with respect to air-side surface area):

$$U_o = \frac{Q}{A_o \Delta TT_{LM}} \quad W/m^2K$$

where, A_o = air-side or outside surface area (see the parameter table)

Questions:

1. Discuss on the rates of heat transfer obtained for the heat exchangers with and without fins
2. Discuss on the overall heat transfer coefficients obtained for the heat exchangers with and without fins
3. Comment on the effectiveness of fins obtained.
4. Discuss on how fin effectiveness can be increased?
5. Discuss on the merits and demerits of using fins in heat exchangers?

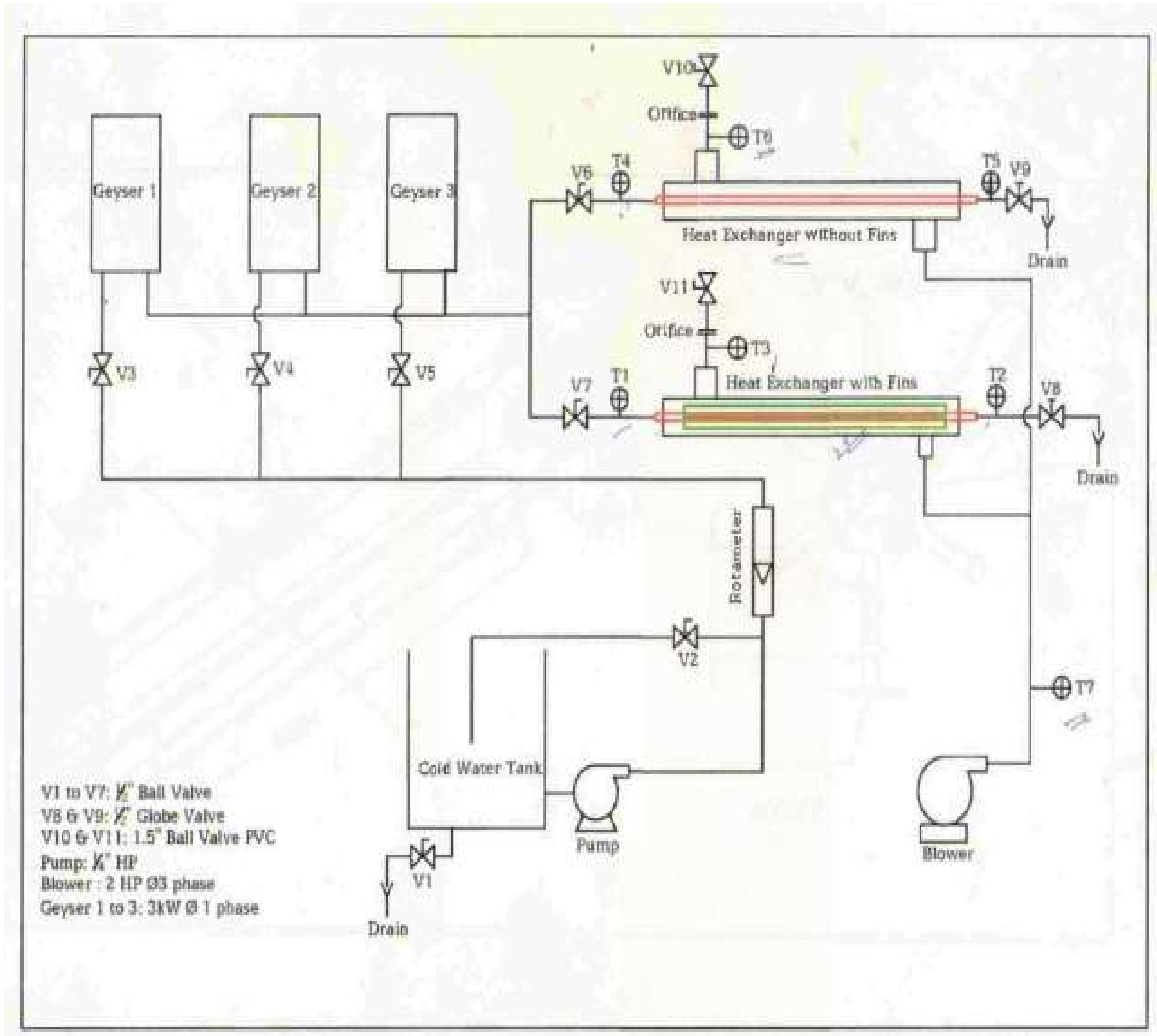


FIGURE 3: SCHEMATIC OF THE EXPERIMENTAL SETUP

TABLE A–9

Properties of air at 1 atm pressure

Temp. T, °C	Density ρ, kg/m³	Specific Heat c_p J/kg·K	Thermal Conductivity k, W/m·K	Thermal Diffusivity α, m²/s	Dynamic Viscosity μ, kg/m·s	Kinematic Viscosity ν, m²/s	Prandtl Number Pr
−150	2.866	983	0.01171	4.158×10^{-6}	8.636×10^{-6}	3.013×10^{-6}	0.7246
−100	2.038	966	0.01582	8.036×10^{-6}	1.189×10^{-6}	5.837×10^{-6}	0.7263
−50	1.582	999	0.01979	1.252×10^{-5}	1.474×10^{-5}	9.319×10^{-6}	0.7440
−40	1.514	1002	0.02057	1.356×10^{-5}	1.527×10^{-5}	1.008×10^{-5}	0.7436
−30	1.451	1004	0.02134	1.465×10^{-5}	1.579×10^{-5}	1.087×10^{-5}	0.7425
−20	1.394	1005	0.02211	1.578×10^{-5}	1.630×10^{-5}	1.169×10^{-5}	0.7408
−10	1.341	1006	0.02288	1.696×10^{-5}	1.680×10^{-5}	1.252×10^{-5}	0.7387
0	1.292	1006	0.02364	1.818×10^{-5}	1.729×10^{-5}	1.338×10^{-5}	0.7362
5	1.269	1006	0.02401	1.880×10^{-5}	1.754×10^{-5}	1.382×10^{-5}	0.7350
10	1.246	1006	0.02439	1.944×10^{-5}	1.778×10^{-5}	1.426×10^{-5}	0.7336
15	1.225	1007	0.02476	2.009×10^{-5}	1.802×10^{-5}	1.470×10^{-5}	0.7323
20	1.204	1007	0.02514	2.074×10^{-5}	1.825×10^{-5}	1.516×10^{-5}	0.7309
25	1.184	1007	0.02551	2.141×10^{-5}	1.849×10^{-5}	1.562×10^{-5}	0.7296
30	1.164	1007	0.02588	2.208×10^{-5}	1.872×10^{-5}	1.608×10^{-5}	0.7282
35	1.145	1007	0.02625	2.277×10^{-5}	1.895×10^{-5}	1.655×10^{-5}	0.7268
40	1.127	1007	0.02662	2.346×10^{-5}	1.918×10^{-5}	1.702×10^{-5}	0.7255
45	1.109	1007	0.02699	2.416×10^{-5}	1.941×10^{-5}	1.750×10^{-5}	0.7241
50	1.092	1007	0.02735	2.487×10^{-5}	1.963×10^{-5}	1.798×10^{-5}	0.7228
60	1.059	1007	0.02808	2.632×10^{-5}	2.008×10^{-5}	1.896×10^{-5}	0.7202
70	1.028	1007	0.02881	2.780×10^{-5}	2.052×10^{-5}	1.995×10^{-5}	0.7177
80	0.9994	1008	0.02953	2.931×10^{-5}	2.096×10^{-5}	2.097×10^{-5}	0.7154
90	0.9718	1008	0.03024	3.086×10^{-5}	2.139×10^{-5}	2.201×10^{-5}	0.7132
100	0.9458	1009	0.03095	3.243×10^{-5}	2.181×10^{-5}	2.306×10^{-5}	0.7111
120	0.8977	1011	0.03235	3.565×10^{-5}	2.264×10^{-5}	2.522×10^{-5}	0.7073
140	0.8542	1013	0.03374	3.898×10^{-5}	2.345×10^{-5}	2.745×10^{-5}	0.7041
160	0.8148	1016	0.03511	4.241×10^{-5}	2.420×10^{-5}	2.975×10^{-5}	0.7014
180	0.7788	1019	0.03646	4.593×10^{-5}	2.504×10^{-5}	3.212×10^{-5}	0.6992
200	0.7459	1023	0.03779	4.954×10^{-5}	2.577×10^{-5}	3.455×10^{-5}	0.6974
250	0.6746	1033	0.04104	5.890×10^{-5}	2.760×10^{-5}	4.091×10^{-5}	0.6946
300	0.6158	1044	0.04418	6.871×10^{-5}	2.934×10^{-5}	4.765×10^{-5}	0.6935
350	0.5664	1056	0.04721	7.892×10^{-5}	3.101×10^{-5}	5.475×10^{-5}	0.6937
400	0.5243	1069	0.05015	8.951×10^{-5}	3.261×10^{-5}	6.219×10^{-5}	0.6948
450	0.4880	1081	0.05298	1.004×10^{-4}	3.415×10^{-5}	6.997×10^{-5}	0.6965
500	0.4565	1093	0.05572	1.117×10^{-4}	3.563×10^{-5}	7.806×10^{-5}	0.6986
600	0.4042	1115	0.06093	1.352×10^{-4}	3.846×10^{-5}	9.515×10^{-5}	0.7037
700	0.3627	1135	0.06581	1.598×10^{-4}	4.111×10^{-5}	1.133×10^{-4}	0.7092
800	0.3289	1153	0.07037	1.855×10^{-4}	4.362×10^{-5}	1.326×10^{-4}	0.7149
900	0.3008	1169	0.07465	2.122×10^{-4}	4.600×10^{-5}	1.529×10^{-4}	0.7206
1000	0.2772	1184	0.07868	2.398×10^{-4}	4.826×10^{-5}	1.741×10^{-4}	0.7260
1500	0.1990	1234	0.09599	3.908×10^{-4}	5.817×10^{-5}	2.922×10^{-4}	0.7478
2000	0.1553	1264	0.11113	5.664×10^{-4}	6.630×10^{-5}	4.270×10^{-4}	0.7539

Note: For ideal gases, the properties c_p, k, μ, and Pr are independent of pressure. The properties ρ, ν, and α at a pressure P (in atm) other than 1 atm are determined by multiplying the values of ρ at the given temperature by P and by dividing ν and α by P.

Experiment No-8

Experiment Name: Performance study of Pelton turbine

Objective: To find out the efficiency of Pelton turbine at constant speed

Theory:

Pelton wheel is an impulse turbine which is used to utilize high heads for generation of electricity. It consists of a runner mounted on a shaft. To this a brake drum is attached to apply brakes over the speed of the turbine. A casing is fixed over the runner. All the available head is converted into velocity energy by means of spear and nozzle arrangement. The spear can be positioned in 8 places that is, 1/8, 2/8, 3/8, 4/8, 5/8 6/8, 7/8 and 8/8 of nozzle opening. The jet of water then strikes the buckets of the Pelton wheel runner. The buckets are in shape of double cups joined at middle portion. The jet strikes the knife edge of the buckets with least resistance and shock. The jet is deflected through more than 160^o to 170^o. While the specific speed of Pelton wheel changes from 10 to 100 passing along the buckets, the velocity of water is reduced and hence the impulsive force is supplied to the cups which in turn are moved and hence the shaft is rotated. The supply of water is arranged by means of centrifugal pump. The speed of turbine is measured with tachometer. Detailed setup arrangements are shown in fig 2.1.

Apparatus and components required: Pelton wheel test rigs, Tachometer, weights

Pelton turbine

Rated supply head	: 20.0 Meters.
Discharge	: 1700 Lpm
Rated speed	: 1000 rpm
Power output	: 1.5 kw (2HP)
Run way speed	: 1700 rpm
Hub diameter	: 78 mm
P.C.D guide vanes	: 230 mm
Runner outside diameter	: 150 mm
No. of guide vanes	: 10
Brake drum diameter	: 300 mm
Rope diameter	: 15 mm

Supply pumpset

Rated head : 13.5 meters

Discharge : 2000 Lpm.

Normal speed : 1440 rpm

Power required : 7.5 HP (5.625 KW)

Type : High speed, Centrifugal

Flow measuring unit

Size of Orifice meter : 150 mm

Area ratio : 0.35 (constant)

Throat diameter for Orifice : 88.74 mm

Meter constant for

Orifice meter : K = 93(Q = K √h) in mm/Hg

Inlet cone angle : 21°

Diverging cone angle : 14°

Manometer : Double column differential type

Fig. 3.1 Pelton turbine test rig for constant speed

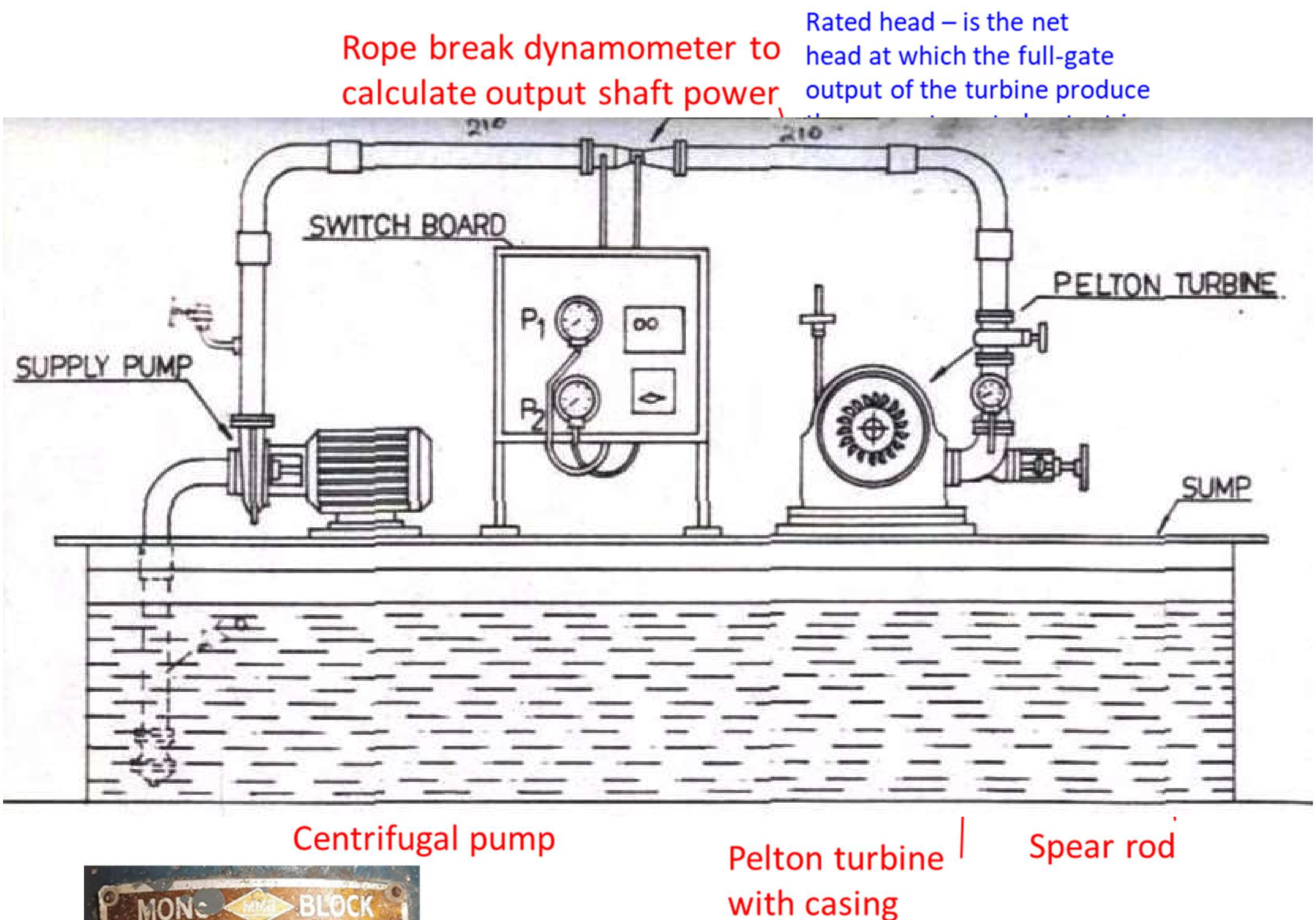


Fig. 3.2 Components of Pelton turbine test rig for constant speed

Experimental and numerical procedure:

1. Initially keep the nozzle opening at about 3/8 th open position
2. Prime the pump if necessary
3. Close the deliver gate valve completely and start the pump.
4. Allow water in the turbine, and then the turbine rotates.
5. Adjust the deliver gate valve opening and note the Turbine inlet pressure.
6. Note the venturimeter pressure gauge readings.
7. Load the turbine by putting weights.
8. Note the speed of the turbine.
9. Note weight on hanger, W1 and spring balance weight W2 and weight of hanger W0
10. *Now consider the speed of turbine as constant. Vary input discharge by operating nozzle as well as dead weight in the hanger of the rope break dynamometer. Repeat the experiment for different dead weight loading and discharge combination (by operating nozzle), by keeping speed constant.*

Observation table and calculation:

$$\text{Input Power} = \frac{\text{Supply head in meters X Discharge in LPM}}{\text{Constant}}$$

$$\text{Brake Power} = \frac{2\pi\, NT}{\text{Constant}}$$

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

** Here N = Turbine speed in RPM. T = Torque in Kg m.

Table for this exercise is attached at the end.

A. To determine discharge: -

Venturimeter line pressure gauge reading $= P_1$ Kg / Sq.cm

Venturimeter throat pressure gauge reading $= P_2$ Kg / Sq.cm

Pressure Different dH $= (P1 - P2) \times 10$ m of water

Venturimeter equation Q $= 0.0055\sqrt{dH}\ m^3/sec$.

Note:-Venturimeter inlet dia. D= 65mm

Throat dia. ratio B= 0.6

Discharge $Q = Cd \times A \times B \times \sqrt{(2 \times 9.81 \times dH \div (1 - B^4)}$

Where, C_d - Venturimeter discharge coefficient = 0.98

A - Inlet area $= 3.14 \times D^2 / 4$

B. **To determine inlet head of water:**

Turbine pressure gauge Reading = G Kg / Sq.cm

Total Head $H = G \times 10$ m of water

C. **Input to the Turbine :-**

Input = $9.81\,Q\,H$ KW

= $1000\,Q\,H / 75$ HP

D. **Turbine output** :

Brake drum diameter = 0.40 m

Rope diameter = 0.15 m

Equivalent drum diameter = 0.415 m

Hunger Weight T0 = 1 Kg

Weight = T_1 Kg

Spring Load = T_2 Kg

Resultant Load T $= (T_1 - T_2 + T_0)$

Speed of Turbine N = rpm

Turbine output $= (3.14 \times D \times NT)/(75 \times 60)$ KW

$= 0.000215\,N\,T$ KW

$= (3.14 \times D \times N \times T)/(75 \times 60)$ HP

E. Turbine Efficiency = Output / Input $\times 100\%$

Result: (i) Turbine efficiency vs loading result and graph

(ii) (i) Turbine efficiency vs different discharge and graph

Question:

1. Efficiency of the pelton turbine is _________ while using constant speed instead of constant discharge.
2. Bypass water flow is done in the break drum of the Pelton turbine to __________________.
3. Role of casing in the pelton turbine is _______________________________.

PELTON
(CONSTANT SPEED)

BRAKE DRUM DIAMETER. : 0.4
ROPE DIA. : 0.15
EQUIVALENT DRUM DIA. : 0.415
WT. OF HANGER T_0 : 1 Kg

Nozzle scale opening : 3.5 / 8th (constant speed)

TURBINE OUTPUT : N T KW.
TURBINE INPUT : 9.81 Q H KW.
DISCHARGE : $\sqrt{H_1}$ m^3/sec.

Efficiency : $\frac{\text{Output}}{\text{Input}} \times 100\%$

OBSERVATION TABLE:

S. NO	Pressure Gauge P Kg/cm²	Vacuum Gauge V mm of Hg	VENTURIMETER READING			Equivalent Head H_1 M of water	Discharge Q M³/sec.	Speed N rpm	Wt. of Hanger T_1 Kg	Spring Balance Reading T_2 Kg	Net Load $(T_1 - P_2)$	Turbine Input KW	Turbine Output KW	Efficiency %
			P_1	P_2	$(P_1 - P_2)$									

Experiment No. 9

Experiment Name: - Performance study of Kaplan turbine

Objective: To determine efficiency of Kaplan turbine under constant discharge and to plot the operating characteristics.

Theory:

A Kaplan turbine is a type of reaction turbine. It is an axial flow turbine which is suitable for relatively low heads, and requires a large quantity of water to develop large amount of power. It is a reaction type turbine and hence it operates entirely in a closed conduit from head race to tail race. The test rig consists of a 1 kW Kaplan turbine supplied with water from a suitable 5HP pump through pipe lines, a valve and a flow measuring venturimeter. The turbine consists of a cast iron body with volute casing, an axial flow gunmetal runner, a ring of adjustable guide vanes and a draft tube. The Runner consists of three aerofoil section. The guide is vanes can be rotated about their axis by means of hand wheel. A rope brake drum is mounted on the turbine to absorb the power developed. Suitable dead weight and a hanger arrangement, a spring balance and cooling water arrangement is provided for the brake drum. Water under pressure from the pump enters through the volute casing and the guide vanes into the Runner .while passing through the spiral casing and guide vanes, a portion of the pressure energy (Potential energy) is converted into velocity energy (kinetic energy) .Water thus enters the runner at high velocity and it passes through the runner vanes, the remaining potential energy is converted into Kinetic energy. Due to the curvature of the vanes, the kinetic energy is transformed into the Mechanical i.e. the water head is converted into mechanical energy hence the runner rotates. The water from the runner is then discharged into the draft tube. The flow through the pipe lines into the turbine is measured with the venturimeter fitted in the pipeline. Two pressure gauges are provided to measure the pressure difference across venturimeter. The net pressure difference across the turbine inlet and exit is measured with a pressure gauge and Vacuum gauge. The turbine output is determined with the rope brake drum. A tachometer is used to Measure the speed.

Apparatus and components required:

Runner: - Runner is of bronze with four aero foil blades, designed to the latest Hydro- dynamic principles. All parts coming in contact with water are made either or Bronze or of stainless steel to prevent corrosion.

Guide vane mechanism: - Consists of bronze vanes cast integral with their spindles by suitable external link mechanism these can be set at different relative position, and two external dummy guide vanes are provided to indicate the exact position in actual guide vanes working inside the turbine, thus showing the relative water passes through the guide apparatus for the different position in the guide vanes.

Shaft: -shaft is made of stainless steel and hollow to accommodate the runner blade control mechanism.

Draught tube: -Draught tube is made of mild steel fabricated construction and length 500 mm is provided at the exist of runner.

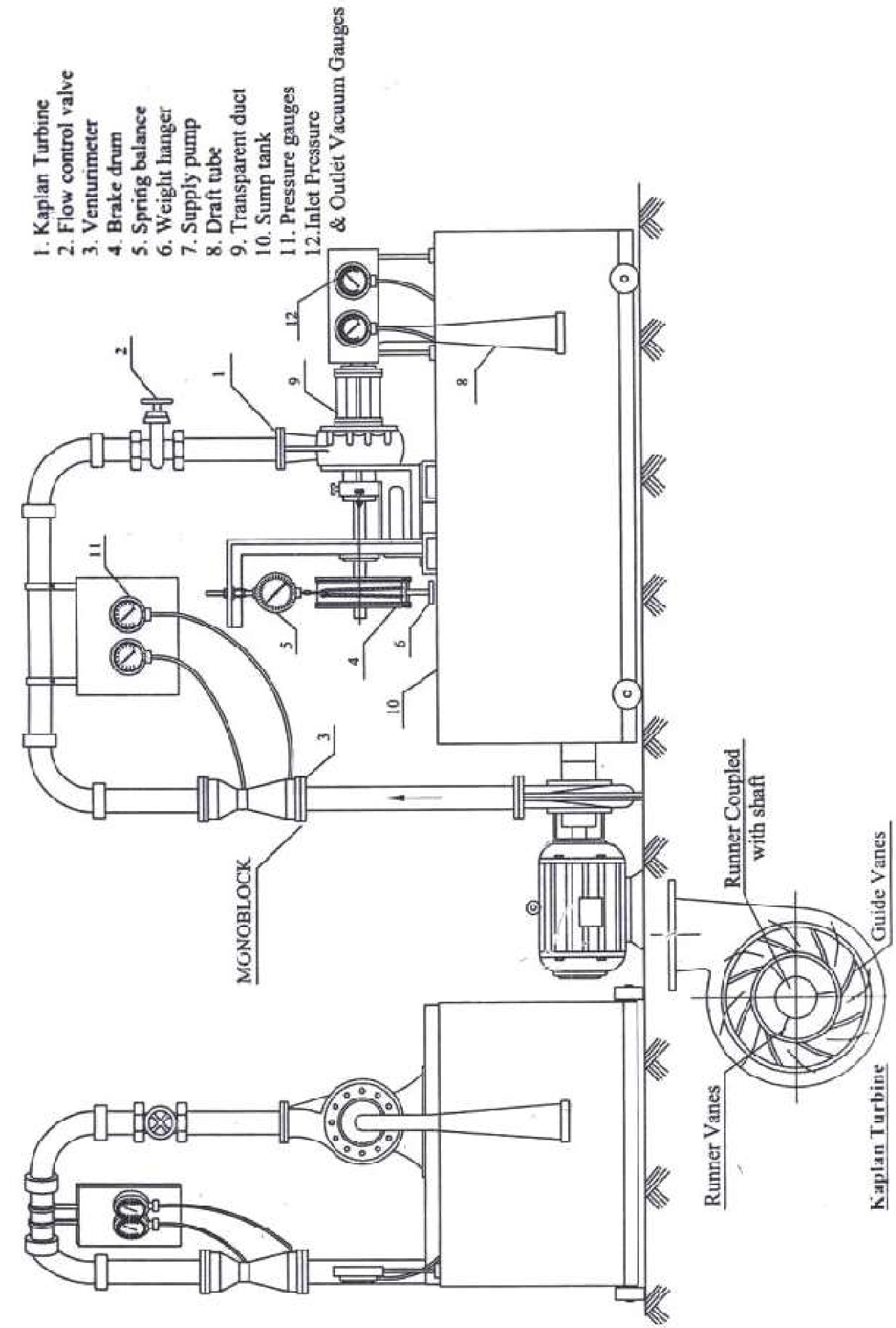


Fig. 5.1 Kaplan turbine test rig

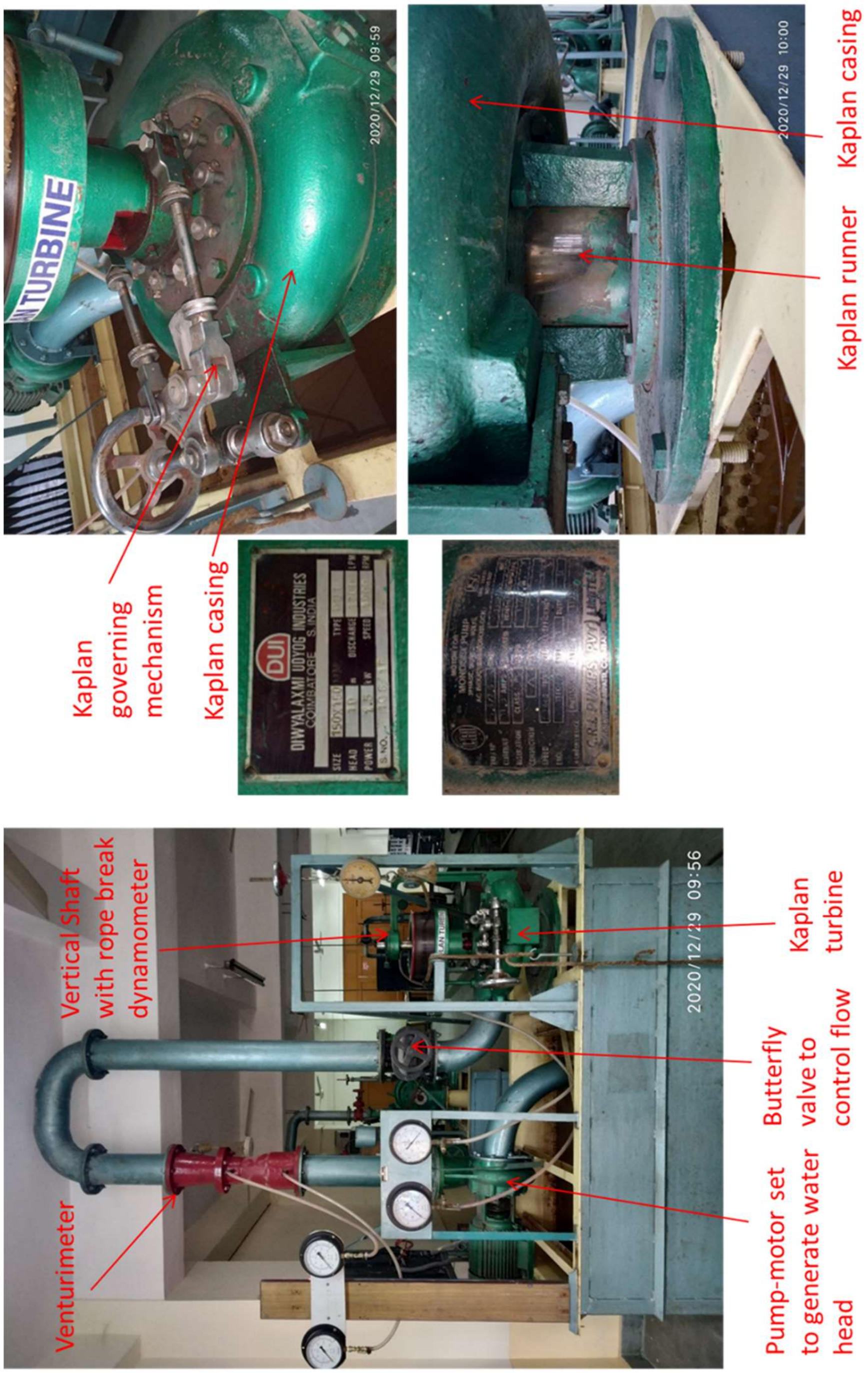


Fig. 5.2 Components of kaplan turbine experiment setup

Kaplan turbine

1. Rated supply head : 20.0 Meters.
2. Discharge : 1700 Lpm

3. Rated speed : 1000 rpm
4. Power output : 1.5 kw (2HP)
5. Run way speed : 1700 rpm
6. Hub diameter : 78 mm
7. P.C.D guide vanes : 230 mm
8. Runner outside diameter : 150 mm
9. No. of guide vanes : 10
10. Brake drum diameter :300 mm
11. Rope diameter : 15 mm

Supply pumpset

Rated head : 13.5 meters

Discharge : 2000 Lpm.

Normal speed : 1440 rpm

Power required : 7.5 HP (5.625 KW)

Type : High speed, Centrifugal

Flow measuring unit

Size of Orifice meter : 150 mm

Area ratio : 0.35 (constant)

Throat diameter for Orifice : 88.74 mm

Meter constant for

Orifice meter : $K = 93 (Q = K\sqrt{h})$ in mm / Hg

Inlet cone angle : 21°

Diverging cone angle : 14°

Manometer : Double column differential type

Experimental and numerical procedure:

$$\text{Input Power} = \frac{\text{Supply head in meters X Discharge in LPM}}{\text{Constant}}$$

$$\text{Brake Power} = \frac{2\pi NT}{\ldots}$$

Constant

Out put

Efficiency = ----------

Input

** Here N = Turbine speed in RPM. T = Torque in Kg m.

Observation Table and Calculation:-

1. **To determine discharge:-**

Orifice meter inlet dia. d = 100mm = 0.1 m

Throat dia. d2 = 67.08mm = 0.6708

d2/ d1 ratio = 0.6708

Orifice meter: pressure gauge reading 1 = P1 m of water

Pressure gauge reading 2 = P2 m of water

Pressure Difference h = P1 – P2 m of water

*Note 1 Kg/cm sq. = 10 meters of water

Orifice meter Equation

Actual discharge $Q_a = K\sqrt{h}$ LPM , K = 93

$$Q_a = \frac{C_d \ a_1 - a_2 \sqrt{2gh}}{\sqrt{a_1 - a_2}} \times 60000 \, \text{LPM}$$

Where c d = Orifice meter discharge co-efficient = 0.98 and

a_1 =is inlet area $= 3.14 \times d_1^2 / 4\, m^2$

a_2 = is throat area = $3.14 \times d_2^2 / 4\, m^2$

The constant 60,000 is used to convert 'Q' value m^3 / sec to LPM

2. **To determine inlet head of water:**

Turbine pressure gauge Reading = H m of water

Turbine Vacuum gauge Reading = Negligible

3. **Input to the Turbine :**

Input power = $H \times Q_a / 4500\, HP$

4. **Turbine output** :

Brake drum diameter D = 0.30 m

Rope diameter $t = 0.15$ m

Effective Radius of brake drum $R = (D/2 + t)$ m

Rope & hunger Weight = 1 Kg

Weight = W1 Kg

Spring Load = W2 Kg

Net Load $W = (W_1 + 1) - W_2$ Kg

Torque $T = W \times R$ Kg.m

Speed of Turbine $N = \text{rpm}$

Output Power $= \dfrac{2\pi NT}{4500} = 2 \times 3.14 \times 0.165 \times W\,N / 4500 = 0.000230266 \times N\,W$ HP

5. Turbine Efficiency $\text{Output} / \text{Input} \times 100\,\%$

Result: Turbine efficiency vs loading result and graph

Question:

1) How many governing mechanisms are installed in Kaplan turbine?

2) Best turbine under partial load condition is ______________________.

KAPLAN TURBINE TEST RIG. (CLOSED CIRCUIT)

Brake drum dia. D= 0.3 m

Rope dia. t = 0.015 m

Effective Radius of brake drum = $(D/2 + t)$

R = 0.165 m

Weight of Rope & hanger = 1 Kg

Guide vane opening = 0.5

Input Total head H = pressure gauge Reading in Kg/cm X 10 mts

Venturimeter head h = Difference in pressure gauge readings = (P1-P2)m

Input Power $IP = H \times Q / 4500\, HP$

Brake Drum net Wt. $W = (W_1 + 1) - W_2\ Kg$

Turbine Output $OP = \frac{2\pi NT}{4500} HP$

Efficiency $= Output / Input \times 100\%$

S.NO.	Pressure(H) gauge reading m of water	Orifice meter head			Discharge Q =$93\sqrt{h}\ LPm$	Speed N	Wt. on hanger W1 Kg	Spring balance W2 Kg	Net Wt. W Kg	Output OP HP	Input IP HP	Efficiency %
		P1 (m of water)	P2	h								
1												
2												
3												
4												
5												
6												

Experiment No.- 10

Experiment Name: Study of air compressor

Objective: To find the efficiency of 2-stage reciprocating air compressor

Theory: Reciprocating compressors work on the principle of reciprocating motion of pistons in cylinder for trapping and compression of air. These are positive displacement compressors. The compression cylinders are known as stages. There are three types of reciprocating compressors based on stages.

1. Single Stage: The compressor has one discharge per revolution of crankshaft.
2. Double Stage: The compressor has two discharge strokes per revolution of the crankshaft. The double stage compressors are most heavy-duty compressors.
3. Multi Stage: The multistage compressors have more than two discharge stages. This leads to increased volumetric efficiency, reduced leaks, better mechanical balance.

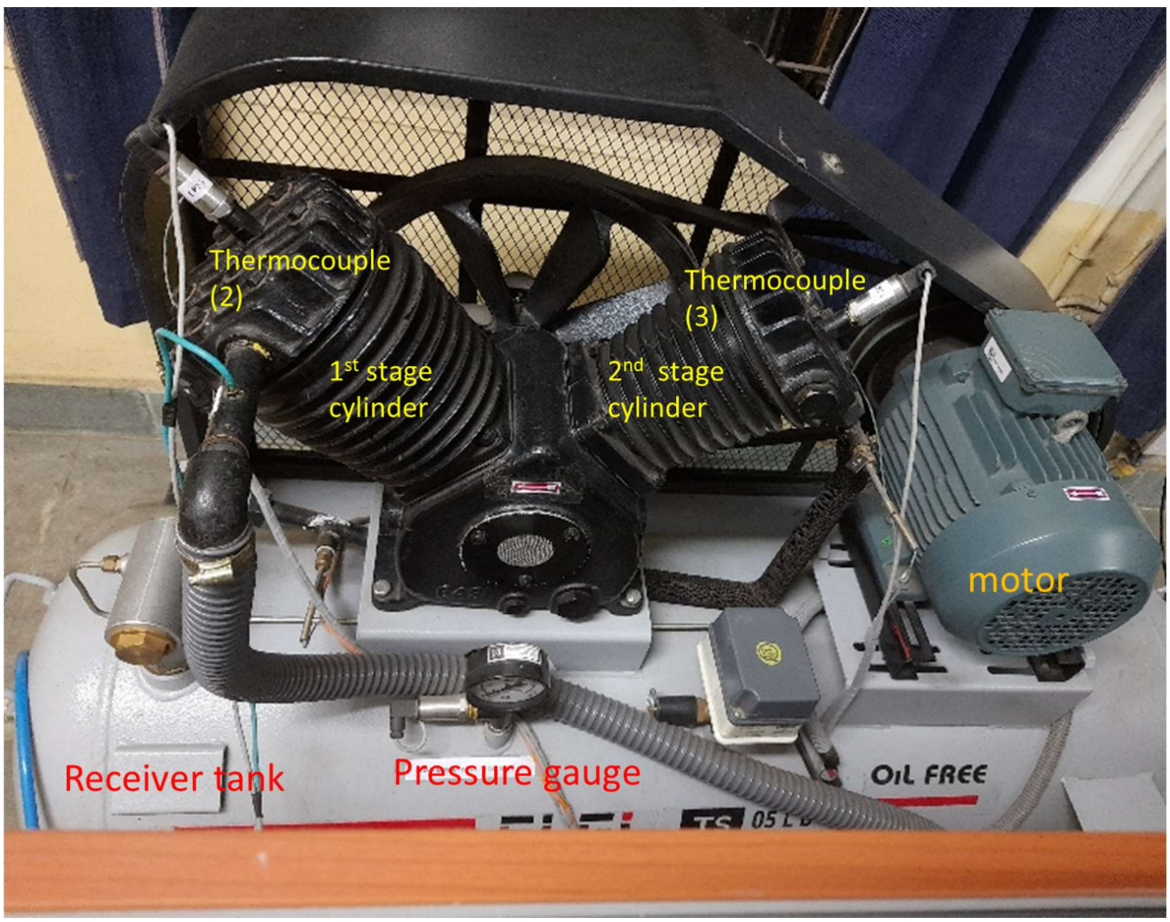


Fig. 6.1 Different components of 2 stage reciprocating air compressor

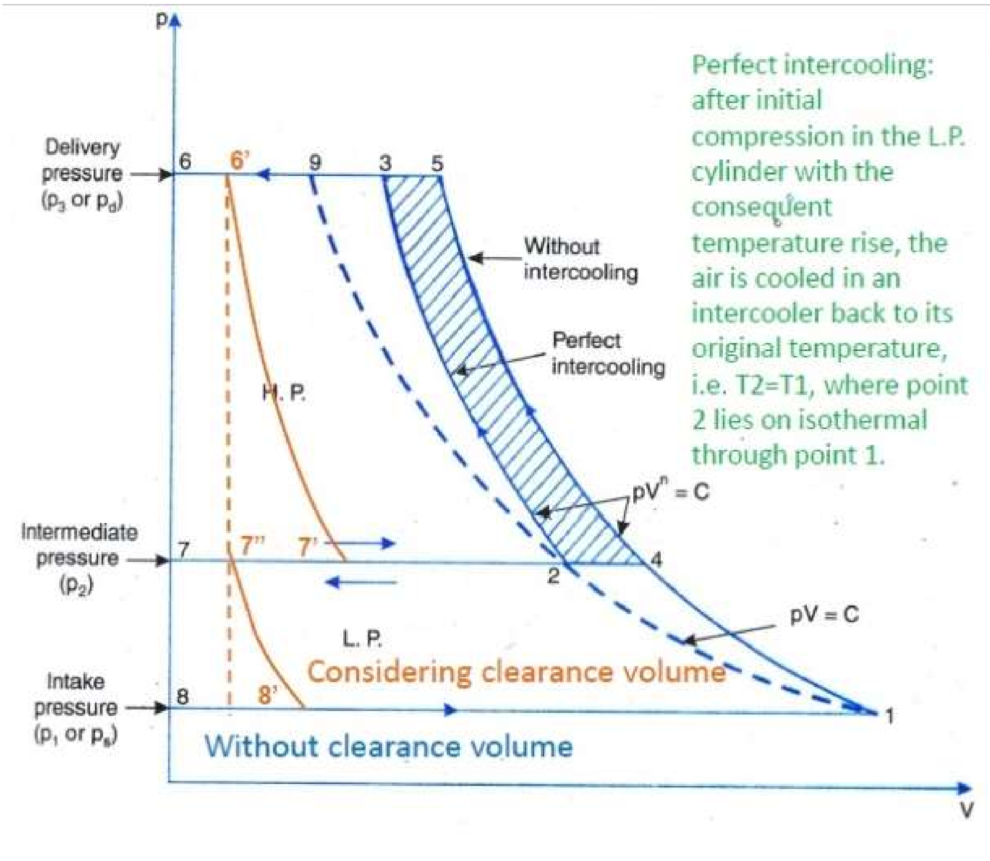


Fig 6.2 p-v diagram of Two-stage reciprocating air compressor

Apparatus and components required: Two-stage reciprocating air compressor

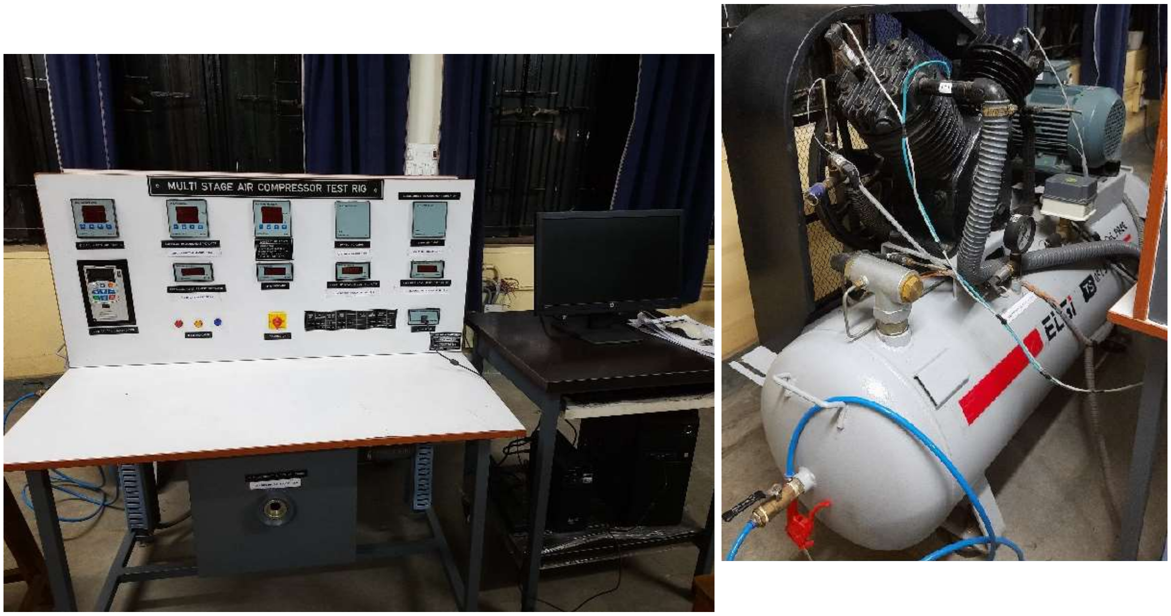


Fig. 6.3 Experiment setup of 2 stage reciprocating air compressor test rig

Experimental and numerical procedure: Study 2-stage reciprocating air compressor

Observation table and calculation:

S. No.	Manometer Reading (cm)			Torque (Kg)	Motor RPM	Comp. RPM	P (Kg/cm^2)	Temperature of Intercooler	
	LH (cm)	RH (cm)	Diff. (H)					Inlet (T_2) °C	Outlet (T_3) °C
1.									
2.									
3.									
4.									
5.									

1. **Volumetric Efficiency:**

<u>Actual air intake</u>

Equivalent air column (H_a) = ($H * W_w$)/W_a

H=Height of water column in meter

W_w=Specific weight of water (1000Kg/cu.m)

W_a=Specific weight of air (1.23 Kg/cu.m)

Diameter of orifice (d) = 0.02m

Area of orifice (A) = $\frac{\pi * d^2}{4}$

Coefficient of discharge (C_d) = 0.62

Volume of actual air intake (V_a) = $C_d.A.\sqrt{2gH_a}$

Theoretical air intake

Piston diameter (D) = 100mm, Stroke length (L) = 89mm, Speed (N) = ______R.P.M.

Theoretical intake volume (V_t) = $\frac{\pi * D^2 * L * N}{4*60}$

Volumetric efficiency = $\frac{Actual\ volume}{Theor\ \ \ \ \ \ \ \ volume} * 100\%$

2. Isothermal Efficiency:

Isothermal H.P. = $\frac{10^5 * 1.03 * V_a * \ln(P_3/P_1)}{750}$

Where, P_3=Delivery pressure in absolute unit
P_1=Inlet pressure in absolute unit

Input shaft power = K * N_m * T * Transmission efficiency * g

Where, K = Dynamometer constant = 0.0005, Transmission efficiency = 0.9

Isothermal efficiency = $\frac{Isothermal\ H.P.}{Input\ shaft\ power} * 100$

3. Heat Rejected by Intercooler

Heat rejected by intercooler = m*c_p*(T_2-T_3)

Where, $m = \frac{1.03*10^4*V_a}{29.3*(t_a+273)}$, c_p=0.24 Kcal/Kg/K & t_a=Room temperature

Results: Study 2-stage reciprocating air compressor

Question:

Benefit of 2-stage reciprocating air compressor is ___________________________________.