ST.ANNE'S

COLLEGE OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF MECHANICAL
ENGINEERING
V – SEMESTER (MECHANICAL)
THERMAL ENGINEERING LABORATORY – I MANUAL

NAME   :_____

ROLL NO.   :_____

YEAR   :_____

BATCH   :_____

THERMAL ENGINEERING LABORATORY
IV SEMESTER   MECHANICAL ENGINEERING

1. IC ENGINES LAB AND FUELS LABORATORY

LIST OF EXPERIMENTS

1. STUDY OF IC ENGINES, COMPONENTS AND LOADING DEVICES
2. VALVE TIMING AND PORT TIMING DIAGRAMS
3. PERFORMANCE TEST ON A 4 STROKE DIESEL ENGINE
4. HEAT BALANCE TEST ON A 4 STROKE DIESEL ENGINE.
5. MORSE TEST ON MULTI CYLINDER DIESEL ENGINE.
6. RETARDATION TEST TO FIND FRICTIONAL POWER OF A DIESEL ENGINE
7. DETERMINATION OF VISCOSITY –RED WOOD VISCOMETER
8. DETERMINATION OF FLASH POINT AND FIRE POINT

2.STEAM LABORATORY

1.STUDY OF STEAM GENERATORS
2.PERFORMANCE AND ENERGY BALANCE TEST ON STEAM GENERATORS
3.PERFORMANCE AND ENERGY BALANCE TEST ON STEAM TURBINE.

| EXPERIMENT 1 : |
| STUDY OF IC ENGINES, COMPONENTS AND LOADING DEVICES |

AIM:
    To identify and study the different parts of an I.C. Engine and the loading mechanisms used in it.

Apparatus required:
                Cut model of an I.C. Engine.

Classifications of an I.C. Engine:
There are a number of ways by which an I.C. Engine is classified. Some of the classifications are given below:
- Based on the type of combustion as:
            Spark ignition & Compression ignition engines
- Based on the no. of power strokes per cycle as:
            4-stroke & 2-stroke engines
- Based on the mounting of the engine as:
            Horizontally mounted & Vertically mounted engines
- Based on the type cooling as:
            Air cooled & water cooled engines
- Based on the type of operation as:
            Reciprocating & Rotary Engines

Cross sectional view of a Compression Ignition Engine:
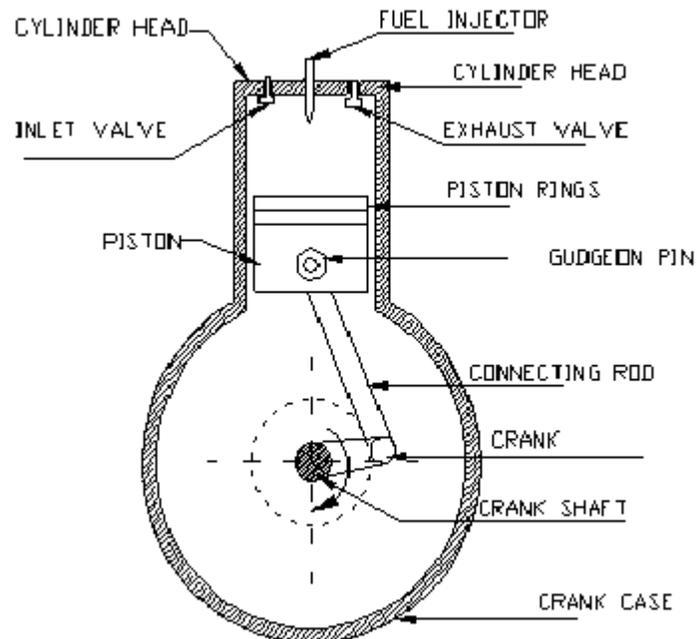
FIGURE 1

Engine Components:

Fig1 shows the cross section of an engine. The major components are listed below:

❖ <u>Cylinder</u>: It is a cylindrical sleeve in to which a close fitting piston reciprocates. The cylinder is supported by the cylinder block.

❖ <u>Piston</u>: A cylindrical component that is fitted snugly in the cylinder providing an air tight space along with the piston rings. The piston provides the combustion space inside the cylinder.

❖ <u>Piston rings</u>: These are rings that are fitted in to the slots around the piston. They provide a pressure tight seal between the piston & the cylinder wall, thus preventing the leakage of gases in to the crank case.

❖ <u>Gudgeon pin</u>: The pin that connects the piston to the connecting rod.

❖ <u>Inlet Manifold</u>: The pipe which connects the intake system to the inlet valve of the engine. It provides the passage for air fuel mixture (in SI Engines) or air alone (in C I Engines).

❖ <u>Exhaust Manifold</u>: The pipe which connects the exhaust valve of the engine to the tail pipe of the automobile. It provides the passage for the exhaust gases to be thrown out of the engine in to the atmosphere.

❖ <u>Connecting rod</u>: It interconnects the piston and the crank shaft and transmits the gas force from the piston to the crankshaft.

❖ <u>Crank shaft</u>: It converts the reciprocatory motion of the piston in to the rotary motion of the out put shaft. The crank shaft of the engine is provided with crank arms & balance weight for static & dynamic balancing.

❖ <u>Inlet & Exhaust Valves</u>: The valves used are mushroom shaped poppet type. They are provided on either side of the cylinder head for regulating the charge coming in to the cylinder and for discharging the products of combustion from the cylinder.

❖ <u>Cam shaft</u>: The shaft used to control the valve movement. It receives power from the crank shaft through a gear arrangement and a speed ratio of 1: 2 is maintained.

❖ <u>Fly wheel</u>: It is a device which is used to provide a uniform torque to the out put shaft. During the operation of an engine, the net torque produced fluctuates between a minimum and maximum value. This torque cannot be put to proper use, so in order to damn out the fluctuations; an inertia mass in the form of a fly wheel is attached to the out put shaft.

❖ <u>Cooling System</u>: During the operation of an engine, enormous heat is developed which if not properly dissipated, can lead to thermal cracks along the walls of the engine resulting in its break down. In order to dissipate this heat, the engine is provided with a cooling system. It can be classified in to air cooling & water cooling systems.

Air cooling: When the load on the engine is very less, the amount of heat produced during the operation is also less. In such cases, air cooling is preferred. Around the engine, extended surfaces called fins (as shown in Fig 2) are fixed. Due to increase in the surface area, the heat transfer rate increases resulting in higher dissipation of heat as the atmospheric air blows past the engine
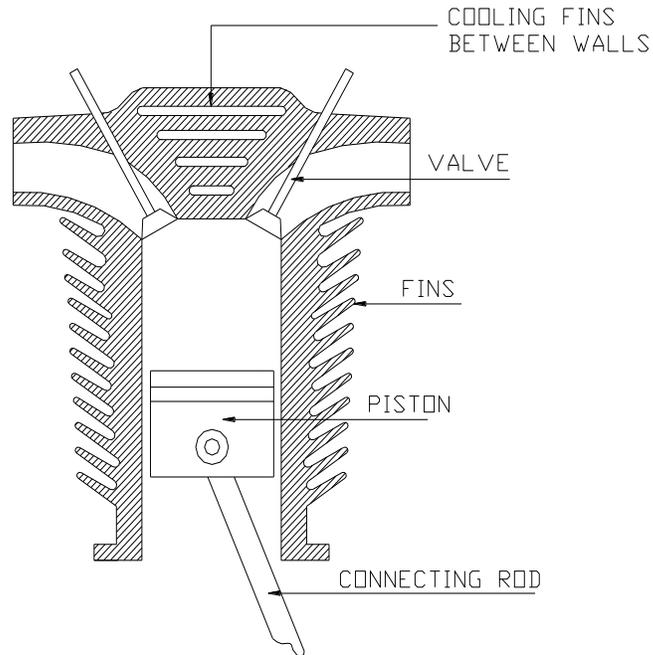
FIGURE 2

Water cooling: Air cooling can be used only in engines where the amount of heat removed is less. When a large amount of heat has to be dissipated, water cooling is always preferred to air cooling. Here water is used as the heat transfer medium. A pump is used to circulate the water around the engine through the water jackets. A heat exchanger called a radiator is used to transfer heat from the hot water to the cool air. A schematic of the water cooling system is shown in Fig 3.
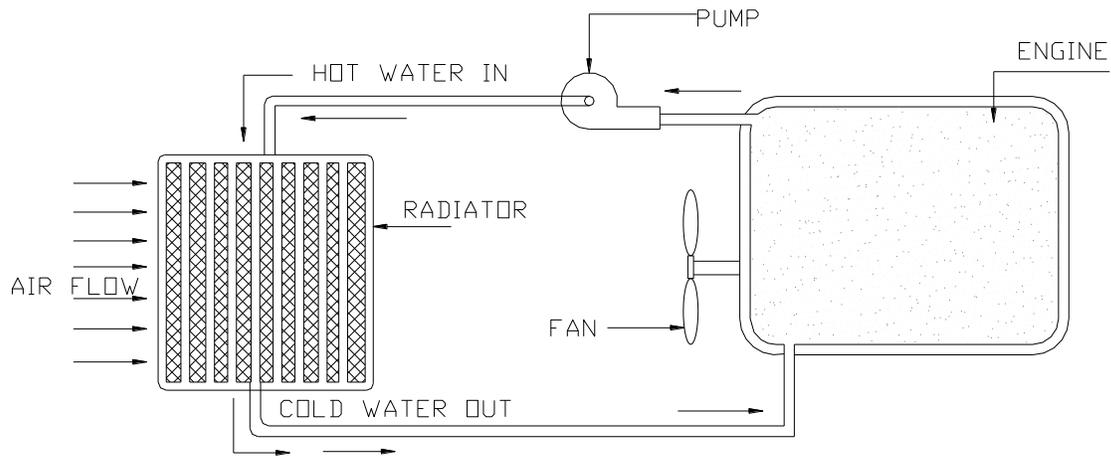
FIGURE 3

Lubrication System: An I.C, Engine has reciprocating parts in it. Due to frequent reciprocation of piston inside the cylinder, friction takes place which results in the wear and tear of engine parts. In order to prevent friction parts from getting worn out due to friction, lubricant oil is used. The system which circulates the lube oil through out the engine parts is called as lubrication system. The lubrication system can be classified as follows:
- ➢ Petroil or Mist lubrication
- ➢ Wet sump lubrication
  - • Splash lubrication
  - • Splash & pressure lubrication
  - • Pressure lubrication
- ➢ Dry sump lubrication

A schematic of the Splash Lubrication System is shown in Fig 4.
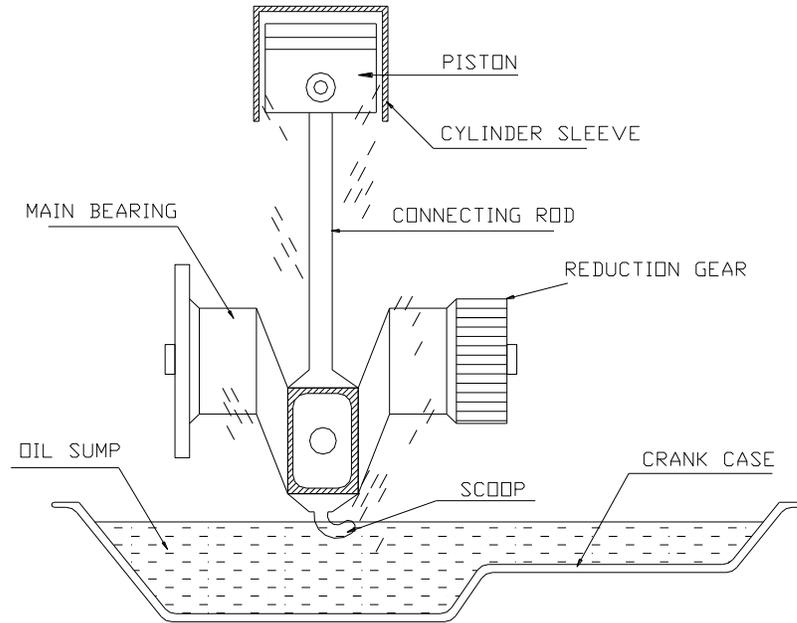
Figure : 4

General Nomenclatures used to specify an engine:

1 Cylinder bore: The nominal inner diameter of the cylinder. It is expressed in mm.

2 Stroke: The nominal distance through which a piston moves between successive reversals of its direction of motion. It is expressed in mm.

3 Piston area: The area of a circle whose diameter is equal to the cylinder bore. It is expressed in cm^2.

4 Dead Centre: The position of the piston at the moment when the direction of the piston motion is reversed at either end of the stroke. There are two dead centres:
       a. Top dead centre (TDC): The dead centre when the piston is farthest from the crank shaft. It is also called Inner Dead Centre (IDC).
       b. Bottom dead centre (BDC): The dead centre when the piston is nearest to the crank shaft. It is also called Outer Dead Centre (ODC).

5 Swept Volume: The nominal volume swept by the piston when traveling from one dead centre to the other. It is also called displacement. It is expressed in cubic centimeters (cc).
$$\text{Swept volume } (V_s) = (\pi * d^2 * L) / 4 \text{ cc}$$
Where
d is the bore in cm
L is the stroke in cm

6 Clearance Volume (V_c): The nominal volume of the combustion chamber when the piston is at the top dead centre.

7 Compression Ratio (r): Ratio of the total volume when the piston is at BDC and the clearance volume (when the piston is at TDC).

Compression ratio (r) = $(V_s + V_c) / V_c$

TERMS RELATED WITH IC ENGINES
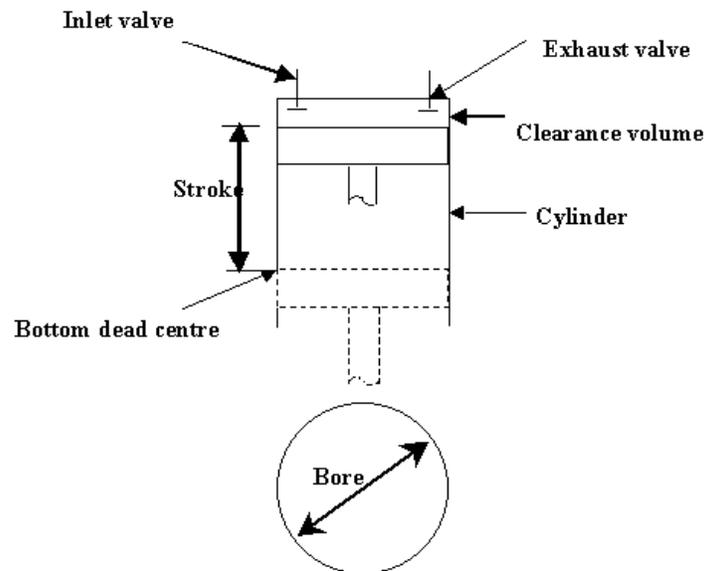
1.BORE

The inside diameter of the cylinder is called bore.

2.STROKE

As the piston reciprocates inside the engine cylinder,it has got limiting upper and lower positions beyond which it cannot move and reversal of motion takes place at these limiting positions.

3.TOP DEAD CENTRE(TDC)

The top most position of the piston towards the cover end side of the cylinder is called top dead centre.In case of horizontal engines, it is known as Inner Dead Centre.

4.BOTTOM DEAD CENTRE (BDC)

The lowest position of the piston towards the crank end side of the cylinder is called bottom dead centre.In case of horizontal engines, it is called the outer dead centre.

5.CLEARANCE VOLUME

The volume contained in the cylinder above the top of the piston when the piston is at top dead centre ,is called the clearance volume.

6. SWEPT VOLUME

The volume swept through by the piston is moving between top dead centre and bottom dead centre, is called swept volume or piston displacement.

7. COMPRESSION RATIO (r)

$$r = \frac{V_s + V_c}{V_c}$$

Where, V_s = swept volume, and V_c = Clearance volume

It is ratio of total cylinder volume to clearance volume.

8. PISTON SPEED

The average speed of the piston is called piston speed.

Piston speed, $= 2L\,N$

Where, L = Length of the stroke and N = Speed of the engine in rpm.

LOADING DEVICES

These devices are also known as Dynamometers, which are used to find the Torque of the engine output shaft. After the determination of the torque, and the angular speed, of the engine, the brake power can be measured .

CLASSIFICATION OF DYNAMOMETER

Dynamometers can be broadly classified as

(i)Absorption Dynamometers

These Dynamometer measure and absorb the power output of the engine to which they are coupled.The power absorbed is usually dissipated as heat by some means. Examples of such dynamometers are prony brake ,rope brake ,hydraulic ,eddy current dynamometers, etc.

(ii) Transmission Dynamometer:

In transmission dynamometers the power is transmitted to the load coupled to the engine after it is indicated on some types of scale. These are also called torque meters.

PRONY BRAKE

- ➢ This is one of the simple methods of measuring power output of an engine.
- ➢ Here ,an attempt to stop the engine by means of a mechanical brake on the flywheel and measure the weight which an arm attached to the brake will support ,as it tries to rotate with the flywheel. This system is known as the prony brake and form its use the expression brake power has come.

CONSTRUCITON

- ➢ The Prony brake consists of frames with two brake shoes gripping the flywheel.
- ➢ The pressure of the brake shoes on the fly wheel can be varied by the spring loaded using nuts on the top of the frame.
- ➢ The wooded block when pressed into contact with the rotating drum opposes the engine torque and the power is dissipated in overcoming frictional resistance.
- ➢ The power absorbed is converted into heat and hence this type of dynamometer must be cooled.
  - ➢   The brake power is given by

  $BP = 2\pi\,NT$

ROPE BRAKE DYNAMOMETER

- ➤ The rope brake is another simple device for measuring BP of an engine. If consists of a number of turns of rope wound around the rotating drum attached to the output shaft.
- ➤ One side of the rope is connected to a spring balance and the other to a loading device.
- ➤ The power absorbed is due to friction between the rope and the drum. The drum therefore requires cooling.
- ➤ Rope brake is quite cheaper and can be easily fabricated but not very accurate because of changes in the friction coefficient of the rope with temperature.
- ➤ The BP is given by

$BP = \pi D N (W - S)$

Where, D is the brake drum diameter

W is the Weight

S is the Spring scale reading

EXP 2 : VALVE TIMING DIAGRAM OF A 4 STROKE ENGINE

AIM: TO DRAW (i) THE VALVE TIMING DIAGRAM FOR A 4 STROKE ENGINE SHOWING THE RELATIVE CRANK ANGLES CORRESPONDING TO OPENING AND CLOSING OF INLET AND EXHAUST VALVES

APPARATUS:
CUT SECTION MODEL OF 4 STROKE
ENGINE,SCALE,CHALK

FORMULA USED:

$$\text{CRANK ANGLE} = \frac{\text{Distance on Flywheel from the nearest dead centre}}{\text{Circumference of Flywheel}} \times 360°$$

PROCEDURE

- ➤ The circumference of the flywheel is measured using the thread and scale.
- ➤ The flywheel is measured in clockwise direction.
- ➤ The markings corresponding to the opening and closing of inlet and exhaust valves are made on the flywheel rim.
- ➤ The distance between these markings and the nearest dead centres are measured (in cms)
- ➤ Using the above mentioned formula, the crank angle from the TDC and BDC are found and the Valve timing diagram drawn.
- ➤ Mark the valve overlap period.

TABULAR COLUMN:

VALVE OPENING /CLOSING	DISTANCE WITH RESPECT TO THE NEAREST DEAD CENTRE	CRANK ANGLE
IVO IVC EVO EVC		

RESULT

Thus, the valve timing diagram has been drawn with relative crank angle.

The angle of overlap =_____

EXP 3:PORT TIMING DIAGRAM OF A 2 STROKE ENGINE

AIM : TO DRAW THE PORT TIMING DIAGRAM OF A TWO STROKE ENGINE.

APPARATUS : CUT SECTION MODEL OF A 2 STROKE ENGINE

PROCEDURE
- ➢ The experiment is conducted in a reduced scaled model of a 2-stroke engine. The aim is to represent diagrammatically the sequence of operation of the inlet port, transfer port and the Exhaust port.
- ➢ The flywheel of the model is rotated till the piston reaches the BDC.
- ➢ The lower most portion of the flywheel and the corresponding portion of the base is properly marked.
- ➢ The total length of the circumference of the flywheel outer rim is measured as 'C' corresponding to 360 degrees of flywheel rotation.
- ➢ The flywheel is rotated till the piston reaches TDC for compression stroke.
- ➢ The following points are marked on the flywheel rim:
  (i)Inlet port opening (IPO) : Fresh charge enters into the crankcase from carburetor.
  (ii) Exhaust Port Closes (EPC): After the full closing of the exhaust port and transfer port, Compression of the charge begins.
  (iii)Transfer port closes(TPC): When the reaches spark ignition accompanied by the explosion.

TABULAR COLUMN

PORT OPENING/CLOSING POSITION	DISTANCE MEASURED ALONG THE FLYWHEEL(cm)	ANGLE (Degrees)
IPO before TDC IPC after TDC EPO before BDC EPC after BDC TPO before BDC TPC after BDC		

RESULT : Hence the port timing diagram has been drawn .

EXP # 4 PERFORMANCE TEST ON SINGLE CYLINDER – 4 STROKE DIESEL ENGINE

AIM:

To conduct a performance test on the given single cylinder 4-stroke diesel engine and to draw the following characteristic curves:
a) Brake Power Vs Specific Fuel Consumption
b) Brake Power Vs Mechanical Efficiency
c) Brake Power Vs Brake Thermal Efficiency
d) Brake Power Vs Indicated Thermal Efficiency

APPARATUS REQUIRED:
Stop watch, Tachnometer

ENGINE DETAILS:
Type   : Single cylinder four stroke Diesel engine
                                      Coupled to an eddy current dynamometer.
Power   : 8 HP (5.9 kW)
Speed   : 850 rpm.
Orifice diameter   : 20 mm.
Effective radius of the brake drum : 0.2 m

PROCEDURE:
  ➢ The cooling water lines are opened.
  ➢ The fuel in the tank and the valve (used to allow fuel from tank) position
       are checked.
  ➢ The engine is started at no load.
  ➢ The time taken for 10 cc of fuel consumption is noted by keeping the right
       side knob in closed position.
  ➢ Supply of fuel from the main tank is ensured after taking the above reading.
  ➢ The manometric heights h_1 and h_2 are taken down in cm.
  ➢ The engine is loaded by adding weights on the mechanical dynamometer.
  ➢ All the above readings are noted down.
  ➢ The experiment is repeated for different current settings.
  ➢ The readings are tabulated neatly.

FORMULAE REQUIRED :

a) Brake Power (BP)   = (V x I) / 1000   kW

b) Fuel consumption (FC) = (10 x 10^{-3} x sp.gr. x 3600) / t   kg / hr

   where ,   t - Time taken for 10 cc of fuel consumption
                    sp. gr. - specific gravity of diesel = 0.86

c) Specific Fuel Consumption (SFC)   =   FC / BP   kg / kW hr

d) Heat Input (HI)   =   FC * CV / 3600   kJ / s
 Where,   CV - Calorific Value of diesel = 43500 kJ/kg

e) Brake thermal efficiency (η_{BTE}) = (BP / HI) * 100 %
f) Mechanical efficiency (η_{mech}) = (BP / IP) * 100 %
Where, BP - Brake Power, kW
 IP - Indicated Power, kW = BP + FP
 FP - Frictional Power, kW (To be determined from "BP Vs FC" plot)
g) Indicated thermal efficiency, : η_{ITE} = (IP / HI) x 100
RESULT:
 A performance test was conducted on the given diesel engine and the following characteristic
curves were drawn.
a) Brake Power Vs Specific Fuel Consumption
b) Brake Power Vs Mechanical Efficiency
c) Brake Power Vs Brake Thermal Efficiency
d) Brake Power Vs Indicated Thermal Efficiency

"WILLAN'S LINE METHOD" TO FIND FRICTIONAL POWER (MODEL GRAPH)
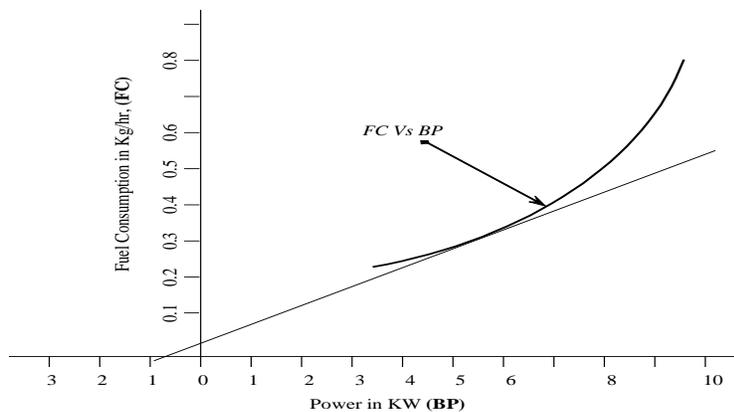
Frictional Power≤ 1/4th of rated power
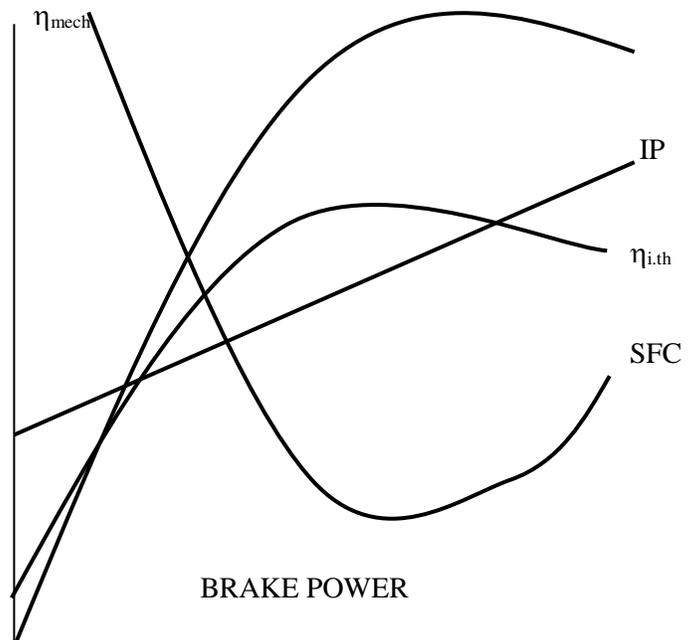
EXPERIMENT # 5
HEAT BALANCE TEST ON 4 STROKE DIESEL ENGINE

AIM :
To conduct heat balance test on the given diesel engine and to draw up a heat balance sheet
showing the proportion of useful work and various losses.

APPARATUS REQUIRED :
Stop watch, tachometer

ENGINE DETAILS:
 Type   : Single cylinder four stroke Diesel engine
                                        coupled to an eddy current dynamometer.
Power   : 8 HP (5.9 kW)
Speed   : 850 rpm.
Orifice diameter   : 20 mm.
Effective radius of the brake drum : 0.2 m

PROCEDURE :

- The maximum load (full load) is calculated from the engine ratings.
- The 1/4, 1/2 and 3/4 of full load are estimated.
- The cooling water lines are opened.
- The fuel in the tank and the valve (to allow fuel from the tank) position
   are checked.
- The engine is started at no load condition.
- The time taken for 10 cc of fuel consumption is noted by keeping the right
    side knob in closed position.
- Supply of fuel from the main tank is ensured after taking the above reading.
- The following readings are also noted:
    - Temperature of cooling water outlet
    - Temperature of exhaust gas
    - Manometer readings
- The engine is loaded (with 1/4 , 1/2 , 3/4 and full load) and all the above
   readings are noted down.
- The readings are tabulated neatly.

FORMULAE REQUIRED :

a) Maximum load / Full load (W_{max}) = BP_{rated} x 60000 / ($2\pi N_{rated}$ x R_{eff} x 9.81)
Where,
BP_{rated} - Rated Brake Power , kW
N_{rated} - Rated Speed, rpm
R_{eff} - Effective Radius of the brake drum

b)   Brake Power (BP)   = $2 \Pi NT/60000$ kW

where ,N - speed in rpm ,T - Torque in N-m $= W_{net}$ x R_{eff}

c) Heat carried away by cooling water (Q_{cw}) = m_w c_{pw} (t_{w2} - t_{w1})
where, m_w - mass flow rate of cooling water = $1/t_2$ kg / s
t_2 - time for 10 litres of water collection
c_{pw} - specific heat of water = 4.187 kJ / kg K
t_{w1} - temperature of cooling water at inlet , $^\circ$ C
t_{w2} - temperature of cooling water at outlet, $^\circ$ C

d) Heat carried away by exhaust gases (Q_{eg})
= $m_g c_{pg}$ (t_{go} - t_{gi})
where,
m_g - mass flow rate of exhaust gases   = $m_f + m_a$
m_f - mass flow rate of fuel = 10 x 10^{-3} x sp.gr / t_1
sp. gr. - specific gravity of diesel = 0.86
t_1 - time taken for 10 cc of fuel consumption
m_a- mass flow rate of air $= \rho_a C_d A_o$ $\sqrt{2g}$ h_a
where, C_d - Co efficient of discharge of orifice meter = 0.62
A_o - Area of orifice meter = $\pi d^2 / 4$
d - diameter of orifice
g - 9.81 m/s^2
h_a = (h_1 - h_2)* ρ_w / (ρ_a * 100)
where,
h_1 h_2 - manometer readings cm
ρ_w - density of water   = 1000 kg / m^3
ρ_a - density of air at room temperature
= (ρ_a at STP) * 273 / (273+t_R)
where,
ρ_a at STP   = 1.18 kg / m^3
t_R - Room Temperature , $^\circ$ C
c_{pg} - specific heat of exhaust gases = 1.005 kJ / kg K
t_{go} - temperature of exhaust gases , $^\circ$ C
t_{gi} - temperature of atmospheric air, $^\circ$ C

e) Heat Input   (HI)   = m_f x C.V.
where, m_f - mass flow rate of fuel , kg / s
 C.V. - Calorific Value of diesel = 40,500 kJ / kg

f) Unaccounted Heat loss (Q_{un}) = HI - (BP + Q_{cw} + Q_{eg})   kJ / s

GRAPH:

Brake power(x axis) Vs Thermal Energy distribution. (Y axis)

Heat input (x axis) Vs Thermal Energy Distribution (Y axis)

RESULT: A heat balance test was conducted on the given diesel engine and a heat

balance sheet has been drawn up for different load conditions.

% of
Heat
Utilis-
ed

A

B

C

D
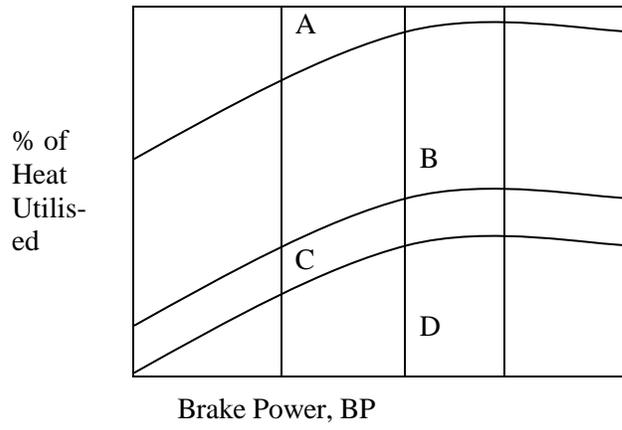
Brake Power, BP

A: Radiation &
Unaccounted loss
B: Exhaust loss

C: coolant
D: Brake Power

EXPERIMENT # 6
MORSE TEST ON A 4 CYLINDER DIESEL ENGINE COUPLED WITH
HYDRAULIC DYNAMOMETER

AIM : To conduct a morse test on a multicylinder engine coupled with hydraulic dynamometer and to find the frictional power.

SPECIFICATIONS:
1. Number of cylinders = 4.
2. Power = 7.36 kW / 10HP
3. Speed = 1500 rpm
4. Type = 4 Cylinder 4 stroke vertical- Diesel engine
5. MAKE = Ambassador
6. Loading = Hydraulic Dynamometer

APPARATUS REQUIRED:
1. Dynamometer.
2. Tachometer.

DEFINITIONS:
1. Brake Power(BP): The net power available at the output shaft of the internal combustion engine is called brake power. It is the power available after some power is utilized for overcoming friction.
2. Indicated Power(IP): The horse power developed inside the cylinder is called Indicated Power.
3. Friction Power(FP): The difference between indicated power and brake power is called Friction Power.
4. Mechanical Efficiency: The ratio of brake power to the indicated power expressed as a percentage is called Mechanical Efficiency.

CALCULATION OF THE MAXIMUM LOAD THAT CAN BE APPLIED TO THE ENGINE :
$BP_{rated} = (W_{max} \times N_{rated}) / 2720$
$W_{max} = 7.36 \times 2720 /1500 = 13.35$ kg
$Bp_{rated} = 7.36$ kW
$N_{rated} = 1500$ rpm
W_{max} is in kg

FORMULAE:
1. Brake Power(BP_T) = (W x N)/ 2720   kW
   where, W = Load applied in kg,
           N = Speed in rpm,
           2720 = Dynamometer constant.
2. Total Indicated Power (IP_T) = [$IP_1 + IP_2 + IP_3 + IP_4$] kW
   where, 1 – I cylinder is cut off.
           2 - II cylinder is cut off.
           3 - III cylinder is cut off.
           4 - IV cylinder is cut off.
3. If ,BP : Brake Power developed when all the cylinders are working, then
   $IP_1 = BP – BP_1$.
   $IP_2 = BP – BP_2$.

$IP_3 = BP - BP_3.$
$IP_4 = BP - BP_4.$

4. $BP_1 = W_1 \times N / 2720$

BP_1 : Brake power of the engine when the first cylinder is cut off .

BP_2 : Brake power of the engine when the second cylinder is cut off.

BP_3: Brake power of the engine when the third cylinder is cut off.

BP_4: Brake power of the engine when the fourth cylinder is cut off.

W_1:Load on the dynamometer when the first cylinder if cut off and the speed is maintained to be N rpm.

5. Mechanical Efficiency $= (BP_T/IP_T)*100\%$.

PROCEDURE:

1. The engine is first started by checking the fuel, lubricating oil, cooling water etc., with all 4 cylinders working.
2. The speed of the engine is adjusted to a particular value say 1500 rpm and the BP of the engine at that speed is calculated.
3. Now cylinder 1 is cut-off and the speed is adjusted to 1500 rpm byn decreasing the load and the BP is found out.
4. The difference of BP of all the 4 cylinders and that of the cut off cylinder gives the IP of the cylinder of the cut-off cylinder.
5. In this way each cylinder is cut-off and the BP is found out.
6. From the value of BP the IP of all the cylinders is found out.
7. The sum of the indicated powers of all the cylinders gives the indicated power of the entire engine.
8. The Mechanical Efficiency is then calculated at that particular speed.

CONDITIONS	LOAD	BRAKE POWER B.P=[(W x N)/2720] kW	INDICATED POWER	MECHANICAL EFFICIENCY
	W kg	kW	Watts	%
SPEED , N, (rpm)	USUALLY , 1200 RPM , 1300 RPM, OR 1500 RPM			
All cylinders working				
First cylinder is cut off				
Second cylinder is cut off				
Third cylinder is cut off				
Fourth cylinder is cut off				

RESULT:
 Thus the Morse Test on the 4-stroke, 4-cylinder diesel engine is carried out and the

mechanical efficiency is determined.

PRECAUTION
 1.Lubricating oil level should be checked.
 2.Cooling water should be supplied to engine and dynamometer.
 3.Water is to be supplied to dynamometer and water pressure is to be 0.5 kg/cm^2.
GRAPH :
SPEED
(i) vs Brake Power (BP)
(ii)vs Indicated power (IP)
(iii)Frictional power (FP)
(iv)Mechanical Efficiency (η_{mech})
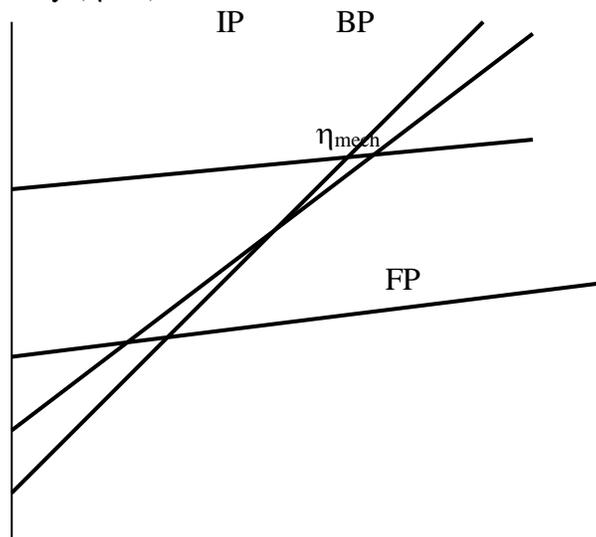
EXPERIMENT # 7: RETARDATION TEST TO FIND THE FRICTIONAL POWER OF A 4 - STROKE DIESEL ENGINE

AIM:

To conduct the retardation test on the given single cylinder 4-stroke diesel engine and to draw the graph between the Drop in speed and the time taken.

APPARATUS REQUIRED:
Stop watch, Tachometer

ENGINE DETAILS:
Type   : Single cylinder four stroke Slow speed Diesel engine,
                    Loaded with a brake drum dynamometer.
Power   : 8 HP (5.9 kW)
Speed   : 850 rpm

PROCEDURE:

➢ The cooling water lines are opened.
➢ The fuel in the tank and the valve (used to allow fuel from tank) position
     are checked.
➢ The engine is started at no load and allowed to run at the rated speed for about 5 minutes..
➢ After the engine has attained the rated speed, the fuel supply is cut off. The time taken for
     the speed to decrease through 100 rpm from the rated speed is noted.
➢ As soon as the reading is taken, the fuel is again allowed to flow and the maximum speed
     is reached to achieve
➢ Time for 200 , 300 and 400 rpm drop of speed from the maximum speed is taken.
➢ The engine is now loaded to 50% of the full load and is allowed to attain the rated speed.
➢ After attaining the rated speed, the same procedure is followed and the time for the
     various speed reductions is noted.
➢ The readings are tabulated neatly.

Calculation of the Maximum load , Wmax
➢ Brake Power (BP)   = $(2\pi N_{rated} T)/ (60 \times 1000)$ kW
➢ Brake Torque (T)   = $(BP \times 60000) / (2\pi N_{rated})$ Nm.
                                          $=(5.9 \times 60 \times 1000)/ (2 \pi \times 850)$
                                    $T = 66.32$ Nm

$T = W_{max} \times R_{eff}$
$W_{max} = T / R_{eff}$
       $=66.32 / 0.2 = 331.58$ N $= 331.58 / g = 331.58 / 9.81 = 33.8$ kg
Hence the maximum load that can be applied to the engine is 33.8 kg.

R_{eff} = Effective radius of the brake drum = 0.2 m

FORMULAE USED FOR CALCULATIONS :

➤ Brake Power (BP)   = $(2\pi NT)/ (60 \times 1000)$ kW

 N: Speed values of the engine from the tabular column.

 T : Brake torque $= W_{net} \times R_{eff}$.

$W_{net} = W_1 + w - W_2$.

W_1:Load added on the weight hanger.

w: Weight of the hanger. = 2 kg

W_2:Spring balance reading, kg

➤ Torque at ½ load ($T_{1/2}$)   =   T / 2   Nm = 66.32 /2 = 33.16 Nm

➤ Frictional que(T_f)   = $(T_{1/2} * t_1) / (t_2 - t_1)$

    Where t_i is the time for a drop of 100 rpm at no load
        t_2 is the time taken for a drop of 100 rpm at 50% load.

➤ Frictional Power (FP)   = $2\Pi NT_f / 60000$.

TABULAR COLUMN :

S. No.	Speed Variation "rpm"	Drop in speed N "rpm"	Time for the speed drop at no load t_1 , sec	Time for the speed drop at 50% load t_2,sec
1	715 – 615			
2	715 - 515			
3	715- 415			
4	715- 315			

MODEL GRAPH :

Time in Secs
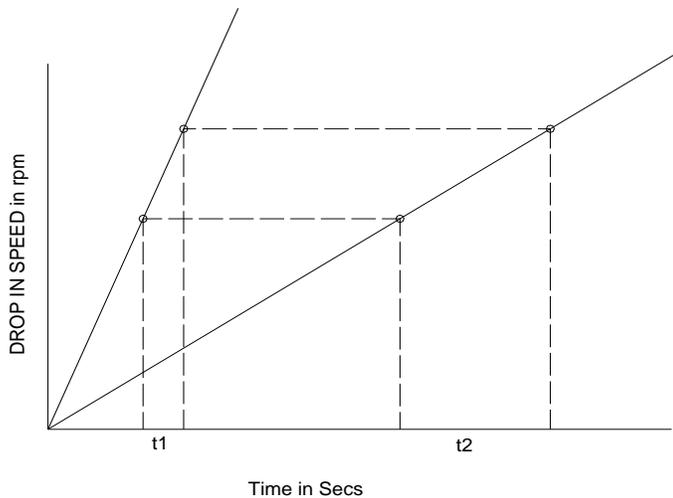
RESULT:

 Thus the retardation test on the single cylinder 4- Stroke diesel engine was conducted and the

frictional power was found to be _____

EXPERIMENT # 8
DETERMINATION OF VISCOSITY USING REDWOOD VISCOMETER

AIM

To determine the viscosity of the given oil at various temperatures and study the variation of viscosity with temperature.

APPARATUS REQUIRED

Thermometer and stop watch

DESCRIPTION

- The given apparatus consists of two metal cups with holes at the bottom.
- The oil in the cup receives heat from the surrounding water which in turn is heated by a coil.
- Provisions are made to measure the temperatures of water and oil.
- To ensure uniform heating an electric stirring arrangement is provided.

PROCEDURE

- The oil cup is cleaned and the oil is poured.
- Sufficient water is poured in the space surrounding the cup.
- The time taken for collection of 60 ml of oil is noted at room temp.
- The heater and stirrer are switched on.
- The time taken for collection of 60 ml of oil is noted at different temperatures from 40° C to 60° C with an interval of 10° C.
- The values of kinematic and absolute(dynamic) viscosities are calculated using Redwood seconds.

FORMULAE REQUIRED

1. Kinematic Viscositym, $\nu = [A t - B / t]$ stokes   where, $A = 0.0026$ & $B = 1.88$

2. Density $\rho = \rho_r - 0.000657 (T - T_r)$ kg / lt

where, ρ_r - density at room temperature $= 0.84$ kg / lt

T - temperature at which viscosity is determined T_r - room temperature

3. Absolute viscosity or dynamic viscosity $\mu = \nu * \rho$ poise

note:
 1 stoke = $1 cm^2 / s$; 10 poise = $1 N s / m^2$

TABULAR COLUMN

Sl.No.	temp. of water	temp. of oil	time for 60ml of oil collection	density	kinematic viscosity	absolute or dynamic viscosity
	° C	° C	sec	kg / lt	stokes or cm^2 /s	Poise

RESULT
The viscosity of the given oil was found out at various temperatures and
following graphs were plotted.

a) temperature Vs density
b) temperature Vs kinematic viscosity
c) temperature Vs absolute viscosity
d)Temp Vs Redwood Seconds

EXPERIMENT # 8
DETERMINATION OF FLASH & FIRE POINT OF LIQUID FUEL

AIM:

To determine the flash and fire points of the given oil using Pensky-Mortein's apparatus.

APPARATUS REQUIRED:

Thermometer

Flash and Fire points:

Flash point is the temperature to which the oil must be heated to give off sufficient vapour to form an inflammable mixture with air.

Fire point is the lowest temperature at which the production of combustible gas from the oil is enough to maintain a steady flame after ignition.

DESCRIPTION:

- The apparatus consists of a brass cup with a filling mark inside.
- The cup is surrounded by electric heating elements.
- The brass cup is closed with a cover where provisions are made to
  insert thermometer,to introduce test flame and to connect the stirrer.

PROCEDURE:

- The oil cup is cleaned and dried.
- The oil is poured in the cup up to the filling mark.
- The flash and fire points are noted in the open conditions.
- The cup is covered with the given lid.
- The heater is connected to the mains and the rate of heating is adjusted.
- As the oil temperature increases, the test flame is applied at an interval
  of 20°C to find the flash and fire points.

TABULAR COLUMN:

sample oil	condition	Sl.No.	Flash point	Fire point
	open cup	1 2		
	closed cup	1 2		

RESULT:

a) The flash point of the oil

    1) in open condition is   _____ ºC

    2) in closed condition is _____ ºC

b) The fire point of the oil

    1) in open condition is   _____ ºC

    2) in closed condition is _____ ºC

EXPERIMENT # 1
STUDY OF STEAM BOILER AND TURBINES

AIM : To study and understand the principle of steam boilers and turbines.

THEORY:
DEFINITION:
Boiler, also called steam generator is the engineering device which generates steam at constant pressure .It is a closed vessel, generally made of steel in which vaporization of water takes place.
          Heat required for vaporization may be provided by the combustion of fuel in furnace ,electricity ,nuclear reactor, hot exhaust gases, solar radiations. etc.

TYPES OF BOILERS:
Boilers are of many types. Depending upon their features they can be classified as given under:
(a)Based upon the orientation /axis of the shell.
(i)Vertical boiler has a vertical shell..
(ii)Horizontal boiler has its shell horizontal.
(iii)Inclined boiler has its shell inclined .

(b)Based upon utility of boiler.
(i)Stationary boiler
(ii)Portable boiler

(c)Based on the type of firing employed.
(i)externally fired boiler; e.g : Lancahsire boiler, Locomotive boiler
(ii)Internally fired boiler ., e.g .Cochran boiler, Babcock and Wilcox boiler

(d)Based on the tube content.
(i)Fire tube boiler e.g : Cornish, Cochran, Lancashire, Locomotive boiler.
Hot gases flow through the tubes and water surrounds them.
(ii)Water tube boiler
Water flows through the tubes and hot gases surrounds them.
e.g : Babcock and Wilcox boiler, Stirling boiler, La- Mont boiler, Benson boiler .

(e)Based on the type of fuel used.
(i)solid fuel boiler :e.g : coal fired boilers.
(ii)Liquid Fuel boiler , e.g: Oil fired boilers.
(iii)Gas fired boiler : e.g: Natural gas fired boilers.

(f)Based on circulation
According to the flow of the water/steam is caused by the density difference which is due to the temperature variation.
(i)Natural circulation
Here, the circulation of water/steam is caused by the density difference which is due to the steam temperature.
(ii)Forced Circulation boilers.
Here, the circulation of water /steam is caused by a pump, or fan.

One Water tube boiler is discussed below.

BABCOCK AND WILCOX BOILER :
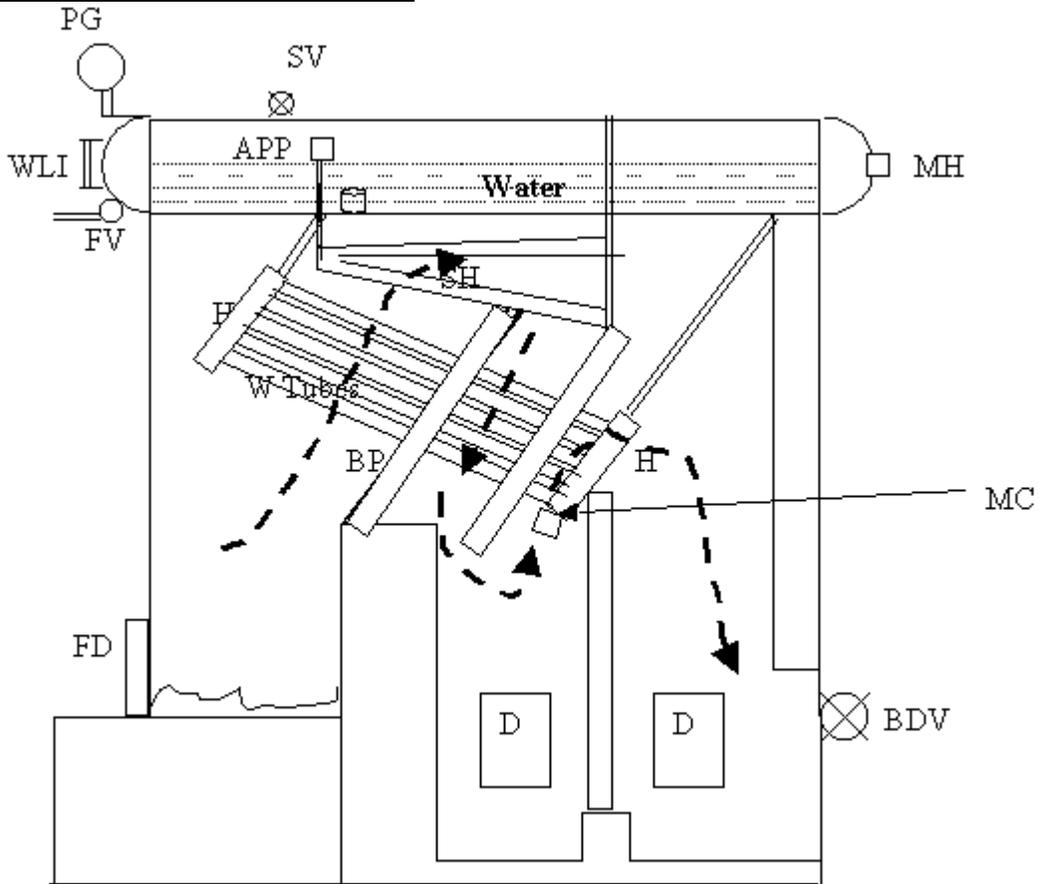
SV : Safety valve
MH :Man hole
PG :Pressure Gauge
BP :Baffle Plate
WLI: Water Level Indicator
APP :Anti priming pipe
SH :Super heater
H :Header
D: Door
BDV: Blow down valve
WT: Water Tubes
FV: Feed Valve
MC: Mud collector
FD :Fire Door
G :Grate

<u>Definition</u>
Babcock and Wilcox boiler is an example of water tube boiler which is horizontal straight tube boiler and may be designed for stationary or marine purposes.
The particulars relating to this boiler are

Diameter of the drum	1.22 to 1.83 m
Length	6.096 to 9.144 m
Size of the water tubes	7.62 to 10.16 cm
Size of the super heater tubes	3.84 to 5.71 cm
Working pressure	40 bar (max)
Steaming capacity	40000 kg/hr (max)
Efficiency	60 to 80 %

The Babcock and Wilcox Boiler consist of a drum connected to a series of front end and rear end header by short riser tubes. To these headers are connected a series of inclined water tubes of solid drawn mild steel.

The angle of inclination of the water tubes to the horizontal is about 15° or more. A hand hole is provided in the header in front of each tube fro cleaning and inspection of tubes. A feed valve is provided to fill the drum and inclined tubes with water the level of which is indicated by the water level indicator. Through the fire door the fuel is supplied to grate where it is burnt.
The water form the drum flows through the inclined tubes via down take header and goes back into the shell in the form of water and steam via uptake header. The steam gets collected in the steam space of the drum. The steam then enters through the anti-priming pipe and flows in the super-heater tubes where it is further heated and is finally taken out through stop valve and supplied to the engine when needed. At the lowest point of the boiler is provided the mud collector to remove the mud particles through a blow down clock.

BOILER MOUNTINGS
1.WATER LEVEL INDICATOR
It is used for knowing the level of water in the boiler.

2.SAFETY VALVE
Its function is to prevent the steam pressure from exceeding a limiting maximum pressure value. Safety valve should operate automatically by releasing excess steam and bring pressure down within safe limits.

3.FUSIBLE PLUG
It is a safety device used for preventing the level of water from going down below a critical point and thus avoid overheating. It is mounted at crown plate of combustion chamber.

4.PRESSURE GAUGE
It is mounted at front top. Pressure is continuously monitored so as to avoid occurrence of over shooting of boiler pressure.

5.STOP VALVE
It regulates the flow of steam from the boiler .This is generally mounted on highest part of boiler shell and performs function of regulating the flow of steam from boiler.

6.FEED CHECK VALVE
It is a non return valve at the end of delivery pipe from feed water pump and is placed on boiler shell slightly below normal water level. It is used to fill the boiler with water.

7.BLOW OFF COCK

It is used for cleaning by discharging the water and sediments from bottom of boiler. Blow off cock also helps in regulating the salt concentration as frequent draining helps in throwing out salt deposited over period of time. Opening blow off cock removes deposited sediments in boiler.

8.MANHOLE AND MUD BOX

Manhole provides the opening for cleaning ,inspection and maintenance purpose.
Mud box is a collection chamber for collecting the mud.

ACCESSORIES

1.SUPER HEATER

Its purpose is to super heat steam and is a type of heat exchanger in which steam flows inside tubes and hot gases surround it.

2.ECONOMISER

An economizer is a device used to heat feed water by utilizing the heat in the exhaust flue gases before leaving through the chimney.

3.AIR PREHEATER

An air preheater is used to recover the heat from the exhaust flue gases. It is installed between the economizer an the chimney. The air required for the purpose of combustion is drawn through the air preheater where its temperature is raised. It is then passed through the ducts to the furnace. The air is passed through the tubes of the heater internally while hot flue gases are passed over the outside of the tubes.

STEAM TURBINES

A steam turbine is a prime mover in which rotary motion is obtained by the gradual change of momentum of the steam.
In general a steam turbine consists of the following
1.The nozzle in which the heat energy of high pressure steam is converted to kinetic energy ,so that the steam issues from the nozzle with a very high velocity.
2.The blades change the direction of steam issuing form the nozzle, so that a force acts on the blades due to the change of momentum and propel them.

PRINCIPLE

The principle of steam turbine is the generation of high velocity steam jet by the expansion of high pressure steam and then conversion of kinetic energy , so obtained into mechanical work on rotor blades.

CLASSIFICATION OF STEAM TURBINE

1.According to the mode of steam action
(i)Impulse turbine (ii)Reaction turbine

2.According to the direction of steam flow
(i)Axial flow turbine (ii)Radial flow turbine

3.According to the exhaust condition of steam

(i)Condensing turbine (ii)Non condensing turbine

4.According to the pressure of steam
(i)High pressure turbine   (ii)Medium Pressure turbine (iii)high pressure turbine

5.According to the number of stages
(i)Single stage turbine   (ii)Multi stage turbine

IMPULSE TURBINE

An impulse turbine is a turbine which runs by the impulse of steam jet of this turbine, the steam is first made to flow through the nozzle. Then the steam jet impinges on the turbine blades (which are curves like blades) and are mounted on the circumference of the wheel. The steam jet after impinging glides over the concave surface of the blades and finally leave the turbine.

REACTION TURBINE

In a reaction turbine, the steam enters the wheel under pressure and flows over the blades.The steam, while gliding ,propels the blades and make them to move.As a matter of fact, the turbine runner is rotated by the reactive forces of steam jets.The backward motion of the blades is similar to the recoil of a gun.

DIFFERENCE BETWEEN THE STEAM AND TURBINE AND A STEAM ENGINE

Sr No	Criteria	Steam Turbine	Steam Engine
1	Thermal Efficiency	High	Less
2	Balancing	As there is no reciprocating parts in steam turbine, perfect balancing is possible.	Hard to achieve perfect balancing and needs heavy foundation.
3	Speed	Higher and greater range of speed is possible	Lesser range of speed.
4	Lubrication	simple	Complicated
5	Need of Flywheel	As the power generation here is at a uniform rate, a flywheel is not required.	A flywheel is needed.
6	Steam consumption	Less	More
7	Compactness	More compact	Bulky
8	Construction	Lighter construction and easier maintenance	Complex construction
9	Cost	Affordable cost than the steam engine	Costly than the steam turbine.

RESULT : Hence , the steam generator and the steam turbine are studied.

EXPERIMENT #2
PERFORMANCE AND ENERGY BALANCE TEST ON A STEAM
GENERATOR

AIM : To conduct a test on an oil fired steam generator and
                (i)   To Calculate the Boiler Thermal Efficiency
                (ii)   To Draw the heat balance test.

SPECIFICATIONS :
TYPE : Non IBR – Automatic , three pass, Oil fired Boiler with Economiser.
CAPACITY : 200 Kg/hr
OPERATING PRESSURE : 12 kg/cm^2.
FUEL : High Speed Diesel
CALORIFIC VALUE : 44500 kJ /kg

APPARATUS :
Steam generator Test Rig, and accessories.

PRECAUTIONS
1.Check the water level in the feed water tank.
2.Check the fuel level in the diesel tank.
3.Switch on the mains.
4.Switch on the side switch , and check the panel./
5.Start the water pump after opening the blow down valve.
6.Wait for two minutes.
7.Ensure that water flow is there and close the blow down valve.
8.Start the burner.
9.Allow the pressure to rise to 10kg/cm^2 in the boiler.
10.Close the steam valve to build the pressure.
11.The steam bypass valve is opened to enable the steam to be exhausted to the turbine,
maintaining the pressure.

The following observations are recorded in the observation table.(TABLE #1)
OBSERVATIONS :
1.Clock time (in minutes)
2.Steam pressure , p
3.Dryness fraction , x = 0.9 (assumed)
4.Initial and final level of water in the feed water tank, W_{h1} and W_{h2}.
5.Temperature of feed water , T_w.
6.Initial and final level of fuel in the Diesel feed tank, D_{h1} an D_{h2}.
7.Flue gas temperature , T_g.
8.Room temperature , T_R.
9.Air flow meter manometer differential reading ΔA_h , in mm.
10.Repeat the above measurements three times every ten minutes.

TABULAR COLUMN

OBSERVATION TABLE :

TIME	Steam Pr	Feed Water Tank Level		Feed Water Temp.	Oil level in Diesel Tank		Flue Gas Temp	Room Temp	Manometer reading	
t	P	Initial Wh1	Final Wh2	Tw	Initial Dh1	Final Dh2	Tg	T_R	Initial Ah1	Final Ah2
MIN	Kg/cm²	cm	cm	°C	cm	cm	°C	°C	cm	cm

FORMULAE AND CALCULATIONS: (for performance test)
1.TOTAL DURATION OF TEST , t_d.
$t_d = (t_4 - t_1)$ minutes.

2.AVERAGE STEAM PRESSURE , p_{avg}.

$$p_{avg} = \left[\frac{p_1 + p_2 + p_3 + p_4}{4} \right] \text{ kg/cm}^2.$$

3.ABSOLUTE STEAM PRESSURE , P.
$P = 0.9807 \times (p_{avg} + 1.032)$ kg/cm².

4.AVERAGE FEED WATER TEMPERATURE , Tw.

$$Tw = \left[\frac{T_{W1} + T_{W2} + T_{W3} + T_{W4}}{4} \right] °C$$

5.AVERAGE ROOM TEMPERATURE , T_R. $_R = \left[\dfrac{T_{R1} + T_{R2} + T_{R3} + T_{R4}}{4} \right] °C$

6.AVERAGE FLUE GAS TEMPERATURE , Tg

$$Tg = \left[\frac{T_{g1} + T_{g2} + T_{g3} + T_{g4}}{4} \right] °C$$

7.MASS OF STEAM GENERATED BY THE BOILER IN ONE HOUR , m_s.

m_s = Fall in water level   x   Area of feed   x 1000   x $\dfrac{60}{t_d}$
        in td minutes   water tank (m²)

$$= \frac{\Delta Wh}{1000} \times (1.252 \times 0.602) \times 1000 \times \frac{60}{t_d} \quad \text{kg /hr}$$

Here ,

ΔW_h = (Final level – Initial level) in water tank in mm.
Area of feed water tank = (1.252 x 0.602) m^2.

8.Mass of fuel oil supplied in one hour, m_f.

m_f = Fall in fuel   level   x   Area of fuel   x 950   x $\frac{60}{t_d}$
         in td minutes   tank (m^2)

where ,
ΔD_h =(Final level – Initial level) in fuel tank in mm.
Area of fuel oil tank =(0.4 x 0.4) mm^2.

(a) Enthalpy, ,h of steam generated at pressure , p
h= h_f + h_{fg} , for dry saturated steam , kJ /kg
h= h_f + x h_{fg} , for wet steam
where   x = 0.9 (assumed)
h_f and h_{fg} , are read from steam tables for absolute steam pressure , P .

(b) Enthalpy , h_w of water at feed water temperature, T_w.
h_w is read from steam tables for T_w in kJ /kg.

10.BOILER THERMAL EFFICIENCY , η_{THERM}

$$\eta_{THERM} = \frac{ms(h-hw)}{mf \times 44500} \times 100 \quad \%$$

RESULT :
Hence the Boiler performance test has been conducted and the efficiency is found out to be _____%.

CALCULATIONS FOR ENERGY BALANCE TEST OF STEAM GENERATOR

1. MASS OF AIR SUPPLIED IN ONE HOUR, m_a.

$$m_a = 1.23 \times 0.62 \times 0.00785 \times \left(2 \times g \times 814 \times \frac{\Sigma \Delta A_h}{4} \right)^{0.5} \times 3600$$

$$m_a = 1362.5 \times \left(\Sigma \Delta A_h \right)^{0.5} kg/hr$$

$$\Sigma \Delta A_h = \Delta A_{h1} + \Delta A_{h2} + \Delta A_{h3} + \Delta A_{h4}$$

ΔA_h is the water level difference in manometer.

Density of Air = 1.23 kg/m3.
Coefficient of orifice = 0.62
Diameter of orifice = 0.1 m
Area of orifice = 0.00785 m^3.
Water to air density ratio = 814

2. HEAT GAINED BY THE STEAM FROM THE BOILER PER HOUR, (Q_S).

$Q_S = m_S \times (h-h_W)$ Kj/hr

3. EVAPORATION RATE , m

$$m = \frac{m_s}{m_f} \quad \text{kg steam / kg fuel}$$

4. EQUIVALENT EVAPORATION , m_e :

$$m_e = m_s \times \frac{h - h_w}{2260} \quad \text{kg/hr}$$

2260 : Latent heat of steam at 1 bar

5. HEAT GENERATED BY BURNT FUEL OIL , Q_f :

$Q_f = m_f \times CV$ kJ /hr
CV : Calorific Value of fuel oil = 44500 kJ /kg

6. HEAT LOST TO FLUE GAS , Q_g:

$Q_g = mg \times C_{pg} \times (T_g - T_R)$

$mg = (m_a + m_f) kg$

8.HEAT BALANCE SHEET
a) HEAT INPUT , Qf
b)useful heat, Qs =
c)Heat in exhaust gas , Qg =
d) Radiation and other unaccounted losses , Qun =

HEAT BALANCE SHEET ON HOUR BASIS :

HEAT SUPPLIED	kJ	Heat utilization , kJ	%
	$Qf = mf \times CV$	Heat used to generate steam Qs=	(Qs/Qf) x 100
HEAT SUPPLIED BY FUEL		Heat carried by dry flue gases , Qg =	(Qg/Qf) x 100
		Heat unaccounted for , Qun=	(Qun x Qf) x 100

GRAPH :

A Graph is drawn between heat balance in % of heat input and % of heat utilized.
  % QunEXPERIMENT # 1
  STUDY OF STEAM BOILER AND TURBINESEXPERIMENT #2
  PERFORMANCE AND ENERGY BALANCE TEST ON A STEAM GENERATOR
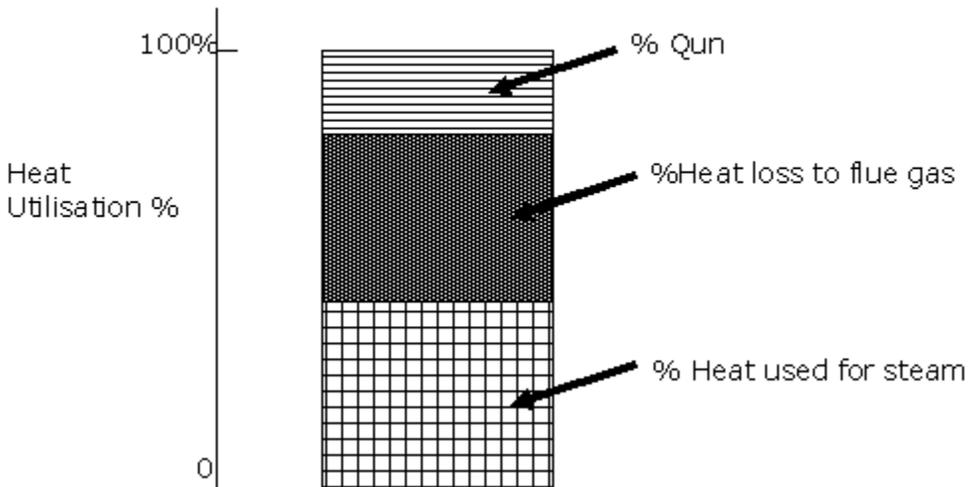
RESULT: Hence A test is conducted on the boiler and the equivalent evaporation
capacity and its thermal efficiency are determined.Also a heat balance sheet is drawn.

EXPERIMENT #3
PERFORMANCE AND ENERGY BALANCE TEST ON A STEAM TURBINE

AIM : To conduct a test on the impulse steam turbine and to draw the performance curves and draw a heat balance sheet.

SPECIFICATION :
TURBINE: IMPULSE
NO. OF NOZZLES : 3
INLET PRESSURE : 10 kg/ cm^2.
STEAM FLOW RATE : 0.01 kg/ s / Nozzle
SPEED OF TURBINE : 3000 RPM

STARTING AND RUNNING PROCEDURE :
1.Start the boiler and maintain a pressure of 10 kg/ cm^2.
2.Switch on the steam turbine panel which is connected to a 3 phase 440 V power source with neutral connection.
3.Swtich on the vacuum reciprocating pump.
4.Mainitch on the turbine panel board is switched on.When sufficient pressure (10 kg/ cm^2 to 12 kg/ cm^2) is built in the boiler, allow cooling water to circulate through the condenser by switching on the condenser water supply pump.Slowly open the boiler main valve a little and simultaneously open the main line valve's bypass valve in the steam line and the ball valve provided under the turbine.
5.When all the condensed water in the steam line and the turbine is driven out close the main line bypass valve and the valve under the turbine.
6.Adjust the handle of dynamometer spring balance screw so that the balance is just loaded to 0 kg.
7.Open the steam valve and adjust so that a pressure of 10kg/cm^2 , is maintained on the turbine pressure gauge.
8.When the turbine speed reaches about 2000rpm, load the turbine by switching on the individual switches to the bulbs.
9.Enter the observations.
10.Switch on another bulb on the loading device and after few minutes note down all the observations.
11.While doing the experiment control the pressure so that the turbine inlet pressure remains at 10 kg/ cm^2 and the sufficient water is in the boiler.

Turbine Speed	Steam Pr		Steam Temp		Time Taken For 4 cm rise in condensate tank	Spring balance reading	Cooling Water		TSC	Turbine Output Power	Cooling Water Flow meter Mano Meter Reading		
	Inlet	Outlet	Inlet	Outlet			Inlet	Outlet			Hm1	Hm2	ΔHm
n	P1	P2	T1	T2	tc	W_D							
rpm	Kg/cm^2												

CALCULATIONS :
1.Converstion of kg/ cm^2 to bar.
$=[\ 0.9807 \times \{\ p_1\ (kg/cm^2\ )\ +\ 1.032\ \}]\ $ bar
p1 : Steam pressure at turbine inlet.

2.Total steam consumption , TSC.

TSC + (1271 / tc) kg/ hr
tc : Time taken for 4 cm rise in water level of condensate tank in sec.

3.Specific Steam consumtion , SSC
SSC = TSC / Pd   kg/ kW
Pd : Turbine Output power

$$P_d = \frac{1.294 \times n \times W_D}{10000}\, kW$$

n : Speed of the turbine in rpm.
W_D: Dynamometer spring balance reading , kg.

4.Rankine Efficiency , η_{RE}:

$$\eta_{RE} = \frac{(T_1 - T_2)\left(1 + \dfrac{h_{fg1}}{T_2}\right) - T_2 \ln\left(\dfrac{T_1}{T_2}\right)}{(T_1 - T_2) + h_{fg2}}$$

T_1 : Temperature of steam at turbine inlet   in °C

T_2 : Temperature of steam at turbine outlet in °C

h_{fg1} : Enthalpy of vaporization from saturated steam tables for T_1 °C

h_{fg2} : Enthalpy of vaporization from saturated steam tables for T_2°C

5.Rankine Engine Efficiency , η_{REE}.

$$\eta_{REE} = \frac{h_1 - h_2}{h_1 - h_{f2}} \times 100 \quad \%$$

h1 = hf1 + x1 hfg1

S1 = S2 = Sf1 + x1 sfg11 = sf2 + x2 Sfg2

Sf2 and sfg2 are found from sat steam tables for T_2 °C.

Find x2

h2 = hf2 + x2 hfg2

hf2 and hfg2 are found for T2 °C

6. Brake Thermal Efficiency , BTE in %

$$BTE = \frac{Pd \times 100 \times 3600}{TSC(h_1 - h_2)}$$

7.Relative Efficiency = (BTE / RE) x 100 %

calculations table :

St Pr.	St Pr	TSC	Turbine Output Power	SSc	Rankine Eff	Rank. Engine Eff.	BTE	Rel Eff.
inlet	Outlet		Pd		ηRE	ηREE		ηRel
P1	P2							
bar	bar	Kg/hr	kW	Kg/ kW hr	%	%	%	%

Total Steam Consumption , kg/ hr

GRAPHS :
1.TSC Vs TURBINE O/P POWER
2.TSC Vs RANKINE EFFICIENCY
3.TSC Vs BRAKE THERMAL EFFICIENCY

HEAT BALANCE CALCULATIONS :
1.HEAT INPUT AT TURBINE INLET , Qi

$Qi = TSC \ X \ h_1 \ kJ \ /s$

2.HEAT CARRIED AWAY BY CONDENSATE , Qc
$Qc = TSC \ X \ hfc$.
Hfc : Enthalpy of condensate liquid for Tc °C

3.HEAT EQUIVALENT OF WORK DONE , Pd , kJ / s

4.HEAT CARRIED AWAY BY CONDENSOR COOLING WATER .

$$Qw = m_c(h_{fo} - h_{fi})$$

m_c = Cooling water mass flow rate measured from flow meter manometer in kg/ s.

$$m_c = K_M \sqrt{\Delta H_m} \quad kg / s$$

ΔHm = cooling water flow meter manometer reading in mm.
$K_M = 2.081 \ x \ 10^{-3}$ constant
h_{fi} : Enthalpy of water at inlet temperature of cooling wateer, T_{w1} °C
h_{fo} : Enthalpy of water at outlet temperature of cooling wateer, T_{w2} °C

5.Unaccounted losses, Qun = 1 – (2+3+4) kJ /s
All the above are calculated for each of the 4 or 5 sets of readings.

1	2	3	4	5	6	7	8	9	10
n	Qi	Qd	Qc	Qw	Qun	Refer below (11)	Refer below (12)	Refer below (13)	Refer below (14)
rpm	kJ/s	kJ/s	kJ/s	kJ/s	kJ/s	%	%	%	%

1.Turbine Speed
2.Heat input at turbine inlet
3.Heat Equivalent of work done
4.Heat carried away by condensate
5.Heat carried away by condensate cooling water
6.Unaccounted losses , Qun
7.% of heat used , = (Qd / Qi) x 100
8.% of heat carried away by condensate , (Qc / Qi) x 100
9.% of heat carried away by condenser cooling water ,
(Qw / Qi) x 100

10.% of unaccounted heat loss (Qun / Qi) x 100
11. (Qd / Qi) x 100
12. (Qc / Qi) x 100
13. (Qw / Qi) x 100
14. (Qun / Qi) x 100

HEAT BALANCE SHEET
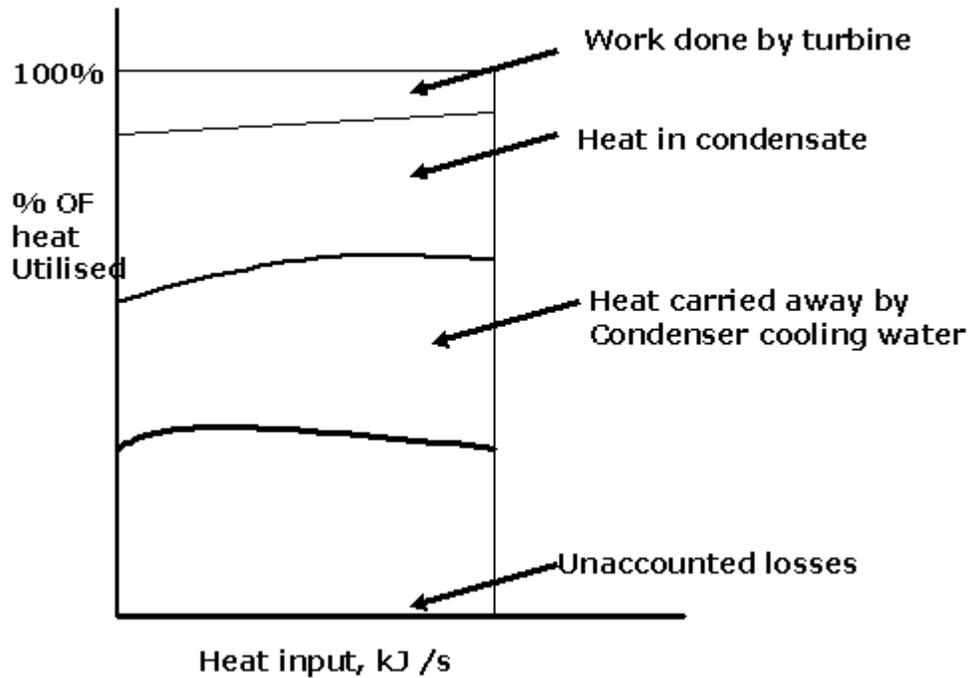
Result : Hence the performance of the steam turbine has been worked out and the graphs drawn .The heat balance sheet has also been drawn.

ST.ANNE'S
COLLEGE OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF MECHANICAL
THERMAL ENGINEERING LAB

NAME   :
ROLL NO.   :
YEAR   :
BATCH   :

THERMAL ENGINEERING LABORATORY

ANNA UNIVERSITY CHENNAI

DEPARTMENT MECHANICAL ENGINEERING

UNIVERSITY PRACTICAL EXAMINATION

Allotment of Marks

Internal Assessment   = 20 marks

Practical Examination   = 80 marks

INTERNAL ASSESSMENT [20 Marks]

Staff should maintain the assessment Register and the Head of the Department should monitor it.

SPLIT UP OF INTERNAL MARKS

Record Note   = 10 marks

Model Exam = 5 marks

Attendance   = 5 marks
           ―――――――

Total   20 marks
           ―――――――

UNIVERSITY EXAMINATION

The examination will be conducted for 100 marks. Then the marks will be calculated to 80 marks.

Split up of Practical Examination Marks

Aim and Procedure	= 25 marks
Tabulation	= 15 marks
Formulae and Calculation	= 30 marks
Graph and Result	= 20 marks
Viva Voce	= 10 marks
	――――――――
Total	= 100 marks
	――――――――

<u>GENERAL INSTRUCTIONS FOR LABORATORY CLASSES</u>

- Enter the Lab with **CLOSED FOOTWEAR.**

- Boys should **"TUCK IN"** the shirts.

- Students should wear **uniform only**.

- **LONG HAIR** should be protected, let it not be loose especially near **ROTATING MACHINERY.**

- Any other machines / equipments **should not be operated** other than the prescribed one for that day.

- **POWER SUPPLY** to your test table should be obtained only through the **LAB TECHNICIAN.**

- Do not **LEAN** and do not be **CLOSE** to the rotating components.

- **TOOLS, APPARATUS and GUAGE** sets are to be returned before leaving the lab.

- **HEADINGS** and **DETAILS** should be neatly written
    i.   Aim of the experiment
    ii.   Apparatus / Tools / Instruments required
    iii.   Procedure / Theory / Algorithm / Program
    iv.   Model Calculations
    v.   Neat Diagram / Flow charts
    vi.   Specifications / Designs Details
    vii.   Tabulations
    viii.   Graph
    ix.   Result / discussions.

- Before doing the experiment, the student should get the Circuit / Program approval by the **FACULTY-IN-CHARGE.**

- **Experiment date** should be written in the appropriate place.

- After completing the experiment, the answer to the **viva-voce questions** should be neatly written in the work book.

- Be **PATIENT, STEADY, SYSTEMATIC AND REGULAR.**

LIST OF EXPERIMENTS

HEAT TRANSFER

1. Thermal conductivity measurement by guarded plate method.
2. Thermal conductivity of pipe insulation using lagged pipe apparatus.
3. Natural convection heat transfer from a vertical cylinder.
4. Forced convection inside tube.
5. Heat transfer from pin-fin(natural & forced convection modes)
6. Determination of Stefan-Boltzmann constant.
7. Determination of emissivity of a gray surface.
8. Effectiveness of Parallel/counter flow heat exchanger.

REFRIGERATION AND AIR CONDITIONING

1. Determination of COP of a refrigeration system.
2. Experiments on air-conditioning system.
3. Performance test on single/two stage reciprocating air compressor.

LIST OF EXPERIMENTS BEYOND THE SYLLUBUS

1. Thermal Conductivity of insulating powder.
2. Thermal Conductivity of metal rod.
3. Calorific value determination by Junker's gas calorimeter.

CONTENTS

OBSERVATION:

MINIMUM 40 VOLTS [BOTH]

S. No.	Volts	Amps	Volts	Amps	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9
1.	39	0.18	44.1	0.14	34.2	32.3	41.3	80.9	62.5	92.1	98.4	42.0	34.6
2.	36	0.16	41	0.13	22.6	34.5	44.4	85.0	66.4	95.6	102.8	44.9	37.4
3.	32	0.14	36	0.12	23.8	35.0	44.5	82.5	65.4	92.0	98.7	45.0	38.2

CALCULATION:

Insulating material	: Asbestos sheet [commercial grade]	
Specimen diameter	= 150 mm = 0.15 m.	
Area of specimen	= $\pi / 4$ x $[0.15]^2$ = 0.018 m^2.	
Specimen thickness	= ΔL = 12 mm = 0.012 m.	
Volts	= 32	
Amps	= 0.14	Main heater
Volts	= 36	
Amps	= 0.12	Ring heater

Heat input q = q [main heater] + q [guard heater]

= [32 x 0.14 x 0.86] + [36 x 0.12 x 0.86]

= 3.85 + 3.71

= 7.56 kcal/hr.

It should be noted that out of this heat input, ideally only a half will pass through each of the specimens [top and bottom].

Hence q = q / 2 = 7.56 / 2 = 3.78 kcal/hr.

ΔT = {[$T_4 - T_3$] + [$T_7 - T_8$]} / 2

= {[82.5 – 44.5] + [98.7 – 45.0]} / 2

= [38 + 53.7] / 2

= 91.7 / 2 = 45.85 ^{0}C.

Thermal conductivity of specimen

K = q ΔL / A ΔT

= 3.78 x 0.012 / 0.018 x 45.85

= 0.04536 / 0.8253

= 0.05496 kcal/hr m^{0}C.

Experiment Number: 1

Title of the Experiment: Thermal Conductivity Measurement By Guarded Plate Method

Date of the Experiment:

OBJECTIVE [AIM] OF THE EXPERIMENT

To determine the thermal conductivity of a poor conducting material, say Asbestos sheet.

RELEVANT THEORY

Thermal conductivity is a specific property of conducting material which is defined below for a homogeneous solid as the quantity of heat conducted across a unit area normal to the flow direction in unit time and for unit temperature gradient along the flow.

$$K = q \, dL / A \, dT$$

Where,

q = heat conducted in watts

dL = thickness [m]

A = Area of conduction heat transfer, m^2

dT = temperature difference across the length dL [^0C]

MEASUREMENT:

Experimental measurement of thermal conductivities of solids can be accomplished by a variety of methods, all based on the observation of the temperature gradient across a given area of the material conducting heat at a known rate.   Each of these methods has certain unique limitations, and the choice of one over another is governed by the general temperature level at which K is measured, by the physical structure of the material in question and by whether the material is a good or poor conductor.

In measuring the thermal conductivity of poor conductors, the specimens are taken in the form of sheets in order that the heat flow path is short and the conducting area large. [low dL, higher A].

FACILITIES REQUIRED AND PROCEDURE

a] Facilities required to do the experiment:

Sl. No.	Facilities required	Quantity
1.	Guarded plate apparatus	1

SPECIFICATIONS:

Material = Asbestos sheet [commercial grade]
Specimen diameter [d] = 150 mm or 0.15 m.
Specimen thickness dL = 12 mm or 0.012 m.
Area of specimen = $\pi / 4$ x $[0.15]^2$ m^2
Heat input = VI watts [q]

b] Guarded Hot Plate method [Solids]

The apparatus consists of a Guarded Hot Plate, the arrangement along with thermocouple positions [T3, T4] across the specimen and T5, T6 guarded heater temperature [only for check] [T1, T2] Top and Bottom pad temperatures.

The panel consists of voltmeter, ammeter, temperature indicator [all digital], dimmer controls, voltmeter and ammeter selector [common switch, thermocouple selector switch].

c] Operation:

a] Connect the three pin plug top to 230 V, 50 Hz, 5 Amps power supply socket, dimmers in OFF position.

b] Keep the voltmeter and ammeter switch in 1 position. Turn the dimmer in clockwise and adjust the power input to main heater to any desired value by looking at voltmeter and ammeter.

c] Turn the voltmeter and ammeter switch to position marked 2 and check the voltage & current are same for ring heater.

d] Allow the unit to stabilize [approx 30 minutes].

e] Note down the temperature indicated by the digital temperature indicator by turning the thermocouple selector switch clockwise step by step [1, 2, 3, 4, 5, and 6].

f] Repeat the experiment for different power inputs to the heater.

g] Tabulate all the readings and calculate for different conditions.

h] After the experiment is over turn all the dimmer knobs anti clockwise, direction to zero.

i] Disconnect the three pin plug top from the mains.

CAUTION:

The equipment should be operated between 0 and 150 V.

d] Procedure for doing the experiment:

Step No.	Details of the Step
1.	Supply a small quantity of energy to the source 'H' [the main heater MH].
2.	Now adjust the input to the guard heaters such that the temperature is same as that of the main heater
3.	Allow water through the cooling circuit slowly.
4.	Allow 30 – 60 minutes for the temperatures to stabilize.
5.	Note down all the parameter
6.	Repeat the experiment at different temperature values by adjusting appropriately the input conditions.

e] Result:

Thus the thermal conductivity of a poor conducting material [Asbestos sheet] is determined.

K= 0.05496 Kcal / hr m^{0}C.

VIVA QUESTIONS

1. **Define heat transfer**.

   Heat transfer can be defined as the transmission of energy from one region to another due to temperature difference.

2. **What are the modes of heat transfer?**
   1. Conduction
   2. Convection
   3. Radiation.

3. **What is conduction?**

   Heat conduction is a mechanism of heat transfer from a region of high temperature to a region of low temperature within a medium [solid, liquid or gases] or different medium in direct physical contact.

4. **State Fourier's law of conduction**.

   The rate of heat conduction is proportional to the area measured normal to the direction of heat flow and to the temperature gradient in that direction.

   $Q \alpha - A \, dT / dx$

   $Q = -kA \, dT / dx$

   Where, A – Area in m^2.

   dT / dx – Temperature gradient, K/m

   k – Thermal conductivity, W/mK.

5. **Define Thermal conductivity**.

   Thermal conductivity is defined as the ability of a substance to conduct heat.

Experiment Number: 2

Title of the Experiment: Thermal Conductivity Of Pipe Insulation Using Lagged Pipe Apparatus

Date of the Experiment:

OBJECTIVE [AIM] OF THE EXPERIMENT:

To plot the radial temperature distribution in the composite cylinder and to determine the thermal conductivity of the pipe insulation.

THEORY

Consider one dimensional radial heat flow through a hollow cylinder, under steady state conditions.

$$q = 2\pi KL [T_1 - T_2] / \ln [r_2/r_1]$$

Where T_1, T_2 are the inner and outer wall temperature r_1 and r_2 are the inner and outer radii of the pipe.

K = Thermal conductivity of the material.

FACILITIES REQUIRED AND PROCEDURE

a] Facilities required to do the experiment:

Sl. No.	Facilities required	Quantity
1.	Lagged Pipe Apparatus	1

b] Description of the Apparatus:

The apparatus consists of a metal pipe with two layers of insulation. An electric heating coil wound on a silica rod is placed at the center. The ends are thickly insulated to prevent heat loss so that, heat flow only in a radial direction. Three thermocouples each are placed at different radii to measure the temperature distribution within the cylinder.

c] Technical Data:

Location of thermocouples 1, 2, 3 at a radius = 25 mm.
Location of thermocouples 4, 5, 6 at a radius = 37.5 mm.
Location of thermocouples 7, 8, 9 at a radius = 50 mm.
Location of thermocouples 10, 11, 12 at a radius = 62.5 mm.
Length of the pipe L = 500 mm.

TABULATION

S.No	Heat Input [watts]			Temp at Radius R_1 ^{0}C			Temp at Radius R_2 ^{0}C			Temp at Radius R_3 ^{0}C			Temp at Radius R_4 ^{0}C		
	V	A	q	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
1.	75	0.44	33	111.8	133.8	102.2	37.2	41.9	37.3	35.4	39.9	39.7	31.8	30.2	30.4

MODEL CALCULATION:

At r_1 = 25 mm

T_1 = (111.8 + 133.8 + 102.2) / 3 = 115.93^{0}C.

At r_2 = 37.5 mm

T_2 = (37.2 + 41.9 + 37.3) / 3 = 38.8^{0}C.

At r_3 = 50 mm

T_3 = (35.4 + 39.9 + 39.7) / 3 = 38.33^{0}C.

At r_4 = 62.5 mm

T_4 = (31.8 + 30.2 + 30.4) / 3 = 30.8^{0}C.

$q = 2 \pi KL [T_2 – T_3] / \ln [r_3/r_2]$

$q = V \times I = 75 \times 0.44 = 33.$

$K = q \ln [r_3/r_2] / 2\pi L [T_2 – T_3]$

$= 33 \ln [0.05/0.0375] / 2\pi \times 0.5 [38.8 – 38.33]$

$K = 0.1948$ W/mK.

d] Procedure for doing the experiment:

Step No.	Details of the Step
1.	Connect the equipment to a 230V, 5 amps, and 50 HZ electrical source.
2.	Twin the dimmerstat knob clockwise and fix the heat input to a desired wattage [V x I]
3.	Allow the equipment to stabilize and attain steady state.
4.	Turn the thermocouple selector switch knob clockwise and note down temperature T_1 to T_{12}.
5.	Repeat the experiment for different heat inputs.

d] Formula:

$$q = 2 \pi KL [T_2 - T_3] / \ln [r_3/r_2]$$

T_2 = Temperature at radius r_2 ^{0} C

T_3 = Temperature at radius r_3 ^{0}C

r = radius of the pipe 'm'

K = Thermal Conductivity – W/m K

L = Length of the pipe – 'm'

e] Result:

Thus the thermal Conductivity of the pipe insulation is determined.

K = 0.1948 W/m K.

VIVA QUESTIONS

1. **What is conduction?**
   Heat conduction is a mechanism of heat transfer from a region of high temperature to a region of low temperature within a medium [solid, liquid or gases] or different medium in direct physical contact.

2. **State Fourier's law of conduction.**
   The rate of heat conduction is proportional to the area measured normal to the direction of heat flow and to the temperature gradient in that direction.

   $Q \, \alpha - A \, dT / dx$
   $Q = -kA \, dT / dx$
   Where, A – Area in m^2.
   dT / dx – Temperature gradient, K/m
   k – Thermal conductivity, W/mK.

3. **Define Thermal conductivity.**
   Thermal conductivity is defined as the ability of a substance to conduct heat.

4. **Write down the equation for conduction of heat through a slab or plane wall.**
   Heat transfer, $Q = \Delta T_{overall} / R$
   Where, $\Delta T = T_1 - T_2$
   $R = L / kA$ – Thermal resistance of slab
   L – Thickness of slab
   K – Thermal conductivity of slab
   A – Area

5. **Write down the equation for conduction of heat through a hollow cylinder.**
   Heat transfer, $Q = \Delta T_{overall} / R$
   Where
   $\Delta T = T_1 - T_2$
   $R = 1 / 2\pi Lk$ in $[r_2 / r_1]$ – Thermal resistance of slab.
   L – Length of cylinder
   k – Thermal conductivity
   r_2 – Outer radius
   r_1 – Inner radius

6. **What are the factors affecting the thermal conductivity?**
   a. Moisture b. Density of material   c. Pressure
   d. Temperature   e. Structure of material.

TABULATION

| S. No. | Volt Meter Reading [Volts] | Am-Meter Reading [I] Amps | In Put Watts | Thermocouple Location in ^{0}C | | | | | | | T_s ^{0}C | [T_8] T_a ^{0}C. | T_{mf} [$T_s + T_a$] / 2 ^{0}C |
				1	2	3	4	5	6	7			
1.	78.125	0.64	50	53	56	62	68	66	71	64	62.857	38	50.429
2.	84.337	0.83	70	83	92	101	107	101	110	103	99.571	38	68.736
3.	91.836	0.98	90	98	102	121	128	123	133	113	116.857	39	77.929

CALCULATION:

[1] Experiment heat transfer co-efficient [Average]

$Q = hA [\Delta T]$ Watts.

` $Q = hA [T_s – T_a]$ Watts.

$h = Q / A [T_s – T_a]$ W/m^{2}K.

$h = 50 / \pi \times d \times l [T_s – T_a] = 50 / \pi \times 0.031 \times 0.5 [62.857 – 38]$

$h_{avg} = 41.309$ W/m^{2}K.

[2] Local heat transfer co-efficient:

$h_{exp}[local] = Q / A[T_x – T_a]$.

$h_1 = 50 / 0.5 \times 0.031 \times \pi \times [53 - 38] = 68.454$ W/m^{2}K.

$h_2 = 50 / 0.5 \times 0.031 \times \pi \times [56 - 38] = 57.045$ W/m^{2}K.

$h_3 = 50 / 0.5 \times 0.031 \times \pi \times [62 - 38] = 42.784$ W/m^{2}K.

$h_4 = 50 / 0.5 \times 0.031 \times \pi \times [68 - 38] = 34.227$ W/m^{2}K.

$h_5 = 50 / 0.5 \times 0.031 \times \pi \times [66 - 38] = 36.672$ W/m^{2}K.

$h_6 = 50 / 0.5 \times 0.031 \times \pi \times [71 - 38] = 31.115$ W/m^{2}K.

$h_7 = 50 / 0.5 \times 0.031 \times \pi \times [64 - 38] = 39.493$ W/m^{2}K.

[3] Theoretical heat transfer co-efficient. h_{theo} [Average]

$Gr = [g \times L^3 \times \beta \times \Delta T] / v^2$

$\beta = 1 / T_{mf}$ in K $= 1 / [50.429 + 273] = 3.092 \times 10^{-3}$ ^{0}K^{-1}.

$\Delta T = [T_s – T_a] = 24.857$ ^{0}C.

$T_f = [T_s + T_a] / 2 = [62.857 + 38] / 2 = 50.429 = 50$ ^{0}C.

Properties of air at 50^{0}C

$\rho = 1.093$ kg/m^3; $Pr = 0.698$; $L = 0.5$ m;

$v = 17.95 \times 10^{-6}$ m^2/s; $K = 0.02826$ W/m K; $g = 9.81$ m/sec^2.

$Gr = [g \times L_x^3 \times \beta \times \Delta T] / v^2 = \{9.81 \times [0.5]^3 \times 3.092 \times 10^{-3} \times 24.857\} /[17.95 \times 10^{-6}]^2$

$Gr = 0.0942 / 3.222 \times 10^{-10} = 2.924 \times 10^8$.

$GrPr = [2.924 \times 10^8] \times 0.698 = 2.040 \times 10^8$.

$Nu = 0.59 [2.040 \times 10^8]^{0.25} = 70.511$

$70.511 = h \times 0.5 / 0.02826$

$h_{theo} = 3.985$ W/m^{2}K.

Experiment Number: 3

Title of the Experiment: Natural Convection Heat Transfer from a Vertical Cylinder

Date of the Experiment:

OBJECTIVE [AIM] OF THE EXPERIMENT

To determine surface heat transfer co-efficient, local heat transfer co-efficient along the length of the tube and also to draw the graph between local heat transfer co-efficient and distance along the length of the tube.

FACILITIES REQUIRED AND PROCEDURE

a] Facilities required to do the experiment:

Sl. No.	Facilities required	Quantity
1.	Natural convection-vertical cylinder apparatus	1

b] Theory

When a hot body is kept in a still air, heat is transferred to the surrounding by natural convection, the fluid layer in contact with the hot surface gets heated, rises up due to decrease in its density and the cold fluid rushes into take its place. The process is continuous and heat transfer takes place due to relative motion of hot and cold fluid. The surface heat transfer co-efficient of a system transferring heat by natural convection depends upon its shape, dimension, orientation and also the temperature difference between the surface and the fluid.

c] Apparatus Description

The apparatus consists of a Brass tube fitted in a rectangular duct in a vertical fashion. 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 up of Perspex sheet for visualization. An electric heating element is kept in the vertical tube which in turn heats the tube to the surrounding air by natural convection. The surface temperature of the vertical tube is measured by seven thermocouple wires. The tube surface is polished to minimize the radiation losses. The temperature of the tube measured by a temperature indicator.

Specification:

[1] Diameter of the tube [d] = 31 mm.
[2] Length of the tube [l] = 500 mm.
[3] Duct size = 200 mm x 200 mm x 750 mm

[4] Theoretical Local heat transfer co-efficient. h_{theo} [Local]

$\quad\quad$ Gr [local] = [g x β x L_x^3 x ΔT] / v^2

[i] $\quad$ T_{mf} [Local] = [T_x + T_a] / 2 = [53 +38] / 2 = 45.5^{0}C.

$\quad\quad$ Properties of air at 45.5^{0}C

$\quad\quad\quad\quad$ ρ = 1.109 kg/m^3; $\quad\quad\quad$ Pr = 0.685; $\quad\quad\quad$ L_x = 0.01 m;

$\quad\quad\quad\quad$ v = 17.505 x 10^{-6} m^2/s $\quad$ K = 0.02795 W/mK; $\quad$ g = 9.81 m^2/s;

$\quad\quad$ Gr = [g x β x L_x^3 x ΔT] / v^2 $\quad\quad$ β = 1 / 318.5 = 3.140 x 10^{-3}.

$\quad\quad\quad$ = 9.81 x 3.140 x 10^{-3} x 0.01^3 x [53 – 38] / [17.505 x 10^{-6}]^2

$\quad\quad$ Gr = 1.508 x 10^3.

$\quad\quad$ Gr Pr = [1.508 x 10^3] [0.685]

$\quad\quad$ Gr Pr = 1.033 x 10^3.

10^4 $\leq$ Gr Pr $\leq$ 10^9 $\quad$ Nu = [0.59] [Gr Pr]$^{0.25}$

$\quad\quad\quad\quad\quad\quad$ = [0.59] [1.033 x 10^3]$^{0.25}$ = 3.345

$\quad\quad$ Nu = h_L L_x / K

$\quad$ 3.345 = h_L [0.01] / 0.02795

$\quad\quad$ h_{L1} = 9.349 W/m^{2}K.

[ii] $\quad$ T_{mf} [Local] = [T_x + T_a] / 2 = [56 + 38] / 2 = 47^{0}C.

$\quad\quad$ Properties of air at 47^{0}C

$\quad\quad\quad\quad$ ρ = 1.104 kg/m^3; $\quad\quad\quad$ Pr = 0.689; $\quad\quad\quad$ L_x = 0.05 m;

$\quad\quad$ v = 17.653 x 10^{-6} m^2/s $\quad$ K = 0.02805 W/mK; β = 1 /320 = 3.125 x 10^{-3}

$\quad\quad$ Gr = [g x β x L_x^3 x ΔT] / v^2

$\quad\quad\quad$ = 9.81 x 3.125 x 10^{-3} x 0.05^3 x [56 - 38] / [17.653 x 10^{-6}]^2

$\quad\quad$ Gr = 2.214 x 10^5.

$\quad\quad$ Gr Pr = [2.214 x 10^5] x [0.689] = 1.525 x 10^5

$\quad\quad$ Nu = [0.59] [1.525 x 10^5]$^{0.25}$ = 11.66.

$\quad\quad$ Nu = h_L L_x / K

$\quad\quad$ 11.66 = [h_L x 0.05] / 0.02805

$\quad\quad$ h_{L2} = 6.54 W/m^{2}K.

[iii] T_{mf} = [T_x + T_a] / 2 = [62 + 38] / 2 = 50^{0}C.

$\quad\quad$ Properties of air at 50^{0}C

$\quad\quad\quad\quad$ ρ = 1.093 kg/m^3; $\quad\quad\quad$ Pr = 0.698; $\quad\quad\quad$ L_x = 0.1 m;

$\quad\quad\quad\quad$ v = 17.95 x 10^{-6} m^2/s $\quad$ K = 0.02826 W/mK; β = 3.0296 x 10^{-3}

$\quad\quad$ Gr = g x β x L_x^3 x ΔT / v^2

$\quad\quad$ Gr = 9.81 x 3.096 x 10^{-3} x 0.1^3 x [62 - 38]/ [17.95 x 10^{-6}]^2 = 2.262 x 10^6.

$\quad\quad$ Gr Pr = [2.262 x 10^6] x [0.698] = 1.579 x 10^6.

$\quad\quad$ Nu = [0.59] [1.579 x 10^6]$^{0.25}$ = 20.91.

$\quad\quad$ Nu = h_L L_x / K

$\quad\quad$ 20.91 = [h_L x 0.1] / 0.02826

$\quad\quad$ h_{L3} = 5.909 W/m^{2}K.

[iv] T_{mf} = [T_x + T_a] / 2 = [68 + 38] / 2 = 53^{0}C.

$\quad\quad$ Properties of air at 53^{0}C

$\quad\quad$ ρ = 1.083 kg/m^3; $\quad\quad\quad$ Pr = 0.697; $\quad\quad\quad$ L_x = 0.2 m;

$\quad\quad$ v = 18.26 x 10^{-6} m^2/s $\quad$ K = 0.02847 W/mK; β = 3.067 x 10^{-3}

[4] Number of Thermocouples = 7 and are shown as [1] – [7] and as marked on temperature indicator switch.

[5] Thermocouple number 8 reads the temperature of the air in the duct.

[6] Temperature indicator 0 – 300^{0}C. Multichannel type, calibrated for chromel – alumel thermo couples.

[7] Ammeter = [0 – 2A]

[8] Voltmeter = [0 – 100/200V]

[9] Dimmer start = 2A/230Volt.

[10] Heater – cartridge type = 400 Watts

d] Procedure for doing the experiment:

Step No.	Details of the Step
1.	Switch on the supply and adjust the dimmerstat to obtain the required heat input.
2.	Wait till the fairly steady state is reached, which is confirmed from temperature readings [T$_1$ to T$_7$].
3.	Note down surface temperature at various points.
4.	Note the Ambient Temperature [T$_8$].
5.	Repeat the experiment at different heat inputs.

Precautions:

[1] Do not exceed 100 Watts.

[2] Operate the change over selector switch gently from position [1] to [8].

Formula Used:

[1] $T_s = [T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7] / 7$ ^{0}C

Where $T_1, T_2, T_3, ... T_7$ are temperature at locations 1, 2 --7

Mean film temperature $[T_{mf}] = [T_s + T_a] / 2$.

Where T_s = Average surface temperature in ^{0}C.

T_a = Ambient Temperature in ^{0}C.

Experiment heat transfer co-efficient [Average]

$Q = hA [\Delta T]$ Watts.

Where h = Experimental convective heat transfer co-efficient [Average] W/m^{2}K.

A = Area of heat transfer πd L m^2.

$\Delta T = T_s – T_a$ in ^{0}C.

T_s = Surface temperature in ^{0}C.

T_a = Ambient temperature in ^{0}C.

Q = Average rate of heat transfer by convection in [Watts].

h_{exp} [average] = $Q / As[T_s – T_a]$ W/m^{2}K.

$Gr = g \times \beta \times L_x^3 \times \Delta T / v^2$

$Gr = 9.81 \times 3.067 \times 10^{-3} \times 0.2^3 \times [68 - 38] / [18.26 \times 10^{-6}]^2 = 21.659 \times 10^6$.

$Gr\, Pr = [21.659 \times 10^6] \times [0.697] = 15.096 \times 10^6$.

$Nu = [0.59] [15.096 \times 10^6]^{0.25} = 36.776$.

$Nu = h_L\, L_x / K$

$36.776 = [h_{L4} \times 0.2] / 0.2847$

$h_{L4} = 5.235$ W/m^{2}K.

[v] $T_{mf} = [T_x + T_a] / 2 = [66 + 38] / 2 = 52^0$C.

Properties of air at 52^0C

$\rho = 1.086$ kg/m^3; $Pr = 0.698$; $L_x = 0.3$ m;

$v = 18.15 \times 10^{-6}$ m^2/s $K = 0.02840$ W/mK; $\beta = 3.077 \times 10^{-3}$

$Gr = g \times \beta \times L_x^3 \times \Delta T / v^2$

$Gr = 9.81 \times 3.077 \times 10^{-3} \times 0.3^3 \times [66 - 38] / [18.15 \times 10^{-6}]^2 = 69.28 \times 10^6$.

$Gr\, Pr = [69.28 \times 10^6] [0.698] = 48.36 \times 10^6$.

$Nu = [0.59] [48.36 \times 10^6]^{0.25} = 49.201$.

$Nu = h_L\, L_x / K$

$49.201 = h_{L5} \times 0.3 / 0.02840$

$h_{L5} = 4.658$ W/m^{2}K.

[vi] $T_{mf} = [T_x + T_a] / 2 = [71 + 38] / 2 = 54.5^0$C.

Properties of air at 54.5^0C

$\rho = 1.078$ kg/m^3; $Pr = 0.697$; $L_x = 0.4$ m;

$v = 18.41 \times 10^{-6}$ m^2/s $K = 0.02858$ W/mK; $\beta = 3.053 \times 10^{-3}$

$Gr = g \times \beta \times L_x^3 \times \Delta T / v^2$

$Gr = 9.81 \times 3.053 \times 10^{-3} \times 0.4^3 \times [71 - 38] / [18.41 \times 10^{-6}]^2 = 186.63 \times 10^6$.

$Gr\, Pr = [186.63 \times 10^6] \times [0.697] = 130.08 \times 10^6$.

$Nu = [0.59] [130.08 \times 10^6]^{0.25} = 63.01$.

$Nu = h_L\, L_x / K$

$Nu = [h_L \times 0.4] / 0.02858$

$63.01 = [h_L \times 0.4] / 0.2858$

$h_{L6} = 4.502$ W/m^{2}K.

[vii] $T_{mf} = [T_x + T_a] / 2 = [64 + 38] / 2 = 51^0$C.

Properties of air at 51^0C

$\rho = 1.090$ kg/m^3; $Pr = 0.698$; $L_x = 0.49$ m;

$v = 18.052 \times 10^{-6}$ m^2/s $K = 0.02833$ W/mK; $\beta = 3.086 \times 10^{-3}$

$Gr = g \times \beta \times L_x^3 \times \Delta T / v^2$

$Gr = 9.81 \times 3.086 \times 10^{-3} \times 0.49^3 \times [64 - 38] / [18.052 \times 10^{-6}]^2 = 284.136 \times 10^6$.

$Gr\, Pr = [284.136 \times 10^6] \times 0.698 = 198.33 \times 10^6$.

$Nu = [0.59] \times [198.33 \times 10^6]^{0.25} = 70.16$

$Nu = h_L\, L_x / K$

$Nu = [h_L \times 0.49] / 0.02833$

$70.16 = h_L \times 0.49 / 0.2833$

$h_{L7} = 4.048$ W/m^{2}K.

[2] Local heat transfer co-efficient:

$h_{exp}[local] = Q / A[T_x - T_a].$

Where T_x = Temperature at locations 1 to 7 in ^0K.

The local heat transfer co-efficient h_1, h_2, h_3, ... h_7 can be calculated from the above equation.

[3] Theoretical heat transfer co-efficient [Average].

Using free convection correlation for vertical cylinder.

$Nu = 0.59 [Gr. Pr]^{0.25}$ for $10^4 \leq Gr. Pr \leq 10^9$.

$= 0.13 [Gr. Pr]^{1/3}$ for $10^9 \leq Gr. Pr \leq 10^{12}$.

Nu = Nusselt Number.

Gr = Grashof Number.

Pr = Prandtl Number.

Grash of Number = $g \times L^3 \times \beta \times \Delta T / v^2$

Where g = Acceleration due to gravity = 9.81 m/s^2.

L = Characteristics dimension in meters, Here L = 0.5 m.

β = Co-efficient of thermal expansion for the fluid

$\beta = 1 / T_f$ in K.

ΔT = Temperature difference in $^0K = [T_s - T_a].$

v = Kinematic viscosity of the air at mean film temperature, m^2/s.

[from the HMT Data book].

p_r = Prandtl Number of air at T_{mf} [from the HMT Data book].

Nu = hL/K.

Where h = Convective heat transfer co-efficient in w/m^{2}K.

L = Characteristic dimension in m. L = 0.5 m.

K = Thermal conductivity of air at T_{mf} [from HMT Data book]

[4] Theoretical Local heat transfer co-efficient. h_{theo} [Local]

$Gr [local] = g \times L_x^3 \times \beta \times \Delta T / v^2$

Where $L_x = L_1, L_2, L_3, ... L_7$ distance from the bottom of the

tube in 'm'

Pr = Prandtl Number [T_{mf}]

$T_{mf} [local] = [T_x + T_a] / 2$

T_x = Temperature at point 1 to 7.

v = Kinematic viscosity at T_{mf} in m^2/s.

ΔT = Temperature difference - $[T_x - T_a]$ in ^0K.

Nu [Local] = $h_l L_l / K$.

Where h_l = Local convective heat transfer co-efficient at point

1 to 7 in w/m^{2}K.

L_l = Characterstics dimension in m.

K = Thermal conductivity of air at T_{mf} in w/m^{2}K.

Result:

Thus the average surface heat transfer co-efficient and local heat transfer co-efficient along the length of the tube are determined and also the graph b/w local heat transfer co-efficient and the distance along the height of the tube is drawn. The results are tabulated.

Experiment local heat transfer co-efficient:

S. No.	Input [watts]	Local heat transfer co-efficient [w/m^{2}K] [experiment]							Average Surface Heat Transfer Co-efficient [w/m^{2}K]
		h_1	h_2	h_3	h_4	h_5	h_6	h_7	
1.	50	68.45	57.045	42.784	34.227	36.672	31.17	39.493	41.309

Theortical Local heat transfer co-efficient:

S. No.	Input [watts]	[Theortical]Local heat transfer co-efficient experiment [w/m^{2}K]							Average Heat Transfer Co-efficient [w/m^{2}K]
		h_1	h_2	h_3	h_4	h_5	h_6	h_7	
1.	50	9.349	6.54	5.909	5.235	4.658	4.502	4.048	3.983

VIVA QUESTIONS

1. **What is meant by free or natural convection?**

   It is fluid motion is produced due to change in density resulting from temperature gradients, the mode of heat transfer is said to be free or natural convection.

2. **Define Grashof number [Gr].**

   It is defined as the ratio of product of inertia force and buoyancy force to the square of viscous force. Gr = Inertia force x Buoyancy force / [Viscous force]^2

3. **Define Stanton number [St].**

   It is the ratio of Nusselt number to the product of Reynolds number and Prandtl number. St = Nu / Re x Pr.

4. **What is meant by Newtonion and non-newtonion fluids?**

   The fluids which obey the Newton's law of viscosity are called Newtonion fluids and those which do not obey are called no-newtonion fluids.

5. **What is meant by laminar flow ?**

   Laminar flow: Laminar flow is sometimes called stream line flow. In this type of flow, the fluid moves in layers and each fluid particle follows a smooth continuous path. The fluid particles in each layer remain in an orderly sequence without mixing with each other.

Experiment Number: 4

Title of the Experiment: Forced Convection inside Tube

Date of the Experiment:

OBJECTIVE [AIM] OF THE EXPERIMENT

To determine the heat transfer coefficient on the given Forced Convection inside tube Apparatus.

FACILITIES REQUIRED AND PROCEDURE

a] Facilities required to do the experiment:

Sl. No.	Facilities Required	Quantity
1.	Forced Convection inside tube Apparatus	1

b] Description

The experimental setup consists of a tube through which air is sent in by a blower. The test section consists of a long electrical surface heater on the tube which serves as a constant heat flux source on the flowing medium. The inlet and outlet temperatures of the flowing air are measured by thermocouples and also the temperatures at several locations along the surface heater from which on average temperature can be obtained. An orifice meter in the tube is used to measure the air flow rate with a 'U tube water manometer.

An ammeter and a voltmeter are provided to measure the power input to the heater.

A power regulator is provided to vary the power input to heater.

A multipoint digital temperature indicator is provided to measure the above thermocouples input.

A valve is provided to regulate the flow rate of air.

c] Procedure for doing the experiment:

Step No.	Details of the Step
1.	Switch on the main.
2.	Switch on the blower.
3.	Adjust the regulator to any desired power into input to heater.
4.	Adjust the position of the valve to any desired flow rate of air.
5.	Wait till steady state temperature is reached.
6.	Note manometer reading h_1 and h_2.
7.	Note temperatures along the tube. Note air inlet and outlet temperature.
8.	Note voltmeter and ammeter reading.
9.	Adjust the position of the valve and vary the flow rate of air and repeat the experiment.
10.	For various valve openings and for various power inputs the readings may be taken to repeat the experiments.

TABULATION:

S.No.	Voltage [V] [Volts]	Current [A] [Amps]	Inlet Temperature of air [T_1] [^{0}C]	Outlet Temperature of air [T_6] [^{0}C]	Temperature along the duct				Manometer reading	
					T_2 [^{0}C]	T_3 [^{0}C]	T_4 [^{0}C]	T_5 [^{0}C]	h_1 [cm]	h_2 [cm]
1	50	1	35	38	42	45	46	47	9	19

MODEL CALCULATIONS:

   EXPERIMENTAL METHOD:

   PI = V x I = 50 watts

   VI = h x A x Δt

   Δt = Average temperature of heater – Average temperature of air

   Δt = 45 – 36.5

   Δt = 8.5^{0}C

Average temperature of heater = $T_2 + T_3 + T_4 + T_5$/ 4 = 42+45+46+47 / 4 = 45^{0}C.

Average temperature of air = $T_1 + T_6$ / 2 = 35 + 33 / 2 = 36.5^{0}C.

   A = Area of heat transfer

   A = π x d x l   Diameter of tube d = 0.04m

                              Length of the tube l = 0.5m

   A = 3.14 x 0.04 x 0.5

   A = 0.0634m^2.

   VI = h x A x Δt

   50 = h X 0.0634 X 8.5

   h = 92.782 W/m^{2}C.

THEORTICAL METHOD

   Q = C_d x a_1 x a_2 $\sqrt{2gh_o}$ / $\sqrt{a_1^2 - a_2^2}$

   h_o = [$h_1 - h_2$] x [ρ_w/ρ_a] m^3/sec

           ρ_w = 1000 kg/m^3

           ρ_a = 1.16 kg/m^3.

[1] EXPERIMENTAL METHOD:

$VI = hA\Delta t$

Where,

Δt = Average temperature of heater – Average temperature of air [^{0}C].

$A = \pi dl$

A = Area of heat transfer.

d = diameter of the tube = 0.04m

l = length of the tube = 0.5m.

h = heat transfer co-efficient [W/m^2 C]

VI = Power input to heater.

[2] THEORITICAL METHOD:

$Q = C_d \times a_1 \times a_2 \sqrt{2gh_o} / \sqrt{a_1^2 - a_2^2}$ m^3/sec.

h_o = head of air causing the flow.

   = [$h_1 - h_2$] x [ρ_w/ρ_a]

ρ_w = Density of water = 1000 kg/m^3.

ρ_a = Density of air = 1.16 kg/m^3.

h_1, h_2 = Manometer reading in m.

a_1 = Area of the tube.

a_2 = Area of the orifice.

Q = Volume of air flowing through the tube.

$C_d = 0.6$

[3] VELOCITY OF AIR:

$V = Q/a$ m/sec.

[4] REYNOLDS NUMBER:

$Re = VD/\upsilon$.

V = Velocity of air

D = Dia. of the pipe.

υ = Kinematic viscosity of air.

[5] Nu = hD/K

K = Thermal conductivity of air.

$Nu = 0.023 \times Re^{0.8} \times Pr^{0.4}$

Re = Reynolds Number.

Pr = Prandtl Number.

d] Result:

Thus the experiment of the forced convection is conducted and heat transfer coefficient are calculated.

Heat Transfer Co-efficient:

Experimental value = 92.782 W/m^{2}C.

Theoretical value = 31.2395763 W/ m^{2}C.

$h_1 = 9$

$h_2 = 19$.

$h_o = [19-9]$ x $[1000/1.16]$

= 10 x 862.069 = 86.20689 m.

$C_d = 0.6$

$a_1 = \pi/4$ x $d_1{}^2$

d_1 = Dia of pipe = 40mm = 0.04m

= $\pi/4$ x $[0.04]^2$

$a_1 = 0.00125664$ m^2.

$a_2 = \pi/4$ x $d_2{}^2$

d_2 = Dia of the orifice = 20mm = 0.02m.

= $\pi/4$ x $[0.02]^2$

$a_2 = 0.00031416$m^2.

Q = 0.6 x 0.00125664 x 0.00031416 x $\sqrt{2}$ x 9.81x 86.20689 / $\sqrt{}$ $[0.00125664]^2 -$

$[0.00031416]^2$

Q = 2.3687 x 10^{-7} x 411.264/1.216 x 10^{-3}

Q = 0.008006376m^3/sec.

VELOCITY OF AIR FLOW

V = Q / a_1

= 0.008006376/0.00125664

= 6.3713m/sec.

REYNOLD'S NUMBER

Re = VD/ υ.

υ - Kinematic viscosity from HMT Data book

$\upsilon = 0.00001696$

= 6.3713 x 0.04 / 0.00001696

Re = 15027.

NUSSELT NUMBER

Nu = hD/K

Nu = 0.023 x $[15027]^{0.8}$ x $[0.698]^{0.33}$

Nu = 43.75290799.

Nu = hD/K

K - Thermal conductivity from HMT Data book

K = 0.02856.

43.75290799 = h x 0.04 / 0.02856

h = 31.2395763 W/m^{2}C.

VIVA QUESTIONS

1. **Define Convection.**

   Convection is a process of heat transfer that will occur between a solid surface and a fluid medium when they are at different temperatures.

2. **Define Reynolds number [Re].**

   It is defined as the ratio of inertia force to viscous force.

   Re = Inertia force / Viscous force

3. **Define Prandtl number [Pr].**

   It is the ratio of the momentum diffusivity to the thermal diffusivity.

   Pr = Momentum diffusivity / Thermal diffusivity

4. **Define Nusselt Number [Nu].**

   It is defined as the ratio of the heat flow by convection process under an unit temperature gradient to the heat flow rate by conduction under an unit temperature gradient through a stationary thickness [L] of metre.

   Nusselt Number [Nu] = q_{conv} /q_{cond}

5. **State Newton's law of convection.**

   Heat transfer from the moving fluid to solid surface is given by the equation.

   Q = h A = [T_w - T_∞]

   This equation is referred to as Newton's law of cooling.

   Where h = Local heat transfer coefficient in W/m^{2}K.

   A = Surface area in m^2.

   T_w = Surface [or] Wall temperature in K.

   T_∞ = Temperature of fluid in K.

6. **What is forced convection?**

   If the fluid motion is artificially created by means of an external force like a blower or fan, that type of heat transfer is known as forced convection.

7. **What are the dimensionless parameters used in forced convection?**

   1. Reynolds number [Re].
   2. Nusselt number [Nu].
   3. Prandtl number [Pr].

Experiment Number: 5

Title of the Experiment: Heat transfer from pin-fin(natural & forced convection modes)
Date of the Experiment:

OBJECTIVE [AIM] OF THE EXPERIMENT

To determine Heat transfer from pin-fin(natural & forced convection modes)

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FACILITIES REQUIRED AND PROCEDURE

a] Facilities required to do the experiment:

Sl. No.	Facilities required	Quantity
1.	Pin-fin Apparatus	1

b] Apparatus Description

The heat transfer from a heated surface to the ambient surrounding is given by the relation, q = h A ΔT. In this relation h_c is the convective heat transfer coefficient, ΔT is the temperature difference & A is the area of heat transfer. To increase q, h may be increased or surface area may by increased. In some cases it is not possible to increase the value of heat transfer coefficient & the temperature difference ΔT & 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 heat transfer rate. "This extra material attached is called the extended surface or fin."The fins may be attached on a plane surface, and then they are called plane surface fins. If the fins are attached on the cylindrical surface, they are called circumferential fins. The cross section of the fin may be circular, rectangular, triangular or parabolic.

c] Procedure for doing the experiment:

Step No.	Details of the Step
1.	Connect the equipment to electric power supply.
2.	Keep the thermocouple selector switch to zero position.
3.	Turn the Variac (dimmerstat) clockwise and adjust the power input to the heater to the desired value and switch on the blower.
4.	Set the air–flow rate to any desired value by adjusting the difference in mercury levels in the manometer and allow the unit to stabilize.
5.	Note down the temperatures, T_1 to T_6 from the thermocouple selector switch.
6.	Note down the difference in level of the manometer and repeat the experiment for different power inputs to the heater.
7.	Connect the equipment to electric power supply.
8.	Keep the thermocouple selector switch to zero position.

FORMULA:

$$\text{Thermal Expansion } (\beta) \ = \frac{d_o}{d_p} =$$

Where;

d_0 = Diameter of the Orifice; d_p = Diameter of the pipe

$$\text{Velocity of orifice } (v_o) = c_d \sqrt{\frac{2gh(\rho_m - \rho_a)}{\rho_a}} \times (1/1 - \beta)$$

Where;

ρ_m = density of manometric fluid = 13.6 x 10³ kg/m³

ρ_a = density of air = 1.17 kg/m³

V_a = Velocity of air in the duct = $\dfrac{\text{Velocity at orifice x cross sectional area of orifice}}{\text{Cross sectional area of duct}}$

$$V_a = \frac{V_0 \times (\pi d_0^2)/4}{W \times B} =$$

Where,

d_p = diameter of pipe

d_0 = diameter of orifice

W = Width of the duct

B = Breadth of duct

Average surface temperature of fin is given by

$$T_s = \frac{T_1 + T_2 + T_3 + T_4 + T_5}{5} + 273.15 = \qquad K$$

$T_\infty = T_6$ = Ambient temperature = $\qquad$ + 273.15 = $\qquad$ K

$$T_m = \text{Mean temperature} = \frac{T_s + T_\infty}{2}$$

Properties of air at _____ **⁰C**

v = $\qquad$, Pr = $\qquad$, K =

$$Re = \frac{V_a \, d_f}{v} = \qquad$$

Re = Reynolds number

Pr = Prandtl number

Nu = Nusselt number

The relationship for Nu is

$$Nu = C \, Re^n \, Pr^{1/3}$$

For   Re = 0.4 to 4.0   C = 0.989 and   n = 0.33

          Re = 4 to 40   C = 0.911 and   n = 0.385

          Re = 40 to 4000   C = 0.683 and   n = 0.466

          Re = 4000 to 40,000   C = 0.293 and   n = 0.618

          Re = 40,000 to 400,000   C = 0.27 and n = 0.805

$$h = \frac{Nu\ k}{d_f}$$

Thermal conductivity of fin material, 'K' = 110.7 W/m–K

$$m = \sqrt{\frac{h\,P}{K\,A}}$$

Temperature distribution is given by

$$\frac{T - T_\infty}{T_0 - T_\infty} = \frac{\cosh m\,(L-x)}{\cosh mL}$$

Therefore, $T = T_\infty + (T_0 - T_\infty)\dfrac{\cosh m\,(L-x)}{\cosh mL}$

Distance x, m	Temperature from Experiment °C	Temperature °C from calculation

$x_1 = 0.045$ $T_1 =$

$x_2 = 0.075$ $T_2 =$

$x_3 = 0.105$ $T_3 =$

$x_4 = 0.135$ $T_4 =$

Effectiveness of fin   = $\sqrt{\dfrac{PK}{hA}} \times \tanh mL$

Efficiency of fin = $\dfrac{\tanh mL}{mL}$

TABULATION:

TABULATION:

Sl. No.	Heat Input		Pressure drop, 'h' mm of mercury,	Temperatures, ^0C					
	V	**A**		**T₁**	**T₂**	**T₃**	**T₄**	**T₅**	**T₆**
1	61	0.27	5mm	70	62	58	56	54	40

CALCULATION:

1. $\beta = \dfrac{d_c}{d_t} = \dfrac{0.02}{0.05} = 0.4$

Thermal Expansion $\beta = 0.4$

2. Velocity of ofifice :

$$v_o = c_d \sqrt{\frac{2gh(lm-la)}{la}} \quad X(1/1-\beta)$$

$$= 0.62 \sqrt{\frac{2 \, X \, 9.81 \, X (13.6 \, X \, 10^3 - 1017) X \, 5 \, X \, 10^3}{1.17}} \quad X \quad \left(\frac{1}{1} - 0.4\right)$$

$$v_o = 27.02 \; m/s$$

.

d] Result:

Thus the heat transfer coefficient under forced convection is found out the efficiency of fin.
(i).Theoretical value of temperature of fin= 327 K
(ii).Effectiveness of fin=0.6
(iii).Efficiency of fin=40%

VIVA QUESTIONS

1. **What is fin?**

   Fins are extended surfaces used primarily to enhance the heat transfer rate between the solid fins and an adjoining fluid

2. **Define Fin effectiveness**

   $$\varepsilon_1 = \frac{\text{Fin Heat Transfer Rate}}{\text{Heat Transfer Rate Without Fin}}$$

3. **List out the Fin types.**
   1. Straight fin of uniform cross section
   2. Straight fin of non-uniform cross section
   3. Annular fin
   4. Pin fin

5. **Sketch all types of fins**

| Straight fin of uniform cross section | Straight fin of non-uniform cross section | Annular fin | Pin fin |
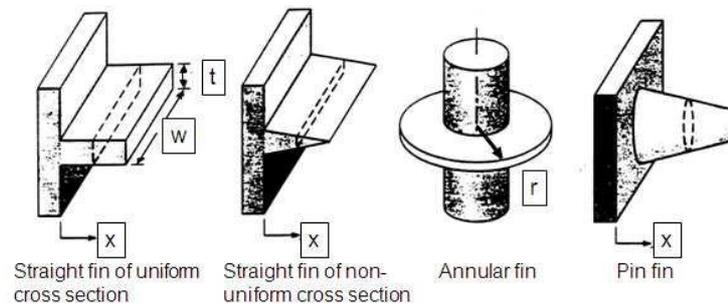
Experiment Number: 6

Title of the Experiment: Determination of stefan-boltzmann constant
Date of the Experiment:

OBJECTIVE [AIM] OF THE EXPERIMENT
To determine the value of Stefan boltzman constant for radiation heat transfer.

FACILITIES REQUIRED AND PROCEDURE

a] Facilities required to do the experiment:

Sl. No.	Facilities required	Quantity
1.	Stefan-Boltzmann constant Apparatus	1

b] Apparatus Description

The apparatus consists of a flanged copper hemisphere fixed on a flat non-conducting plate. A test disc made of copper is fixed to the plate. Thus the test disc is completely enclosed by the hemisphere. The outer surface of the hemisphere is enclosed in a vertical water jacket used to heat the hemisphere to a suitable constant temperature. Three Cr-Al thermocouples are attached at four strategic places on the surface of the hemisphere to obtain the temperatures. The disc is mounted on an ebonite rod which is fitted in a hole drilled at the center of the base plate. Another Cr-Al thermocouple is fixed to the disc to record its temperature. Fill the water in the SS water container with immersion heater kept on top of the panel.

c] Procedure for doing the experiment:

Step No.	Details of the Step
1.	Remove the test disc before starting the experiment.
2.	Heat the water in the ss containers to its boiling point .
3.	Allow the boiling water into the container kept at the bottom containing copper bemisphere units it is full .allow sufficient time to attain thermal equilibrium which is indicated by the four thermocouple provided on the hemisphere.
4.	Insert the test disc fixed on the ebonite rod sleeve completwly inside and lock it. Start the stop clock simultaneously .
5.	Note down the temperature of the test disc at an inter val of about 15 sec for about 15 to 20 minutes.
6.	Remove the test disc before starting the experiment.
7.	Heat the water in the ss containers to its boiling point .
8.	Allow the boiling water into the container kept at the bottom containing copper bemisphere units it is full .allow sufficient time to attain thermal equilibrium which is indicated by the four thermocouple provided on the hemisphere.

FORMULA:

$$E_b = \sigma T^4$$

Where, σ = Stefan Boltzman constant = 5.6697 x 10^{-8} W/ (m^2 K^4)

1. Temperature of disc v/s time to obtain the slope (dT/dt) of the line, which passes through/nearer to all points.

    dT/dt=

2. Average temperature of the hemisphere

$$T_{avg} = \frac{(T_1 + T_2 + T_3)}{3} + 273.15 = \qquad K$$

3. T_d = Temperature of the disc before inserting to test chamber ° K (ambient)=

4. Rate of change of heat capacity of the disc = m C_p (dT /dt)
    Net energy radiated on the disc = σ A_d (T^4_{avg} – T^4_d)

    Where, A_d = area of the disc = $\dfrac{\pi d^2}{4}$ m^2
    d = 20 mm
    C_p = specific heat of copper = 0.38 kJ/kg–K

    Rate of change of heat capacity of the disc = Net energy radiated on the disc

$$m\, C_p\ (dT /dt) = \sigma\, A_d\ (T^4_{avg} – T^4_d)$$

Thus 'σ' can be evaluated as shown

$$\sigma = \frac{m\, C_p\ (dT /dt)}{A_d\ (T^4_{avg} – T^4_d)} =$$

TABULATION:

Thermocouple	Temperature of the copper hemisphere
T_1	35
T_2	35
T_3	35
T_4	36

CALCULATION:

Rate of change of heat capacity of the disc = Net energy radiated on the disc

$$m \, C_p \, (dT/dt) = \sigma \, A_d \, (T^4_{avg} - T^4_d)$$

Thus 'σ' can be evaluated as shown

$$\sigma = \frac{m \, C_p \, (dT/dt)}{A_d \, (T^4_{avg} - T^4_d)} = 4.67 \times 10^{-8} \text{ W/ (m}^2 \text{ K}^4)$$

d] Result:

Thus the Stefan Boltzman constant for radiation heat transfer is found out and draw the graph.
Stefan Boltzman constant (σ) = 4.67 × 10⁻⁸ W/m²k⁴

VIVA QUESTIONS

1. **Mention Stefan boltzman contant.**

   σ = Stefan Boltzman constant = 5.6697 x 10^{-8} W/ (m² K^4)

2. **Define Stefan boltzman contant.**

   Stefan Boltzman law states that the total emissive power of a perfect black body is proportional to

   fourth power of the absolute temperature of black body surface

   $E_b = \sigma T^4$

   σ = Stefan Boltzman constant = 5.6697 x 10^{-8} W/ (m² K^4)

3. **Define Emissive power [E_b].**

   The emissive power is defined as the total amount of radiation emitted by a body per unit time
   and unit area. It is expressed in W/m^2.

4. **Define monochromatic emissive power. [$E_{b\lambda}$]**

   The energy emitted by the surface at a given length per unit time per unit area in all directions
   is known as monochromatic emissive power.

5. **What is meant by absorptivity?**

   Absorptivity is defined as the ratio between radiation absorbed and incident radiation.
   Absorptivity, α = Radiation absorbed / Incident radiation.

Experiment Number: 7

Title of the Experiment: Determination of Emissivity of a Grey Surface

Date of the Experiment:

OBJECTIVE [AIM] OF THE EXPERIMENT
To determine the emissivity of the test plate at any desired temperature.

FACILITIES REQUIRED AND PROCEDURE
a] Facilities required to do the experiment:

Sl. No.	Facilities required	Quantity
1.	Emissivity Measurement Apparatus	1

b] Apparatus Description

The experimental setup consists of two circular Al plates identical in size and is provided with heating coils at the bottom. The plates are mounted on an asbestos cement sheet and are kept in an enclosure so as to provide undisturbed natural convection surroundings.

The heat input to the heaters is varied by separate dimmerstats and is measured by a wattmeter with the help of a double pole double throw switch. The temperatures of the plates are measured by separate thermocouples which are connected diametric opposite points to get the average temperature of the places. Other thermocouples are kept in the enclosure to read the ambient temperature.

Plate 1 is blackened by a thick layer of lamp black to form the idealized black surface where as the plates 2 is the test plate whose emissivity is to be determined.

c] Procedure for doing the experiment:

Step No.	Details of the Step
1.	Switch on the power supply.
2.	Keep the thermocouple selector switch in first position.
3.	Adjust the position of the regulator to provide desired input to heater.
4.	Allow the unit to stabilize.
5.	Note down the temperature indicated by temperature indicator.
6.	Tabulate the readings and calculate.
7.	After the experiment is over turn both the energy regulators 1 and 2 to zero position.
8.	For various power input repeat the experiment.

FORMULA:

Emissivity $\varepsilon_p = \varepsilon_b[T_b^4 - T_a^4] / [T_p^4 - T_a^4]$

Where ε_b = Emissivity block body Temperature [$\varepsilon_b = 1$]

T_b = Block Body Temperature in K.

T_p = Polished Body Temperature in K.

T_a = Chamber Temperature in K.

TABULATION:

S.No.	Voltage	Current	Black Body Temperature [^{0}C]	Polished Body Temperature [^{0}C]	Chamber Temperature [^{0}C]
1	100	0.4	80	90	40

CALCULATION:

[1] Black body Temperature   [Tb] = $80^0 + 273 = 353$ K.

[2] Polished body Temperature [Tp] = $90^0 + 273 = 363$ K.

[3] Chamber Temperature [Ta] $= 40^0 + 273 = 313$ K.

EMISSIVITY:

$$\varepsilon_p = \varepsilon_b [T_b^4 - T_a^4] / [T_p^4 - T_a^4] \qquad\qquad [\varepsilon_b = 1]$$

$$= 1 \times [353^4 - 313^4] / [363^4 - 313^4]$$

$$= [1.55 \times 10^{10} - 9.59 \times 10^9] / [1.736 \times 10^{10} - 9.59 \times 10^9]$$

$$\varepsilon_p = 0.7626.$$

d] Result:

Thus the Emissivity of the test plate is determined.

Emissivity $\varepsilon_p = 0.7626.$

VIVA QUESTIONS

6. **Define Radiation.**

    The heat transfer from one body to another without any transmitting medium is known as radiation. It is an electromagnetic wave phenomenon.

7. **Define Emissivity.**

    It is defined as the ability of the surface of a body to radiate heat. It is also defined as the ratio of emissive power of any body to the emissive power of a black body of equal temperature.

    Emissivity, $\varepsilon = E / E_b$.

8. **Define Emissive power [E_b].**

    The emissive power is defined as the total amount of radiation emitted by a body per unit time and unit area. It is expressed in W/m^2.

9. **Define monochromatic emissive power. [$E_{b\lambda}$]**

    The energy emitted by the surface at a given length per unit time per unit area in all directions is known as monochromatic emissive power.

10. **What is meant by absorptivity?**

    Absorptivity is defined as the ratio between radiation absorbed and incident radiation.

    Absorptivity, α = Radiation absorbed / Incident radiation.

11. **What is meant by reflectivity?**

    Reflectivity is defined as the ratio of radiation reflected to the incident radiation.

    Reflectivity, ρ = Radiation reflected / Incident radiation.

12. **What is meant by transmissivity?**

    Transmissivity is defined as the ratio of radiation transmitted to the incident radiation.

    Transmissivity, τ = Radiation transmitted / Incident radiation.

13. **What is black body?**

    Black body is an ideal surface having the following properties.
    1. A black body absorbs all incident radiation, regardless of wav e length and direction.
    2. For a prescribed temperature and wave length, no surface can emit more energy than black body.

14. **What is meant by gray body?**

    If a body absorbs a definite percentage of incident radiation irrespective of their wave length, the body is known as gray body. The emissive power of a gray body is always less than that of the black body.

PARALLEL FLOW SIDE

HOT WATER SIDE			COLD WATER SIDE		
Flow rate [kg/s]	T_{hi} [^{0}C]	T_{ho} [^{0}C]	Flow rate [kg/s]	T_{ci} [^{0}C]	T_{co} [^{0}C]
400ml/10sec.	56	45	400ml/12sec	34	39

COUNTER FLOW SIDE

HOT WATER SIDE			COLD WATER SIDE		
Flow rate [kg/s]	T_{hi} [^{0}C]	T_{ho} [^{0}C]	Flow rate [kg/s]	T_{ci} [^{0}C]	T_{co} [^{0}C]
800ml/10sec.	82	57	800ml/15sec	35	51

CALCULATION:

PARALLEL FLOW:

LMTD = $[T_{hi} – T_{ci}]$ **-** $[T_{ho} – T_{co}]$ / ln $[T_{hi} – T_{ci}/T_{ho} – T_{co}]$

T_{ci} = Entry temperature of cold fluid [^{0}C].

T_{co} = Exit temperature of cold fluid [^{0}C].

T_{hi} = Entry temperature of hot fluid [^{0}C].

T_{ho} = Exit temperature of hot fluid [^{0}C].

= [329 – 307] – [318 – 312] / ln [(329 – 307) / (318 – 312)]

= 12.31 K.

Mass flow rate of hot water m_h = 400/10 x 10^{-6} x 1000 = 400 x 10^{-4} Kg/s.

Mass flow rate of cold water m_c = 400 / 12 x 10^{-6} x 1000 = 333.3 x 10^{-4} Kg/s.

Q_h = m_h x C_{ph} $[T_{hi} – T_{ho}]$

= 400 x 10^{-4} x 4.187 x [329 – 318]

Q_h = 1.842 KJ/sec.

Q_c = m_c x c_{pc} $[T_{co} –T_{ci}]$

= 333.3 x 10^{-4} x 4.187 [312 – 307]

Q_c = 0.698 KJ/sec.

Q_{act} = $[Q_h + Q_c]$ / 2 = [1.842 + 0.698] / 2

Q_{act} = 1.27 KJ/sec.

Overall heat transfer co-efficient

A = π x D x L

= π x 0.013 x 1.5

= 0.06123 m^2.

U = Q_{act}/A x LMTD

= 1.27 / 0.06123 x 12.31

= 1.685 W/m^{2}K.

U = Overall heat transfer co-efficient.

Experiment Number: 8

Title of the Experiment: Effectiveness Of Parallel / Counter Flow Heat Exchanger

Date of the Experiment:

OBJECTIVE [AIM] OF THE EXPERIMENT

To determine the overall heat transfer co-efficient on the given double pipe parallel flow and counter flow heat exchanger.

FACILITIES REQUIRED AND PROCEDURE

a] Facilities required to do the experiment:

Sl. No.	Facilities required	Quantity
1.	Parallel/Counter flow heat exchanger apparatus.	1

b] Theory:

A heat exchanger is defined as equipment which transfers the heat from a hot fluid to a cold fluid.

Types of Heat Exchanger

There are several types of heat exchangers which may be classified on the basis of

      I.   Nature of heat exchange process

      II.   Relative direction of fluid motion

      III.   Design and constructional features

      IV.   Physical state of fluids.

I. Nature of heat exchange process

On the basis of the nature of heat exchange process, heat exchangers are classified as

    a] Direct contact heat exchangers or Open heat exchangers

    b] Indirect contact heat exchangers.

a] Direct contact heat exchangers or Open heat exchangers

In direct contact heat exchanger, the heat exchange takes place by direct mixing of hot and cold fluids. This heat transfer is usually accompanied by mass transfer.

Examples: Cooling towers, direct contact feed heaters.

b. Indirect contact heat exchangers

In this type of heat exchangers, the transfer of heat between two fluids could be carried out by transmission through a wall which separates the two fluids.

It may be classified as

    [i] Regenerators

    [ii] Recuperators [or] Surface heat exchangers.

EFFICTIVENESS:

$\varepsilon = [1 - \exp(-U_A/C_{min} \{1 + C_{min}/C_{max}\})] / 1 + [C_{min}/C_{max}]$

$C_h = C_{pn} \times m_h = 4.187 \times 400 \times 10^{-4} = 0.167 = C_{max}$

` $C_c = C_{pc} \times m_c = 4.187 \times 333.3 \times 10^{-4} = 0.140 = C_{min}$

$= [1 - \exp(-(1.685) \times (0.6123))] / 0.140 \times [1 + 0.663]] / 1 + [0.839]$

Effictiveness $= \varepsilon = 0.52$.

COUNTER FLOW:

$\text{LMTD} = \quad [T_{hi} - T_{ci}] \quad - [T_{ho} - T_{co}] / \text{in} [T_{hi} - T_{ci}/T_{ho} - T_{co}]$

$= [355 - 324] - [330 - 308] / \text{in} [355-324/330-308]$

$= 26.24 \text{ K}.$

$Q_h = m_{ch} C_{ph} [T_{hi} - T_{ho}]$

$= 0.08 \times 4.187 [355-330]$

$Q_h = 8.374 \text{ KJ/sec}.$

$Q_c = M_c C_{pc} [T_{co} - T_{ci}]$

$= 0.053 \times 4.187 [324 - 308]$

$Q_c = 3.551 \text{ KJ/sec}.$

$Q_{act} = 8.374 + 3.551 / 2$

$= 5.962 \text{ KJ/sec}.$

Overall heat transfer co-efficient

$U = Q_{aet}/A \times \text{LMTD}$

$U = \text{Overall heat transfer co-efficient } [W/m^2 K]$

$A = \pi D L = 3.14 \times 0.013 \times 1.5$

$= 0.06213.$

$U = 5.962 / 0.06123 \times 26.24$

$= 3.543 \text{ W/m}^2 K$

EFFICTIVENESS

$\varepsilon = 1 - \exp[-U_A/C_{min} [1 + C_{min}/C_{max}]] / 1 + [C_{min}/C_{max}]$

$\varepsilon = [1 - \exp[-3.543 \times 0.06123/0.222] [1 + 0.663]] / 0.663 + 1$

$C_c = M_c C_{pc} = 0.053 \times 4.187$

$= 0.222 \text{ KJ/sec}.$

$C_h = M_h C_{ph} = 0.68 \times 4.187$

$= 0.333 \text{ KJ/sec}.$

$U = \text{Overall heat transfer co-efficient } [W/m^2 K]$

$A = \text{Area} = M^2$

$\varepsilon = 0.62\%$

 [i] Regenerators

In this type of heat exchangers, hot and cold fluids flow alternately through the same space.

Examples: IC engines, gas turbines.

[ii] Recuperators [or] Surface heat exchangers

This is the most common type of heat exchanger in which the hot and cold fluid do not come into direct contact with each other but are separated by a tube wall or a surface.

Examples: Automobile radiators, Air pre heaters, Economisers etc.

Advantages

1. Easy construction
2. More economical
3. More surface area for heat transfer.

Disadvantages

1. Less heat transfer co-efficient
2. Less generating capacity.

II. Relative direction of fluid motion

This type of heat exchangers are classified as follows

a] Parallel flow heat exchanger

b] Counter flow heat exchanger

c] Cross flow heat exchanger.

a] Parallel flow heat exchanger

In this type, hot and cold fluids move in the same direction.

b] Counter flow heat exchanger

In this type, hot and cold fluids move in parallel but opposite directions.

c] Cross flow heat exchanger

In this type, the hot and cold fluids move at right angles to each other.

III Design and constructional features

On the basis of design and constructional features, the heat exchangers are classified as follows.

a] Concentric tubes

b] Shell and tube

c] Multiple shell and tube passes

d] Compact heat exchangers.

a] Concentric tubes

In this type, two concentric pipes, each carrying one of the fluids are used as a heat exchanger. The direction of flow may be parallel or counter.

b] Shell and tube

In this type of heat exchanger, one or the fluids move through a bundle of tubes enclosed by a shell. The other fluid is forced through the shell and it moves over the outside surface of the tubes.

c] Multiple shell and tube passes

In order to increase the over all heat transfer, multiple shell and tube passes are used. In this type, the two fluids traverse the exchanger more than one time. This type of exchanger is preferred due to its low cost of manufacture, and easy to repair.

d] Compact heat exchangers

There are many special purpose heat exchangers called compact heat exchangers. They are generally employed when convective heat transfer co-efficient associated with one of the fluids is much smaller than that associated with the other fluid.

IV Physical state of fluids

Based on the physical state of fluids inside the exchanger, heat exchangers are classified as

a] Condensers

b] Evaporators.

a] Condensers

In a condenser, the condensing fluid remains at constant temperature throughout the exchanger while the temperature of the colder fluid gradually increased from inlet to outlet.

In other words, the hot fluid loses latent heat which is accepted by the cold fluid.

b] Evaporators

In a evaporator, the cold fluid remains at constant temperature while the temperature of hot fluid gradually decreases from inlet to outlet.

APPARATUS DESCRIPTION

Apparatus consists of the constrict tube heat exchanger. The hot fluid that is hot water is obtained from an electric geyser and it flows through the outer tube. The cold fluid that is cold water can be admitted at one of the ends enabling the heat exchanger to run as parallel flow apparatus [or] a counter flow apparatus. This can be done by operating the different valves can be provided.

Temperature of the fluid can be measured using thermometer. Flow rate can be measured using stopwatch and measuring clock. The outer tube is provided with adequate asbestos rope insulation to minimize the heat loss to the surroundings.

FORMULA USED:

Heat Transfer rate 'q' is calculated

Q_h = Heat transfer rate from hot water.

$Q_h = m_h \times C_{ph} [T_{hi} - T_{ho}]$

Where

m_h = Mass flow rate of hot water [Kg/s]

C_{ph} = Specific heat of hot water [KJ/KgK]

T_{hi} = Hot water inlet temperature [^{0}C]

T_{ho} = Hot water outlet temperature [^{0}C]

Q_c = Heat Transfer rate to the cold water

$Q_c = m_c \times C_{pc} [T_{co} - T_{ci}]$

Where

m_c = Mass flow rate of cold water [Kg/s]

C_{pc} = Specific heat of cold water [KJ/KgK]

T_{co} = Cod water outlet temperature [^{0}C]

T_{ci} = Cold water inlet temperature [^{0}C]

Q = [Qh + Qc] / 2

Specific heat of cold water and heat water = 4.187 KJ/KgK.

LMTD = Logarithmic Mean Temperature Difference.

FOR PARALLEL FLOW:

$$LMTD = [\Delta T]_m = [\Delta T_1 - \Delta T_o] / \ln[\Delta T_1/\Delta T_o]$$
$$= [T_{hi} - T_{ci}] \text{ - } [T_{ho} - T_{co}] / \ln [T_{hi} - Tc_i] / [T_{ho} - T_{co}]$$

FOR COUNTER FLOW:

$$[\Delta T]_m = [T_{hi} - T_{co}] - [T_{ho} - T_{ci}] / \ln [T_{hi} - T_{co}] / [T_{ho} - T_{ci}]$$

OVERALL HEAT TRANSFER CO-EFFICIENT:

$Q = UA [\Delta T]_M$

Where

Q = Heat transfer rate W

U = Overall Heat transfer co-efficient W/m^{2}K

$[\Delta T]_M$ = LMTD

A = Area = πdl

$d = 0.013$ m

$l = 1.5$ m

$U = q / A \times [\Delta T]_M$ W/m^{2}K

U = Overall heat transfer co-efficient W/m^{2}K

Q = Heat transfer rate W

A = Area m^2.

EFFICITIVENESS

$\varepsilon = 1 - \exp [-U_A/C_{min} [1+ C_{min}/C_{max}]] / 1 + [C_{min}/C_{max}]$

$C_h = C_{ph} \times m_h; C_c = C_{pc} \times m_c$

U = Overall heat transfer co-efficient [W/m^{2}K]

A = Area [m^2].

$A = \pi DL = D = 0.013$ m

$L = 1.5$ m

c] Procedure for doing the experiment:

Step No.	Details of the Step
1.	Connect the water supply at the back of the unit. The inlet water flows through the geyser and outer pipe of the heat exchanger and flows through the inner pipe of the heat exchanger and flows out.
2.	Switch on the Geyser allow the temperature to reach steady state.
3.	The constant flow rate is maintained for both hot and cold fluid.
4.	Note the inlet and outlet temperature [cold and hot water].
5.	The flow rate is measured.
6.	The experiment is repeated for different flow.

d] Result:

Thus the heat transfer experiment was conducted in a double pipe parallel flow and counter flow heat exchanger.

PARALLEL FLOW:

LMTD = 12.31 K

Heat Transfer Q = 1.27 KJ/sec.

Overall heat transfer
  co-efficient U = 1.685 W/m^{2}K

Effectiveness ε = 0.52 = 52%

COUNTER FLOW

LMTD = 26.24 K

Heat Transfer Q = 5.962 KJ/sec.

Overall heat transfer
  co-efficient U = 3.543 W/m^{2}K

Effectiveness ε = 0.62 = 62%

VIVA QUESTIONS

1. **What is heat exchanger?**

   A heat exchanger is defined as an equipment which transfers the heat from a hot fluid to a cold fluid.

2. **What is meant by Direct heat exchanger [or] open heat exchanger?**

   In direct contact heat exchanger, the heat exchange takes place by direct mixing of hot and cold fluids.

3. **What is meant by Indirect contact heat exchanger?**

   In this type of heat exchangers, the transfer of heat between two fluids could be carried out by transmission through a wall which separates the two fluids.

4. **What is meant by parallel flow heat exchanger?**

   In this type of heat exchanger, hot and cold fluids move in the same direction.

5. **What is meant by counter flow heat exchanger?**

   In this type of heat exchanger, hot and cold fluids move in parallel but opposite directions.

6. **What is meant by cross flow heat exchanger?**

   In this type of heat exchanger, hot and cold fluids move at right angles to each other.

7. **What is meant by Shell and tube heat exchanger?**

   In this type of heat exchanger, one of the fluids moves through a bundle of tubes enclosed by a shell. The other fluid is forced through the shell and it moves over the outside surface of the tubes.

8. **What is meant by LMTD?**

   We know that the temperature difference between the hot and cold fluids in the heat exchanger varies from point to point. In addition various modes of heat transfer are involved. Therefore based on concept of appropriate mean temperature difference, also called logarithmic mean temperature difference, the total heat transfer rate in the heat exchanger is expressed as

   Q = U A [ΔT]$_m$ Where, U=Overall heat transfer co-efficient [W/m^{2}K], A=Area, m^2
   [ΔT]$_m$ = Logarithmic mean temperature difference.

9. **What is meant by Effectiveness?**

   The heat exchanger effectiveness is defined as the ratio of actual heat transfer to the maximum possible heat transfer.

   Effectiveness ε = Actual heat transfer / Maximum possible heat transfer = Q / Q$_{max}$

Experiment Number: 9

Title of the Experiment: Determination of COP of a Refrigeration System
Date of the Experiment:

OBJECTIVE [AIM] OF THE EXPERIMENT

To determine the [i] Theoretical COP, [ii] Experimental COP, [iii] Carnot COP, [iv] Relative COP on a refrigeration system.

FACILITIES REQUIRED AND PROCEDURE

a] Facilities required to do the experiment:

Sl. No.	Facilities required	Quantity
1.	Refrigeration test rig.	1

b] Description

Vapour compression cycle is widely used refrigeration cycle. The main object of the trainer is to demonstrate refrigeration system with basic components and necessary controls. The practical working is demonstrated in the system and considerable amount of theoretical analysis and performance can be studied.

The trainer consists of components of a refrigeration system viz. Hermetically sealed components, evaporator, condenser, capillary tube. The condenser is air cooled type for which a condenser fans and motor has been provided. Evaporator is water immersion type which is housed in a thermally insulated calorimeter. Calorimeter is provided with a electric heater which can be used for heating the water initially to be desired temperature.

In addition to capillary tube a thermostatic expansion valve is also provided. We have to select either a capillary tube or thermostatic expansion valve at a time. A toggle switch has been provided to facilitate this selection.

A temperature indicator with six point selection switch has been provided to get the various temperature of Freon – 12 viz. Compressor suction, compressor discharge after condenser and after expansion and water temperature.

Special gauges have been provides for indicating Freon – 12 pressure at above mentioned points except for colorimeter water.

An energy meter has been provided which indicates the consumption of energy of compressor. An additional energy meter has been provided to indicate the energy consumption of water heater.

The students are advised to find out the saturation temperature of F – 12 after knowing the pressures at various points and based on the saturation temperatures study the working of refrigeration considering the cycle based on

[a] Reversed Carnot cycle,
[b] Simple vapour compression cycle.

TABULATION

S. No.	Time [s]	Energy Meter Reading For 10 Rev. in sev.	Pressure				Temperature [^{0}C]				
			P_1	P_2	P_3	P_4	T_1	T_2	T_3	T_4	T_5
1..	2.15	176	25	195	150	20	20	52	22	-12	29.5
2.	2.25	186	22.5	195	150	20	20	53	24	-14	29
3.	2.35	191	24	195	160	22	22	54	23	-13	28
4.	2.45	201	24	200	160	22	22	55	24	-15	27
5.	2.55	206	25	200	160	25	22	53	24	-17	26
6.	3.05	209	24	200	165	25	24	51	26	-19	22
7.	3.15	212	24	200	170	24	26	49	23	-21	19
8.	3.25	208	24	200	170	22	20	46	27	-20	16

Quantity of water in tank: 10 kg.
Initial temperature of water: 30^{0}C.]

Pressure in bar:
Convert all the pressures in [PSIG] to bar [multiply the value in PSIG by 0.06894 and add 1.013 to convert to bar abs.]

P_1 = 25 x 0.06894 + 1.013 = 2.736 bar.
P_2 = 195 x 0.06894 + 1.013 = 14.456 bar.
P_3 = 150 x 0.06894 + 1.013 = 11.354 bar.
P_4 = 20 x 0.06894 + 1.013 = 2.391 bar.

[1] Total Refrigerant Effect:

Q = mC$_p$ ΔT/Δt.
Q = 10 x 4.186 x [30-16] / 60 x 60
Q = 0.1627 KJ/sec.

[2] Theoretical COP. = [h$_1$ - h$_3$]/ [h$_2$ - h$_1$]

h$_1$ corresponding to P_1 and T_1 = 370 KJ/kg.
h$_2$ corresponding to P_2 and T_2 = 382 KJ/kg.
h$_3$ = h$_4$ corresponding to P_3 and T_3 = 350 KJ/kg.
Where h$_1$, h$_2$, h$_3$ are enthalpies of refrigerant taken from p-h chart.
Theoretical COP = [370 – 350] / [382 – 370]
Theoretical C.O.P. = 1.667.

The interested students can also study the saturation temperature against the actual temperatures obtained during the experimentation and thus study the actual cycle of refrigeration system.

Specification:
    [1] Compressor: Hermetically sealed compressor.
    [2] Air cooled condenser.
    [3] Expansion valve
        [a] Capillary tube.
        [b] Thermostatic Expansion valve.
    [4] Evaporator.
    [5] Rota meter: For liquid refrigerant flow rate.
    [6] Refrigerant: Freon – 12.
    [7] Energy meters for power measurement of compressor and the fans and heater.
    [8] Pressure gauges – 4 Nos. [Two for H.P. and Two for L.P.]
    [9] Temperature indicator.
    [10] Solenoid valves.
    [11] H.P. / L.P. cut out.
    [12] Ammeter.
    [13] Voltmeter.
    [14] Thermostat.

c] Procedure for doing the experiment:

Step No.	Details of the Step
1.	Switch on the main.
2.	Switch on the fan motor and then compressor motor.
3.	Allow the plant to run to reach steady conditions. Take readings for every 10 minutes to know the steady state.
4.	Observe the readings in compressor motor energy meter. Freon flow meter, pressure gauges and thermometer and record it is a tubular form.
5.	Switch off the plant after experiment is over by switching off the compressor motor first. Allow the fan motors to run for 10 minutes and then switch off.

Specimen Calculations:
    P_1 = Pressure of the Refrigerant before the compressor.
    P_2 = Pressure of the Refrigerant after the compressor.
    P_3 = Pressure of the Refrigerant before the expansion valve.
    P_4 = Pressure of the Refrigerant after the expansion valve.

Sensor Meter Reading:
    T_1 = Temperature of Refrigerant before compression.
    T_2 = Temperature of Refrigerant after compression.
    T_3 = Temperature of Refrigerant before evaporation.
    T_4 = Temperature of Refrigerant after evaporation.

[3] Experimental COP

        Time for 10 rev. of energy meter, t = 208 sec.

                t = 208 sec.

       Energy consumed by the compressor

                P = 10/t x 1/1500 x 3600 x 0.9 KW.

                 = 10/208 x 1/1500 x 3600 x 0.9

                P = 0.104 KW.

       Experimental COP = Actual Refrigeration effect / workdone

                = Q / p = 0.1627 / 0.104

       Experimental COP = 1.564.

[4] Carnot COP = T_L / [T_H - T_L]

                T_L = P_{min} = [P_1 + P_4] / 2 = [2.736 + 2.391] / 2 = 2.5635 bar.

                T_H = P_{max} = [P_2 + P_3] / 2 = [14.456 + 2.391] / 2 = 12.905 bar.

       Lowest Temperature from table.

                T_L = -12^0C = 261 K. Corresponding to P_{min}

       Highest Temperature from table.

                T_H = 56^0C = 329 K   Corresponding to P_{max}

       Carnot COP = T_L/T_H - T_L

             = 261 / [329 – 261]

             = 3.84.

[5] Relative COP   = Actual COP / Carnot COP

             = 1.564 / 3.84

             = 0.407.

Formula:

[1] Total Refrigerating effect $Q = mC_p \, \Delta T/\Delta t$.

Where, m = Mass of water in kg.

C_p = Specific heat of water = 4.186 KJ/kg.

ΔT = Temperature drop in the water.

[2] Theoretical COP = $[h_1 - h_3]/[h_2 - h_1]$

[Enthalpy is to be found out from the P-h diagram of R-12]

Where, h_1 = Enthalpy corresponding to pressure P_1 and refrigerant entering temperature at $T_1{}^0$C.

h_2 = Enthalpy corresponding to pressure P_2 and refrigerant leveling temperature at $T_2{}^0$C.

$h_4 = h_3$ = Enthalpy corresponding to pressure P_3 and refrigerant temperature after condensing at $T_3{}^0$C.

[3] Experimental COP = [Actual Refrigeration Effect/time] / Workdone.

Actual Refrigeration effect/time = $m \, C_p \, \Delta T/\Delta t$.

Where, m_w = mass of water in kg.

C_p = Specific heat of water = 4.186 KJ/kg.

ΔT = Temperature drop in the water.

Workdone = Energy consumed by the compressor motor to be found out from the energy meter.

Workdone = $(10/t) \times (3600/x) \times 0.9$.

Where, x = Energy meter constant = 1500 rev./Kw-hr.

t = Time taken in sec. for 10 revolutions of energy meter reading.

Experimental COP = $mC_p \, \Delta T/\Delta t$ / workdone.

[4] Carnot COP = $T_L / [T_H - T_L]$

$T_L = P_{min} = [P_1 + P_4] / 2;$ $T_H = P_{max} = [P_2 + P_3] / 2;$

Where, T_L = Lower temperature to be maintained in the evaporator in absolute units [^{0}K]

T_H = Higher temperature to be maintained in the condenser in absolute units [^{0}K]

[5] Relative COP. = Actual COP / Carnot COP

d] Result:

The COP of the Refrigeration system were determined and tabulated.

Theortical COP.	Experimental [Actual] COP	Carnot COP	Relative COP
1.667	1.564	3.34	0.407

VIVA QUESTIONS

1. **Power requirement of a refrigerator is_____.**

   Inversely proportional to COP.

2. **In SI units, one ton of refrigeration is equal to _____.**

   210 kJ/min.

3. **Define tons of refrigeration and COP.**

   A tonne of refrigeration is defined as the quantity of heat required to be removed from one tonne of water [1000 kg] at 0^0C to convert that into ice at 0^0C in 24 hours. In actual practice,

   1 tonne of refrigeration = 210kJ/min = 3.5kW.

4. **The capacity of a domestic refrigerator is in the range of _____.**

   1 to 3 tonne.

5. **Name four important properties of a good refrigerant.**

   1. Low boiling point.
   2. High critical temperature & pressure.
   3. Low specific heat of liquid.

6. **What is the difference between air conditioning and refrigeration?**

   Refrigeration is the process of providing and maintaining the temperature in space below atmospheric temperature.

   Air conditioning is the process of supplying sufficient volume of clean air containing a specific amount of water vapour and maintaining the predetermined atmospheric condition with in a selected enclosure.

7. **Name any four commonly used refrigerants.**

   1. Ammonia [NH_3].
   2. Carbon dioxide [CO_2].
   3. Sulphur di oxide [SO_2].
   4. Freon – 12.

8. **What are the advantages and disadvantages of air refrigeration system?**

   Advantages:
   1. The refrigerant used namely air is cheap and easily available.
   2. There is no danger of fire or toxic effects due to leakages.
   3. The weight to tonne of refrigeration ratio is less as compared to other systems.

   Disadvantages:
   1. The quantity of refrigerant used per tonne of refrigeration is high as compared to

      other system.
   2. The COP of the system is very low. Therefore running cost is high.
   3. The danger of frosting at the expander valves is more as the air contains moisture content.

9. **What is net refrigerating effect of the refrigerant?**

   Refrigerating effect is the total heat removed from the refrigerant in the evaporator.

   COP = Refrigeration effect / Work done.

   Refrigeration effect = COP x Work done.

10. **Define refrigerant.**

    Any substance capable of absorbing heat from another required substance can be used as refrigerant.

TABULATION:

S. No.	Ammeter Reading In [Amps]	Volt meter Reading In Volts	Pressure Reading in				Temperature [^{0}C]				Mano Meter Reading In [mm] [h_2-h_1]	Before Evapo-ration Inlet		After Evapor-ation Outlet	
			P_1	P_2	P_3	P_4	T_1	T_2	T_3	T_4		DBT [^{0}C]	WBT [^{0}C]	DBT [^{0}C]	WBT [^{0}C]
1.	5	200	55	280	265	65	28	120	110	36	4	38	27	32	29
2.	6	210	55	280	265	65	30	120	120	38	3.5	37	27	31	29
3.	7	190	55	280	265	65	30	120	120	38	4	37	27	31	30
4.	7	190	55	285	265	67.5	30	120	120	40	3.5	37	28	31	25

EVAPORATOR:

Length of the grill [L] = 14.8 Cm = 0.148 m.

Height of the grill [H] = 14.3 Cm = 0.143 m.

Area [A] = L x H

= 0.148 x 0.143

A = 0.0212 m^2.

MODEL CALCULATION:

AMBIENT AIR:

DBT of the ambient air [t_d] = 37^{0}C.

WBT of the ambient air [t_w] = 28^{0}C.

h_1 = 90 KJ/kg   [from psychometric chart]

CONDITION AIR:

DBT of conditioned air [t_{d1}] = 31^{0}C.

WBT of conditioned air [t_{w1}] = 25^{0}C.

h_2 = 76 KJ/kg   [from psychometric chart]

V_{s_2} = 0.89 m^3/kg.

[1] Pressure head in terms of air [h_a].

ρ_w h_w = ρ_a h_a = h_a = ρ_w h_w/ ρ_a.

Where ρ_w = Density of water [1000 kg/m^3]

h_w = Manometer reading [3.5mm = 3.5 x 10^{-3}m]

ρ_a = Density of air.

ρ_a = 1 / V_{s_2}

ρ_a = 1/0.89 = 1.123 kg/m^3.

h_a = 1000 x 3.5 10^{-3} / 1.123

h_a = 3.117 m.

Experiment Number: 10

Title of the Experiment: Experiments on Air Conditioning System
Date of the Experiment:

OBJECTIVE [AIM] OF THE EXPERIMENT

To determine the carnot COP, theoretical COP and capacity of the refrigeration and air conditioning system.

FACILITIES REQUIRED AND PROCEDURE

a] Facilities required to do the experiment:

Sl. No.	Facilities required	Quantity
1.	Air-conditioning test rig.	1

b] Introduction:

Air Conditioning for human comfort or industrial process requires certain processes to be carried out on air to vary the psychometric properties of air to requirements. These processes may involve the mixing of air streams, heating of air, cooling of the air, humidifying air, and dehumidifying air and combination of the process. All such processes are studied with the given air-condition test rig.

c] Procedure for doing the experiment:

Step No.	Details of the Step
1.	Switch on the mains.
2.	Switch on the condenser, fan and blower.
3.	Switch on the compressor and allow the unit to stabilize.
4.	Note down the following. a] Pressure P_1, P_2, P_3 and P_4 from the respective pressure gauge. b] Note the corresponding Temperatures T_1, T_2, T_3 and T_4 at the respective state points. c] Monometer readings. d] Note DBT and WBT at the inlet of the duct [before evaporation]. e] Note DBT and WBT at the outlet of the duct [after evaporation].

FORMULA:

DBT = Dry Bulb Temperature [T_d]

WBT = Wet Bulb Temperature [T_w]

[1] $h_a = \rho_w h_w / \rho_a$

ρ_w = Density of water [1000 kg/m^3].

h_w = Manometer reading.

ρ_a = Density of air [1.123 kg/m^3].

[2] V_a = Velocity of air

$V_a = \sqrt{2} \times g \times h_a$

g = acceleration due to gravity 9.81m/s^2.

[2] Velocity of air [V_a]

$$V_a = \sqrt{2} \times g \times h_a$$
$$= \sqrt{2} \times 9.81 \times 3.117$$
$$V_a = 7.82 \text{ m/s.}$$

[3] Mass of air [m_a] = $\rho_a \times A \times V_a$

$$= 1.123 \times 0.0212 \times 7.82$$
$$m_a = 0.186 \text{ kg/sec.}$$

[4] Refrigeration effect = $m_a [h_2 - h_1]$.

$$= 0.186 [90-76]$$
$$= 2.604 \text{ KJ/sec. [or] KW.}$$

[5] Capacity = Refrigeration effect / 3.5

$$= 2.604 / 3.5 \qquad \text{[1 tonne of refrigeration = 210 KJ/min. = 3.5 KW]}$$
$$= 0.744 \text{ tonne of refrigeration.}$$

[6] Carnot COP = $T_L / [T_H - T_L]$

T_L = Lower temperature to be maintained in the evaporator.

P_1 = 55 PSI = 55 x 0.07 + 1.013 = 4.863 bar.

P_4 = 67.5 PSI = 67.5 x 0.07 + 1.013 = 5.738 bar.

$$P_{min} = [P_1 + P_4] / 2$$
$$= [4.863 + 5.738] / 2$$
$$= 5.3 \text{ bar.}$$

From Table   R – 22 $T_L = 2^0C = 275$ K

T_H = Higher temperature to be maintained in the condenser.

P_2 = 285 PSI = 285 x 0.07 + 1.013 = 20.963 bar.

$P3$ = 270 PSI = 270 x 0.07 + 1.013 = 19.913 bar.

P_{max} = [$P_2 + P_3$] / 2 = [20.963 + 19.913] / 2 = 20.438 bar.

From Table Freon – 22, $T_H = 52^0C = 325$ K.

Carnot COP   = $T_L / [T_H - T_L]$

$$= 275 / [325 – 275]$$
$$= 5.5$$

Carnot COP   = 5.5.

[7] Theoretical COP

Theoretical COP = [$h_1–h_3$] / [$h_2–h_1$]

[Where h_1, h_2, h_3 are enthalpies of refrigerant taken from p-h chart.]

P_1 = 4.863 bar; T_1 = 1.112^0C; h_1 = 260 KJ/kg.

P_2 = 5.738 bar; T_2 = 48.88^0C; h_2 = 300 KJ/kg.

P_3 = 19.913 bar; T_3 = 48.88^0C; h_3 = 100 KJ/kg.

Theoretical COP = [260 – 100] / [300 – 260]

Theoretical COP = 4.

[3] Mass of air $m_a = \rho_a$ x A x V_a

ρ_a = Density of air [kg/m^3]

V_a = Velocity of air [m/s]

A = H x L

[4] Refrigeration effect = m_a [$h_2 - h_1$].

h_2 = Enthalpy of ambient air [KJ/kg.]

h_1 = Enthalpy of condition air [KJ/kg.]

[5] Capacity = Refrigeration effect /3.5

[6] Carnot COP = T_L / [$T_H - T_L$]

T_L = Lower temperature to be maintained in the evaporator in absolute unit [^{0}K].

T_H = Higher temperature to be maintained in the condenser in absolute unit [^{0}K].

[7] Theoretical COP = [h_1-h_3] / [h_2-h_1]

h_1 corresponding to P_1 and T_1.

h_2 corresponding to P_2 and T_2.

h_3 corresponding to P_3 and T_3.

[Enthalpy is to be found out from the P-h diagram of R-22]

d] Result:

Thus the experiment on the air condition system was conducted and result were tabulated.

Carnot COP	Theoretical COP	Capacity TR
5.5	4	0.744

VIVA QUESTIONS

1. **What is psychrometry?**

   Psychrometry is a study of properties of moist air.

2. **Define DPT and degree of saturation.**

   DPT [Dew point Temperature] is the temperature to which moist air is to be cooled before it starts condensing.

   Degree of saturation is the ratio of specific humidity of moist air to the specific humidity of saturated air at temperature.

3. **Degree Relative Humidity [RH] and Specific humidity.**

   RH is the ratio of the mass of water vapour [m_v] in a certain volume of moist air at a given temperature to the mass of water vapour [m_{vs}] in the same volume of saturated air at the same temperature.

   i.e., RH [or] $\varphi = m_v / m_{vs}$

   Specific humidity [ω] is the ratio of mass of water vapour [m_v] to the mass of dry air in the given volume of mixture.

   i.e., $\omega = m_v / m_a$

4. **How are air-conditioning systems classified?**

   I. Based on construction of components:

   [i] Unitary system,

   [ii] Central system,

   [iii] Package system,

   [iv] Split units.

   II. Based on fluid flow methods:

   [i] Direct expansion [DX] system,

   [ii] Chilled water [DX] system,

   [iii] Chilled water air washer system.

5. **How does humidity affect human comfort?**

   If the humidity is above a certain level, water vapour from human body moisture cannot be absorbed by the atmospheric air. It results in discomfort because of sweating.

6. **What are the various sources of heat gain of an air-conditioned space?**

   [i] Solar gain through glass panes.

   [ii] Solar gain through roof and walls.

   [iii] Heat gain from occupants.

[iv] Heat gain from appliances and lights.

[v] Duct leakage.

[vi] Infiltration.

[vii] Vapour transmission.

7. **Define bypass factor [BPF] of a coil.**

   The ratio of the amount of air which does not contact the cooling coil [amount of bypassing air] to the amount of supply air is called BPF.

   i.e., BPF = Amount of air bypassing the coil / Total amount of air passed.

8. **What factors affect by pass factor?**
   1. Pitch of fins.
   2. Number of coil tubes.
   3. Air velocity over the coil.
   4. Direction of air flow.

9. **What are the requirements of comfort a/c?**
   1. Supply of O_2 and removal of CO_2.
   2. Removal of heat of occupants.
   3. Removal of moisture of occupants.
   4. Good air distribution.
   5. Maintaining air purity.

10. **What factors affect effective temperature?**
    1. Climatic and seasonal differences.
    2. Clothing.
    3. Age and sex.
    4. Activity.
    5. Stay duration.
    6. Air velocity.

TABULATION:

S. No.	Receiver Pressure Kgf/cm^2	Speed of the compressor [RPM]	Manometer Reading		h$_1$- h$_2$ cm	V$_{actual}$ m^3/s	V$_{Theoretical}$ m^3/s	Volumetric Efficiency V$_{act}$ / V$_{theo}$ x 100%
			h$_1$ cm	h$_2$ cm				
1	2	880	10.3	8.3	2	3.58 x 10^{-3}	5.08 x 10^{-3}	70.47%
2	4	870	10.2	8.2	2	3.58 x 10^{-3}	5.02 x 10^{-3}	71.3%
3	6	850	9.9	8	1.9	3.49 x 10^{-3}	4.90 x 10^{-3}	71.22%
4	8	840	9.7	7.8	1.9	3.49 x 10^{-3}	4.85 x 10^{-3}	71.96%
5	10	830	9.5	7.7	1.8	3.39 x 10^{-3}	4.79 x 10^{-3}	70.77%

MODEL CALCULATION

[1] ACTUAL VOLUME OF AIR:

$V_{act} = C_d \times A \times \sqrt{2gH}$ m^3 / sec.

$C_d = 0.62.$ = Coefficient of discharge.

d = 20 mm.

$A = \pi/4 [20/1000]^2 = 0.000314$ m^2.

g = 9.81 m/sec^2

h = h$_1$ – h$_2$ = 10.3 – 8.3 = 2 Cm.

$H = [h \times \rho_w] / 100 \times \rho_{air}$ ρ_{air} = Density of air kg/m^3.

                                         ρ_w = Density of water kg/m^3.

    = [2 x 1000] / 100 x 1.162] ρ_w = 1000 kg/m^3.

                                           ρ_{air} = 1.162 kg/m^3.

H = 17.21.

$V_{act} = C_d \times A \times \sqrt{2gH}$ m^3 / sec.

    = 0.62 x 0.000314 x $\sqrt{2}$ x 9.81 x 17.21

V_{act} = 3.58 x 10^{-3} m3 / sec

[2] THEORTICAL VOLUME OF AIR:

$V_{theo} = 3.14 \times D^2 \times L \times N_c / 4 \times 60$

    = 3.14 x [0.07]^2 x 0.09 x 880 / 4 x 60.

                                           D = 0.07 m.

V_{theo} = 5.08 x 10^{-3} m^3/sec   L = 0.09 m.

                                           N$_c$ = 880 rpm.

[3] VOLUMETRIC EFFICIENCY:

Volumetric Efficiency $\eta_v = V_{act} / V_{theo} \times 100$

                         = [3.58 x 10^{-3}] / [5.08 x 10^{-3}] x 100

                         = 70.47%

Experiment Number: 11

Title of the Experiment: Performance test on Two stage reciprocating Air Compressor

Date of the Experiment:

OBJECTIVE [AIM] OF THE EXPERIMENT

To conduct a performance test on a two stage air compressor and determine its volumetric efficiency.

FACILITIES REQUIRED AND PROCEDURE

a] Facilities required to do the experiment:

Sl. No.	Facilities required	Quantity
1.	Two stage reciprocating air compressor.	1

b] Description

The air compressor is a two stage reciprocating type. The air is sucked from atmosphere and compressed in the first cylinder. The compressed air then passes through an inter cooler into the second stage cylinder, where it is further compressed. The compressed air then goes to a reservoir through a safety valve. This valve operates an electrical switch that shuts off the motor when the pressure exceeds the set limit.

The test unit consists of an air chamber containing an orifice plate and a U – tube manometer; the compressor and an induction motor.

Compressor Specification:

Diameter of low pressure piston = 70 mm.
Diameter of high pressure piston = 50 mm.
Stroke = 90 mm.

KC Compressor Details:

Model : DPS
S. No. 317
RPM 900

Induction Motor Details:

S. No. 1970
KW : 2.2
RPM 1440

Precautions:

1. Check oil level in the compressor crank case.
2. The orifice should never be closed, test the manometer liquid [water] will be sucked into the tank.
3. At the end of the experiment the outlet valve at the air reservoir should be opened as the compressor is to be started again at low pressure to prevent undue strain on the piston.

c] Procedure for doing the experiment:

Step No.	Details of the Step
1.	Close the outlet valve.
2.	Fill up the manometer with water up to the half level.
3.	Start the compressor and observe the pressure developing slowly.
4.	At the particular test pressure, the outlet valve is opened slowly and adjusted so that the pressure in the tank is maintained constant.
5.	Observe the following readings. [i] Speed of the compressor – Nc R.P.M. [ii] Manometer reading h_1 and h_2 cm of water. [iii] Pressure gauge reading P Kg/cm^2.

FORMULA:

Volumetric Efficiency $\eta_v = V_{act} / V_{theo}$ x 100

V_{act} = Actual volume of air compressed.

$V_{act} = C_d$ x A x $\sqrt{2gH}$ m^3 / sec.

C_d = Co-efficient of discharge of Orifice = 0.62.

A = Orifice Area [Dia. = 20 mm]

g = 9.81 m/sec^2.

h = Water head causing flow.

Theoretical Volume of air

V_{theo} = [3.14 x D^2 x L x N_c] / 4 x 60.

D = Dia. Of piston = 0.07m.

L = Stroke length = 0.09 m.

N_c = RPM of the compressor.

ρ_w = Density of water   Kg/m^3.

ρ_{air} = Density of air   Kg/m^3.

d] Result:

Thus the volumetric efficiency of the reciprocating air compressor are determined.

S. No.	Pressure [Kgf/cm^2]	Volumetric Efficiency [τ_{vol}]
1.	2	70.47%
2.	4	71.3%
3.	6	71.22%
4.	8	71.96%
5.	10	70.7%

VIVA QUESTIONS

1. **Classify the various types of air-compressors.**
   1] According to the design and principle of operation
      a] Reciprocating compressors.
      b] Rotary compressors.
   2] According to the action
      a] Single acting compressors.
      b] Double acting compressors.
   3] According to the number of stages
      a] Single stage compressors.
      b] Multistage compressors.
   4] According to the pressure limit
      a] Low pressure compressors.
      b] Medium pressure compressors.
      c] High pressure compressors.
   5] According to the capacity
      a] Low capacity compressors [Volume delivered 0.15 m^3/s or less].
      b] Medium capacity compressors [Volume delivered 0.15 m^3/s to 5m^2/s].
      c] High capacity compressors [Volume delivered is above 5 m^3/s].

2. **What is meant by single acting compressor?**
   In single acting compressor, the suction, compression and delivery of air takes place on one side of the piston.

3. **What is meant by double acting compressor?**
   In double acting reciprocating compressor, the suction, compression and delivery of air takes place on both sides of the piston.

4. **What is meant by single stage compressor?**
   In single stage compressor, the compression of air from the initial pressure to the final pressure is carried out in one cylinder only.

5. **What is meant by multistage compressor?**
   In multistage compressor, the compression of the air from the initial pressure to the final pressure is carried out in more than one cylinder.

6. **Indicate the applications of reciprocating compressors in industry.**
   The applications of compressed air are as follows:
   1. Pneumatic brakes.
   2. Pneumatic drills.
   3. Pneumatic jacks.
   4. Pneumatic lifts.
   5. Spray painting.
   6. Shop cleaning.
   7. Injecting fuel in diesel engines.
   8. Supercharging internal combustion engines.
   9. Refrigeration and air conditioning systems.

7. **Define the terms as applied to air compressors: Volumetric efficiency and isothermal compression efficiency.**
   Volumetric efficiency:
   Volumetric efficiency is defined as the ratio of volume of free air sucked into the compressor per cycle to the stroke volume of the cylinder.
   η_{Vol} = Volume of free air taken per cycle / Stroke volume of the cylinder.
   Isothermal compression efficiency:
   Isothermal efficiency is defined as the ratio between isothermal work to the actual work of the compressor.
   Isothermal efficiency, $\eta_{Isothermal}$ = Isothermal work / Actual work.
   Mechanical efficiency:
   Mechanical efficiency is defined as the ratio between brake power to the indicated power.
   Mechanical efficiency, η_{mech} = Brake power / Indicated power.

8. **Define clearance ratio.**
   Clearance ratio is defined as the ratio of clearance volume to swept volume [or] stroke volume.
   $C = V_c / V_s$
   V_c = clearance volume.
   V_s = swept volume.

9. **Define isentropic efficiency.**
   It is the ratio of the isentropic power to the brake power required to drive the compressor.
   Isentropic efficiency = Isentropic power / Actual brake power.

10. **What is compression ratio?**
    Compression ratio is defined as the ratio between total volume and clearance volume.
    Compression ratio = Total volume / Clearance volume.

Experiment Number: 12

Title of the Experiment: Thermal Conductivity of insulating powder

Date of the Experiment:

OBJECTIVE [AIM] OF THE EXPERIMENT
To determine the Thermal Conductivity of insulating powder

[a] Description

The apparatus consists of two thin walled concentric copper spheres. The inner sphere houses the heating coil. The insulating powder [Asbestos powder – Lagging Material] is packed between the two shells. The powder supply to the heating coil is by using a dimmer stat and is measured by Voltmeter and Ammeter. Choromel Alumel thermocouples are use to measure the temperatures. Temperature readings in turn enable to find out the Thermal Conductivity of the insulating powder as an isotropic material and the value of Thermal Conductivity can be determined.

Consider the transfer of heat by conduction through the wall of a hollow sphere formed by the insulating powdered layer packed between two thin copper spheres.

Let, r_i = Radius of inner sphere in meters.

r_o = Radius of outer sphere in meters.

T_i = Average Temperature of the inner sphere in ^{0}C.

T_o = Average Temperature of the outer sphere in ^{0}C.

Where, T_i = [T1+T2+T3+T4] / 4

and T_o = [T5+T6+T7+T8+T9+T10] / 6

Note that T1 to T10 denote the temperature of thermocouples [1] to [10].
From the experimental values of q, T_i and T_o the unknown thermal conductivity K cal be determined as ……

$$K = q[r_o – r_i] / 4\pi r_i \times r_o[T_i+T_o]$$

Specifications:
1. Radius of the inner copper sphere, r_i = 50 mm.
2. Radius of the outer copper sphere, r_o = 100 mm.
3. Voltmeter [0 – 100 – 200 V].
4. Ammeter [0 – 2 Amps.]
5. Temperature Indicator 0 – 300^{0}C calibrated for chromel alumel.
6. Dimmerstat 0 – 2A, 0 – 230 V.
7. Heater coil - Strip Heating Element sandwiched between mica sheets – 200 watts.

8. Chromel Alumel Thermocouples – No. [1] to [4] embedded on inner sphere to measure T_i.
9. Chromel Alumel Thermocouples – No [5] to [10] embedded on outer sphere to measure T_o.
10. Insulating Powder – Asbestos magnesia commercially available powder and packed between the two spheres.

Precautions:
1. Keep dimmerstat to zero volt position before and after the experiment. Check this before switching ON the supply.
2. Handle the changeover switch of temperature indicator gently.

b] Procedure for doing the experiment:

Step No.	Details of the Step
1.	Start main switch on control panel.
2.	Increase slowly the input to heater by the dimmerstat starting from zero volt position.
3.	Adjust input equal to 40 Watts Max. by Voltmeter and Ammeter. Wattage W = VI
4.	See that this input remains constant throughout the experiment.
5.	Wait till fairly steady state condition is reached. This can be checked by reading temperatures of thermocouples [1] to [10] and note changes in their readings with time.
6.	Note down the readings in the observations table as given below: **Observation Table:** 1. Voltmeter reading [V] = Volts. 2. Ammeter reading [I] = Amps. 3. Heater input [VI] = Watts.

INNER SPHERE:

Thermocouple No.	1	2	3	4	
	T1	T2	T3	T4	Mean Temp. T_i T_i = [T1+T2+T3+T4] / 4
Temp. ^{0}C					

OUTER SPHERE:

Thermocouple No.	5	6	7	8	9	10	
	T5	T6	T7	T8	T9	T10	Mean Temp. T_i T_i = [T5+T6+…..T10] / 6
Temp. ^{0}C							

CALCULATION:

W = V x I Watts.

T_i = Inner sphere mean temp. ^{0}C.

T_0 = Outer sphere mean temp. ^{0}C.

r_i = Radius of inner copper sphere = 50 mm.

r_o = Radius of outer copper sphere = 100 mm.

Using Equation:

q = 0.86 W Kcal/hr [In MKS units]

K = 0.86 W [r_o – r_i] / $4\pi r_i$ x r_o[T_i+T_o]

q = V x Iw/m – k [In SI units]

K = q[r_o – r_i] / $4\pi r_i$ x r_o[T_i+T_o]

d] Result:

Thus Thermal Conductivity of insulating powder is determined

VIVA QUESTIONS

1. **What are the modes of heat transfer?**

   1. Conduction

   2. Convection

   3. Radiation.

2. **What is conduction?**

   Heat conduction is a mechanism of heat transfer from a region of high temperature to a region of low temperature within a medium [solid, liquid or gases] or different medium in direct physical contact.

3. **State Fourier's law of conduction**.

   The rate of heat conduction is proportional to the area measured normal to the direction of heat flow and to the temperature gradient in that direction.

   Q α – A dT / dx

   Q = -kA dT /dx

   Where, A – Area in m^2.

   dT / dx – Temperature gradient, K/m

   k – Thermal conductivity, W/mK.

4. **Define Thermal conductivity**.

   Thermal conductivity is defined as the ability of a substance to conduct heat.

Observation Table:

S. No.	Mass Flow Rate in Kg/Min.	Temperature in Degree Centigrade T1, T2, T3, T4 .... T13
1.		
2.		
3.		
4.		
5.		

Experiment Number: 13

Title of the Experiment: Thermal Conductivity of Metal Rod

Date of the Experiment:

OBJECTIVE [AIM] OF THE EXPERIMENT
To determine the Thermal Conductivity of Metal Rod.

[a] Introduction:
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.

Table 1 lists the values of thermal conductivity for some common metal

METAL	THERMAL CONDUCTIVITY Kcal/hr – m – ^{0}C	STATE
SOLID'S Pure Copper	330	20 degree
Brass	95	-do-
Steel [0.5%C]	46	-do-
S. S.	14	-do-

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 s 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.

Apparatus:

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 shell filled with the asbestos insulating powder. The temperature of the bar is measured at eight different sections. While the radial temperature distribution is measured by separate thermocouples at two different sections in the insulating shell.

The heater is provided with a dimmerstat for controlling the heat input. Water under constant heat condition is circulated through the jacket and its flow rate and temperature rise are noted.

Specification:

1. Length of the metal bar [total]   : 410 mm.
2. Size of the metal bar [diameter]   : 25 mm.
3. Test length of the bar   : 200 mm.
4. No. of thermocouple mounted on the bar   : 9
5. No. of thermocouples in the insulation shell   : 2
6. Heater coil [Bald type]   : Nichrome
7. Water jacket diameter   : 80 mm.
8. Temperature indicator, 13 channel   : 200 Degree
9. Dimmerstat for heater coil   : 2A/230V.
10. Voltmeter 0 to 300 Volts.
11. Ammeter 0 to 2 Amps.
12. Measuring flash for water flow rate.
13. Stop clock.

Theory:

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 flowing out of bar = Heat gained by water
$Q_w = m_w \times Cp_w \times [T_{out} - T_{in}] = m_w Cp_w[\Delta T_w] = m_w[Cp_w[T_{out} - T_{in}]$

Where, m_w = Mass flow rate of the cooling water in Kg/hr.
        C_p = Specific Heat of water [Given 1]
        $T = [T_{out} - T_{in}]$ for water

Thermal Conductivity of Bar
1. Heat Conducted through the Bar [Q]
        $Q = Q_w + \{2\pi KL[T_o - T_1]\} / \{Log\ e\ [r_o/r_i]\}$

Where, Q_w = Heat conducted through water

K   = Thermal conductivity of Asbestos powder is 0.3 Kcal/hr – m – degree

r_o & r_i = Radial distance of thermocouple in insulating shell.

2. Thermal conductivity of Bar [K]

$$Q = K [dt/dx] \times A$$

Where, dt = Change in temperature [T1 – T9]

dx = Length across temperature [0.2]

A = Area of the bar [$\pi/4 \times d2$]

$\pi/4 \times [0.025]2 = 4.9 \times 10^{-4}$ m^2

b] Procedure for doing the experiment:

Step No.	Details of the Step
1.	Start the electric supply.
2.	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]
3.	Give input to the heater by slowly rotating the dimmer stat and adjust it to voltage equal to 80 V, 120 V etc.
4.	Start the cooling water supply through the jacket and adjust it about 350cc per minute.
5.	Go on checking the temperature at some specified time interval say 5 minute and continue this till a satisfactory steady state condition is reached.
6.	Note the temperature reading 1 to 13.
7.	Note the mass flow rate of water in Kg/minute and temperature rise in it.

Observations:

Mass flow rate of water [m] : Kg/min

Water inlet temperature [T12] : Degree Centigrade

Water outlet temperature [T13] : Degree Centigrade

Rod Temperature [T1 to T9] : Degree Centigrade

Radial distance of Thermocouples [r_o] : 40 mm.

Insulating shell   [r_i] : 25 mm.

Specific heat of water [Cp] : 1 Kcal/Kg^{0}K = 4.186 KJ/Kg K

Thermal conductivity of Asbestos powder [K] : 0.3 Kcal/hr-m-^{0}C

0.3 x 4.18 KJ/Kg K

Length of bar [L]   : 200 mm.

Demeter of bar [d]   : 50 mm

Area of the bar [A]   : 4.9 x 10^{-4} m^2.

Plot the temperature distribution along the length of the bar using observed values.

CALCULATIONS:

1. Heat flowing out of bar. Q bar = Q_w

   Q_w = m x Cp x [ΔTw] [Kcal/hr]

   Where, m = Mass flow rate of the cooling water in Kg/hr.

       Cp = Specific Heat of water [Given 1]

      ΔTw = [T_{out} – T_{in}] for water

2. Heat conducted through the bar [Q]

   Q = Q_w + {2πKL[T10 – T11]} / {Log e [r_o/r_i]} [Kcal / Hr]

   Where, Qw = Heat conductivity of bar [K]

       K = Thermal conductivity of Asbestos powder is 0.3 Kcal/hr-m-degree

       r_o& r_i = Radial distance of thermocouple in insulating shell.

3. Thermal conductivity of Bar [K]

       Q = K [dt/dx] x A [Kcal/Hr-m-^{0}C]

       Where, dt = Change in temperature [T1 – T9]

           dx = Length Across temperature [0.2]

           A = Area of the bar [n/4 x d2].

             n/4 x [0.025]2 = 4.9 x 10^{-4} m^2

c] Result:

Thus Thermal Conductivity of Metal Rod is determined.

VIVA QUESTIONS

1. **Define heat transfer**.

   Heat transfer can be defined as the transmission of energy from one region to another due to temperature difference.

2. **What are the modes of heat transfer?**

   1. Conduction

   2. Convection

   3. Radiation.

3. **What is conduction?**

   Heat conduction is a mechanism of heat transfer from a region of high temperature to a region of low temperature within a medium [solid, liquid or gases] or different medium in direct physical contact.

4. **State Fourier's law of conduction**.

   The rate of heat conduction is proportional to the area measured normal to the direction of heat flow and to the temperature gradient in that direction.

   $Q \alpha - A \, dT / dx$

   $Q = -kA \, dT / dx$

   Where, A – Area in m^2.

   dT / dx – Temperature gradient, K/m

   k – Thermal conductivity, W/mK.

5. **Define Thermal conductivity**.

   Thermal conductivity is defined as the ability of a substance to conduct heat.

Observation Table:

Sl. No.	Description	Set - I	Set - II
1.	Volume of water collected during test period [m^3]		
2.	Inlet temperature of water [T_1 ^0C]		
3.	Outlet temperature [T_2 ^0C]		
4.	Gas inlet temperature [T_{act} ^0C]		
5.	Duration of test period [t sec.]		
6.	Volume of gas burnt during test period [V_g lit]		
7.	Barometer reading [mm Hg]		

Experiment Number: 14

Title of the Experiment: Calorific Value Determination by Junker's Gas Calorimeter

Date of the Experiment:

OBJECTIVE [AIM] OF THE EXPERIMENT

To determine the higher calorific value of given gaseous fuel using gas calorimeter.

FACILITIES REQUIRED AND PROCEDURE

a] Facilities required to do the experiment:

Sl. No.	Facilities required	Quantity
1.	Junker's gas calorimeter	1
2.	LPG cylinder with pressure regulator	1
3.	Gas flow meter	1
4.	Measuring jar of two lit capacity	1
5.	Thermometers [0 – 100^{0}C]	3
6.	Stop watch	1

b] Theory:

The calorific value of a gaseous fuel is the total amount of energy liberated in the form of heat due to the combustion of unit volume of fuel under standard conditions. The unit of calorific value is KJ/m^3. The heat energy liberated by the controlled combustion of LPG fuel is transferred to the circulating cooling water in the calorimeter. Under steady state conditions, the heat energy liberated by burning the fuel is equal to the energy gained by the water. By calculating this, the calorific value of the fuel can be found out.

c] Description:

The instrument consists of a gas-meter, a gas pressure regulator, vertical cylindrical chamber and a burner to maintain perfect combustion. The gas first passes through the gas flow meter and then through a regulator, finally the gas is burned by the Bunsen burner. The gas is burned in a burner placed underneath of the chamber and then downward through the tubes. The tubes are surrounded by continuously flowing water which enters at the bottom and leaves at constant head to ensure uniform circulation. The flowing water absorbs the heat produced by the burning gas whose calorific value is to be determined. Water which is flowing through the calorimeter is collected and weighed.

Precaution:

1. Check the rubber hose joints at the regulator valve, gas flow meter for leak proof.
2. Keep the LPG cylinder in vertical position.

3. Ensure no gas leak.
4. Ensure proper flame in the burner.
5. Pour water in the pressure regulator till it over flows.
6. Pour water to the level marked in the flow meter.
7. Before inserting the lighted burner, ensure proper circulation of water through the calorimeter.
8. After the completion of the experiment, the water supply should be closed only after the gas supply is closed.

c] Procedure for doing the experiment:

Step No.	Details of the Step
1.	Level the calorimeter by adjusting the legs.
2.	Insert thermometers and check all the connections to ensure that there is no leakage of gas.
3.	Open the water tap and circulate water through the calorimeter and ensure that the water is flowing through the flow pipe uniform and continuous.
4.	Open the regulator on the LPG cylinder and measure the gas flow using gas flow meter. The time taken for a required volume of gas to pass the flow meter is noted.
5.	The air regulator on the Bunsen burner is adjusted to get a blue non-luminous flame.
6.	The water flow to the calorimeter is adjusted to get a temperature difference of 10^0C to 15^0C between the inlet and outlet.
7.	The water coming out of the calorimeter is collected using a measuring jar and the time taken is noted.
8.	Take all the readings after steady state conditions are reached.
9.	Repeat the experiment by altering the quantity of water and the tabulate the readings.

Specimen Calculation:

1. Volume of gas burnt per sec at STP is obtained from the following relation:
   $\{[P_{act} \text{ x } V_{act}] / T_{act}\} - \{[P_{STP} \text{ x } V_{STP}] / T_{STP}$

   Where,
   V_{STP} = Volume of gas burnt as STP [m^3/s]
   P_{act} = Actual pressure of gas [mm of Hg]
   P_{STP} = Standard atmospheric pressure [760 mm Hg]
   T_{act} = Actual room temperature [K]
   V_{act} = V_g x 10^{-3} / t [m^3/sec]
   T_{STP} = Standard atmospheric temperature [25^0C]

2. Water flow rate, [m_w] = [Volume of water collected in m^3 x density]xTime taken kg/s

3. Higher calorific value [HCV] = $\{m_w \text{ x } C_{pw} \text{ x } [T_2-T_1]\}/V_{STP}$ kJ/m^3

Where,

C_{pw} = Specific heat of water = 4.187 kJ/kg K.

$T_2 - T_1$ = difference in temperature between inlet and outlet, ^0C.

d] Result:

The average higher calorific value of give LPG gas at standard conditions =----------MJ/m^3

VIVA QUESTIONS

1. **Define Calorific Value.**

   The amount of heat released in one kg of fuel in one hour is called as calorific value. It is denoted by CV. It's unit is kJ/hr.

2. **State the types of fuels**
   1. Solid fuels
   2. Liquid fuels.
   3. Gaseous fuels.

3. **State advantages of Liquid fuels.**
   1. It has higher calorific value.
   2. It requires lesser space in use.
   3. It keeps cleanliness surroundings.
   4. It eliminates wear and tear of grate.
   5. It is easy to control of combustion.
   6. It is easy to handle and supply.

QUESTION BANK
THERMAL ENGINEERING LAB II

HEAT TRANSFER

1. Determine Thermal conductivity measurement by guarded plate method.
2. Determine Thermal conductivity of pipe insulation using lagged pipe apparatus.
3. Determine Natural convection heat transfer from a vertical cylinder.
4. Determine Forced convection inside tube.
5. Determine Heat transfer from pin-fin(natural & forced convection modes)
6. Determination of Stefan-Boltzmann constant.
7. Determination of emissivity of a gray surface.
8. Find Effectiveness of Parallel/counter flow heat exchanger.

REFRIGERATION AND AIR CONDITIONING

9. Determination of COP of a refrigeration system.
10. Determine COP on air-conditioning system.
11. Conduct Performance test on single/two stage reciprocating air compressor.

LIST OF QUESTIONS BEYOND THE SYLLUBUS

12. Determine the Thermal Conductivity of insulating powder.
13. Determine the Thermal Conductivity of metal rod.
14. Determine the higher calorific value of given gaseous fuel using gas calorimeter.