# Civinnovate

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**OBJECTIVES**

- To investigate Fourier's Law of linear conduction.

**RELEVANT THEORY AND WITH RELEVANT EQUATIONS**

Heat transfer has *direction* as well as *magnitude.* The rate of heat conduction in a specified direction is proportional to the *temperature gradient,* which is the change in temperature per unit length in that direction. Heat conduction in a medium, in general, is three-dimensional and time dependent. That is, $T$ _ $T(x, y, z, t)$ and the temperature in a medium varies with position as well as time. Heat conduction in a medium is said to be *steady* when the temperature does not vary with time, and *unsteady* or *transient* when it does. Heat conduction in a medium is said to be *one-dimensional* when conduction is significant in one dimension only and negligible in the other two dimensions, *two-dimensional* when conduction in the third dimension is negligible, and *three-dimensional* when conduction in all dimensions is significant.

Conduction is a mode of heat transfer in which energy transfer takes place from high temperature region to low temperature region when a temperature gradient exists in a body. The basic law of conduction was established by Fourier. According to Fourier's law, heat flow by conduction in a certain direction is proportional to the area normal to that direction and to the temperature gradient in that direction.

$$Q=-kA\frac{dT}{dx}$$

Where Q=transferred heat

k = thermal conductivity

A = area

$\frac{dT}{dx}$ = temperature gradient

The minus sign in the equation above shows that heat flows in the direction of decreasing temperature.

Thermal conductivity is the property of materials which shows heat conduction per unit length of material per degree of temperature difference.

Heat is conducted in solids in two ways: transport of energy by free electrons and lattice vibration. In good conductors a large number of free electrons move about in lattice structure of the material which transports heat from high temperature region to the low temperature region. The portion of the energy transported by the free electrons is larger than that by the lattice vibrations. An increase in temperature causes increase in both the lattice vibration and the speed of free electrons, but increased vibration of lattice disturbs the movement of free electrons causing reduction in the transport of energy by free electrons which means the overall conduction is reduced. In insulators and alloys, the transport of energy is mainly due to the lattice vibration and an increase in temperature increases conduction.

Conduction of heat along a simple bar

Let us consider Fourier's law of conduction for the case of a simple bar with lateral surface insulated as shown in *Fig. 1.1*.

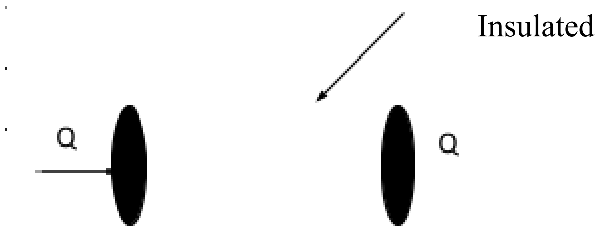



*Fig* 1.1.

*Fig* 1.2.

This is approximation of one dimensional conduction for a plane wall as shown in Fig 1.2. For steady state condition, it is assumed that the power generated by an electrical heater enters at one end and leaves from the other end uniformly. Then the thermal conductivity of the specimen can be determined as:

$$k(T) = \vec{k}(T) = \frac{Q}{A}\,\frac{\Delta x}{\Delta T} \qquad \text{w/m.K}$$

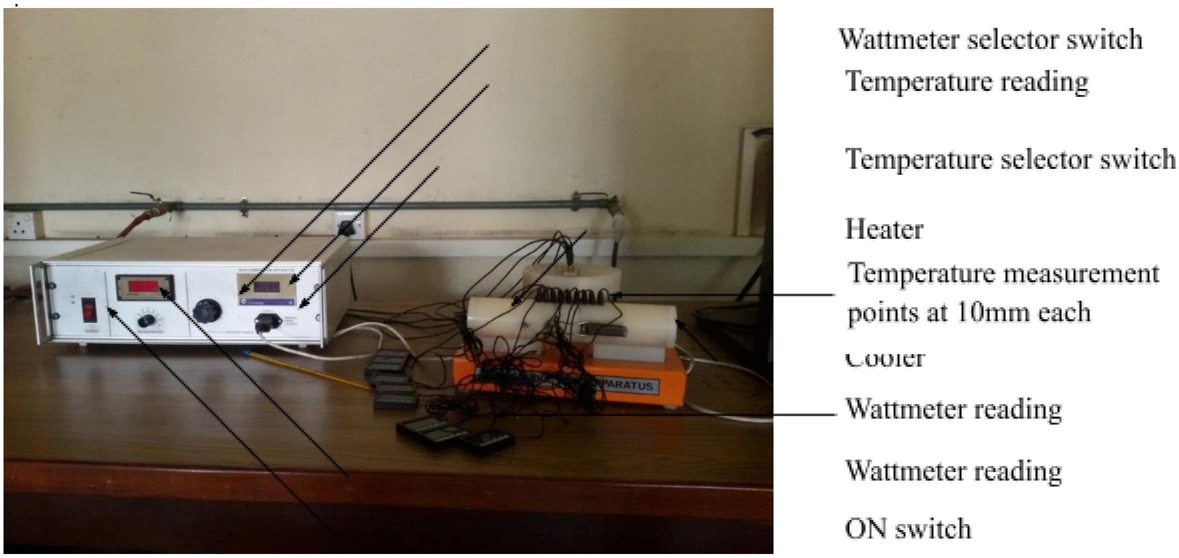
where, Q = heat power

k (T) = mean value of thermal conductivity between $T_1$ and $T_2$.

T=mean value of $T_1$ and $T_2$.

**APPARATUS USED**

Arm field Thermal Conduction apparatus.




**OBSERVATIONS**

Specimen material: Brass

Thermal conductivity of the specimen from tables:

Diameter of the specimen: 25 mm

Length of specimen: 30 mm

Distance between temperature probes: 10 mm

Observation table:

| Test no. | Wattmeter Watts, Q | $T_1$ ºC | $T_2$ ºC | $T_3$ ºC | $T_4$ ºC | $T_5$ ºC | $T_6$ ºC | $T_7$ ºC | $T_8$ ºC | $T_9$ ºC |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 40.7 | 40.1 | 36.7 | 29.4 | 26.6 | 25.8 | 19.5 | 18.7 | 18 |
| 2 | 15 | 45.4 | 44.4 | 40.3 | 31.6 | 27.5 | 20.7 | 19.5 | 18.5 | 17.6 |
| 3 | 20 | 52.3 | 51.2 | 46.3 | 34.5 | 29.5 | 28.5 | 20.7 | 18.7 | 18 |

**CALCULATIONS**

Area of cross section (A) = $\frac{1}{4}\pi D^2$

$= \frac{1}{4}\pi \times (25\times 10^{-3})^2 \quad = 4.91\times 10^{-4}$ m^2

For Q= 10

| SN. | Δx(m) | ΔT(K) | k=Q*Δx/(ΔT*A) |
|---|---|---|---|
| 1 | 0.1 | 1.2 | 107.06 |
| 2 | 0.1 | 4.7 | 43.42 |
| 3 | 0.1 | 11.8 | 17.14 |
| 4 | 0.1 | 5.0 | 40.8 |
| 5 | 0.1 | 1.1 | 185.52 |
| 6 | 0.1 | 7.8 | 26.16 |
| 7 | 0.1 | 1.9 | 107.41 |
| 8 | 0.1 | 0.8 | 255.1 |

k(avg)= 105.70

For Q= 15

| SN. | Δx(m) | ΔT(K) | k= Q*Δx/(ΔT*A) |
|---|---|---|---|
| 1 | 0.1 | 1.0 | 306.12 |
| 2 | 0.1 | 3.9 | 78.5 |
| 3 | 0.1 | 9 | 34.01 |
| 4 | 0.1 | 4 | 76.53 |
| 5 | 0.1 | 0.8 | 382.65 |
| 6 | 0.1 | 7.3 | 41.5 |
| 7 | 0.1 | 0.8 | 382.65 |
| 8 | 0.1 | 0.9 | 340.1 |

k(avg)= 205.3

For Q=20

| SN. | Δx(m) | ΔT(K) | k= Q*Δx/(ΔT*A) |
|---|---|---|---|
| 1 | 0.1 | 0.9 | 453.5 |
| 2 | 0.1 | 3.0 | 136.0 |
| 3 | 0.1 | 7.3 | 55.9 |
| 4 | 0.1 | 2.6 | 156.98 |
| 5 | 0.1 | 1.3 | 313.98 |
| 6 | 0.1 | 5.6 | 72.88 |
| 7 | 0.1 | 1.1 | 317.15 |
| 8 | 0.1 | 0.7 | 583.09 |

k(avg)= 267.93

therefore,

Thermal conductivity of material (k)= (105.7+205.3+267.92)/3 =192.97 W/mK

## RESULTS AND ANALYSIS

Arm field Thermal Conduction Apparatus was used during this experiment. In the apparatus the specimen material used was brass with 9 temperature probes having each temperature probes at a distance of 10mm. On different power input, we found out the temperature of the brass rod on different point and calculate the temperature gradient of the rod in order to find the thermal conductivity of the rod. From the calculation we found two different value of thermal conductivity at different power input as per 192.97 $Wm^{-1}K^{-1}$ .

But we know that the thermal conductivity of the substance depends only on its material and for Brass it should be constant for a given power input. The standard value of thermal conductivity as published is 109 $Wm^{-1}K^{-1.}$ The fluctuation in the conductivity might be because of the insufficient cooling system. It might be because of the malfunctioning of the temperature probes or due to errors in the procedure. However, the mean thermal conductivity from the three calculated value was found to be 192.97 $Wm^{-1}K^{-1}$. We also found that heat that flows in certain direction by conduction is directly proportional to the cross sectional area normal to that direction and the temperature gradient in that direction. The Temperature vs Length graph is shown below.

## CONCLUSION

From the experiment, it was found that the heat that flow through the conducting rod is directly proportional to the cross sectional area normal to the direction of flow of heat and temperature gradient. Hence, Fourier's law of linear conduction was verified. And the value of thermal conductivity calculated is 192.97$Wm^{-1}K^{-1}$.

## SAFETY CONSIDERATIONS

1. Temperature should not exceed 100ºC in linear conduction apparatus.
2. After finishing the experiment, the specimen should be removed from the linear conduction apparatus, which may be hot, so should be careful to handle.
3. A continuous flow of cooling water is necessary for the experiment, otherwise the apparatus may get damaged.

## OBJECTIVES

1. To determine power input, power output as well as coefficient of performance of heat pump.
2. To draw the actual vapor compression refrigeration cycle and compare it with ideal cycle.

## RELEVANT THEORY

According to the second law of thermodynamics, heat cannot spontaneously flow from a colder location to a hotter area; work is required to achieve this. Heat pumps and refrigerators are the examples of machines which transfer heat from a low to high region temperature by consuming energy.

Vapor compression refrigeration cycle can be used in countless industrial, commercial and domestic situations throughout the world. The vapor compression cycle may equally be utilized to upgrade heat flow from low grade source such as the atmosphere, a river or the soil so that it may be discharged at a more useful higher temperature for some applications or to increase temperature of specified area.

Heat pump is a device that transfers the heat from low temperature reservoir to the high temperature reservoir to the high temperature reservoir in order to maintain the temperature of a specified space higher than the surroundings by consuming energy.

Refrigerator is a device that transfers the heat from the low temperature reservoir to the high temperature reservoir in order to maintain the temperature of a specified space lower than surroundings by consuming energy.

The ideal vapor compression cycle is represented below in which heat is taken from a constant low temperature source and is rejected to a constant higher temperature sink.

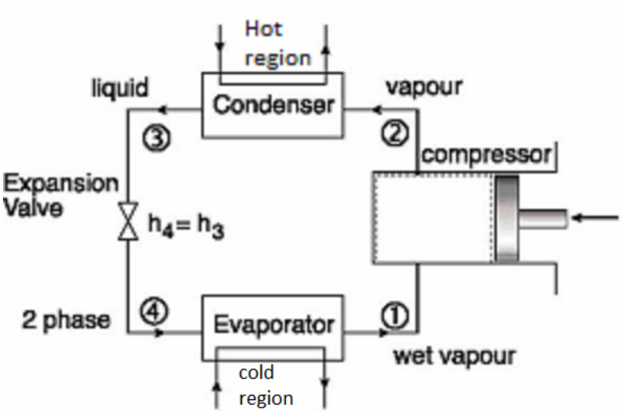



Figure 1: vapor compression refrigeration cycle

Above figure provides a schematic diagram of the components of a typical vapor - compression refrigeration system.

The absorbtion of low grade heat in either the air or water source evaporator generates HFC134a vapor which is drawn into compressor. This extraction of heat from air or water reduces the temperature of the air or water flow leaving the unit. There is increase in the pressure and temperature of the refrigerant vapor because work is done on the gas by the compressor. This hot high pressure gas flows to a concentric tube water cooled condenser.

A large volume into which excess refrigerant can flow during certain operating conditions is given by a liquid receiver as well as it ensures that the liquid is always available for changes in demand due to evaporator loading. The compressor motor has winding resistance losses, internal friction and the compression process is not isentropic. All of these conditions result in some of the electrical energy input being converted into heat. The compressor and motor are contained within thermetically sealed steel casing and run in oil which during normal operation is warmed by circulation around the casing and collects at the base of the unit. Some oil will be carried out and might even appear in the variable area flow meter as a discoloration to the flow. It is a normal thing to happen and will vanish during normal running process.

Through a panel mounted flow meter to a thermostatically controlled expansion valve, sub - cooled liquid HFC134a at high pressure is passed. The HFC134a is eco friendly gas. On passing through the valve, the pressure is reduced to that of evaporator and two phase mixture of liquid and vapor begins to evaporate within the selected evaporator.

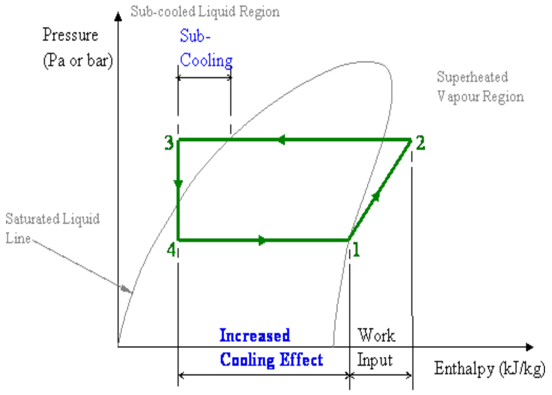
As the compressor is specifically designed for heat pump a copper heat transfer coil is located at the base of the compressor within the oil reservoir. By passing the cold water from the mains supply through this coil before the water is transferred to the condenser the normally waste heat from the oil can be added to that given up to the condenser.

Sub-cooled liquid HFC134a at high pressure passes through a panel mounted flow meter to a thermostatically controlled expansion valve. On passing through the valve the pressure is reduced to that of the evaporator and the two phases mixture of liquid and vapor begins to evaporate within the elected evaporator.

Control of heat pump is by variation of the condensing temperature by the source air(or water) temperature and flow rate,and by variation of the condensing temperature b the flow rate of the condenser water.The range of the source temperature can be extended directing warmed air from a fan heater at the air intake or warmed or chilled water to the source water inlet.

Relevant system temperatures are recorded by thermocouples and a panel mounted digital temperature indicator. The thermocouples used are type K (Nickel-chrome, Nickel-Aluminum).Condenser and evaporator pressures are indicated by panel mounted pressure gauges. Water and refrigerant flow rates are indicated by panel mounted variable area flow meters.

The efficiency of a heat pump is given by a parameter called the coefficient of performance (COP).




p-H Diagram of Refrigeration Cycle
with Sub-Cooling

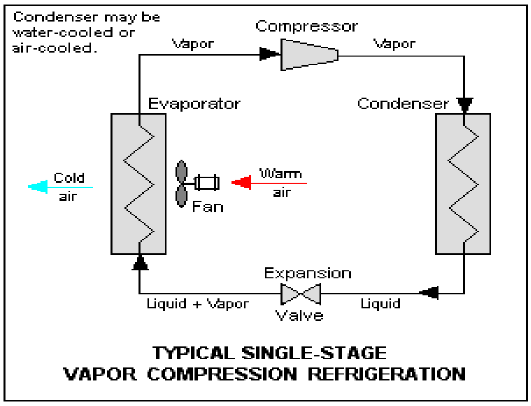



Figure 2: graph of pressure vs enthalpy

The cycle is as follows, saturated vapor at state1 and at low pressure is compressed isentropically to high pressure. Superheated vapor at state2 is passed into a condenser and heat is rejected at constant pressure to a cooling medium so that the vapor condenses and becomes saturated liquid at state 4. The high pressure saturated liquid is throttled and the resulting very wet vapor is passed into an evaporator at state 6.In the evaporator the vapor evaporates at a low temperature taking in heat from the low temperature heat reservoir and reaches state 1. The cycle now repeats.

The practical cycle differs from the idealized cycle in the following ways:

a) Due to friction, there will be a small pressure drop between the compressor discharge and expansion valve inlet, and between the expansion valve outlet and the compressor suction.
b) The compression process is neither adiabatic nor reversible. (There will usually be a heat loss from the compressor and, obviously, there are frictional effects.)
c) The vapor leaving the evaporator is usually superheated. (This makes possible automatic control of the expansion valve and prevents compressor damage by ensuring no liquid enters the suction valve.)
d) The liquid leaving the condenser is usually slightly sub-cooled, i.e., it is reduced below saturation temperature corresponding with its pressure. (This improves the

COP and reduces the possibility of the formation of vapor due to the pressure drop in the pipe leading to the expansion valve.)

e) There may be small heat inputs or losses to and from the surroundings to all parts of the circuit depending upon their temperature relative to the surrounding. The net effect of these "losses" or irreversibility on the cycle diagram is shown below.

APPARATUS USED FOR EXPERIMENT

Name of apparatus: Air and water heat pump

Maker: P.A. Hilton Ltd.           Model: R831

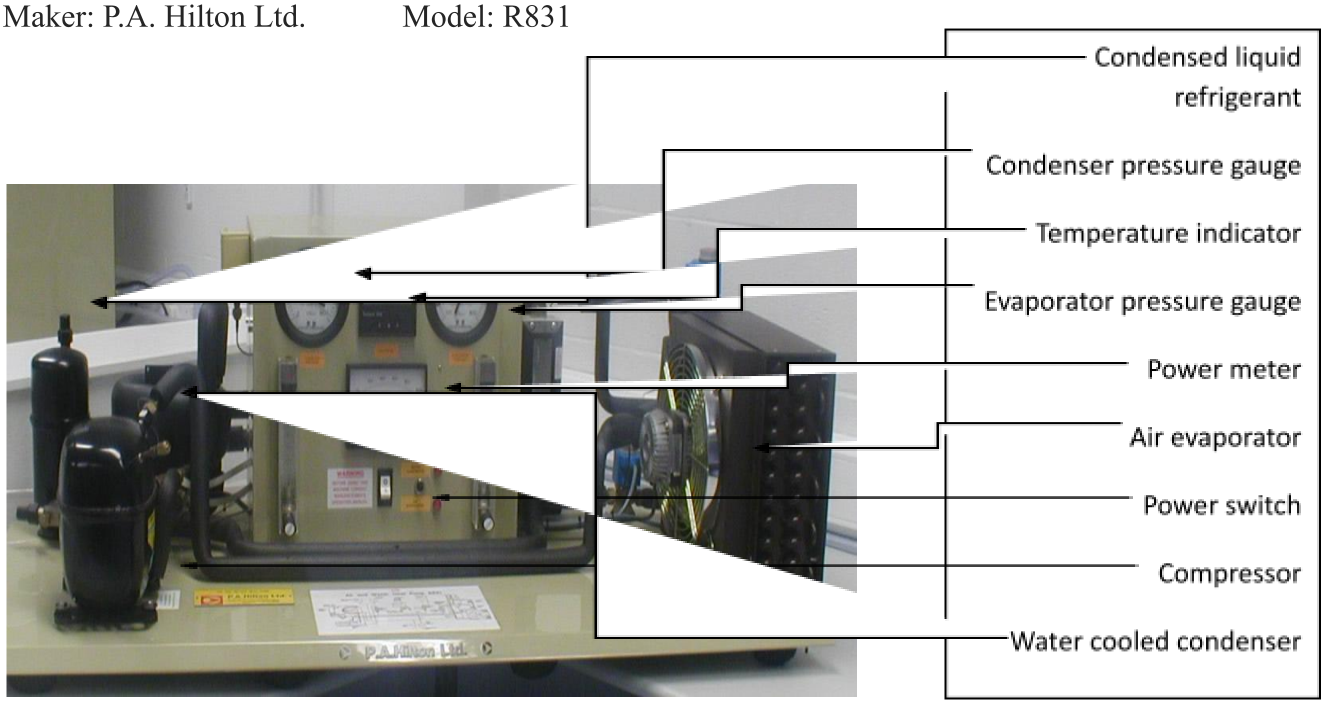



Figure: Air and water heat pump

RELEVANT EQUATIONS

The COP of a heat pump is given by the following equation:

$COP_{HP}$ = Desired Output/Required Input = Heating Effect/Work Input = $Q_H/W$

So,for an ideal heat pump:

$COP_{HP} = T_H/ (T_H-T_L)$

$Q_{comp}= m_cC_{pw}(t_6-t_5)$

$Q_c= m_cC_{pw}(t_7-t_6)$

$COP_{HP}$= Rate of heat delivered/compressor electrical power input

If the heat delivered to the condenser only is considered, then

$COP_{HP}=Q_c/W$

If the total heat delivered to the water is considered, i.e., including the waste heat from the compressor cooling coil, then

$COP_{HP}=(Q_c+Q_{comp})/W$

Where,

$COP_R$= Coefficient of performance of Refrigerator

$COP_{HP}$= Coefficient of person of Heat Pump
$Q_{comp}$= Heat delivered to cooling water from compressor
$Q_c$= Heat delivered to condenser cooling water
$C_{pw}$= Specific heat of water (4.18 kJ/kg°C)

OBSERVATIONS

Table no 1: For source of low grade heat: Air evaporator

| S.NO | PARTICULARS | UNITS | |
|---|---|---|---|
| 1 | Compressor electrical power input(W) | Watts | 380 |
| 2 | Cooling water inlet temperature($t_5$) | °C | 16 |
| 3 | Compressor cooling water outlet temperature($t_6$) | °C | 18 |
| 4 | Condenser water outlet temperature ($t_7$) | °C | 20 |
| 5 | Condenser water mass flow rate($m_c$) | $g/s_2$ | 40 |

Table no 2: For source of low grade heat: Water evaporator

| S.NO | PARTICULARS | UNIT S | |
|---|---|---|---|
| 1 | Compressor electrical power input(W) | Watts | 400 |
| 2 | Cooling water inlet temperature($t_5$) | °C | 16 |
| 3 | Compressor cooling water outlet temperature($t_6$) | °C | 19 |
| 4 | Condenser water outlet temperature ($t_7$) | °C | 22 |
| 5 | Condenser water mass flow rate($m_c$) | $g/s_2$ | 25 |

Table 3:

| S.NO | PARTICULARS | UNITS | |
|---|---|---|---|
| 1 | HFC134a gauge pressure at compressor suction($p_1$) | $kN/m^2$ | 180 |
| 2 | HFC134a absolute pressure at compressor suction($p_1$) | $kN/m^2$ | 285 |
| 3 | HFC134a gauge pressure at compressor discharge($p_2$) | $kN/m^2$ | 800 |
| 4 | HFC134a absolute pressure at compressor discharge($p_2$) | $kN/m^2$ | 905 |

| | | | |
|---|---|---|---|
| 5 | HFC134a temperature at compressor suction($t_1$) | ºC | 11 |
| 6 | HFC134a temperature at compressor discharge ($t_2$) | ºC | 39 |
| 7 | HFC134a temperature condensed liquid ($t_3$) | ºC | 21 |
| 8 | HFC134a temperature at expansion valve outlet ($t_4$) | ºC | 11 |

CALCULATION

For Air Evaporator

$Q_{comp}=m_c.C_{pw}(t_6-t_5) = 40\times10^{-3}\times4180\times(18-16)=334.4W$

$Q_c=m_c.C_{pw}(t_7-t_6) = 40\times10^{-3}\times4180\times(20-18)=334.4W$

When heat from both the compressor and condenser are considered,

$$COP_{HP} = \frac{Qcomp.+Qc.}{W} = \frac{334.4+334.4}{380} = 1.76$$

If heat is delivered to condenser only

$$COP_{HP} = \frac{Qc}{W} = \frac{334.4}{380} = 0.88$$

For water evaporator

$Q_{comp.} = m.C_p.(t_6–t_5) = 25\times10^{-3}\times4180\times(19-16) = 313.5W$

$Q_{c.} = m.C_p.(t_7–t_6) = 25\times10^{-3}\times4180\times(22-19) = 313.5 W$

When heat from both the compressor and condenser are considered,

$$COP_{HP} = \frac{Qcomp.+Qc..}{W} = \frac{313.5+313.5}{400} = 1.5675$$

If heat is delivered to condenser only

$COP_{HP} = \frac{Qc}{W} = \frac{313.5}{400} = 0.784$

RESULTS AND ANALYSIS

From the experiment the coefficient of performance of air evaporator was found to be 1.76 and the coefficient of performance of water evaporator was found to be 1.5675. COP or coefficient of performance is a measure of the efficiency of the heat pump. The heat pump used in the experiment had a COP greater than 1. For air source, it was 1.76 which means at this condition, 1.76 kJ of heat energy can be extracted from the system air with the input of 1 kJ of work. Similarly for water source, it was 1.5675 which means at this condition, 1.5675 kJ of heat energy can be extracted from the system water with the input of 1 kJ of work. From the experiment we found out that the value of COP of any thermodynamic cycle ranges from 0 to any higher value. We also came to know that the practical vapor cycle differs from the idealized cycle because in idealized we don't take account of frictional pressure drop in the system, slight internal irreversibility during the compression of the refrigerant vapor, or non-ideal gas behavior (if any).

CONCLUSION AND OBJECTIVE FULFILLED

From this experiment on heat pump and refrigerant, we get familiar with the practical vapor compression cycle. We learnt to draw the p-h diagram. We know the working principle of heat engines. We studied the temperature of compressor inlet, outlet and the condenser outlet temperature and hence calculated the power input, heat output and COP. From above experimental data and calculations, it is clear that for greater amount of work or highest performance by heat pump, we have to use water evaporator rather than air. Water evaporator is more efficient than air evaporator. Similarly we got conclusion that there are several reasons to make difference between actual vapor compression cycle and ideal vapor compression cycle. The system should be ensured to be stable while taking data. Extreme high pressure should be controlled otherwise system may crash. Electrical panel should be grounded in order to control risks of possible accidents.

**Title:**

Vapor Compression Refrigeration Cycle

**Objective:**

1. To get introduced with practical vapor compression cycle.
2. To determine power input, heat output and CoP.

**Working Formula:**

**Observation Table:**

Table I:

| | | |
|---|---|---|
| HFC134a,gauge pressure at compressor suction | $P_1$,kn/m$^2$ | 200 |
| HFC134a, Absolute pressure at compressor suction | $P_1$,kn/m$^2$ | 300 |
| HFC134a,gauge pressure at compressor discharge | $P_2$,kn/m$^2$ | 800 |
| HFC134a absolute pressure at compressor suction | $P_2$,kn/m$^2$ | 900 |
| HFC134a,temperature at compressor suction | $T_{1,}$ degree Celsius | 12 |
| HFC134a, temperature at compressor discharge | $T_{2,}$ degree Celsius | 43 |
| HFC134a,temperature of condensed liquid | $T_{3,}$ degree Celsius | 23 |
| HFC134a,temperature at expansion valve outlet | $T_{4,}$ degree Celsius | 9 |

Table II:

**For air Evaporator**

| | | |
|---|---|---|
| Compressor Electrical Power input | W, watts | 390 |
| Compressor cooling water inlet temperature | $T_{5,}$ degree Celsius | 15 |
| Compressor cooling outlet temperature | $T_{6,}$ degree Celsius | 17 |
| Condenser water outlet temperature | $T_{7,}$ degree Celsius | 20 |
| Condenser water mass flow rate | M , g/s | 37 |

**For water evaporator:**

| | | |
|---|---|---|
| Compressor Electrical Power input | W, watts | 400 |
| Compressor cooling water inlet temperature | $T_{5,}$ degree Celsius | 15 |
| Compressor cooling outlet temperature | $T_{6,}$ degree Celsius | 18 |
| Condenser water outlet temperature | $T_{7,}$ degree Celsius | 20 |
| Condenser water mass flow rate | M , g/s | 37 |

**Calculations**

**For air evaporator (air heat pump)**

$Q_{comp.} = m.C_p.\ \Delta t_{comp}$

where, $\Delta t_{comp}$ = temperature difference of water entering and leaving compressor

$= t_6 – t_5 = 17\text{-}15 = 2$ K

$C_p$ = specific heat of water in J/kgK

m = rate of mass flow of water in kg/sec

$\therefore Q_{comp.} = 37\times10^{-3}\times4200\times2 = 310.8$ W

$Q_{cond.} = m.C_p.\ \Delta t_{cond.}$

where, $\Delta t_{cond.}$ = temperature difference of water entering and leaving condenser

$= t_7 – t_6 = 20\text{-}17 = 3$ K

$\therefore Q_{cond.} = 37\times10^{-3}\times4200\times3 = 466.2$ W

Thus, when heat from both the compressor and condenser are considered,

$CoP_{HP} = \frac{Qcomp.+Qcond..}{W} = \frac{310.8+466.2}{390} = 1.99$

If heat is delivered to condenser only

$CoP_{HP} = \frac{Qcomd.}{W} = \frac{466.2}{390} = 1.19$

**For water evaporator (refrigerator)**

$Q_{comp.} = m.C_p.(t_6 – t_5) = 37\times10^{-3}\times4200\times(18\text{-}15) = 466.2$ W

$Q_{cond.} = m.C_p.(t_7 – t_6) = 37\times10^{-3}\times4200\times(20\text{-}18) = 310.8$ W

When heat from both the compressor and condenser are considered,

$$\text{CoP}_{\text{HP}} = \frac{Qcomp.+Qcond..}{W} = \frac{310.8+466.2}{400} = 1.94$$

If heat is delivered to condenser only

$$\text{CoP}_{\text{HP}} = \frac{Qcond.}{W} = \frac{310.8}{400} = 0.77$$

When heat from both the compressor and condenser are considered,

$$\text{CoP}_{\text{ref}} = \frac{Q_{comp.}+Q_{cond.}}{W} = \frac{310.8+466.2}{400} = 1.94$$

**Analysis**:

From the experiment we found out that the value of Cop of any thermodynamic cycle ranges from 0 to any higher value. From the experiment we found out that the actual coefficient of performance of heat pump and that of refrigerator were 1.19 and 0.77. The theoretical difference between the $(\text{CoP})_{\text{HP and}}$ $(\text{CoP})_{\text{Ref.}}$ is 1 but in lab from the experiment it was found to be 0.42. It is not due to the calculation error but due to the improper data reading, malfunctioning of the device or due to other some reasons.Ideal refrigeration cycle is represented by the reversed Carnot cycle in which heat is taken from a constant low temperature source and is rejected to a constant higher temperature as shown in figure:-

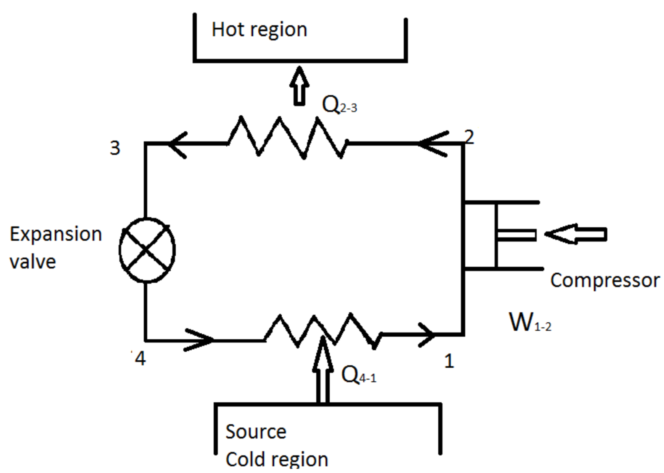


Fig: idealized vapor compression cycle

The heat pump and refrigerator work on the same principle. The only difference is the source and the sink. In a heat pump external work is applied to the system and heat is delivered to the sink at higher temperature while in case of refrigeration system, external work is applied to the system and heat is taken from low temperature source.

**Conclusion:**

From this experiment on heat pump and refrigerant, we get familiar with the practical vapor compression cycle. We learnt to draw the p-h diagram. We know the working principle of heat engines. We studied the temperature of compressor inlet, outlet and the condenser outlet temperature and hence calculated the power input, heat output and CoP.

**Title:**

Conduction of Heat

**Objective:**

1. To investigate Fourier's law of linear conduction.
2. To investigate the temperature profile and heat transfer in radial direction of a cylinder
3. To study the effect of change in cross sectional area on the temperature profile.
4. To investigate conduction along a composite bar and evaluate the overall heat transfer coefficient.
5. To investigate the effect of insulation upon conduction of heat between adjacent metals.

**Calculation:**

Distance between each temperature probes= 10mm

Diameter of specimen (D) = 25mm= 25 ×10-3m

Area of cross section (A) = $\frac{1}{4}\pi D^2$

$= \frac{1}{4}\pi \times (25\times 10^{-3})^2$

$=4.91\times 10^{-4} m^2$

**Observation table:-**

| Test No. | Wattmeter watts, Q | $T_1$ °c | $T_2$ °c | $T_3$ °c | $T_4$ °c | $T_5$ °c | $T_6$ °c | $T_7$ °c | $T_8$ °c | $T_9$ °c |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 55.4 | ---- | 54.3 | 30.2 | ---- | 28.6 | 22.5 | 21.5 | 20.9 |
| 2 | 15 | 55.6 | ---- | 55 | 36.4 | ---- | 34.2 | 22.7 | 21.7 | 21.1 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 20 | 57.3 | ---- | 57.0 | 37.0 | ---- | 35.0 | 22.9 | 21.9 | 21.5 |

For Heater power (Q =10 watts)

$$\frac{dT}{dx} = \frac{T_9 - T_1}{8\times10^{-2}} = 431.25 \text{ Km}^{-1}$$

$$\therefore K = \frac{Q}{A\frac{dT}{dx}} = \frac{10}{4.9\times10^{-4}\times431.25} = 47.32 \text{ Wm}^{-1}\text{K}^{-1}$$

For Heater power (Q =15 watts)

$$\frac{dT}{dx} = \frac{T_9 - T_1}{8\times10^{-2}} = 418.75 \text{ Km}^{-1}$$

$$\therefore K = \frac{Q}{A\frac{dT}{dx}} = \frac{15}{4.9\times10^{-4}\times418.75} = 73.1 \text{ Wm}^{-1}\text{K}^{-1}$$

For Heater power (Q =20 watts)

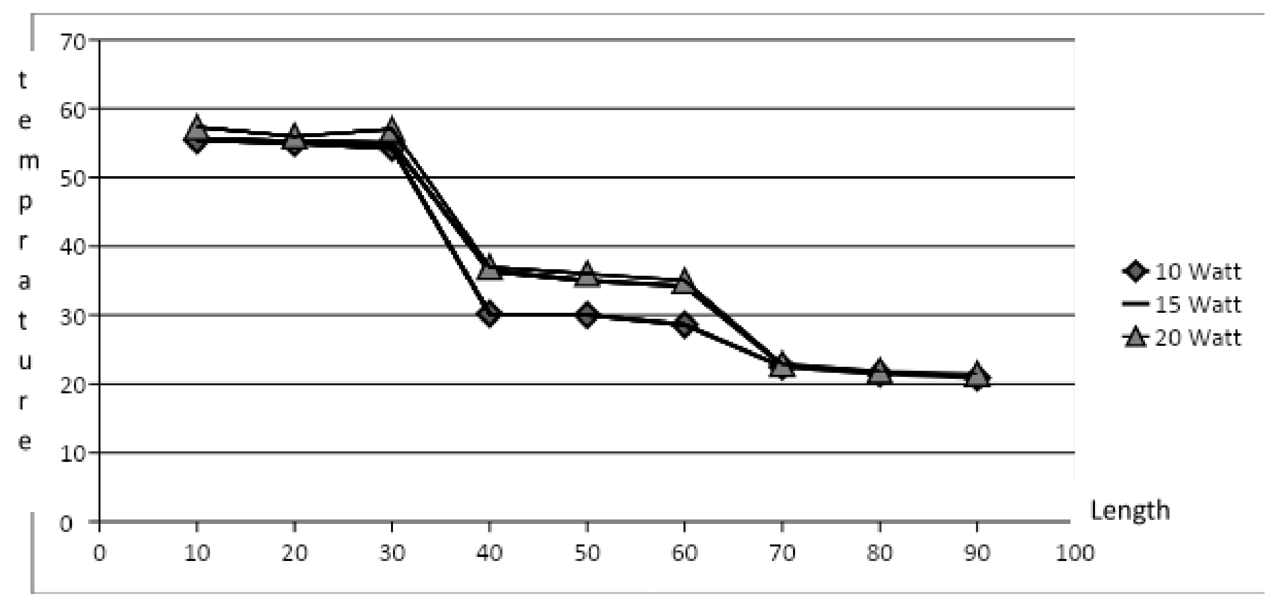
$$\frac{dT}{dx} = \frac{T_9 - T_1}{8*10^{-2}} = 447.5 \text{ Km}^{-1}$$

$$\therefore K = \frac{Q}{A\frac{dT}{dx}} = 91.2 \text{ Wm}^{-1}\text{K}^{-1}$$

$K_{mean} = 70.54 \text{ Wm}^{-1}\text{K}^{-1}$

**Analysis:**

In this experiment, we use an Armfield Thermal Conduction Apparatus. In the apparatus the specimen material used was brass with 9 temperature probes having each temperature probes at a distance of 10mm. On different power input, we found out the the temperature of the brass rod on different point and calculate the temperature gradient of the rod in order to find the thermal conductivity of the rod. From the calculation we found three different value of thermal conductivity at different power input. But we know that the thermal conductivity of the substance depends only on its material and for brass it should be constant for a given power input. The fluctuation in the conductivity might be because of the insufficient cooling system. It might be because of the malfunctioning of the temperature probes or due to errors in the procedure. However, the mean thermal conductivity from the three calculated value was found to be 70.54 $Wm^{-1}K^{-1}$. We also found that heat that flows in certain direction by conduction is directly proportional to the cross sectional area normal to that direction and the temperature gradient in that direction. The Temperature Vs Length graph is shown below.




**Conclusion:**

From the experiment we know that the thermal conductivity of the material slightly increases with the increase with the temperature. Since it was found that the heat that flow through the conducting rod is directly proportional to the cross sectional area normal to the direction of flow of heat and temperature gradient Fourier's law of linear conduction was verified.

**Title:**

Radiation of Heat

**Objective:**

1. To investigate Stefan-Boltzmann Relationship.
2. To determine the emissivity of different surface.
3. To demonstrate the effect of view factor on radiation heat transfer.

**Observations and calculation:**

**For Black Body**

$\sigma = 5.67\times10^{-8}$ W/m$^2$K$^4$

| Source temperature $T_S$ K | Ambient temperature $T_A$ K | Radiometer reading(R) W/m$^2$ | $E_b=\sigma(T_S^4-T_A^4)$ W/m$^2$ | $\beta=E_b/R$ |
|---|---|---|---|---|
| 313 | 291 | 48 | 137.61 | 2.86 |
| 323 | 291 | 100 | 210.5 | 2.10 |

$\beta_{mean} = 2.48$

**For White Body**

$\beta$ = 2.48 (from above table)

| Source temperature $T_S$ K | Ambient temperature $T_A$ K | Radiometer reading(R) $W/m^2$ | $E_b = \beta R$ | $\varepsilon = \frac{E_b}{\sigma(T_S^4 - T_A^4)}$ |
|---|---|---|---|---|
| 313 | 291 | 32 | 79.36 | 0.576 |
| 321 | 291 | 62 | 153.76 | 0.786 |

$\varepsilon_{mean}$=0.681

**Analysis:**

In this experiment, firstly we calculated the energy emitted by a black body and calculated β for the body. On changing the source temperature we found different value of β for the same body. This may be because of the malfunctioning of the equipment, the body which we considered as a black body may not be perfectly black and because of the instrumental errors. However the two values we obtained for different source temperature are comparable. So we take out the mean value of the obtained two values.

Then in the second case, we calculated the energy emitted by a white body and hence calculated the emissivity of the body. The emissivity of the body was found to be less than 1. This is because only a perfectly black body absorbs or emits the entire heat radiant incident on it. The less the value of ε towards 0 the less the body emits or absorbs heat radiant. We obtained two unequal values of the emissivity of the second body. It is due to the instrumental error or malfunctioning of the equipments.

**Conclusion:**

From this experiment, we know that a black body is the one which absorbs all the radiation incident upon it and is also a perfect emitter, whereas other bodies cannot absorb all the incident radiation or emit perfectly. There occurs a fixed ratio of energy emitted by a perfectly black body and other body at any source temperature.

We also found that the intensity of radiation varies as the fourth power of the source temperature and the intensity of heat radiation is maximum for the perfectly black body. The thermal radiation is a mode of heat transfer which differs significantly from conduction and convection. It does not require any material medium for energy transfer. The energy is transferred from one surface to another by means of electromagnetic waves.

**TRIBHUVAN UNIVERSITY**

**INSTITUTE OF ENGINEERING**

**CENTRAL CAMPUS, PULCHOWK**

**A LAB REPORT ON:**

FUNDAMENTALS OF THERMODYNAMICS AND HEAT TRANSFER

**LAB NUMBER**: 1

**TITLE OF EXPERIMENT:** Thermal Radiation

**SUBMITTED BY**:

**NAME**:Ashok Sapkota

**ROLL NO:**073BCE030

**GROUP**: B

**SUBMITTED TO:**

DEPARTMENT OF MECHANICAL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

**DATE OF EXPERIMENT:**December 16, 2016 **DATE OF SUBMISSION**:January 5,2016

# Heat Radiation

# Introduction

The process of transfer of heat in which medium is not needed is known as heat radiation. The body that can absorb all heat radiations incident on it and also can radiate all wavelengths if heated to high temperature is known as black body. The energy radiated per unit area per unit time is known at a temperature is known as emissive power.

Stefan's law

The energy radiated per unit area per unit time of a perfectly black body is directly proportional to fourth power of absolute temperature.

E $\propto T^{4}$

I.e. E=σ$T^{4}$

Where σ=5.678x10^-8w$m^{-2}k^{-4}$

If A be the surface area of the body then,

Power(p)= $\sigma A T^{4}$

Emissivity(ε)

The ratio of energy radiated per unit area per unit time of a body and perfectly black body at same temperature is called emissivity. It's value is 1 for perfectly black body and less than 1 for any other bodies.

For any body,

E= $\sigma A e T^{4}$

View factor(β)

View factor is the fraction of energy exiting an isothermal, opaque, and diffuse surface 1(by emission or reflection), that directly impinges on surface 2(to be absorbed, reflected, or transmitted).View factor depend only on geometry. View factor also has a maximum value of unity.

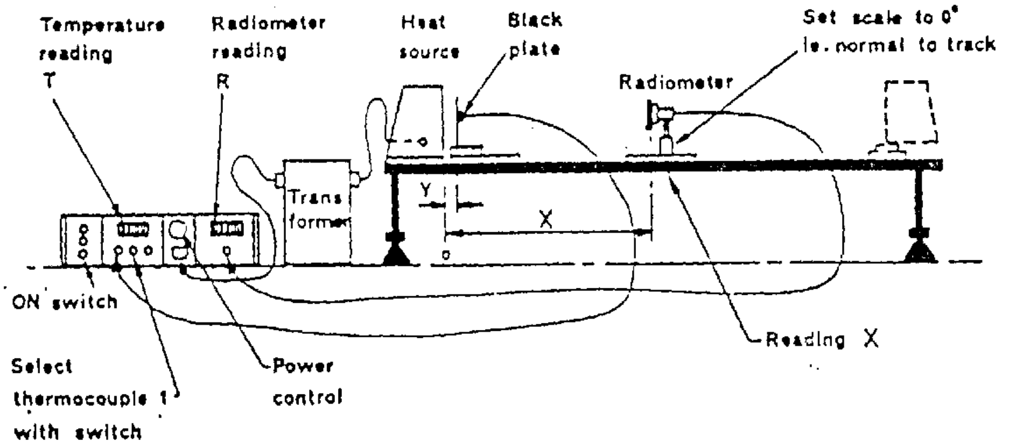



Fig: Laboratory setup for practical of heat radiation

**PROCEDURE**:

a. The apparatus was set up as shown in figure.
b. The heater power control knob was fully countered clockwise and heater was turned on.
c. The radio meter was placed 110mm from heat source.
d. A black plate was placed 50mm from heat source.
e. The radiometer cover was not opened until the temperature stabilized.
f. The temperature and radiometer reading was noted at ambient condition.
g. The temperature was increased through selected increments and ambient temperature and radiometer reading was noted.

**OBJECTIVES:**

a. To calculate emissivity of different surface.

**DATA:**

1. For black surface

| Source temperature (degree Celsius) | Surrounding Temperature (degree Celsius) | Radiometer reading(R) (W/$m^2$) | Energy emitted by black body Eb= $\sigma(T_1^4 - T_2^4)$ | View factor $\beta = R/Eb$ |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| 304 | 292.4 | 34 | 69.78 | 0.48 |
| 305 | 292.4 | 38 | 76.30 | 0.49 |
| 308 | 292.4 | 49 | 95.91 | 0.51 |

$\beta_{mean}$ =(0.48+0.49+0.51)/3=0.49

2. For grey surface

| Source temperature (degree Celsius) | Surrounding Temperature (degree Celsius) | Radiation per meter square | Ex=R/β | E=Ex/Eb |
|---|---|---|---|---|
| 31 | 19.4 | 24 | 50 | 0.71 |
| 33 | 19.4 | 27 | 55.1 | 0.72 |
| 35 | 19.4 | 29 | 59.18 | 0.71 |

$E_{mean}$=(0.71+0.71+0.72)/3=0.71

**RESULT:**

From above we found out that the emissivity of grey body to be 0.71. View factor is calculated to be 0.49. The value for view factor is different in all three observations.

**DISCUSSION:**

Anodizing is an electrolytic passivation process used to increase the thickness of the natural oxide layer on the surface of metal parts.

The process is called anodizing because the part to be treated forms the anode electrode of an electrical circuit. Anodizing increases resistance to corrosion and wear, and provides better adhesion for paint primers and glues than bare metal. Anodic films can also be used for a number of cosmetic effects, either with thick porous coatings that can absorb dyes or with thin transparent coatings add interference effects to reflected light. The plate is anodized with silver color and emissivity of it is calculated by the above setup.

From this experiment we calculated the value of view factor. The value of view factor is different in all three readings. But we know that from geometry it should be same in all cases. This may be due to the manufacturing defect of the material. Other reason is that the black body used does not absorb all the radiations falling on it.

Also the value of emissivity of grey body was found to be 0.71. It is true for every body other than perfectly black body to have its value less than one.

The value for emissivity is less than one for a black body as it can neither emit nor absorb all the radiations falling on it.

For a given temperature the emissivity of a body is constant according to the definition: emissivity is the ratio of emissive power of the body to emissive power of the body at the same temperature.

**CONCLUSION:**

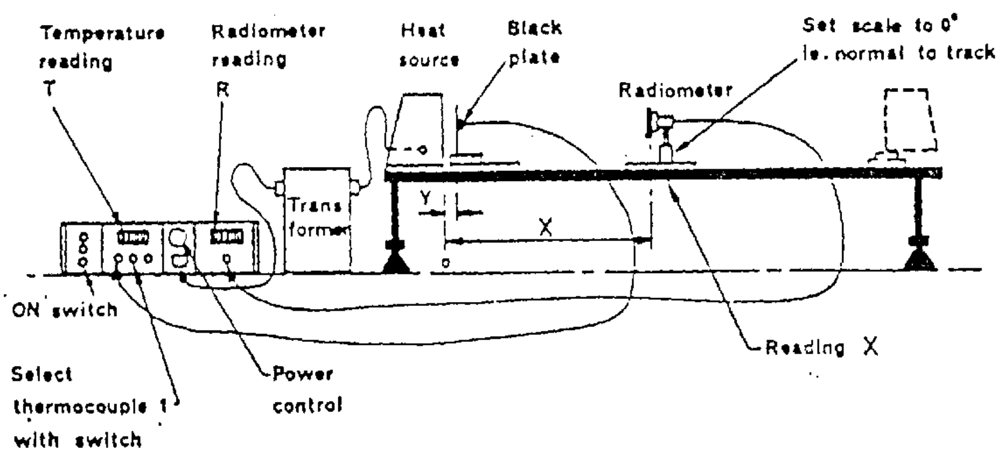
Thus Stefan-Boltzmann law was verified in the lab using Armfield Thermal Radiation Apparatus. The value of emissivity can be calculated in the lab and the polished plate was found to be a good emitter. Bodies other than the black body has emissivity always less than unity as other bodies cannot absorb or emit all the incident radiation falling on it.

**PRECAUTIONS**

a. The plate used should not move.
b. Apparatus should be handled carefully.
c. Steady temperature should be obtained before taking any readings.

**RECOMMENDATIONS:**

1. The orientation and distance between plates should be same throughout experiment.
2. The apparatus must be connected in proper manner and equipment should be kept in good shape.


Temperature reading T
Radiometer reading R
Heat source
Black plate
Set scale to 0° ie. normal to track
Radiometer
Trans former
Y
X
ON switch
Select thermocouple 1 with switch
Power control
Reading X

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