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 For N. Ranniyer

INSTITUTE OF ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

EG801ME - Thermodynamics and Heat transfer

LAB SHEETS ON

FUNDAMENTALS OF

THERMODYNAMICS, HEAT AND MASS TRANSFER

EG 469 ME

(Electronics and Computer)

Experiment no. 1

Air and water heat pump

1..1 Relevant theory:

The Second Law of thermodynamics states that it is impossible to transfer heat from a region at a low temperature to another at a high temperature without the expenditure of energy. Heat pumps and Refrigerators are examples of machines which transfer heat from a low to high temperature region consuming energy.

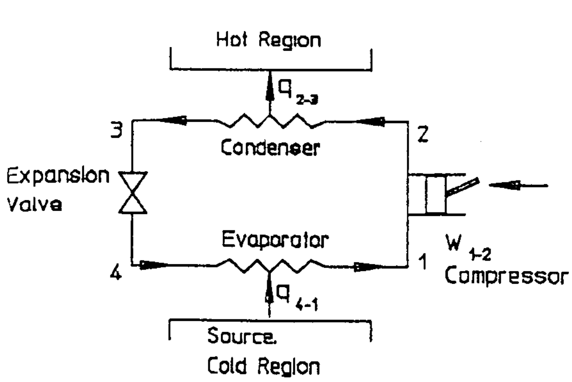
The vapor compression refrigeration cycle finds applications in countless industrial, commercial and domestic situations throughout the world. In the majority of these applications the emphasis is upon maintaining a product or air stream at a low temperature whilst rejecting the heat extracted to a sink at a higher temperature. However the vapor compression refrigeration cycle may equally be utilized to upgrade heat from a 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 application. These application may be space heating or water heating.

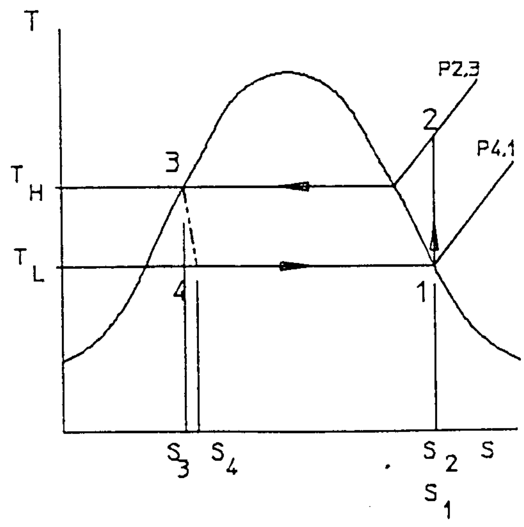
Heat pump: It is a device that transfer the heat from the low temperature reservoir to the high temperature reservoir in order to maintain the temperature of a specified space higher than the surroundings by consuming energy.

Refrigeration machine: It is a device that transfer the heat from the low temperature reservoir to the high temperature reservoir in order to maintain the temperature of a specified space lower than the surroundings by consuming energy.

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

The Idealised Vapour Compression Cycle.





The liquid receiver gives a large volume into which excess refrigerant can flow during certain operating conditions. In addition the receiver ensures that 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 the hermetically 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. during normal operation some oil will be carried around the system and under certain conditions may appear in the variable area flow meter as a discoloration to the flow. This is quite normal and will disappear during normal running.

As the compressor is designed specifically for heat pump use 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.

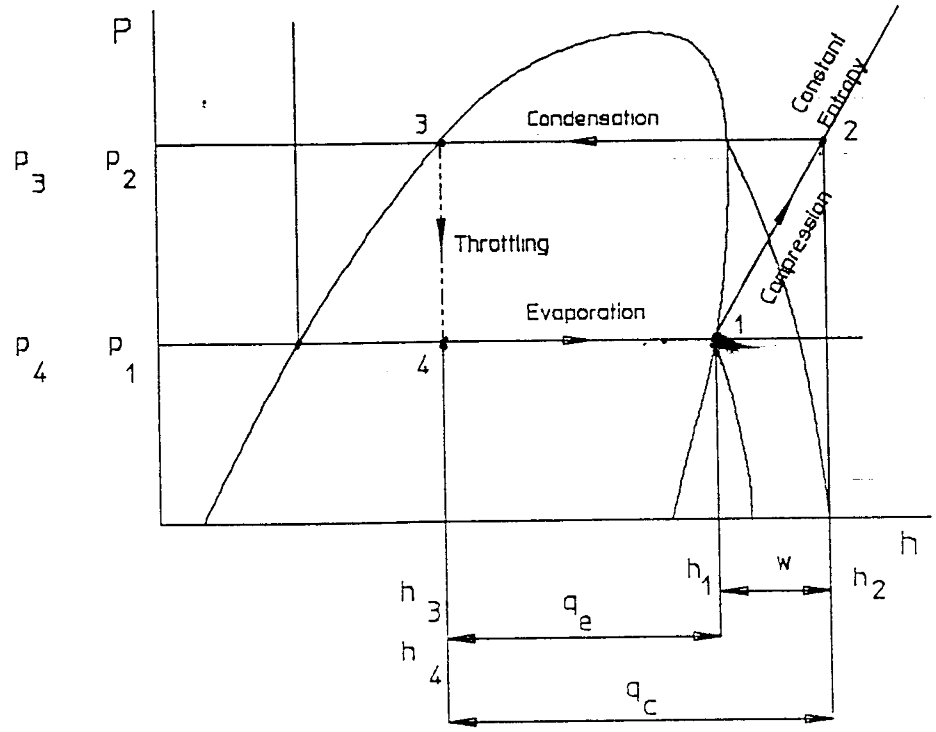
Sub-cooled liquid HFC134a at high pressure passes through a panel mounted flow meter to a thermostatically controlled expansion valve. On passing through the valve the pressure is reduced to that of the evaporator and the two phase mixture of liquid and vapor begins to evaporate within the selected evaporator.
Control of the 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 by 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 by 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 electrical input to the compressor motor is indicated by a panel mounted analogue meter.



The cycle is as follows:

Saturated vapor at 1 is compressed isentropically from a low pressure P1 to a high pressure P2. Superheated vapor at state 2 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 3. The high pressure saturated liquid is throttled from P3 to P4 and the resulting very wet vapor is passed into a evaporator at state 4. 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 vapor compression cycle

The practical cycle differs from the idealised 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.

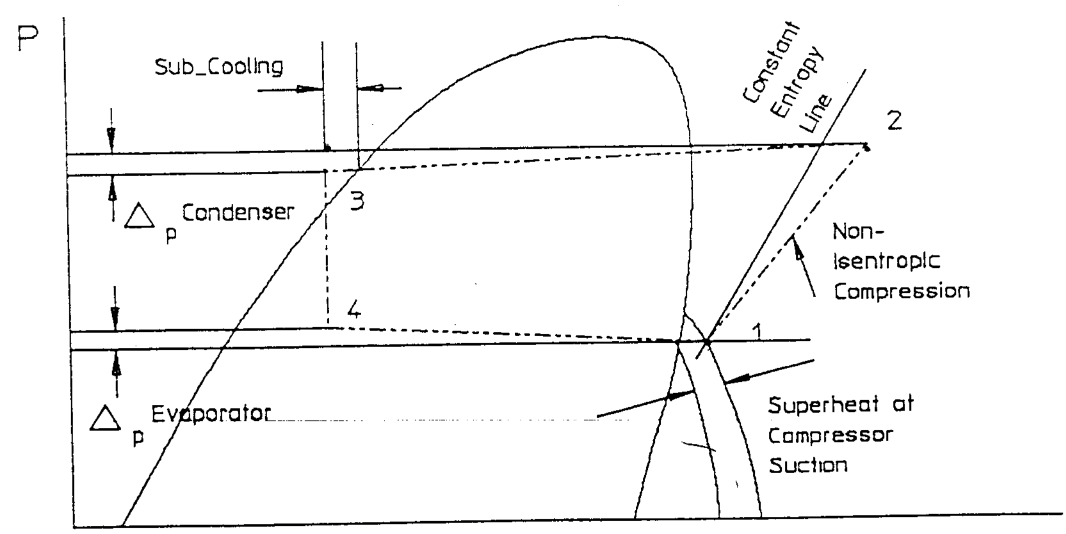
b) The compression process is neither adiabatic nor reversible. (There will usually be a heat loss from the compressor and, obviously, there are frictional effects.)

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 subcooled, 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 surroundings. the net effect of these "losses" or irreversibilities on the ~~cycle~~ diagram is shown below.

p-h Diagram for Simple Practical Vapour Compression Cycle



1..2 **Set up requirements:**

Air and water heat pump
Make : P. A. Hilton Ltd.
Model: R831

Refer the attached sheet.

1..3 **Equipment Description**

HFC134a vapor generated by absorbtion of low grade heat in either the air or water source evaporator is drawn into the compressor. This extraction of heat from air or water reduces the temperature of the air or water flow leaving the unit.

The woke done on the gas by the compressor increases the pressure and temperature of the refrigerant vapor. This hot high pressure gas flows to a concentric tube water cooled condenser.

In the condenser the gas is desuperheated and then condensed at essentially constant temperature. before leaving the condenser the liquid refrigerant is slightly subcooled below the saturation temperature for the condensing pressure and this liquid then flows to a liquid receiver.

Experiment no. 1 a

1 .1 Objective:

The objective of this experiment is to determine the power input, power output as well as coefficient of performance of heat pump.

1 .2 Experimental Procedure

1 Turn on the water supply to the unit turn on the main switch.

2 Select the air evaporator by pressing the evaporator change over switch down.

3 Set the condenser gauge pressure to between 700 and 1100 kN/m2 by adjustment of the condenser cooling water flow rate.

4 Allow the unit time for all of the system parameters to reach a stable condition and fill up the observation sheet.

5 Repeat the above procedures for water evaporator by switching the change over switch up condition and fill up the observation sheet.

1 .3 Obsevation Sheet:

For source of low grade heat : Air

S. No.	PARTICULARS	UNITS	
1	Compressor electrical power input (W)	Watts	
2	Cooling water inlet temperature (t_5)	°C	
3	compressor cooling water outlet temperature (t_6)	°C	
4	Condenser water outlet temperature (t_7)	°C	
5	Condenser water mass flow rate (m_c)	g/s_2	

For source of low grade heat : Water

S. No.	PARTICULARS	UNITS	
1	Compressor electrical power input (W)	Watts	
2	Cooling water inlet temperature (t_5)	°C	
3	compressor cooling water outlet temperature (t_6)	°C	
4	Condenser water outlet temperature (t_7)	°C	
5	Condenser water mass flow rate (m_c)	g/s_2	

.4 Relavent equations:

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

$Q_c = m_c C_{pw} (t_7 - t_6)$

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,

Q_{comp} ⇒ Heat delivered to cooling water from compressor
Q_c ⇒ Heat delivered to condenser cooling water
COP_{hp} ⇒ Coefficient of performance of heat pump
C_{pw} ⇒ Specific heat of water (4.18 kJ/kg °C)

.5 Result and Analysis

Experiment no. 1 b

1.1 Purpose:

The purpose of this experiment is to draw the actual vapor compression refrigeration cycle on a P-h diagram and compare it with the ideal cycle.

1.2 Experimental Procedure

1. Turn on the water supply to the unit turn on the main switch.
2. Select the water evaporator by pressing the evaporator change over switch up.
3. Set the condenser cooling water flow rate to approximately 50 % of full flow and evaporator water flow as set by instructor.
4. Allow the unit time for all of the system parameters to reach a stable condition and fill up the observation sheet.

1.3 Obsevation Sheet:

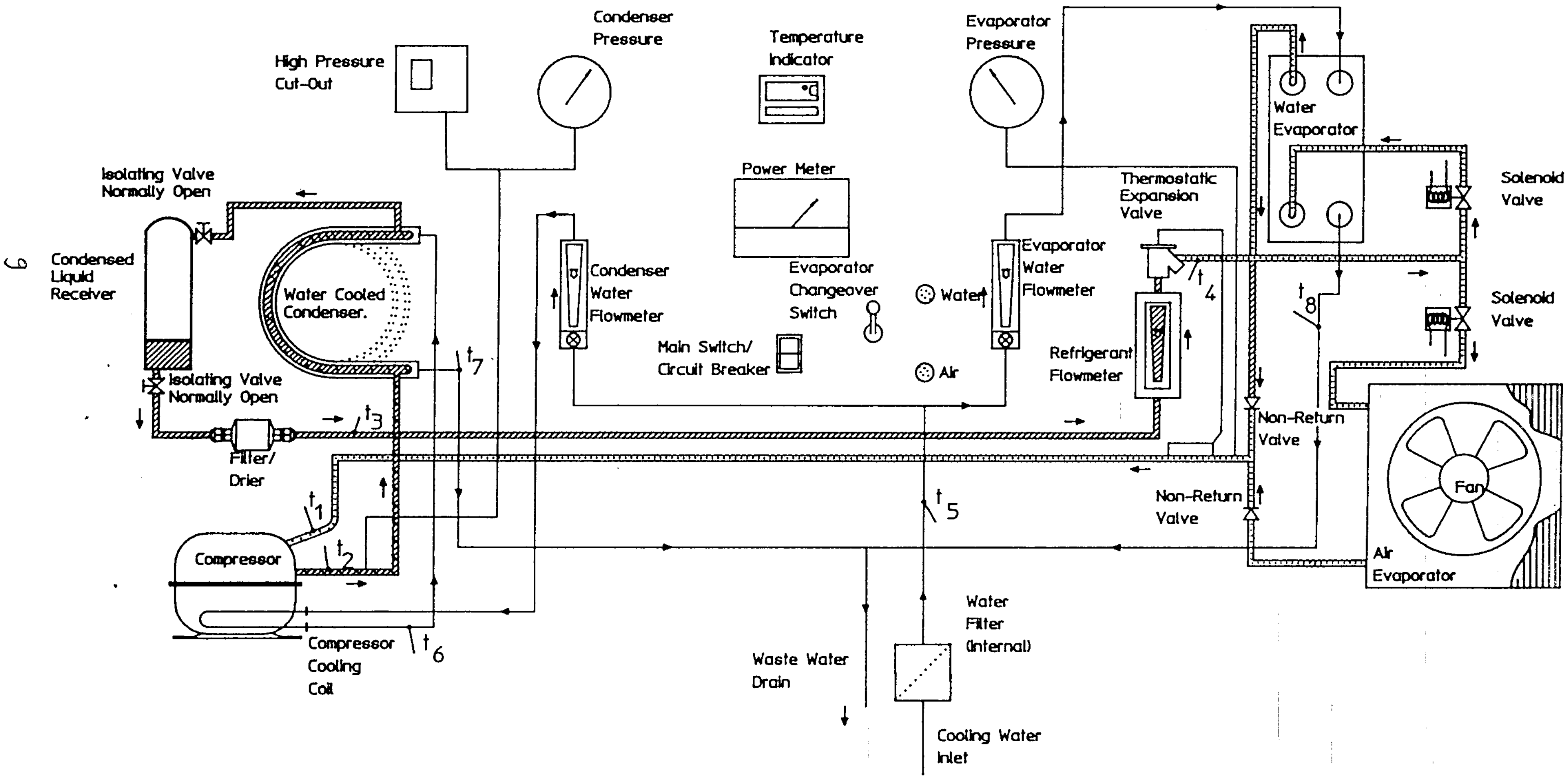
Atmospheric pressure = 1.05 bar = 105 kN/m_2

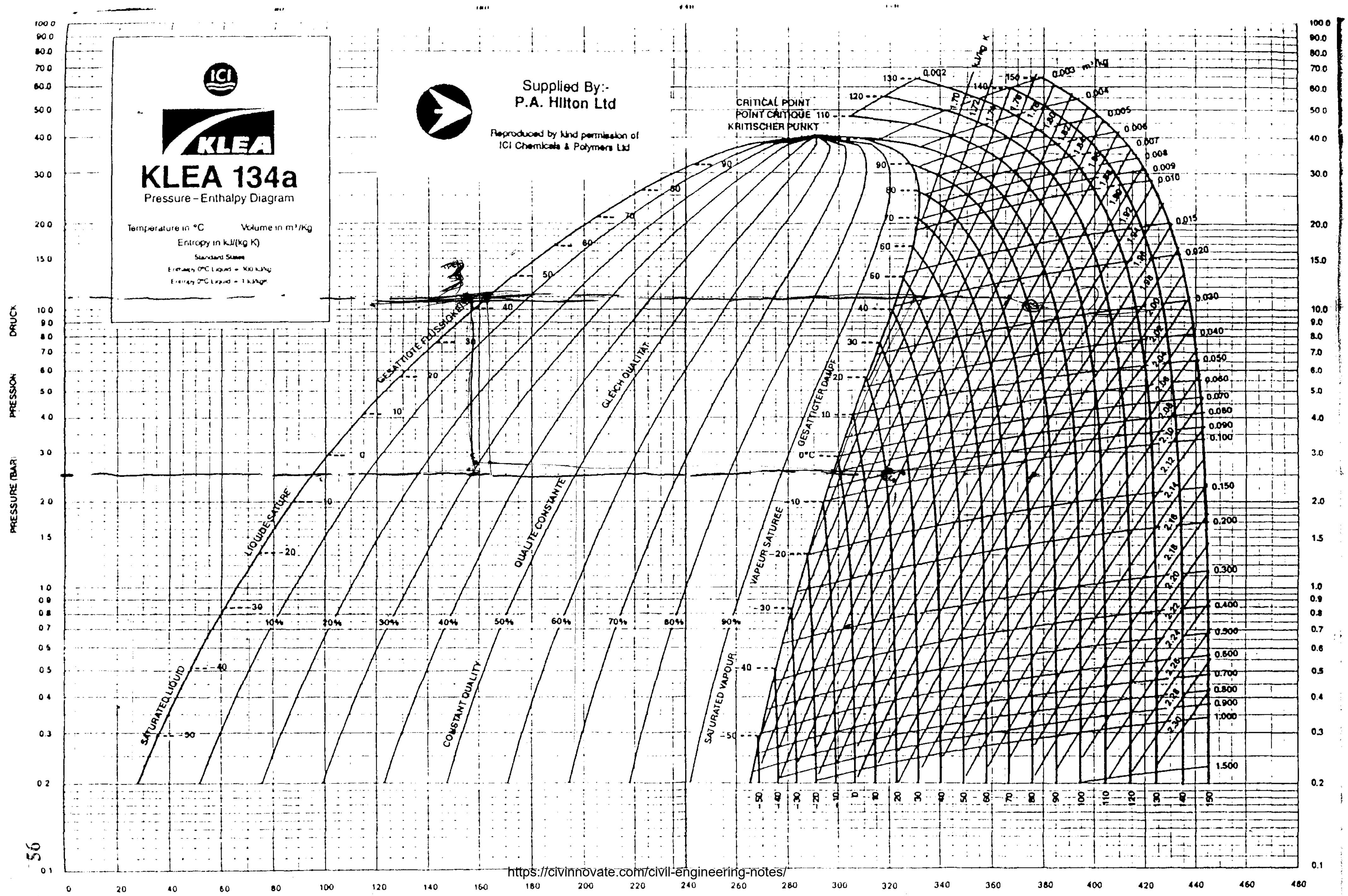
S. No.	PARTICULARS	UNITS	
1	HFC134a gauge pressure at compressor suction (p_1)	kN/m_2	
2	HFC134a absolute pressure at compressor suction (p_1)	kN/m_2	
3	HFC134a gauge pressure at compressor discharge (p_2)	kN/m_2	
4	HFC134a absolute pressure at compressor discharge (p_2)	kN/m_2	
5	HFC134a temperature at compressor suction (t_1)	°C	
6	HFC134a temperature at compressor discharge (t_2)	°C	
7	HFC134a temperature condensed liquid (t_3)	°C	
8	HFC134a temperature at expansion valve outlet (t_4)	°C	

1.4 Result and Analysis

Draw ideal as well as practical vapor compression cycle in the P-h diagram and compare their energy input, desired output as well as COP.

Air and Water Heat Pump R831





ICI
KLEA
KLEA 134a
Pressure-Enthalpy Diagram
Temperature in °C
Volume in m³/Kg
Entropy in kJ/(kg K)
Standard States
Supplied By:-
P.A. Hilton Ltd
Reproduced by kind permission of
ICI Chemicals & Polymers Ltd
CRITICAL POINT
POINT CRITIQUE
KRITISCHER PUNKT
GESÄTTIGTE FLÜSSIGKEIT
LIQUIDE SATURE
SATURATED LIQUID
GLEICH QUALITÄT
QUALITE CONSTANTE
CONSTANT QUALITY
GESÄTTIGTER DAMPF
VAPEUR SATUREE
SATURATED VAPOUR
10% 20% 30% 40% 50% 60% 70% 80% 90%
DRUCK
PRESSION
PRESSURE (BAR)
0.002
0.003 m³/kg
0.004
0.005
0.006
0.007
0.008
0.009
0.010
0.015
0.020
0.030
0.040
0.050
0.060
0.070
0.080
0.090
0.100
0.150
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
1.500
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400 420 440 460 480

Thermodynamics/Heat Transfer
EG569ME

LABORATORY 2

Title: Heat Conduction

Objective: To investigate Fourier's Law of linear conduction

Introduction:

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

dT/dx = temperature gradient

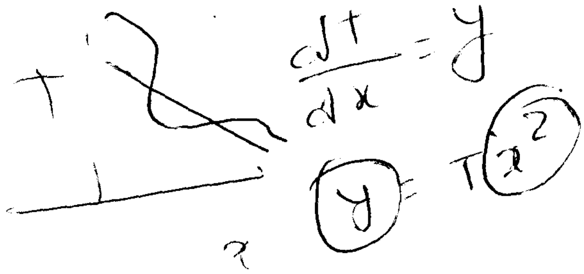
The minus sign in the equation above shows that heat flows in the direction of decreasing temperature.

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 the lattice structure of the material which transport heat from high temperature region to the low temperature region. The portion of energy transported by free electrons is larger than that by lattice vibration. An increase in temperature causes increase in both the lattice vibration and speed of free electrons, but increased vibration of lattice disturbs the movement of free electrons causing reduction in 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 lattice vibration and an increase in temperature increases conduction.

Conduction of Heat Along a Simple Bar

In this experiment, Fourier's law of conduction is investigated for the case of a simple bar with lateral surface insulated as shown in Fig.1.



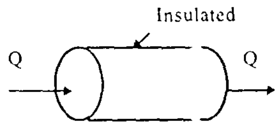


Fig.1

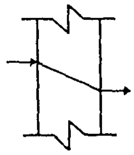


Fig.2

This is an approximation of one-dimensional conduction for a plane wall as shown in Fig.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:

$$k(T) = \bar{k}(T) = \frac{Q}{A}\frac{\Delta x}{T} \qquad w/m.K \qquad (1)$$

Where, Q is heater power,

k(t) mean value of thermal conductivity between T1 and T2

T = mean value of T1 and T2

Laboratory Setup

Equipment:

The equipment used in the above experiments is the Armfield Thermal Conduction Apparatus which consists of two electrically heated modules mounted on a bench support frame. One module contains multiple cylindrical metal bar arrangement for a variety of linear conduction experiments and the other module consists of a disk for radial profile studies. all test sections are equipped with an array of temperature sensors. Cooling water from laboratory tap is fed to one side of the test pieces in order to maintain a steady temperature gradient.

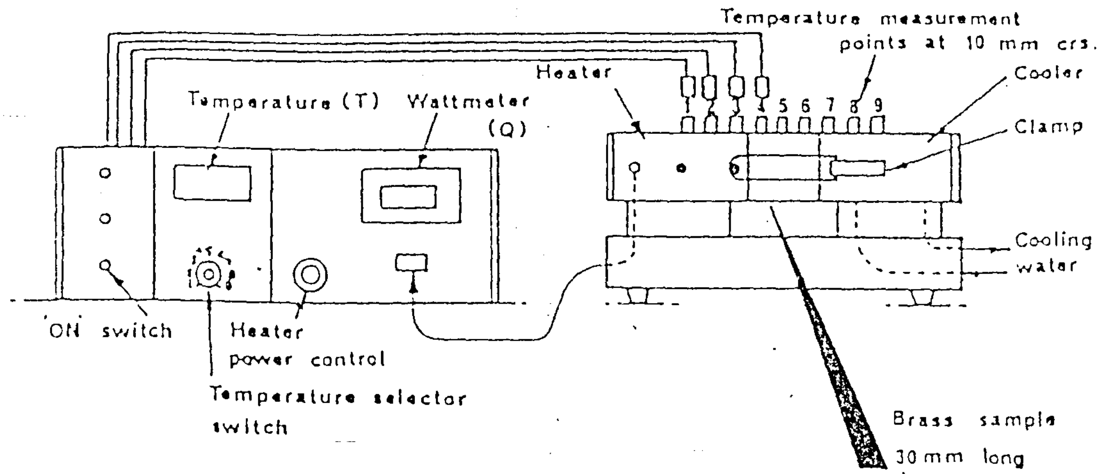
An electrical console provides electrical power for heaters in the specimen and digital readout of the temperature at selected points along the heat conduction path. The temperature probes have a resolution of 0.1 degree Celsius. The power control circuit provides a continuously variable electrical output of 0-80 watts with direct digital readout with a resolution of 0.1 watt.

Safety Considerations

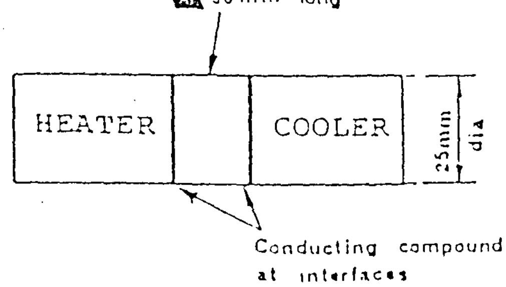
1) Do not exceed 100^{o}C on the linear conduction apparatus.
2) After finishing the experiment, the specimen removed from the linear conduction apparatus may be hot, be careful and handle with care.
3) A continuous flow of cooling water is necessary for the experiment, otherwise the apparatus may get damaged.

Laboratory Procedure:

1. The equipment should be setup as shown in figure. Ask for your instructor's help.
2. Apply conducting compound at the metal interface in order to reduce thermal contact resistance and install the specimen. When assembling the specimen between the heater and the cooler, take care to match the shallow shoulders in the nylon housing.
3. Ensure that the temperature measurement points are aligned along the longitudinal axis of the unit. Make sure that the temperature sensor wires are connected correctly.
4. Turn the heater power control knob fully counter-clockwise then turn ON the heater power. Make sure that the reading from the watt meter is zero.
5. Check the temperature readings from all the temperature probes. They should be equal to room temperature. If they are not contact your instructor.
6. Gradually increase the heater power by turning the knob clockwise. Set the heater power to 20W. Allow enough time to reach steady-state condition
7. Note the temperatures from all the probes by turning the selector switch.
8. After completing the experiment, reduce the heating power to zero, turn OFF the heater power but let the cooling water run for some five more minutes to ensure that the specimen is cooled down.



Core:



Observation Sheet:

Specimen material:
Thermal conductivity of the specimen from tables:
Diameter of specimen:
Length of specimen:
Distance between temperature probes: 10mm

Test Results:

Test No.	Wattmeter watts, Q	T1, °C	T2, °C	T3, °C	T4, °C	T5, °C	T6, °C	T7, °C	T8, °C	T9, °C
1	20									

Plot the temperature profile along the length of the core. Determine the thermal conductivity of the test specimen. Comment on the effect of increasing heater power on the thermal conductivity of the specimen. Compare the calculated thermal conductivity with the published data and comment on the difference if any. Apply proper conversion factor whereever necessary.

Thermodynamics/Heat Transfer
EG 569 ME

Laboratory 4

Title: Heat Radiation

Objective: To investigate Stefan-Boltzmann relationship

Introduction:

Thermal radiation is a mode of heat transfer which differs significantly from conduction and convection in that it does not require any medium for energy transfer. The energy is transferred from one surface to another surface by means of electromagnetic waves.

Stefan-Boltzmann law states that the intensity of radiation varies as the fourth power of the source temperature.

$E_b \propto T^4$

or, $E_b = \sigma T^4$

If two surfaces are participating in radiation,

$E_b = \sigma(T_1^4 - T_2^4)$

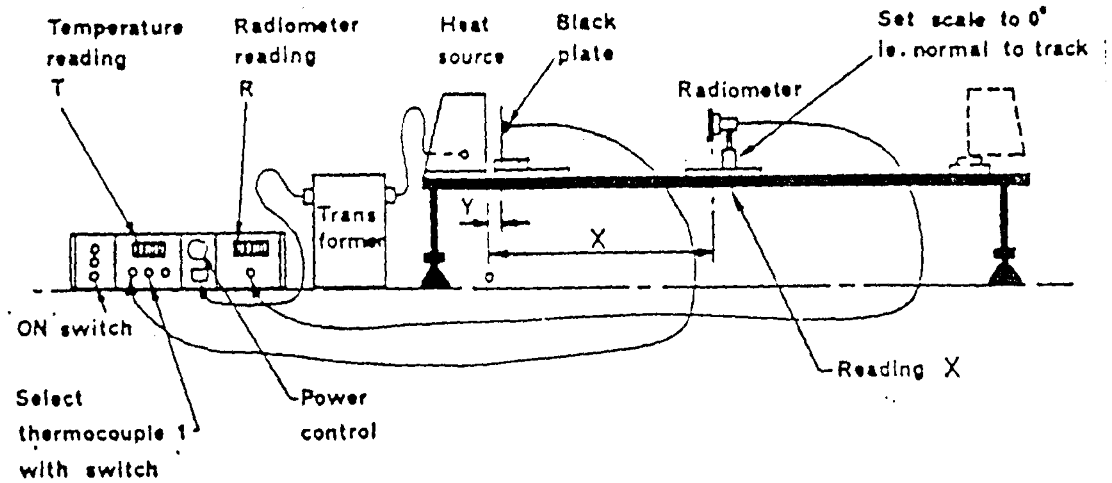
Where E_b = energy emitted by a black body surface, W/m^2
T_1 and T_2 = absolute temperatures of the surfaces, K
σ = Stefan-Boltzmann constant, 5.67×10^{-8} W/m^2K^4

A black body is the one which absorbs all the radiation incident upon it and is also a perfect emitter, where as other bodies can not absorb all the incident radiation or emit perfectly. There exists a fixed ratio of energy emitted by a black body and other bodies at any source temperature. If we know black body temperature and sorrounding temperature, we can calculate the energy emitted by a black body. The energy absorbed by the other body can be measured with the help of instruments. The ratio of these two values of energy must be same at any source temperature. If so, the Stefan-Boltzmann law is satisfied.

Laboratory Procedure:

1) The equipment should be set up as shown in fig. Your instructors will help to setup the equipment.
2) Turn the heater power control knob fully counter clockwise and then turn ON the heater

3) Place the radio meter at a distance of 110 mm from the heat source
4) Place the black plate at a distance of 50 mm from the heat source
5) Do not open the radiometer cover until the black plate temperature stabilizes
6) Record the temperature reading and radiometer reading at ambient condition
7) Increase the temperature through selected increments and record both ambient temperature and radiometer reading



Observation Sheet

T = (t + 273) K
$\sigma = 5.67 \times 10^{-8}\ W/m^2K^4$

Source temp, Ts, K	Ambient temp. T_A, K	Radiometer reading, R, W/m^2	$E_b = \sigma(T_s^4 - T_A^4)$ W/m^2	$\beta = \frac{E_b}{R}$

βave =

Compare calculated values of β and comment on it.

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