University of Jordan
School of Engineering
Department of Chemical Engineering

Thermals Lab.
0905466

Experiment Number -1-

Vapor-Liquid Equilibrium

Objective:

In this experiment equilibrium data for the binary system: n-hexane (1) – toluene (2) will be obtained, or for any other system assigned by the lab instructor. Subsequently, the equilibrium data are reduced to obtain the activity coefficients. The determined activity coefficients are fitted to a suitable model such as the two-suffix Margules, Van Laar, NRTL, UNIQUAC, and Wilson equations. The experimental data are to be compared with the predicted activity coefficients using the UNIFAC method, also to be compared with the reported literature values for the system assigned to the group.

Equipment:

The main features of the apparatus are illustrated in figures (1&2). It consists of a boiling chamber (A) in which the mixture under test is vigorously heated to produce a vapor-liquid mixture that passes the glass spiral tube (B) at a high velocity. The rising vapor entrains drops of the liquid which equilibrates with the vapor and this mixture emerges from the tube at equilibrium, striking the thermometer’s pocket (C), which contains a thermocouple (1) to measure the boiling temperature. The vapor then rises gently through the central tube (E) while the liquid drops fall back into the chamber (F). The vapor emerging from the tube (E) passes through the annulus (G), its temperature is measured by thermocouple (2), it is then heated electrically in order to prevent condensation and therefore the entire vapor passes to the water cooled condenser (H) where they are totally condensed. The liquid so formed accumulates in the receiver (J) from which a sample of the vapor phase is obtained. When the receiver (J) is full of condensate, the condensate overflows and passes through the tube (P) to mix with the liquid flowing down the tube (K) from the chamber (F). This mixture enters the heater (A) to be re-vaporized and discharged as a mist into the spiral (B) where it is equilibrated on emerging against the thermometer pocket (C).

The apparatus also contains a refractometer, constant temperature water circulating unit and temperature reading device.

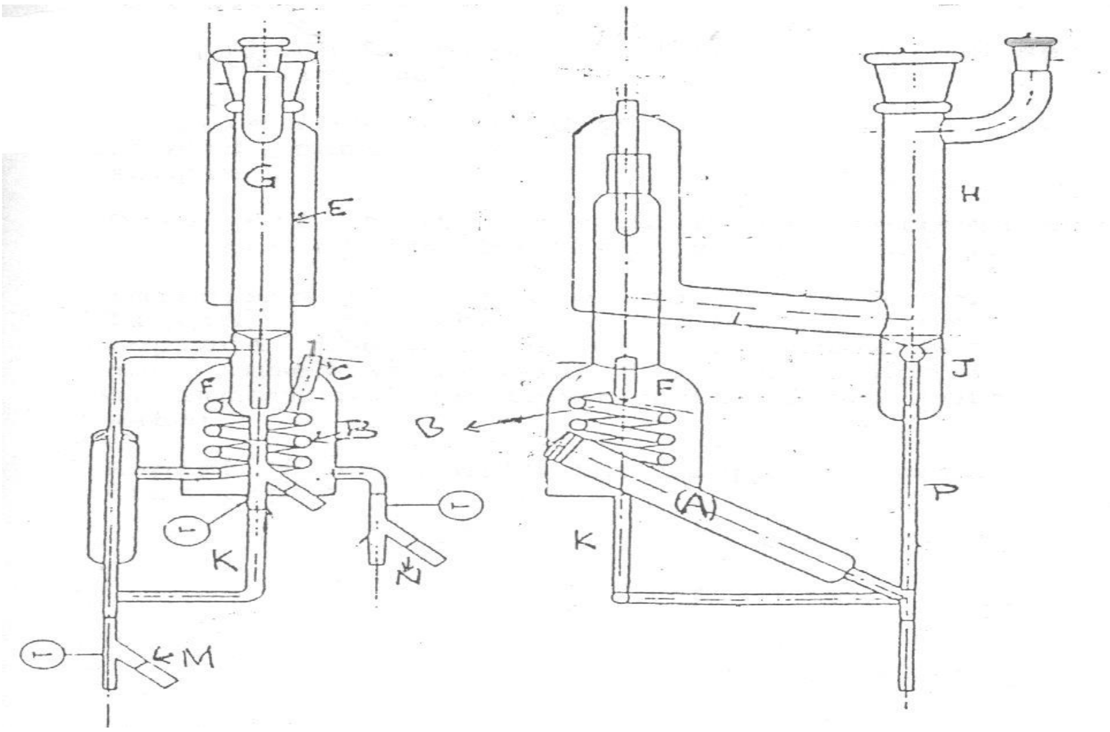

Figure (1): The vapor-liquid equilibria still.

Vapor-Liquid equilibria still

Boiling chamber

Temperature reading system

Refractometer

Photos courtesy of DaliaN.Saleh

Figure (2): Main components and accessories of vapor-liquid apparatus

Theory:

If a liquid mixture of two volatile components (A) and (B) is heated in a closed vessel, the temperature rises and the rate of vaporization of each component increases. As the temperature is raised, the vapor pressure of the liquid mixture, (P_T) increases until it is equal to the pressure applied on the system (P). At this temperature the liquid mixture starts to bubble and the temperature is called the bubble point (T_{bp}) of that mixture at the pressure (P). The first bubble of vapor is in equilibrium with the liquid mixture at that temperature (T_{bp}).

The partial pressure exerted by each component depends on the composition of the liquid mixture and the temperature. If the liquid mixture is ideal, it obeys “Raoult’s Law":

$$P_T = \sum_{i=1}^{C=2} P_i = \sum_{i=1}^{C=2} x_i \, {P_i}^{sat}(T) \dots\dots\dots (1)$$

Where (x_i) is the mole fraction of component (i) in the liquid phase, ($P_i = y_i P$) is the partial pressure of component (i), (y_i) is the mole fraction of component (i) in the vapor phase, and (P_i^{sat}) is the saturation pressure of component (i) which is a function of temperature.

If the components form an ideal mixture, the composition of the liquid and the vapor in equilibrium can be predicted from Raoult’s Law and Dalton’s Law, and this represents the maximum separation (or purification) of the two components that could be achieved by a simple distillation comprising a single vaporization and a single condensation step. In practice most mixtures are not ideal and therefore, equation (1) must be modified by introducing an activity coefficient such that

$$P_T = \sum_{i=1}^{C=2} P_i = \sum_{i=1}^{C=2} \gamma_i \, (\boldsymbol{x}, P_{T,} T) x_i {P_i}^{sat}(T) \dots\dots\dots (2)$$

Equation (2) is termed the modified Raoult’s law. Modified Raoult’s law is strictly valid at low pressure assuming that the vapor phase forms an ideal gas mixture i.e., the nonideality is accounted for solely by the activity coefficients in the liquid phase,(γ_i). The activity coefficient of a component in a mixture varies with temperature, pressure and composition, and must therefore be determined experimentally. It is most frequently calculated from the vapor-liquid equilibria data using the modified Raoult’s law in the form:

$$\gamma_i(\boldsymbol{x}, P, T) = \frac{y_i . P_T}{x_i . P_i^{sat}\,(T)} \dots\dots\dots (3)$$

Thus, (x_i), (y_i), (P_T) and (P_i^{sat}(T))should be known before being able to determine the activity coefficients. There are many ways to determine the composition in the vapor and liquid phases including, but not limited to: gas chromatography (GC), HPLC and refractive index. In this lab, you are going to determine the composition in the two phases by measuring the refractive indices of liquid phase and the condensate of the vapor phase in equilibrium with it. The saturation pressures as function of temperature are easily calculated from empirical equations such as the Antoine equation:

$$logP_i^{sat} = A - \frac{B}{T + C} \dots\dots\dots (4)$$

Where the parameters (A), (B), and (C) are specific to a particular component and can be found from any reference book or simulation package recently.

Activity Coefficient Models

The activity coefficient of a volatile liquid component in solution can be calculated from many models. Examples of the activity coefficients models written for a binary system are:

1. Two-Suffix Margules Equation

$$ln\gamma_1 = A_{12} . {x_2}^2$$
$$ln\gamma_2 = A_{12} . {x_1}^2 \dots\dots\dots (5)$$

Where (A_{12})is the parameter in this equation specific to any binary system. This parameter can be obtained from fitting of the experimental activity coefficients with composition.

2. Van Laar Model

$$ln\gamma_1 = \frac{A_{12}}{\left[1 + \frac{A_{12}}{A_{21}} . \frac{x_1}{x_2}\right]^2}$$

$$ln\gamma_2 = \frac{A_{21}}{\left[1 + \frac{A_{21}}{A_{12}} . \frac{x_2}{x_1}\right]^2} \quad \dots\dots\dots (6)$$

Where (A_{12}) and (A_{21}) are parameters in this model specific to a binary system. These parameters can be obtained from fitting of the experimental activity coefficients with composition.

Consistency Tests

Gibbs-Duhem equation states that:

$$(x_1 . dln\gamma_1 + x_2 . dln\gamma_2)_{T,P} = 0 \ldots\ldots\ldots (7)$$

From this equation, these two equations could be derived:

$$\frac{dln\gamma_2}{dx_2} = -\frac{x_1}{1-x_1}\frac{dln\gamma_1}{dx_2} \ldots\ldots\ldots (8)$$

$$\int_0^1 \ln(\frac{\gamma_1}{\gamma_2}). dx_1 = 0 \ \ldots\ldots\ldots (9)$$

The consistency of data could be checked using one of these tests:

1. The differential test: This test applies at a specific composition using equation (8). If (ln γ_1) and (ln γ_2) are plotted with respect to (x_2), the slopes at any given concentration should satisfy this equation.
2. The integral test: The consistency of experimental activity coefficients which are available over the entire concentration range can be checked by plotting(ln (γ_1/γ_2)) versus (x_1). The net area beneath the curve should equal zero, as indicated by equation (9). The plot must be extrapolated and integrated in the interval x_1 Є [0, 1].

Procedure:

1. Remove the condenser and pour 120 mL of one of the pure components via a clean dry funnel to the still.
2. Replace the condenser; turn on the cooling water through the condenser.
3. Switch on the electricity to the heater and the heating jacket.
4. When boiling commences, reduce the control so that about 20 drops per minute fall from the base of the condenser into the receiver.
5. Note the temperature of the boiling liquid recorded by thermocouple number (1) and continue boiling the mixture at this constant rate until this temperature remains constant.
6. When temperature (1) is constant adjust the jacket heater so that the temperature recorded by the thermocouple number (2) registers about (0.5-1.0°C) higher than the boiling temperature recorded by thermocouple by thermocouple number (1).
7. Continue boiling for at least one hour. After this period of equilibration take samples of the liquid from tap (N) (at the bottom of the main still) and of condensed vapor from tap (M) (at the bottom of reservoir which receives the drops of condensed vapor), by the following methods:

   a. Prepare four clean dry sample bottles, two for the liquid sample and two for the condensed vapor sample.
   b. Draw off about 2 mL of liquid through the tap (N) into one of the bottles (this is not the sample).
   c. Immediately withdraw about 2 mL of the same liquid into the second bottle from tap (N) and replace the stopper of the sample bottle quickly and immediately cool the bottle and its contents by immersing the lower half of the bottle in cold water.

8. Repeat b and c with the sample of condensed vapor from tap (M).
9. Switch on the water bath, and set the temperature as that recorded on the calibration curve supplied for the system used.
10. Measure the refractive index of the liquid and vapor by the refractometer
11. Add a known volume of the other component (B) to the pure liquid (A) and repeat steps (5 – 10) to obtain new results.
12. Add another volume of component (B) to the liquid in step (11) and also repeat steps (5-10) to obtain new results.
13. In the second period of experiment, starts with the other liquid (B) and after equilibrium of this run, add increments of the other component (A) to obtain result for many mixture of different composition.
14. At the end of the other period of experiment, switch off the apparatus, the water bath and the refractometer. Then drain the contents of the still.
15. Record the operating atmospheric pressure in the Lab.

Calculation:

1. Using the measured refractive indices, find the mole fractions of the volatile component in liquid and vapor phases at equilibrium from the calibration curve of the system.
2. Plot the boiling point-composition diagram (T_{xy}) of the system.
3. Calculate the activity coefficients of the components in the liquid phase using equation (3).
4. Fit the two-suffix Margules, van Laar, Wilson, and NRTL parameters to your data and report them. You may want to use the THERMOSOLVER software to carry out the fitting process.
5. At each equilibrium composition, estimate the activity coefficients using UNIFAC method. You may want to use Sandler's modified UNIFAC software.
6. Obtain estimates of the activity coefficients based on literature values. Go to the binary vapor-liquid equilibrium data of the Korean Thermophysical

Properties Data Bank CHERIC-KDB for experimental results of the system you have studied. The address is http://www.cheric.org/research/kdb.

7. Plot both ($\ln\gamma_1$) and ($\ln\gamma_2$) versus (x_1) using your experimental values, predicted values from the four models: two-suffix Margules, Van Laar, Wilson, and NRTL and that of UNIFAC.
8. Check the consistency of the data using the differential and integral tests.

References:

1. Balzhiser, R.E.; Samules, M.R.; and Eliassen, J.D., ‘Chemical engineering thermodynamics’. Prentice-Hall, Inc. 1972.
2. Hala, E; pick, Jiri; Fried, Vojtech; and vilim, otakar, ‘Vapour-Liquid Equilibrium’. Second edition, Pergamon Press, 1967.
3. Poling, B.E.; Prausnitz, J.M.; and O’connell, J.P., ‘The Properties of Gases and Liquids’, 5th edition, McGraw-Hill, NY, 2001.
4. Sandler, S.I., ‘Chemical, Biochemical and Engineering Thermodynamics’,4th edition, JohnWiley and Sons, NY, 2006.
5. Smith, J.M.; Van Ness, H.C.; Abbott, M.M., ‘Introduction to Chemical Engineering Thermodynamics’, 7th edition, McGraw-Hill, NY, 2006.
6. Winnick, J., ‘Chemical Engineering Thermodynamics’, John Wiley and Sons, NY, 1997.

Vapor-Liquid Equilibrium Data Sheet

Atmospheric pressure: --------------

Mixture used	Equilibrium Temperature	RI of vapor	RI for liquid

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Date:

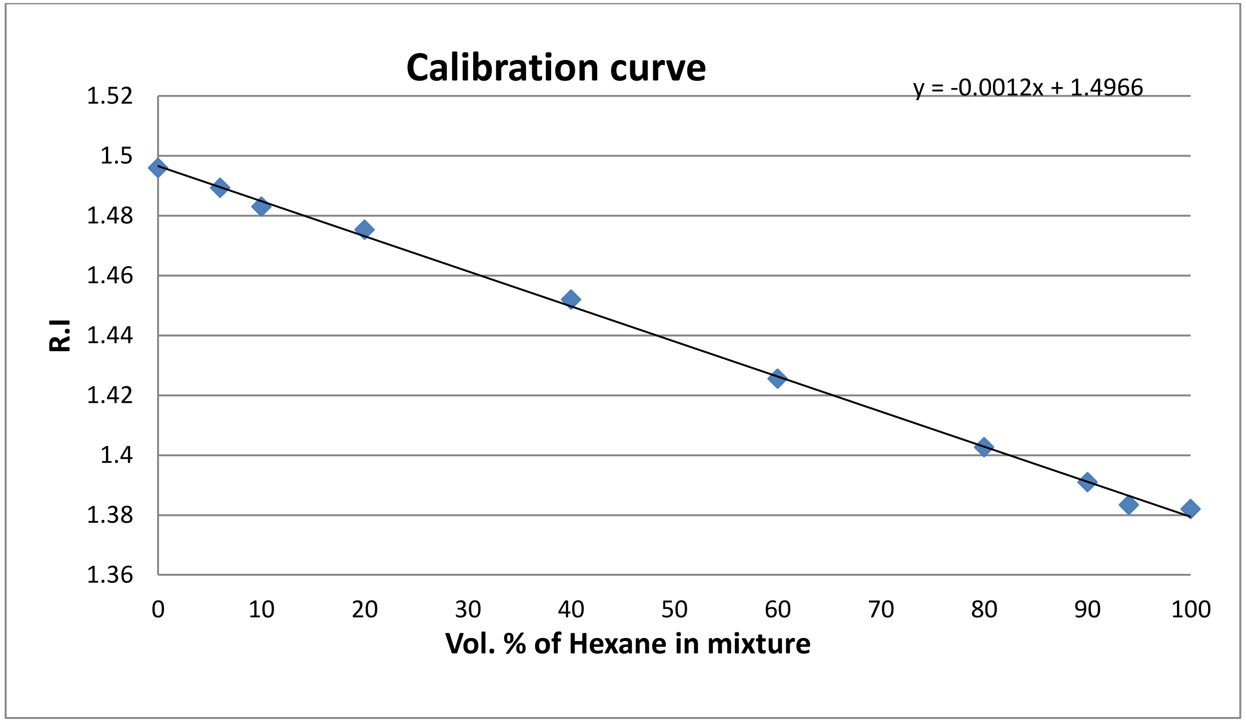

Figure (3): Refractive index Vs volume percentage for (Hexane + Toluene) system

Experiment Number -2-

Liquid-Liquid Equilibrium

Objective

To be familiar with mass transfer processes and the phase equilibria involved in liquid-liquid extraction.

Equipment

The apparatus consists of three cells. Each cell has a central 100 ml. capacity glass vessel with a side arm near the top for charging the liquids. Each glass vessel is surrounded by a glass jacket through which water is circulated to maintain the cell contents at constant temperature. The cell is provided with an agitator. It also contains a valve for emptying the contents on completion of experiment. The general arrangement of liquid-liquid equilibria apparatus is illustrated in figures (5&6).

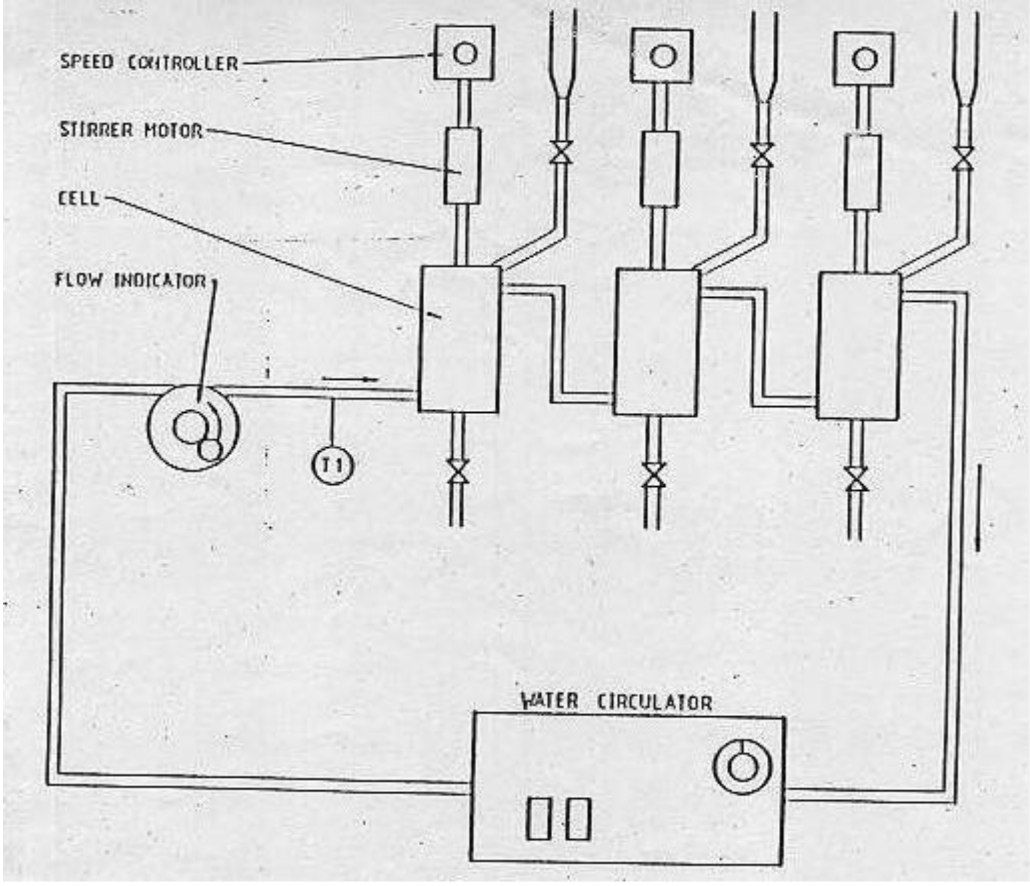

Figure (4): General Arrangement of liquid-liquid Equilibria apparatus

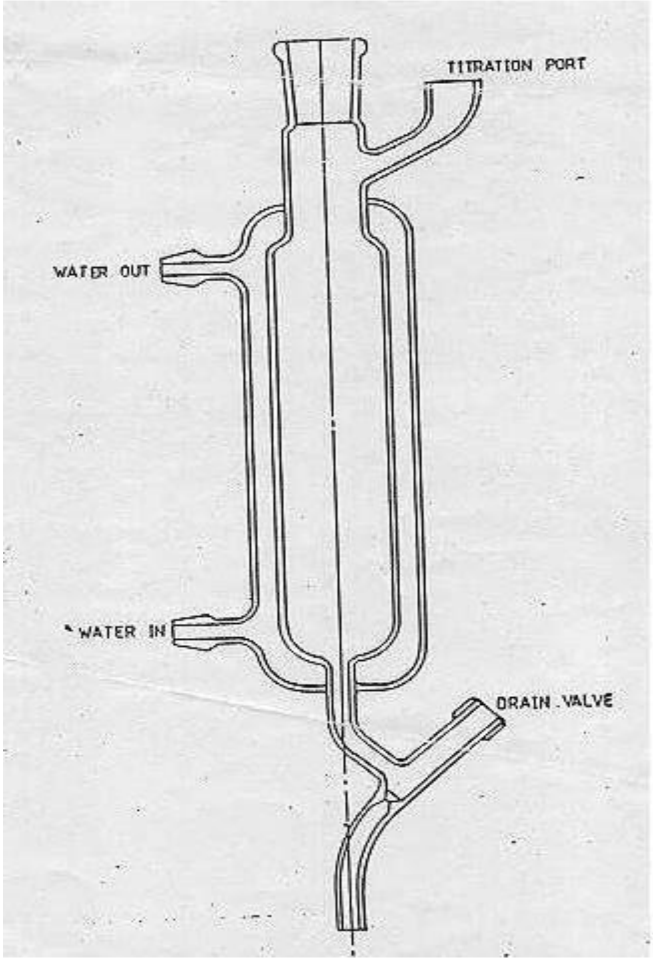

Figure (5): Agitated glass cell for liquid-liquid equilibria determinations

Theory:

Liquid- liquid extraction is the term applied to any operation in which a material dissolved in one liquid phase is transferred to a second liquid phase. The solvent must be insoluble or soluble to a limited extent only, in the solution to be extracted. If the solvent and the solution were completely miscible, there would be no opportunity for transferring the solute from the original solution to a second liquid phase. The degree of solubility of the solvent in the solution, and of the solution and its components in the solvent, are important considerations in the selection of the solvent and in the operation of the extraction process.

Liquid-liquid extraction consists of two basic steps:

1. Intimate mixing or contact of the solvent with the solution to be treated, so as to transfer the solute from the solution to the solvent.
2. Separation of the liquid solution phase from the liquid solvent phase.

The complete extraction process may involve other operations such as the separation and recovery of the solvent from the solute and of the solvent which may be dissolved in the solution, the removal and recovery of the solvent may be more important in determining the successful application of the extraction process than the degree of extraction and separation accomplished in the two basic steps, particularly when special or costly solvents are employed. The separation and recovery of the solvent may be accomplished by various methods such as distillation or simple heating or cooling to diminish the solubility of the solute or of the solvent.

Liquid-liquid-extraction is widely used for the separation of the components of a solution, particularly when:

1. The components are relatively nonvolatile.
2. The components have substantially the same volatilities from the mixture.
3. The components are sensitive to the temperatures required for the separation by distillation.
4. The desired less-volatile component is present in the solution only in relatively small amounts. In such a case, the less volatile component may be extracted solution from which it may be recovered more economically; or similar economics may be accomplished with a solvent less volatile than the desired component, even if the increase in concentration of the desired component is not particularly significant.

Usually the different distribution of the components of the feed mixture between the two layers at equilibrium is depended upon to effect the desired separation. The layer containing the greater concentration of the solvent and the smaller concentration of the feed liquid is referred to as the "extract" layer. The other layer, containing the greater concentration of the feed liquid and the smaller concentration of solvent is referred to as the "raffinate" layer.

All states of equilibrium between extract and raffinate can be represented in either a right triangle or an equilateral triangle phase diagram as you had learned before. For each state of equilibrium, there is only one specific tie line which represents it.

Reliability Using the Othmer-Tobias Correlation

The reliability of equilibrium data for any system may be tested by applying the Othmer-Tobias correlation. This correlation states that:

$$log\frac{(1-a)}{a} = n\ log\frac{(1-b)}{b} + s \ldots\ldots\ldots(1)$$

which indicates that there is a linear relation between the values of ($log\ \frac{(1-a)}{a}$) and ($log\ \frac{(1-b)}{b}$) where:

a: weight fraction of the solvent in the extract phase.
b: Weight fraction of the carrier liquid in the reffinate phase.
s:the intercept
n:slope
The system to be used in this lab will be in general: water, an organic solvent and a solute.

Procedure

A. To determine the ternary mutual solubility curve

a. For water rich phase:

1. Fill the cell with a solution consisting of 20mls of distilled water and 5mals of the solute.
2. Switch on the thermostat unit and check that water is circulating through the jacket of the cell. Then set the temperature as required.
3. Switch on the stirrer and adjust the speed control to the midpoint of the range.
4. Allow 10 minutes for the contents of the cell to reach the set temperature.
5. Slowly titrate the organic solvent into the mixture in the cell unitl "Cloudiness" appears and persists. Record the volume of the solvent in the mixture. This is the "cloud point" at which the three components in the mixture are in equilibrium. It represents one point on the ternary curve.
6. Add another 5mls of the solute to the mixture and repeat the steps (2-5).
7. Repeat step 6.
8. Clean the cell and fill it with a solution consisting of 10mls of distilled water and 10mls of the solute. Repeat the steps (2-7). Adding 10mls of the solute each time, as shown in this table1.

Table (1): Water Rich Phase

Volume (ml)		Volume (ml)	
Water	Solute	Water	Solute
20	5	10	10
20	10	10	20
20	15	10	30

b. For the organic solvent rich phase:

Repeat the same procedure in (a) using solute-organic solvent solution and titrating with water.

Use the following compositions in table (2):

Table (2): Organic Rich Phase

Volume (ml)		Volume (ml)	
Organic Solvent	Solute	Organic Solvent	Solute
20	5	10	10
20	10	10	20
20	15	10	30

B. Tie Line determination:

1. Fill the cell with a heterogeneous mixture consisting of 20mls of water, 15mls of the solute and 15mls of the other solvent.
2. Agitate the mixture using the mid-point speed for 20 minutes at the desired temperature.
3. Stop the agitator, and leave the mixture foe about 20 minutes to settle into two layers.
4. Withdraw a sample of each phase in a sample bottle and measure the refractive index of each sample.
5. Using the calibration curves, determine the percentage of the solute in each phase.
6. Repeat the steps (1-5) using the mixtures in Table (3).

Table (3): Tie-lines Determination

Component	mls of component			
Solute	13	8	5	3
Organic solvent	20	17	25	29
Water	18	26	20	19

Calculation

A. For ternary mutual solubility curve:
   1. Calculate the composition of each mixture at its cloud point.
   2. Plot the mutual solubility curve for the ternary system on an equilateral triangle.

B. For tie-line determination:
    1. Calculate the overall composition of each mixture.
    2. Locate on the phase diagram the point which represents the overall composition for each mixture.
    3. Find on the mutual solubility curve the points which represent the composition of the extract and the raffinate phases for each mixture.
    4. Construct the tie line corresponding to each mixture.
    5. Check the linearity of the points which represent the overall composition of each mixture, the composition of extract phase, and the composition of raffinate phase.
    6. Check the reliability of the equilibrium data.

References

1. Coulson, J.M.; and Richardson, J.F., "Chemical Engineering ", volume two. Pergamon Press Inc. third edition, 1978.
2. Felder, R.M.; and Roussean R.W., "Elementary Principles of Chemical Processes". John Wily and Sons. second edition, 1986.
3. McCabe, W.L.; and Smith, J.C., "Unit Operations of Chemical Engineering". McGraw-Hill, Inc. third edition, 1976.

Liquid-Liquid Equilibrium Data Sheet

Tie-Lines Determination:

Volume of water (ml)	Volume of Toluene (ml)	Volume of Acetone (ml)	RI of water layer	RI of Toluene layer
20	15	15		
18	20	13		
26	17	8		
20	25	5		
19	29	3		

Solubility curve

A. Water rich phase:

Volume of Acetone (ml)	Volume of water (ml)	Volume of Toluene (ml)
5	20	
10	20	
15	20	
10	10	
20	10	
30	10	

B. Organic solvent rich phase:

Volume of Acetone (ml)	Volume of Toluene (ml)	Volume of water (ml)
5	20	
10	20	
15	20	
10	10	
20	10	
30	10	

Instructor signature:
Date:

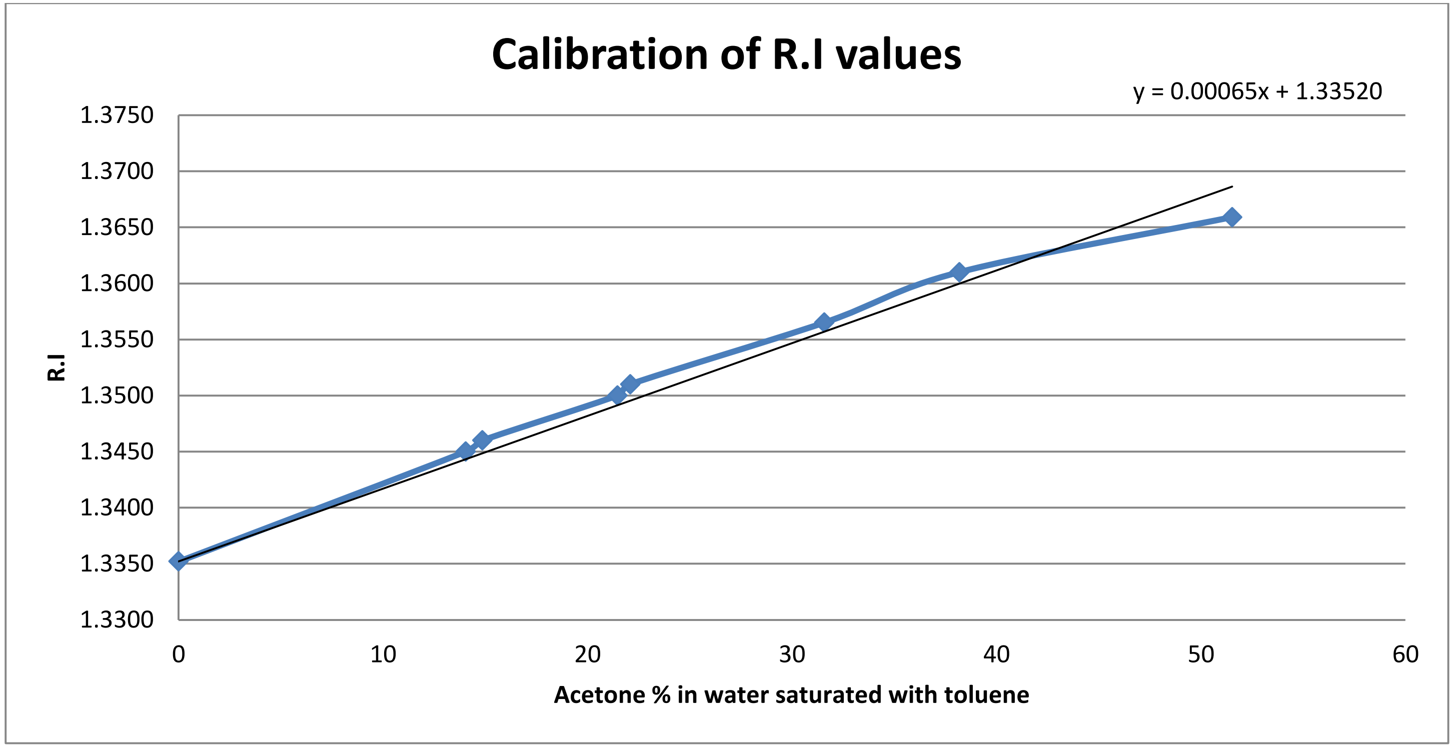

Figure (6): Wt% of Acetone in watersaturated with Toluene Vs Refractive Index

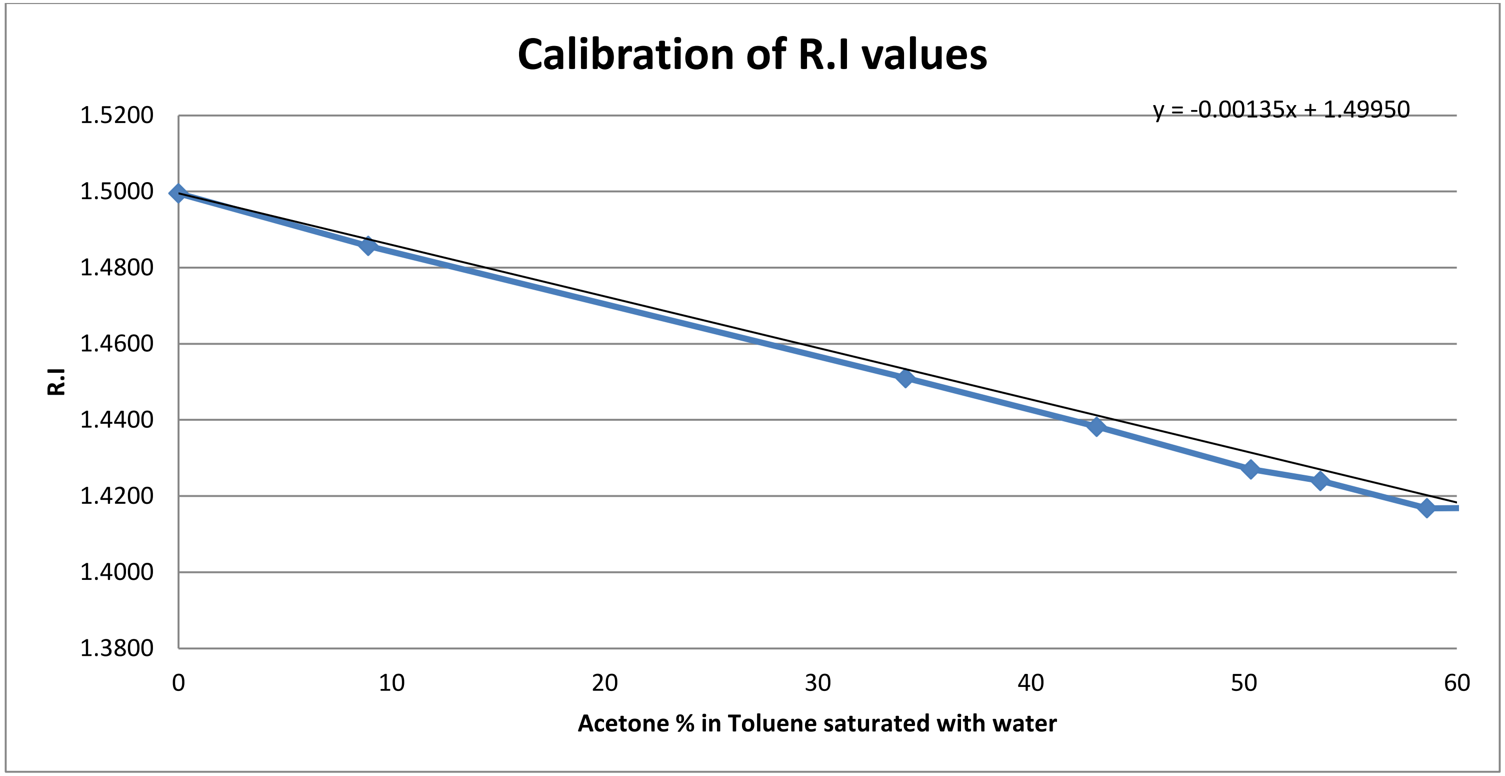

Figure (7): Wt% of Acetone in Toluenesaturated with water Vs Refractive Index

Experiment Number -3-

Digital Joulemeter

Equipment

The digital Joulemeter measures electrical energy directly in joules and power in watts. It has clear digital display which is most valuable for many demonstrations.

The instrument can be used with both direct and alternating current. It has four internal shunts to give maximum current ranges of 0.7mA, 7mA, 0.7A, and 7A, with a maximum input of 15V for (a.c.) the voltage maximum for (d.c.) is 20V with corresponding maximum current of 1mA, 10mA, 1A, and 10A. A three position "JOULES" switch applies multipliers of x1, x10, and x100 to the four ranges. In the x1 setting the right hand digit of the display will be counting in the unit written above the blue external load socket in use. In the x10 setting the right hand digit of the display will count in units ten times that written above the socket. In the x100 setting the units will be one hundred times that written.

Experiment 1

Objective

To determine the specific heat capacity of a metal.

Requirements

Power supply unit 12V (a.c.), immersion heater (12V, 50A), Aluminum block, calorimeter, thermometer, micrometer and 4mm plug leads.

Procedure

1. Connect the circuit as shown in figure (9):

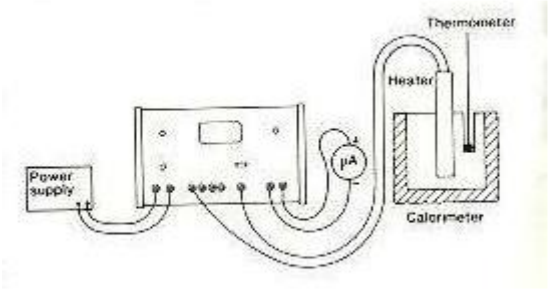

Figure (8): Specific heat capacity of metal circuit.

2. Switch on the heater and once the temperature of the block has risen to about 2ºC reset the joulemeter. When the temperature of the block has risen by about 20ºCread the thermometer and read the joulemeter.

Calculations

Refer to the basic definition of specific heat capacity to calculate it for the metal used.

Experiment 2

Objective

To determine the specific latent heat of vaporization of liquids.

Requirements

An isolated beaker, immersion heater, thermometer, power supply unit, and 4mm plug leads.

Procedure

1. Fill the beaker with a certain amount of the liquid to be tested, put its cover, and then insert the heater and thermometer in it.
2. Connect the circuit as shown in figure (10):

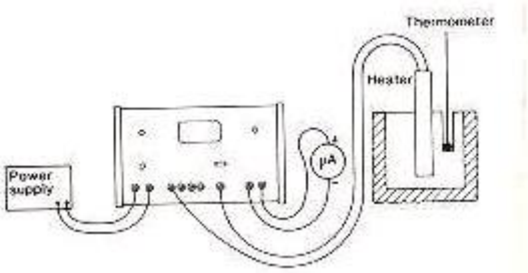

Figure (9): specific heat of vaporization of liquids circuit.

3. Switch on the heater and wait until the liquid boils and record its boiling temperature.
4. Put the beaker on a balance, record the initial weight of the beaker with the liquid in it.
5. Remove the cover of the beaker and let the liquid to vaporize, and then record the final weight of it, and the Joulmeter reading.

Calculations

Refer to the basic definition of specific latent heat of vaporization to calculate it for the liquid used.

Experiment 3

Objective

To investigate the efficiency of a small electrical motor and study its variation with load and applied voltage.

Requirements

Power supply unit (d.c.), electrical motor unit, rheostat (2A, 50A), line shaft unit, load masses, voltmeter (12V), switch (single pole), and 4mm plug leads.

Procedure

1. Connect the circuit as shown in figure (11) using the (d.c.) power supply :

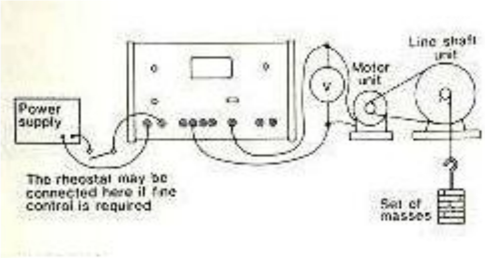

Figure (10):Efficiency of small electrical motor circuit.

2. Adjust the voltage of the power supply until the motor can lift the weight as at a convenient speed.
3. Reset the joulemeter and switch on for as long as it takes the motor to lift the weights through a measured height. Read the voltmeter during the lift.
4. Repeat the experiment at different load masses when the voltage is the same, or at different voltages when the mass lifted remains the same.

Calculations

Calculate the efficiency of the motor, and study its variation with load and applied voltage.

Digital Joulemeter Data Sheet

1. Specific heat Capacity:

Mass of AL-Block	
Joule meter reading	
T_1	
T_2	

2. Specific latent heat of vaporization:

Initial mass of liquid	
Final mass of liquid	
Temperature of liquid	
Joule meter reading	

3. Efficiency of a motor:

Change in height=……………….cm

Mass of hanger=………………..g

a. At constant Voltage=…………..V

Mass lifted (g)	Joule meter reading

a. At constant mass=……………g

Voltage (V)	Joule meter reading

Instructor signature:

Date:

Experiment Number -4-

Shell and Tube Heat Exchanger

Objective:

1. To perform energy balances across a Shell and Tube Heat Exchanger andcalculate the Overall Efficiency at different fluid flow rates.
2. To demonstrate the differences between co-current flow (flows in same direction) and countercurrent flow (flows in the opposite direction), and the effect on heat transfer coefficient and temperature efficiencies
3. To determine the Overall Heat Transfer Coefficient for a Shell and Tube Heat Exchanger using the Logarithmic Mean Temperature Difference to perform the calculations (for co-current and countercurrent flow).
4. To investigate the effect of changes in hot and cold fluid flowrate on the Temperature Efficiencies and Overall Heat Transfer Coefficient.

Equipment:

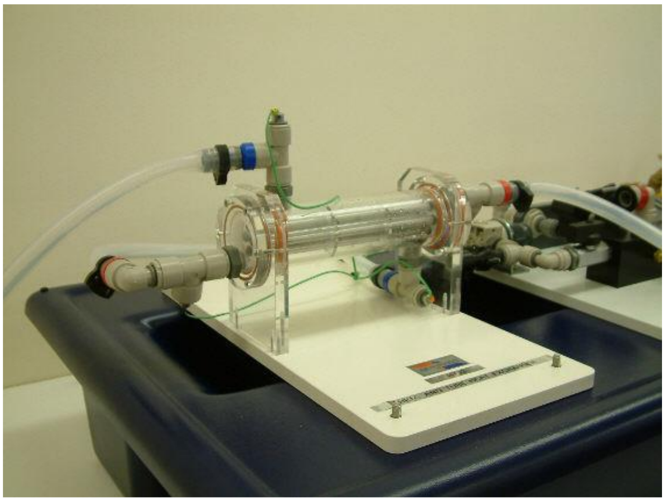

Figure (11): Shell and Tube Heat Exchanger

The shell and tube heat exchanger is commonly used in the food and chemical process industries. This type of exchanger consists of a number of tubes in parallel enclosed in a cylindrical shell. Heat is transferred between one fluid flowing through the tubes and another fluid flowing through the cylindrical shell around the tubes.

In this miniature exchanger, baffles inside the shell increase the velocity of the fluid and hence the rate of heat transfers. The exchanger has one shell and seven tubes with two transverse baffles in the shell.

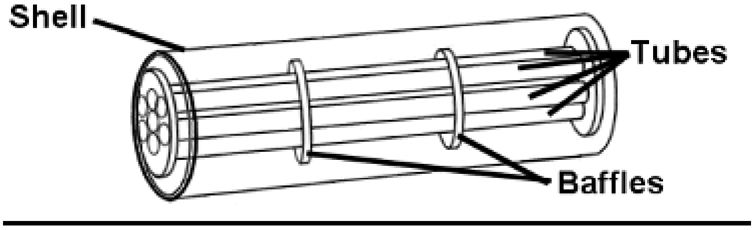

Figure (12): Parts of the exchanger

In normal operation the hot fluid from the hot water circulator enters the header at one end of the shell and passes through the bundle of stainless steel tubes.

The cold fluid from the cold water supply passes through the cylindrical shell. This arrangement minimizes heat loss from the exchanger without the need for additional insulation and allows the construction of the exchanger to be viewed.

The outer annulus, caps and baffles are constructed from clear acrylic to allow visualization of the heat exchanger construction and minimize thermal losses. These provide a liquid seal, accommodate differential expansion between the metal and plastic parts and allow the inner metal tubes to be removed for cleaning.

'O' ring seals allow differential expansion between the metal and plastic parts and allow the inner metal tubes to be removed for cleaning. The end housings incorporate the necessary fittings for sensors to measure the fluid temperatures and connections to the hot and cold water supplies, which is colored coded red for hot water and blue for cold water.

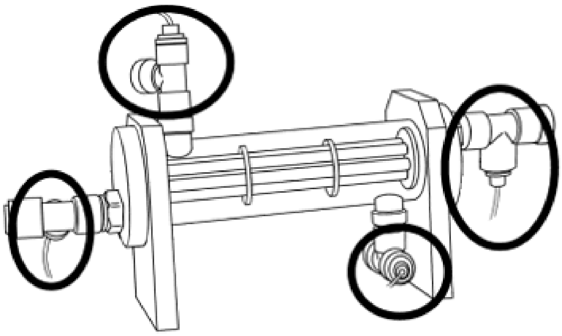

Figure (13):'O' ring seals

Four thermocouple temperature sensors are labeled T_1 to T_4 for identification and each lead is terminated with a miniature thermocouple plug for connection to the appropriate socket.

Theory:

If the fluids flow through the exchanger in the same direction, then the unit is said to operate in parallel or co-current flow. Flow in opposite direction is called counter-current flow.

The mass flow rate can be calculated from the volumetric flow rate as flow:

$$m = \dot{V} * \rho \quad \dots\dots\dots (1)$$

where:

m:mass flow rate (kg/s)
$\dot{V}$: volumetric flow rate (m^3/s)
ρ: density of the fluid in (kg/m^3)
Then the heat duty Q calculated from the equation (2):

$$Q = m.c_p.\Delta T \quad \dots\dots\dots (2)$$

therefore:

$$Q_e = m_h.c_{phot}.(T_1 - T_2) \quad \dots\dots\dots (3)$$

$$Q_a = m_c.c_{pcold}.(T_4 - T_3) \quad \dots\dots\dots (4)$$

Then:

$$Q_l = Q_e - Q_a \quad \dots\dots\dots (5)$$

andthe overall heat transfer efficiency can be calculated from equation:

$$\eta_{overall} = \frac{Q_{absorbed}}{Q_{emitted}} \dots\dots\dots (6)$$

where:

Q_e: Heat power emitted from hot fluid (W)
Q_a: Heat power absorbed by cold fluid (W)
O_l: Heat power lost or gained (W)
m_h ,m_c: mass flow rate for hot and cold fluid respectively (kg/s).
C_{phot}: specific heat capacity for hot fluid (kJ/kg.K)
C_{pcold}: specific heat capacity for cold fluid (kJ/kg.K)
T_1, T_2: hot fluid inlet or outlet temperatures (according to flow direction) (°C).
T_3: cold fluid inlet temperatures (°C).
T_4: cold fluid outlet temperatures (°C).

For the overall heat transfer coefficient:

$$U = \frac{Q_e}{A.L_{MTD}} \quad \dots\dots\dots (7)$$

where:

U: the overall heat transfer coefficient referred to area A (W/m^2.K).

A: the heat transfer area required in the exchanger (m^2).

L_{MTD}: the mean temperature difference between the two fluids.

The heat transmission area (A) in the exchanger must be calculated using the arithmetic mean diameter of the inner tubes.

$$d_m = \frac{d_o + d_i}{2} \quad \dots\dots\dots (8)$$

where:

d_m : is the arithmetic mean diameter (m) (d_m can be used since $r_2/r_1<1.5$ otherwise the logarithmic mean radius d_{lm} must be used).
d_i: inner tube inside diameter = 0.00515(m).
d_o: inner tube outside diameter = 0.00635(m).

Heat transmission length $L = n.l$ (m)
where n = number of tubes = 7
l = heat transmission length of each tube = 0.144 (m)
then L = 1.008 (m)
and the heat transmission area:

$$A = \pi . d_m . L \quad \dots\dots\dots (9)$$

The overall heat transfer efficiency can be calculated from equation:

And the thermal efficiency for the cold side:

$$\eta_{cold} = \frac{\Delta T_{cold}}{\Delta T_{max}} \dots\dots\dots (10)$$

And the thermal efficiency for hot side:

$$\eta_{cold} = \frac{\Delta T_{hot}}{\Delta T_{max}} \dots\dots\dots (11)$$

Where:

$\Delta T_{cold}=T_{c.out}-T_{c.in}$

$\Delta T_{hot}=T_{h.in}-T_{h.out}$.

$\Delta T_{max}=T_{h.in}-T_{c.in}$.

Then the efficiency of exchanger $= \frac{\eta_{cold}+\eta_{hot}}{2}$.

Procedure:

1. Set the temperature controller to 60°C.
2. Set the hot water valves to have co-current direction.
3. Adjust the cold water control valve setting to give a cold water flow rate of 2litre/min.
4. Click on the button for the hot water flow rate controller, set the controller to Automatic and enter a Set Point value of 1 liters/min. Apply and click ‘OK’.

5. Allow the temperatures to stabilize for 10 min, and thenselect the icon (Go) to record the following, or manually note the values: T_1, T_2, T_3, T_4, F_{hot}, F_{cold}.
6. Adjust the hot water control valve to give 2liters/min.
7. Allow the heat exchanger to stabilize then repeat the above readings with 3, 4, 5 liters/min for hot water flow rate.
8. Repeat with counter flow direction.

Calculation:

1. Calculate the heat duty emitted, absorbed, and lost.
2. Calculate the efficiency of the exchanger for both co-and counter arrangement.
3. Calculate the overall heat transfer coefficient.
4. Calculate the temperature efficiency of the heat exchanger.
5. Plot the temperature profile for both the co-current and counter current at one and same hot water flow rate.
6. Plot the efficiency of the exchanger with the hot water flow rate.

References:

1. Coulson J.M. and Richardson J.F., "Chemical Engineering", Volume 1, 2nd Edition, Pergamon Press.
2. Kern D.Q., "Process Heat Transfer ", McGraw Hill.
3. Perry R.H., Chilton C.H., "Chemical Engineering Handbook". 5th Edition, MacGraw Hill.
4. Armfield Instruction manual, Shell and tube heat Exchanger HT33, ISSUE 17, November 2015.

Shell and Tube Heat Exchanger Data Sheet

Cold water flow rate: _______________

Co-current flow:

Hot water flow rate (Liter/min)	$T_{hot,in}$ (ºC)	$T_{hot,out}$ (ºC)	$T_{cold,in}$ (ºC)	$T_{cold,out}$ (ºC)

Counter-current flow:

Hot water flow rate (Liter/min)	$T_{hot,in}$ (ºC)	$T_{hot,out}$ (ºC)	$T_{cold,in}$ (ºC)	$T_{cold,out}$ (ºC)

Instructor signature:
Date:

Experiment Number -5-

Concentric Tube Heat Exchanger

Objective:

1. To demonstrate the working principles of a concentric tube heat exchanger operating under co-and counter flow arrangements.
2. To demonstrate the effect of hot water temperature variation, flow rate variation on the performance characteristics of a concentric tube heat exchanger.

Equipment:

A supply of hot water at temperature up to 80ºC is maintained in a storage tank at the rear of the apparatus by an integral heating element. Power to the electric element is regulated by a controller, which is mounted on the front panel and incorporates a decade switch to set the desired water temperature, a deviation meter to indicate the deviation of the water temperature from the set point. Water is continuously recirculated through the tank by a pump.

Hot water for the exchanger is taken from the pump discharge and passes through the inner pipe of the concentric tube arrangement before returning to the tank for reheating. Flow through this circuit is regulated by a control valve (18) and indicated at the flow meter (19). Thermometer (15) and (17) installed at the inlet, midpoint and outlet of the exchanger hot water circuit indicate the respective water temperature. As shown in figure (14)

Cold water for the exchanger is supplied from an external source to the outer annulus of the concentric tube arrangement. Co-or counter-flow configuration may be obtained by appropriate setting of the selector valve (16). Valve (11) at the top of the exchanger permits air to be bled from the system and facilitate drainage.

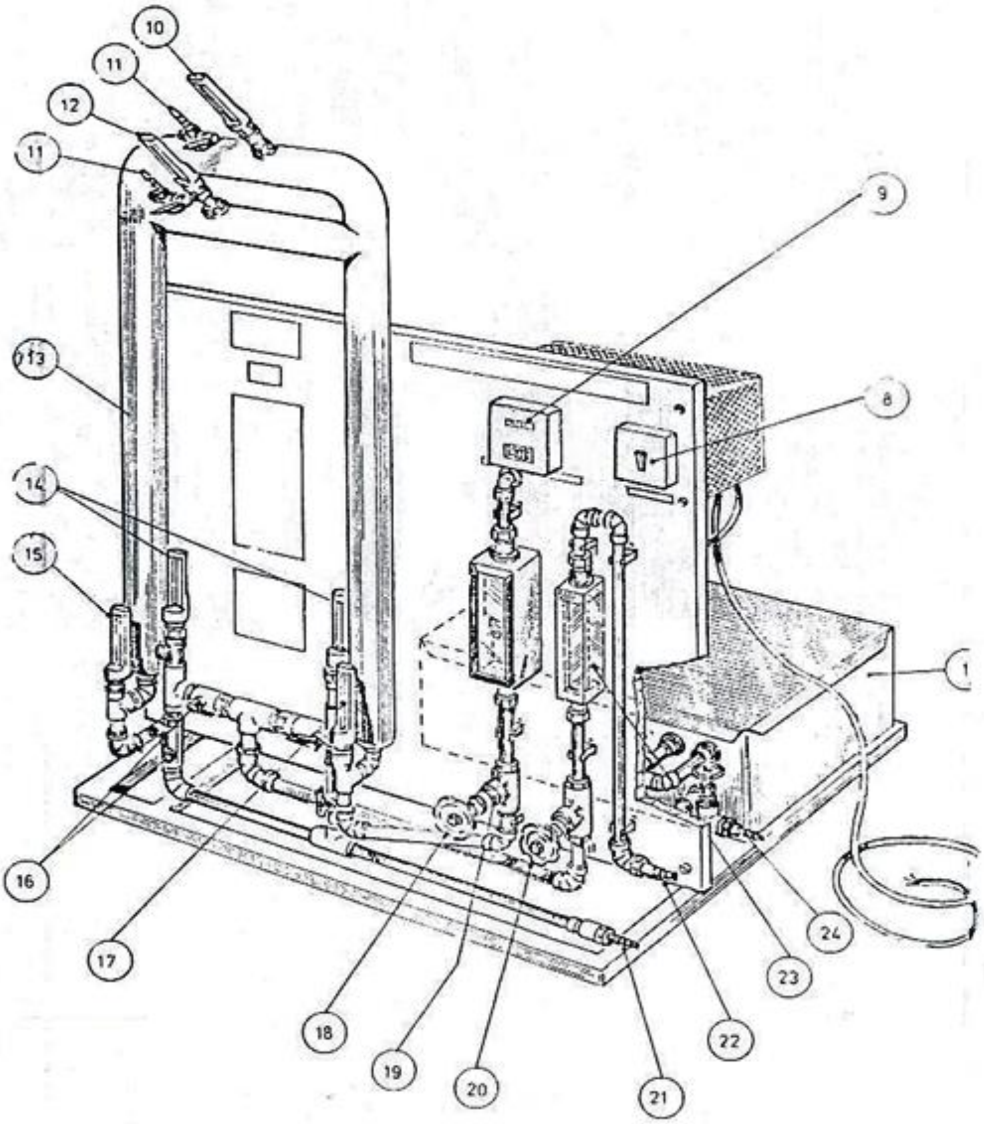

Figure (14): Schematic diagram for concentric tube heat exchanger.

Theory:

One of the simplest forms of heat exchanger is the so-called double-pipe exchanger. One of the fluids passes through the tube whilst the second fluid flows through the annular space. If the fluids flow through the exchanger in the same direction, then the unit is said to operate in parallel or co-current flow. Flow in opposite direction is called counter-current flow. The duty Q of the exchanger can be calculated from the change/unit time in sensible heat content of a fluid being heated or cooled, and/or the latent heat extracted or supplied in condensation or evaporation processes respectively.

In terms of heat transfer, the duty of the exchanger can be described by the simple equation:

$$Q=U.A.\,(L_{MTD})\ldots\ldots\ldots(1)$$

where:

U: the overall heat transfer coefficient referred to area A.

A: the heat transfer surface required in the exchanger.

L_{MTD}: the mean temperature difference between the two fluids.

The overall heat transfer efficiency can be calculated from equation:

$$\eta_{overall}=\frac{Q_{absorbed}}{Q_{emitted}}\ldots\ldots\ldots(2)$$

And the thermal efficiency for the cold side:

$$\eta_{cold}=\frac{\Delta T_{cold}}{\Delta T_{max}}\ldots\ldots\ldots(3)$$

And the thermal efficiency for hot side:

$$\eta_{cold}=\frac{\Delta T_{hot}}{\Delta T_{max}}\ldots\ldots\ldots(4)$$

Where:

$\Delta T_{cold}=T_{c.out}-T_{c.in}$.

$\Delta T_{hot}=T_{h.in}-T_{h.out}$.

$\Delta T_{max}=T_{h.in}-T_{c.in}$.

Then the efficiency of exchanger equal$\frac{\eta_{cold}+\eta_{hot}}{2}$.

Procedure:

1. Fill the storage tank with clean water.
2. Close the air bleed valve (11) at the top of the heat exchanger.
3. Connect the cold water inlet to a source of cold water using flexible tubing.
4. Close the hot water flow control valve (18).
5. Set the selector switch on the side of the pump motor to the maximum setting.
6. Set the temperature controller to zero using the decade switches on the front panel.
7. Set the electrical supply switch on the ON position and observe operation of the pump.
8. Open the hot water flow control valve (18) to a medium value and allow water to flow through the exchanger until a steady flow of water is indicated on hot flowmeter (19).
9. Open the cold water flow control valve. Set the selector valves to co-current position. Allow water to flow through the exchanger until a steady flow of water is indicated on the cold flowmeter.
10. Set the temperature controller to 50ºC.
11. Take the thermometers readings once they are stabilized as well as the flowrates on the flowmeters.
12. Increase the controller set point to 60ºC, 70ºC, 80ºC and note the thermometers readings.
13. Set the controller temperature to 60ºC and change the flowrate of hot water, making sure to note the readings of the thermometers for each flowrate.
14. The above procedure can be repeated for counter current.

Calculation:

7. Calculate the efficiency of the exchanger for both co-and counter arrangement.
8. Calculate the overall heat transfer coefficient.
9. Calculate the temperature efficiency of the heat exchanger.
10. Plot the temperature profile for both the co-current and counter current.

References:

5. D.Q. kern, "Process Heat Trancfer ". McGraw Hill, 1982.
6. Coulson & Richardson, "Chemical Engineerning ", Vol. 1.1980.

Concentric Tube Heat Exchanger Data Sheet

Heat transfer area: _______________

Heat transfer length: ______________

Cold water flow rate:_______________

Co-current flow:

Hot water flow rate (cm^3/min)	$T_{hot,in}$ (ºC)	$T_{hot,out}$ (ºC)	$T_{cold,in}$ (ºC)	$T_{cold,out}$ (ºC)

Counter-current flow:

Hot water flow rate (cm^3/min)	$T_{hot,in}$ (ºC)	$T_{hot,out}$ (ºC)	$T_{cold,in}$ (ºC)	$T_{cold,out}$ (ºC)

Instructor signature:
Date:

Experiment Number -6-

Heat Conduction

Objective:

1. To measure the temperature distribution for steady state conduction of energy through a uniform cross-section and demonstrate the effect of a change in heat input.
2. To determine the thermal conductivity of a material and the effect of temperature on thermal conductivity.
3. To measure the application of poor thermal conductors and determine the thermal conductivity K of a poor thermal conductor.

Equipment:

The unit consists of a heat service unit, supplying a variable A.C. voltage to vary heater power. A heat conduction unit and 12 type K thermocouple sockets allow connection of this unit to the service unit. Three fixed thermocouples T_1, T_2, T_3, are positioned along the heated section at 15 mm intervals. Three fixed thermocouples T_6, T_7, T_8, are positioned along the cooled section at 15 mm intervals, and four intermediate sections are supplied to place between the heated and cooled sections. Water for the cooled section is supplied from the tap via a hose.

The specimens are brass or stainless steel of 30 mm and 25 mm diameter.

Theory:

The fundamental law of heat conduction is that of Fourier:

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

Q: is the rate of heat input.

K: is the thermal conductivity.

x: is the distance from the hot end.

T: is the temperature.

The negative sign being inserted because the heat is flowing towards the lower temperature face.

Integrating the above equation gives.

a. For linear conduction through a uniform bar.

$$Q = -KA\frac{T_1 - T_2}{L}$$

b. For radial conduction through a cylinder.

$$Qln\frac{R_2}{R_1} = 2\pi KL(T_1 - T_2)$$

where :

A: is the cross-sectional area of the bar.
L: is the length of the specimen.
$R_1$and R_2: is the radius of the specimen at T_1 and T_2.

Procedure:

1. Ensure that the main switch is in the off position and the voltage controller is in the anti-clockwise position.
2. Make sure that the heat transfer unit is connected to the heat transfer service unit, and the specimen is installed in the heat transfer unit.
3. Open the water tap until the water flows through the drain.
4. Turn on the main switch and set the temperature selector switch to T_1.
5. Rotate the voltage controller clockwise to increase the voltage to the specified value, and observe the temperature T_1.
6. Allow the system to reach stability and take the reading of temperatures, voltage and current.
7. Repeat at different heat input or different specimens.
8. It is possible to connect the unit to the computer via the interface to monitor and record the temperature along the specimen, and have them on a printer paper. (You have to follow the instruction of your supervisor).

Calculation:

1. Draw graph of temperature gradient at steady state at different heat input.
2. Draw graph of temperature variation with time.
3. Calculate the thermal conductivity of the material under investigation and investigate the effect of changing heat transfer coefficient on the conductivity.

References:

Christie J. Geankolis,” Transport Processes and Unit Operation”, 3rd Edition, Perntic Hall.

Experiment Number -7-

Free and forced convection

Objective:

- To study how heat convects from a choice of three different surfaces (flat plate, pinned surface, and finned surface) both under free convection and under forced convection.
- To determine free and forced convection heat transfer coefficient for the three surfaces.

Equipment Description:

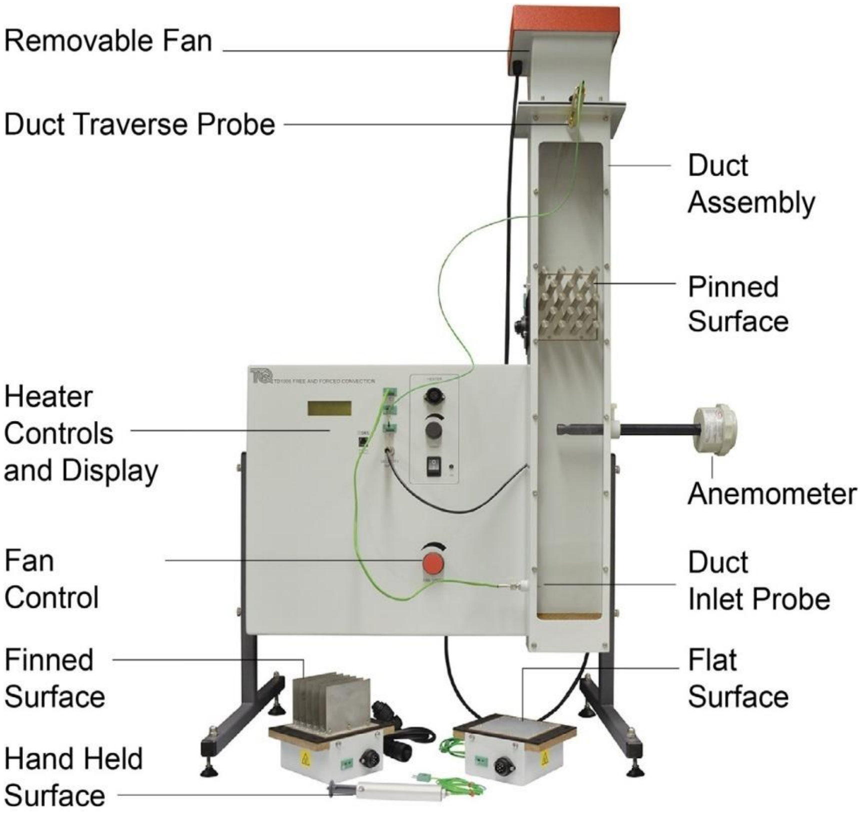

Figure (15): the free and forced convection apparatus (TD1005)

The Main Unit is a compact bench-mounting frame that connects to a suitable electrical supply. It has a vertical duct assembly and a main ‘Control Panel’ with electrical controls and displays.

Each of the three heat transfer surfaces (supplied) fit into the back of the vertical duct, at just above half- way up the duct.

The vertical duct allows air to pass over the heat transfer surface, both by free convection, or by forced convection using a removable variable speed electric fan at the top of the duct. A fixed thermocouple probe measures the inlet (ambient) air temperature in the duct. A movable thermocouple probe in a traversing mechanism allows measurement of the temperature distribution across the duct at the outlet. This allows students to find the bulk outlet temperature for the more advanced calculations. An anemometer measures air velocity in the duct.

Each heat transfer surface includes a built-in thermocouple to measure its surface temperature. The equipment also includes a hand-held thermocouple probe for heat distribution measurement along the finned and pinned heat transfer surfaces. The user inserts the probe tip into a selection of six equally- spaced holes in the side of the duct. A magnetic cover allows the holes to be covered completely or so that only use one at a time can be used, reducing stray convection caused by the other holes.

The Base Unit supplies safe, low-voltage electrical power to the heater (heat source) in each heat transfer surface and a variable supply for the fan at the top of the duct. The thermocouples in the duct and the thermocouple on the heat transfer surface connect to sockets on the front of the control panel. For heat distribution experiments with the hand-held probe, the user connects the probe to any unused thermocouple socket (not all are used for each experiment). A display on the control panel shows the electrical power supplied to the heater in the heat transfer surface, the air velocity in the duct and the temperature at each of the three thermocouples connected.

A socket on the control panel allows connection to TecQuipment’s optional VDAS for data acquisition from this equipment, with the use of a suitable computer

The heat transfer surfaces:

This experiment includes three different heat transfer surfaces to allow students to compare their performance Each heat transfer surface fits quickly and easily into a square opening in the back side of the duct. A foam gasket around each surface helps to sea it from stray convection when fitted to the duct.

Each heat transfer surface has two sides:

An exposed front side:. It has a light grey bare metal finish. This helps to ensure more accurate experiment results because most heat transfer are then by convection rather than radiation (a dark matt black surface increases heat loss by radiation). In actual applications, heat transfer surfaces are often coated matt black to maximize heat transfer by both convection and radiation.

An enclosed back side: This has a surface-bonded electrical heater and a centrally-mounted thermocouple. The heater includes a thermal safety cut-out switch to help prevent overheating. Insulation surrounds the back side. This prevents unnecessary heat loss which would affect the experiment results.

Flat plate:

Figure (16): the flat plate.

This is simply a flat aluminum plate. This surface is unique from the other two, in that it fits completely flush with the inner wall of the duct and has no extra fins or pins that penetrate the duct airflow

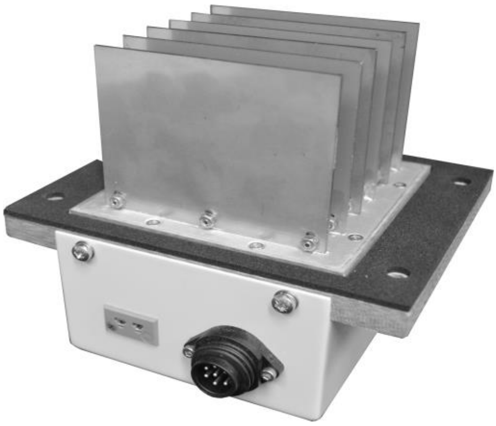

Figure (17): the finned surface.

Finned surface:

This is a popular surface design used in for ‘heat sinks’ to transfer heat away from components in electrical and electronic circuits. It effectively increases the available heat transfer surface area to help transfer more heat into the surrounding air (or capture heat from the surrounding air if used in reverse). This surface is useful for a demonstration of free convection both vertically (up from the fins) and horizontally (with finsh orizontal).

Figure (18): the pinned surface.

Pinned surface:

This is a popular surface design used in ‘heat exchangers’, where one fluid flows along the pins (usually hollow tubes) atright angles to the flow of another fluid that passes around the pins. The heat energy in the hotter fluid passes through the surface of the pins or tubes into the colder fluid. Again, as with the finned surface, this surface effectively increases the available heat transfer surface area to help transfer more heat into the surrounding fluid (or air as used here).

Note: all technical details were listed in the appendices.

Theory:

Heat transfers from one body to another by three methods, conduction, convection and radiation. Most real-world heat transfer uses elements of all three. Here in our experiment we are talking about convection, while the heat transfers by a fluid (liquid, air or gas).

Free Convection

This is when the heat transfers from the object under the influence of fluid (air) density changes. The heat energy around the object causes the air density around the surface of the object to decrease. The reduced density air is more buoyant than the surrounding air and rises, transporting the heat energy away naturally. In normal conditions gravity is the main force affecting buoyancy and therefore convection. However, where the object forms part of a rotating machine, centrifugal force can be a driving force for convection.

Forced Convection

Thisiswhenanexternalforcemovesairaroundoracrossthesurface.Themovementofairtransports the heated air away from the object. The higher the air velocity, the faster it transports heat away from the object.

Heat Transfer Coefficient (Convective) (h_C)

Heat transfer coefficient is a material’s ability to conduct heat to another material. Convective heat transfer occurs between the surface of a material and a moving fluid. Typical values of heat transfer to air are:

5to 25 W/m^{2}K in **free** convection

10to 200 W/m^{2}K in **forced** convection

(Showing that heat transfers to air better in forced convection than it does in free convection).

$$h_c = \frac{Q}{A_S \times T_m} \qquad (1)$$

Where Q is the rate of heat energy transfer from the surface to the air in J/s.

A_s is the cross sectional area of the surface in m^2.

And T_m is the logarithmic mean temperature.

$$T_m = \frac{T_{out} - T_{in}}{log \frac{T_s - T_{in}}{T_s - T_{out}}} \qquad (2)$$

Experiment 1: Free convection.

Note: This experiment works for all three heat transfer surfaces.

Procedures:

1. Remove the fan from the top of the duct.
2. Fit the chosen heat transfer surface.
3. For reference only, take readings of the surface and inlet temperatures with no power applied.
4. Switch on the heater and set to 5 watts power.
5. Wait for the temperatures to stabilizes, under free convection, it may take up to 30 minutes for temperatures to stabilize, and then record surface and inlet temperature.
6. Repeat for several more heater powers as shown in the table, stopping before the surface reaches 95ºC.
7. If there is time, Repeat the experiment for the other heat transfer surfaces (pinned or finned).
8. Switch off the heater and allow the surface to cool down to near ambient temperature.

Table 1 : result table for flat plate

Heat Transfer Surface: flat plate			
	T_2	**T_1**	
Power (W)	**Surface T_S (°C)**	**Duct Inlet (ambient) T_{IN} (°C)**	**Difference T_S - T_{IN} (°C)**
0			
5			
10			
15			
20			
25			
30			
35			
40			
45			
50			

Result analysis:

For each table of results, subtract the inlet temperature from the heat transfer surface temperature to complete the results tables. The temperature difference gives a value with respect to ambient, helping to allow for changes in local conditions.

Create a chart of temperature difference against power (horizontal axis). Add to this chart the results from both surfaces to see the relationship and compare results.

Compare the results. Which surface created the highest temperature difference in free convection? What does this say about this surface?

Experiment 2: Forced convection – Effect of velocity

Note: This experiment works for both the pinned and finned heat transfer surfaces.

Procedures:

1. Fit the fan to the top of the duct.
2. Fit either the finned or pinned heat transfer surface.
3. Set the fan to give an air velocity of 1 m/s.
4. Set the heater power to 50 W.
5. Wait for the temperature to stabilize.
6. Record the surface and inlet temperatures.
7. Repeat for increased air velocities of approximately 1.5, 2, 2.5, and 3 m/s.
8. Repeat for the other surface.

Table 2: Results for exp. 2

Heat transfer Surface: **Power:**			
	T_2	**T_1**	
Air velocity ($m.s^{-1}$)	**Surface Ts (°C)**	**Duct Inlet (ambient) Tin (°C)**	**Difference T_S - T_{IN} (°C)**

Result analysis:

for each surface, create a chart of $T_s – T_{in}$ (vertical axis) against velocity.

What does the chart say about temperature and velocity?

Which surface has the coolest temperature for any given air velocity?

Experiment 3: Heat transfer coefficient.

Note: This experiment works for all three heat transfer surfaces, and for both free and forced convection.

Procedures:

1. Make sure the duct is perfectly vertical, as this will affect the results.
2. Remove the fan from the top of the duct.
3. Fit one of the heat transfer surfaces.
4. Set the heater to 20 W.
5. Move the duct traverse probe so it reads zero. Check that its tip touches the opposite wall of the duct at this position. Now move it to 1 mm position.
6. Wait for the temperature to stabilize and then take readings of the surface, inlet and outlet (duct probe) temperatures.
7. Take readings using large steps and stop when on reaching 74 mm. and recheck the inlet and surface temperatures.
8. For forced convection, repeat the experiment with the fan fitted and airflow of 3 m/s.

Duct Traverse Probe Position (mm)	T_1	T_2	T_3	Ts-Tin (°C)	Tp-Tin (°C)
	Ambient Temperature (Probe) Tin(°C)	Heat Transfer Surface Temperature Ts (°C)	Duct Traverse Probe Tp (°C)		

Result analysis:

For each set of results (free and forced):

1. Produce a chart of T_p-T_{in} to see the outlet temperature profile with respect to inlet (this allows for changes in ambient temperature).
2. Find T_{out} by calculating the average of T_{out} readings.
3. Find average values for the other temperature readings.
4. Use the T_{out} and the average readings to find the logarithmic mean temperature difference T_m using Equation2.
5. Use this to find the heat transfer coefficient (h_c) (assuming heat flow to the air is equal to the power applied).
6. Compare the values with those given in the theory.

References:

- Basic Engineering Thermodynamics, by Rayner Joel, published by Longman ISBN 0-582-25629-1
- Engineering Thermodynamics, by G.F.C Rogers and Y.R Mayhew, published by Longman, ISBN 0-582-02704-7
- Heat transfer, by J.P Holman, published by McGraw Hill, ISBN 978-0-07-352936-3.

Experiment Number -8-

Fluidized Bed Heat Transfer Unit

Objective:

1. To calculate the heat transfer coefficient in fluidized bed.
2. To show the effect of fluid velocity on pressure drop through the fluidized bed.

Equipment:

The equipment consists of a glass cylinder through which a controllable flow of air is passed. It is mounted vertically with a diffuser/ filter at the lower end. A further filter at the upper end prevents solid particles suspended in the air stream from escaping. Air from a blower fan is produced controlled by a bleed control valve. This valve is progressively closed causing air to pass through two flow meters in turn and then the chamber at the lower end of the glass cylinder below the diffuser/filter before passing through the solid particles held above the filter.

Two flow meters is used, one having approximately one tenth the range of the other. This ensures that both the initial onset of fluidization can be measured as well as the full range which exceeds the Fluidization velocity. An electric heating element in mounted in such a manner that it can be held at any height within the glass cylinder, the surface area of the heating element is 20 cm^2. The power input is controlled by a variable transformer and the surface temperature of the element is measured by a thermocouple located close under the surface of the thin copper cylinder which surrounds the heating element. By this means the cooling effect of the air and solid particle can be accurately measured.

Additional thermocouples are placed, one under the diffuser to measure air entry temperature and the other one on a movable probe to enable temperature measurement at any part in the cylinder. The thermocouple marked "X" is located close under the surface of the copper cylinder and is coupled directly to a high temperature cut out.

Pressure drop through the fluidized bed of solid particles is measured by tubular pressure probe which can be adjusted vertically to sense pressure just above the diffuser/filter. See figure (19).

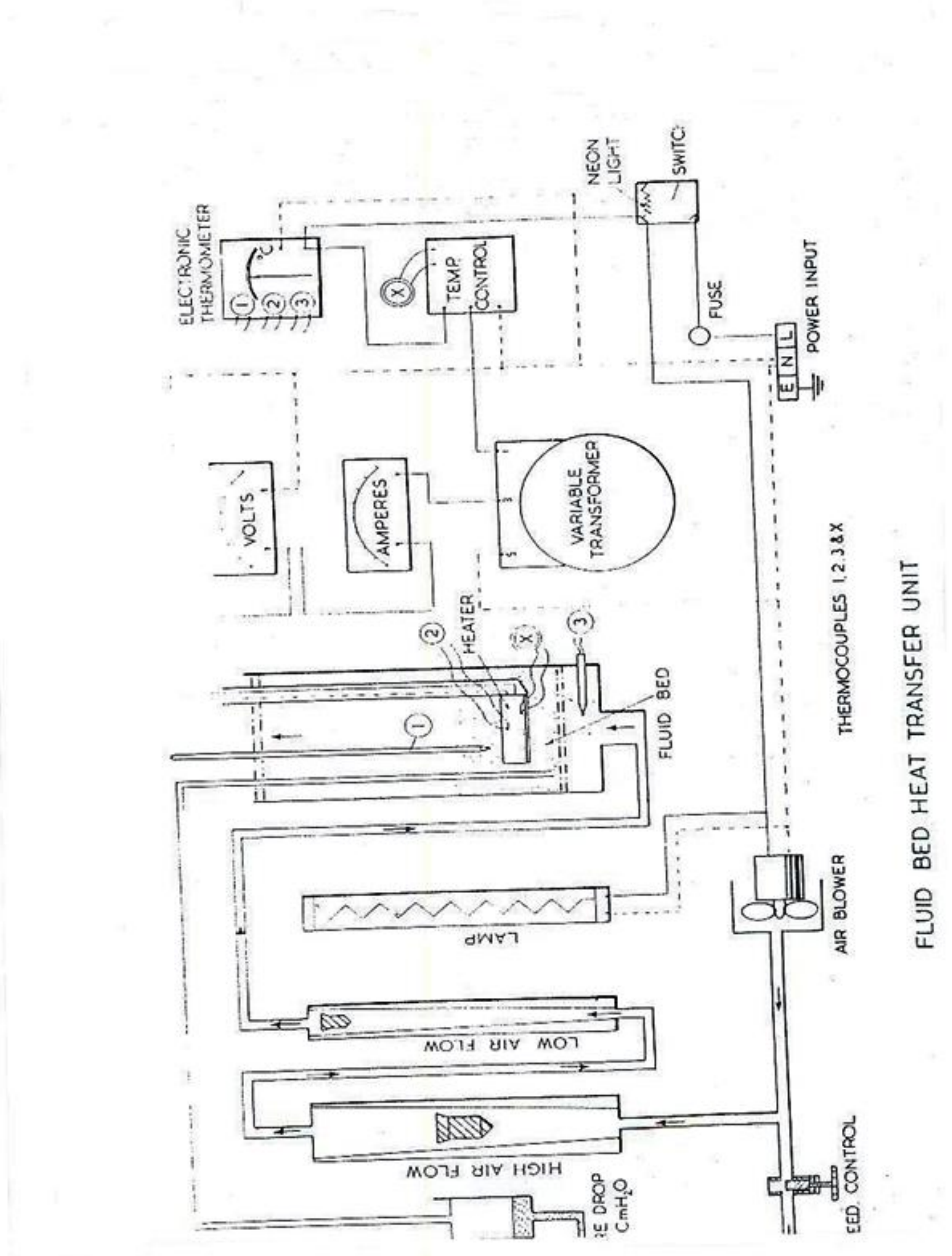

Figure (19): Schematic diagram for fluid bed heat transfer unit.

Theory:

Throughout the whole range of industry there can be found important processes which depend for their success upon good contact between fluid and a particulate solid. A major advantage of fluidized bed operation in heat transfer processes is that the rate of heat transfer is enhanced compared to similar conditions in traditional operations. Applications of fluidization include catalytic petroleum processes, ion exchange water treatment, separation processes and the combustion of solid fuels.

The heat transfer coefficient can be calculated by using the following equation for both (fixed and fluidized bed).

$$Q = h.A.(T_2 - T_1)$$

where:

Q: heat input (Q=V.I).

A: surface area of the heating element.

T_1: temperature of the bed.

T_2: Temperature of the heating element.

Procedure:

1. With the air bleed control opened fully, switch on the blower.
2. Immerse the heating element fully in the bed.
3. Adjust the variac to maintain the heating element at some predetermined temperature as controlled by the thermostat, and at the same time close the bleed control valve progressively so that the air is induced through the bed material causing the pressure to rise across the bed.
4. Wait for the steady state temperatures to be reached.
5. Record the flow rate, bed pressure drop, air temperature, element temperature, voltage and current at each air flow rate, and also record your observation.

Calculation:

1. Plot the bed pressure drop against air flow rate.
2. Plot the heat transfer coefficient against the air flow rate

References:

1. J.M. Coulson and J.F. Richardson, "Chemical Engineering", Vol.2, Third Edition, 1978, Pergamon Press.
2. D.Q. kern, "Process Heat Transfer ", McGraw Hill, 1982.

Fluidized Bed Heat Transfer Unit Data Sheet

Flow rate	T_1 (ºC) Bed Temp.	T_2 (ºC) Heater Temp.	T_3 (ºC) Air Temp.	Voltage (V)	Current (A)	ΔP(cmH_2O)	Observation

Instructor signature:

Date:

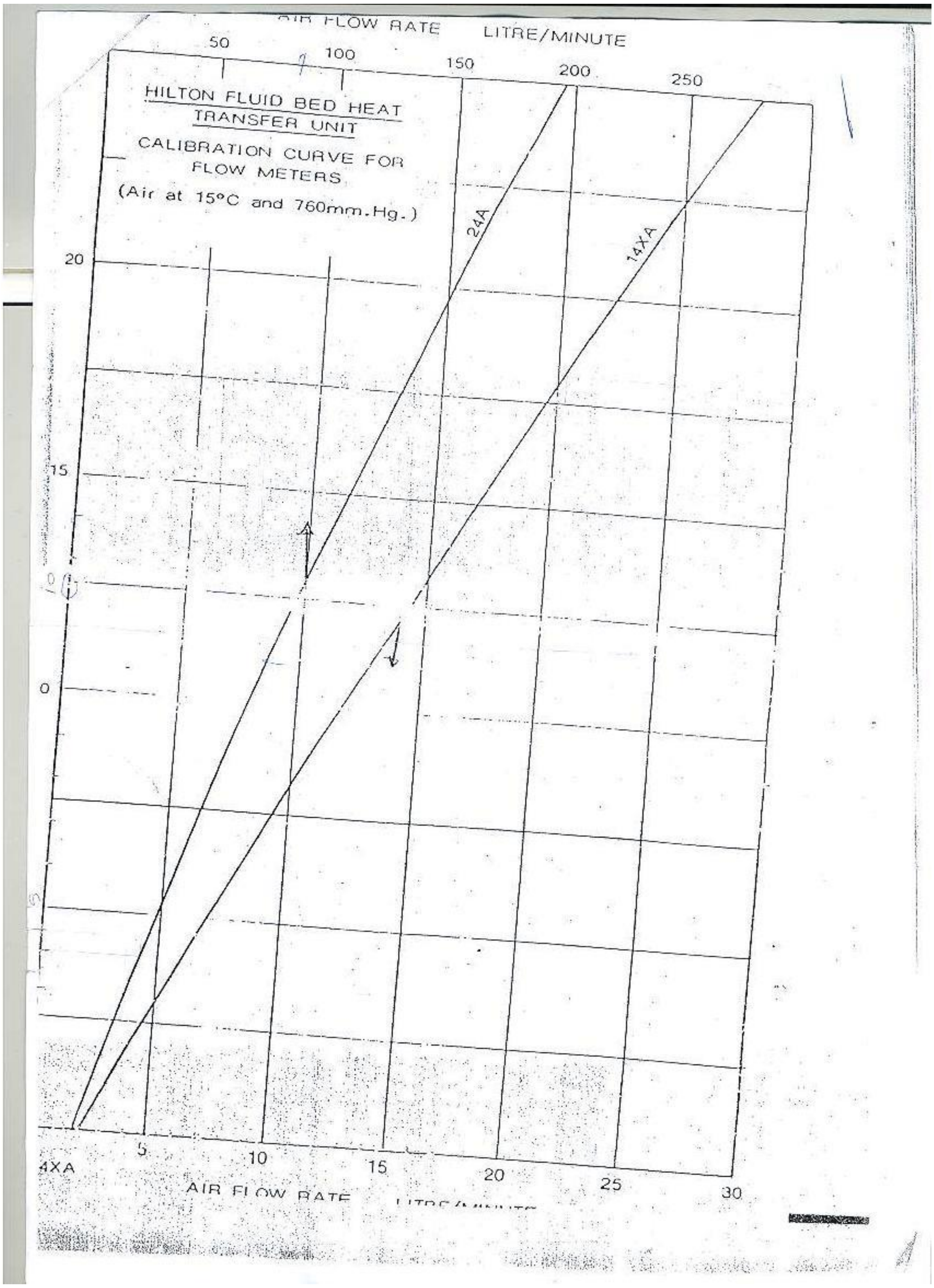

Figure (20): Calibration curve for flow meters for fluid bed heat transfer unit.