CHEMICAL ENGINEERING LABORATORY – II
(HEAT AND MASS TRANSFER LABORATORY)

NAME :

REG. NO. :

DEGREE : B.Tech.

BRANCH : CHEMICAL ENGINEERING

YEAR : III

SEMESTER : V

SUBJECT CODE : 18CHC305L

SUBJECT TITLE : CHEMICAL ENGINEERING LABORATORY – II

ACADEMIC YEAR : 2023 – 2024 (ODD)

DEPARTMENT OF CHEMICAL ENGINEERING

COLLEGE OF ENGINEERING AND TECHNOLOGY

SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

KATTANKULATHUR – 603 203

CHENGALPATTU DISTRICT

TAMILNADU, INDIA

SRM INSTITUTE OF SCIENCE AND TECHNOLOGY
(Under Section 3 of UGC Act, 1956)
KATTANKULATHUR - 603 203
CHENGALPATTU DISTRICT

BONAFIDE CERTIFICATE

Register Number: ----------------------------------

Certified to be the bonafide record of work done by ______________________

of ***III Year B. Tech. Chemical Engineering*** *Degree course in the Practical* ***18CHC305L - CHEMICAL ENGINEERING LABORATORY – II*** *in SRM Institute of Science and Technology, Kattankulathur during the Odd semester of the academic year* ***2023 – 2024.***

Lab In charge

Date: **Head of the Department**

Submitted for University Examination held on ________________*, at SRM Institute of Science and Technology, Kattankulathur – 603 203.*

Date **Examiner 1** **Examiner 2**

INDEX

Name : **Register No.:**

Expt. No.	**Date**	**Title of the Experiment**	**Marks**	**Signature**
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2		Heat Transfer by Natural Convection		
3		Heat Transfer by Forced Convection		
4		Stefan Boltzmann Apparatus		
5		Shell and Tube Heat Exchanger		
6		Simple Batch Distillation		
7		Drying Characteristics		
8		Single Stage Leaching		
9		Multi Stage Leaching		
10		Adsorption Isotherm		

Department of Chemical Engineering
College of Engineering and Technology
SRM Institute of Science and Technology

B.Tech. in Chemical Engineering

Vision of the Department

To utilize Chemical Engineering and Technology and ensure overall socio-economic growth, welfare, and progress of Indian society and the World-at-large by supporting Academia, Industries through Research and Development, Consultancy and graduating high-quality Chemical Engineers

Mission of the Department

Mission Statement - 1	To facilitate high quality education, well grounded in the fundamental and applied areas of engineering necessary for learners to contribute effectively to chemical and allied industries
Mission Statement - 2	To educate, prepare, inspire and mentor learners with the technical and professional skill-set necessary to excel as professionals, grow in their careers and contribute to chemical engineering science and technology
Mission Statement - 3	To inculcate social-responsibility in learners and train them to contribute effectively to science and society

Program Educational Objectives (PEO)

Within a few years of graduation, the students of the program will be able to attain the following:

PEO - 1	Utilizing their strong fundamental knowledge from the program be able to solve technical problems and contribute to chemical and allied industries
PEO - 2	Pursuing higher studies and/or continuously upgrading their skill-sets with technological advances leading to personal and professional growth and successful careers
PEO - 3	Establishing themselves with successful careers in industry, academia and/or as entrepreneurs that will enable them to address social, economic and environmental challenges and contribute to science and society

Mission of the Department to Program Educational Objectives (PEO) Mapping

	Mission Statement - 1	Mission Statement - 2	Mission Statement - 3
PEO - 1	3	2	1
PEO - 2	2	3	1
PEO - 3	2	1	3

3 – High Correlation, 2 – Medium Correlation, 1 – Low Correlation

Mapping Program Educational Objectives (PEO) to Program Outcomes (PO)

	Program Outcomes (PO)														
	Graduate Attributes (GA)												Program Specific Outcomes (PSO)		
	Engineering Knowledge	Problem Analysis	Design & Development	Analysis, Design, Research	Modern Tool Usage	Society & Culture	Environment & Sustainability	Ethics	Individual & Team Work	Communication	Project Mgt. & Finance	Life Long Learning	PSO - 1	PSO - 2	PSO - 3
PEO - 1	*3*	*3*	*3*	*3*	*2*				*2*	*2*	*2*		*3*	*3*	*2*
PEO - 2	*3*	*3*	*3*	*3*	*2*		*2*	*2*				*2*	*3*	*2*	*2*
PEO - 3	*2*	*2*	*2*	*2*		*3*	*2*	*2*	*3*	*3*	*3*	*2*	*3*	*2*	*3*

3 – High Correlation, 2 – Medium Correlation, 1 – Low Correlation

PSO – Program Specific Outcomes (PSO)

PSO - 1	*Ability to understand and differentiate processes*
PSO - 2	*Apply the fundamentals to perform equipment design and process design*
PSO - 3	*Evaluate the process plants from Energy, Environment and Safety related aspects*

COURSE ARTICULATION MATRIX
CO – PO MAPPING
SYLLABUS

Course Code	18CHC305L	Course Name	CHEMICAL ENGINEERING LABORATORY - II	Course Category	C	Professional Core	L	T	P	C
							0	0	4	2

Pre-requisite Courses	*Nil*	Co-requisite Courses	*Nil*	Progressive Courses	*Nil*
Course Offering Department	*Chemical Engineering*	Data Book / Codes/Standards	*Heat and mass transfer data book*		

Course Rationale (CR):	*The purpose of learning this course is to:*
CR-1 :	*Provide the students the firsthand experience of verifying various theoretical concepts learnt in heat and mass transfer. To Understand heat transfer mechanism, and to determine thermal conductivity.*
CR-2 :	*Determine the heat transfer coefficient in natural and forced convection. Design the double pipe and shell and tube heat exchanger. Determine the effectiveness of the heat exchanger.*
CR-3 :	*Determine the Stefan-Boltzmann law constant and emissivity of a real surface (gray surface).*
CR-4 :	*Verify the Rayleigh's equation in simple bath distillation. Determine the vapour efficiency for steam distillation. Determine the VLE data*
CR-5 :	*Study the drying characteristics. Determine the recovery of solute by simple leaching process. Verify the Freundlich Adsorption isotherm.*

Course Outcomes (CO):	*At the end of this course, learners will be able to:*	Learning	Program Outcomes (PO)														
		1	1	2	3	4	5	6	7	8	9	10	11	12	PSO1	PSO2	PSO3
		Level of Thinking (Bloom)	Engineering Knowledge	Problem Analysi	Design & Developm	Analysis, Design, Resea	Modern Tool Usag	Society & Cult	Environment & Sustainability	Ethi	& Team W Individu	Communic	Project Mgt. & Fina	Life Long Learning	Ability to understand proces	*Apply the fundamentals to Perf* *process desi*	*Evaluate to Energy, Environment an* *Safety related aspect*
CO-1 :	*Determine the thermal conductivity of a material and heat transfer coefficient for forced convection*	*3*	*1*	*2*											*2*		
CO-2 :	*Determine the heat transfer coefficient for forced convection and the effectiveness of a heat exchanger*	*4*		*2*	*2*	*2*										*3*	
CO-3 :	*Examine the Stefan-Boltzmann law constant and the Rayleigh's equation*	*4*		*2*	*2*										*1*		
CO-4 :	*Calculate the percentage recovery for single and multistage leaching*	*3*	*1*	*2*													
CO-5 :	*Examine the Freundlich Adsorption isotherm and Phase diagram for three component system*	*4*		*2*	*3*	*1*										*2*	

Duration (hour)		12	12	12	12	12
S 1-4	SLO-1	*Introduction to all the experiments*	*Heat transfer by natural convection*	*Determination of emissivity*	*Drying characteristics*	*Verification of Freundlich Adsorption isotherm*
	SLO-2					
S 5-8	SLO-1	*Heat transfer through Composite lagged pipe*	*Shell and tube heat exchanger*	*Stefan-Boltzmann apparatus*	*Estimation of percentage recovery of solute for single stage leaching*	*Phase diagram for three component system*
	SLO-2					
S 9-12	SLO-1	*Heat transfer by forced convection*	*Parallel flow and counter current flow Heat exchanger*	*Verification of Rayleigh equation for simple batch distillation*	*Estimation of percentage recovery of solute for multi stage leaching*	*Determination of vapor efficiency for simple steam distillation*
	SLO-2					

Learning Resources	1. *Warren L. McCabe, Julian C. Smith and Peter Harriott, "Unit Operations of Chemical Engineering", 7th Edn., McGraw Hill Education (India)* 2. *Edition, 2014 Robert E. Treybal," Mass-Transfer Operations", 3rd Edn., McGraw Hill Education (India) Edition, 2012* 3. *Binay K Dutta, "Heat Transfer: Principles and Applications", PHI Publishers, Delhi,2010* 4. *Laboratory Manual*

Learning Assessment											
	Bloom's Level of Thinking	Continuous Learning Assessment (50% weightage)								Final Examination (50% weightage)	
		CLA – 1 (10%)		CLA – 2 (15%)		CLA – 3 (15%)		CLA – 4 (10%)			
		Theory	Practice	Theory	Practice	Theory	Practice	Theory	Practice	Theory	Practice
Level 1	Remember	-	30 %	-	20 %	-	20 %	-	-	20 %	-
Level 2	Understand	-	30 %	-	20 %	-	20 %	-	-	20 %	-
Level 3	Apply	-	40 %	-	30 %	-	30 %	-	-	30 %	-
Level 4	Analyze	-		-	30 %	-	30 %	-	-	30 %	-
Level 5	Evaluate	-	-	-	-	-	-	-	-	-	-
Level 6	Create	-	-	-	-	-					
	Total	100 %		100 %		100 %		100 %		100 %	

CLA – 4 can be from any combination of these: Assignments, Seminars, Tech Talks, Mini-Projects, Case-Studies, Self-Study, MOOCs, Certifications, Conf. Paper etc.,

Course Designers		
Experts from Industry	Experts from Higher Technical Institutions	Internal Experts
1. *Mr. A. Subramaniam, PESCO Beam Environmental Solutions Pvt. Ltd.,*	1. *Dr. Lima Rose Miranda, Anna University, email: limamiranda2007@gmail.com*	1. *Ms.E.Kavitha, SRMIST*
2. *Mr. S. T. Kalaimani, CPCL, Chennai*	2. *Dr. T. R. Sundararaman, Rajalakshmi Engineering College*	2. *Dr. K.Sofiya, SRMIST*

LIST OF EXPERIMENTS

Exp. No.	Title of the Experiment
1	Heat Transfer Through Composite Lagged Pipe
2	Heat Transfer by Natural Convection
3	Heat Transfer by Forced Convection
4	Stefan Boltzmann Apparatus
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6	Simple Batch Distillation
7	Drying Characteristics
8	Single Stage Leaching
9	Multi Stage Leaching
10	Adsorption Isotherm

MAPPING OF COURSE OUTCOMES WITH PROGRAM OUTCOMES

S. No.	Course Outcomes (COs)	Program Outcomes (POs)	Experiment Details
1	Determine the thermal conductivity of a material and heat transfer coefficient for natural convection	PO - 1: Engineering Knowledge PO - 2: Problem Analysis	Exp. 1 - Heat Transfer Through Composite Lagged Pipe Exp. 2 - Heat Transfer by Natural Convection
2	Determine the heat transfer coefficient for forced convection and the effectiveness of a heat exchanger	PO - 2: Problem Analysis PO - 3: Design & Development PO - 4: Analysis, Design, Research	Exp. 3 - Heat Transfer by Forced Convection Exp. 5 - Shell and Tube Heat Exchanger Exp. 7 - Drying Characteristics
3	Examine the Stefan-Boltzmann law constant and the Rayleigh’s equation	PO - 2: Problem Analysis PO - 3: Design & Development	Exp. 4 - Stefan Boltzmann Apparatus Exp. 6 - Simple Batch Distillation
4	Calculate the percentage recovery for single and multistage leaching	PO - 1 : Engineering Knowledge PO - 2: Problem Analysis	Exp. 8 - Single Stage Leaching Exp. 9 - Multi Stage Leaching
5	Examine the Freundlich Adsorption isotherm and Phase diagram for three component system	PO - 2: Problem Analysis PO - 3: Design & Development PO - 4: Analysis, Design, Research	Exp. 10 - Adsorption Isotherm

Scheme of Evaluation

18CHC305L Chemical Engineering Laboratory - II

S. No.	Assessment Tool	Weightage	Component	Marks
1	Total In Semester Assessment	50 %	CLA P1	10
			CLA P2	15
			CLA P3	15
			CLA P4	10
2	End Semester Examination	50 %	Title, Aim, Apparatus required, Chemicals required (5)	50
			Short Correct Procedure (5)	
			Observation (5)	
			Formula, Calculation & Graph (20)	
			Result (5)	
			Viva (10)	
3	**Total**	**100 %**	**Total**	**100**

RUBRICS

Course Outcomes	Allocated Marks	High (4 – 5)	Medium (2 – 3)	Low (0 – 1)
Pre-Lab	5	Thorough study and all the questions have been answered correctly	Adequate study and more than half of the questions have been answered correctly	No understanding of any experimental concepts
Post-Lab	5	Objectives of experiment are fully grasped Developed theoretical understanding of concept	Objectives of experiment are fully grasped	No idea is built from experiment
Experiment Performance (Observation and Result Analysis)	5	Proper data is collected from experiment	Inconsistency in data	Wrong Observation made
	5	Accurate and reproducible results Analysis of data	Accurate and reproducible results and absence of analysis of data	No results Calculated No idea has been built from data and results

SAFETY PRECAUTIONS

Lab Safety Do's and Don'ts for Students

Use this handy checklist to acquaint students with safety dos and don'ts in the laboratory.

Conduct

- Never run in the laboratory.
- The use of personal audio or video equipment is prohibited in the laboratory.
- Do not engage in practical jokes or boisterous conduct in the laboratory.
- Do not sit on laboratory benches.

General Work Procedure

- Know emergency procedures.
- Never work in the laboratory without the supervision of an instructor.
- Immediately report any spills, accidents, or injuries to your instructor.
- Never leave experiments while in progress.
- Do not remove any equipment or chemicals from the laboratory.
- Store coats, bags, and other personal items in designated areas.
- Keep the floor clear of all objects (e.g., ice, small objects, spilled liquids).

Housekeeping

- Keep work area neat and free of any unnecessary objects.
- Thoroughly clean your laboratory work space at the end of the laboratory session.
- Do not block the sink drains with debris.
- Never block access to exits or emergency equipment.
- Properly dispose of broken glassware and other sharp objects (e.g., syringe needles) immediately in designated containers.
- Properly dispose of weigh boats, gloves, filter paper, and paper towels in the laboratory.

Apparel in the Laboratory

- Always wear personal protective equipment like goggles, gloves when handling hazardous materials.
- Wear a full-length, long-sleeved laboratory coat or chemical-resistant apron.
- Wear shoes that adequately cover the whole foot.
- Secure long hair and loose clothing (especially loose long sleeves, neck ties, or scarves).

Emergency Procedure

- Know the location of all the exits in the laboratory and building.
- Know the location of the emergency phone.
- Know the location of and know how to operate the following: Fire extinguishers, Eye washes, First aid kits

Chemical Handling

- Check the label to verify it is the correct substance before using it.
- Always use a spatula to remove a solid reagent from a container.
- Do not directly touch any chemical with your hands.
- Hold containers away from the body when transferring a chemical or solution from one container to another.

- Use a hot water bath to heat flammable liquids. Never heat directly with a flame.
- Clean up all spills properly and promptly.
- Dispose of chemicals as instructed.

Exp. No:

Date:

HEAT TRANSFER THROUGH COMPOSITE LAGGED PIPE

AIM:

To determine the thermal conductivity of saw dust by knowing the thermal conductivity of Asbestos/MgO using lagged pipe.

APPARATUS REQUIRED:

Heater, Asbestos/MgO, Saw dust, Power supply

SPECIFICATIONS

k_1=Thermal conductivity of MgO = --------------- W/ m K

k_1 = Thermal conductivity of Asbestos = -------------- W/ m K

L= Length of cylinder

r_1=Radius of heater pipe

r_2=Radius of MgO/Asbestos lagging pipe

r_3=Radius of saw dust lagging pipe

THEORY:

Thermal insulation is a material which retards heat flow with reasonable effectiveness. Heat is transferred through insulation by conduction, convection and radiation or by the combination of these three. There is no insulation, which is 100 % effective to prevent the flow of heat under temperature gradient.

PROCEDURE:

1. Switch ON the power supply
2. Switch ON the heater and set the dimmer to required position.
3. Wait for the steady state condition.
4. Note down the temperature readings, Ammeter and Voltmeter readings.
5. Substitute the recorded readings in the required formula.
6. Repeat the above for different heat inputs.

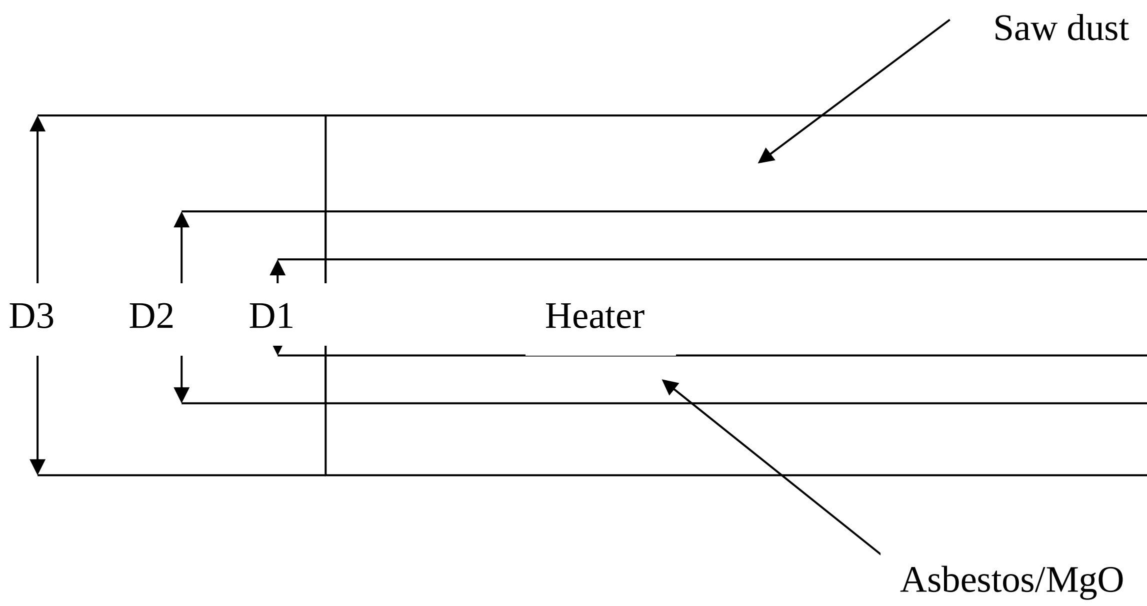


Fig. Heater rod with composite insulating Materials

OBSERVATION :

TABULATION: V = ………….. V   I = …………………… A

Sl. No	Heater Rod Temperature in °C at r_1			Lagging 1 (Asbestos/MgO) Temperature in °C at r_2			Lagging 2 (Saw Dust) Temperature in °C at r_3		
	T_1	T_2	T_{avg12} (T_A)	T_3	T_4	T_{avg34} (T_B)	T_5	T_6	T_{av45} (T_C)

FORMULAE & CALCULATION:

$$V * I = Q = \frac{2\pi L k_1 \Delta T_1}{\ln\left(\frac{r_2}{r_1}\right)} + \frac{2\pi L k_2 \Delta T_2}{\ln\left(\frac{r_3}{r_2}\right)}$$

Where,

$\Delta T_1 = T_A - T_B$ (°C)

$\Delta T_2 = T_B - T_C$ (°C)

k_2 = Thermal conductivity of saw dust

Q = Heat flow through lagging material

Pre-Lab Questions	Post Lab Questions
1. Define conduction. 2. Define heat flux. 3. Define thermal conductivity. 4. Define thermal resistance. 5. Arrange the following materials in ascending order of their thermal conductivity value: Aluminium, copper, gold, silver	1. Effect of temperature on thermal conductivity of pure metals. 2. Effect of temperature on thermal conductivity of insulators. 3. Write the expression of rate of heat transfer through a plane wall. 4. Write the expression of rate of heat transfer through a hollow cylinder. 5. Write the expression of thermal resistance for a hollow cylinder.

RESULTS:

Thermal conductivity of saw dust $\mathbf{k_2}$ = ___________ **W/m K**

REPORT:

Particulars	Maximum Marks	Marks Obtained
Pre-Lab Q & A	5	
Post-Lab Q & A	5	
Experimental Performance	10	

Exp. No:

Date:

HEAT TRANSFER BY NATURAL CONVECTION

AIM:

To find out the natural (free) convection heat transfer coefficient of a vertical heated tube kept in air, experimentally and using empirical relations.

TESTS-RIG SPECIFICATIONS:

Length of the tube L =
Diameter of the tube D =
Duct size =

THEORY:

Convection is one of the three modes of heat transfer which can be further classified into natural convection heat transfer and forced convection heat transfer.

Heat transfer occurs between the surface and the fluid due to the temperature difference between them. In forced convection heat transfer, a fluid is forced to flow over a surface. Where as in natural convection heat transfer, fluid is not forced to flow over the surface, but the molecules of fluid coming in contact with the surface change in density because of change in their temperature due to heat transfer.

When the surface is hot and the fluid is cold, molecules of fluid coming in contact with the hot surface become less dense and rise up, thereby allowing other denser molecules to come in contact with the hot surface. Similarly, when the surface is cold and the fluid is hot, molecules of fluid coming in contact with the cold surface becomes denser and move down allowing the less dense molecules to come in contact with the cold surface.

This density change exerts buoyancy force which results in movement of molecules over the surface called free or natural convection. The flow velocity in free convection is much smaller than that encountered in forced convection heat transfer; therefore, heat transfer by natural convection is much smaller than that by forced convection.

In many systems involving multi-mode heat transfer effects, free convection provides the largest resistance to heat transfer and therefore plays an important role in the design or performance of the system. When it is desirable to minimize heat transfer rates or to minimize operating cost, free convection is always preferred to forced convection.

Free convection strongly influences heat transfer from pipes and transmission lines, as well as from various electronic devices. It is important in transferring heat from electric base board heaters or steam radiators to room air and in dissipating heat from the coil of refrigeration unit to the surrounding air. It is also relevant to the environmental sciences where ocean and atmospheric motions are related with heat transfer processes.

PRECAUTIONS:

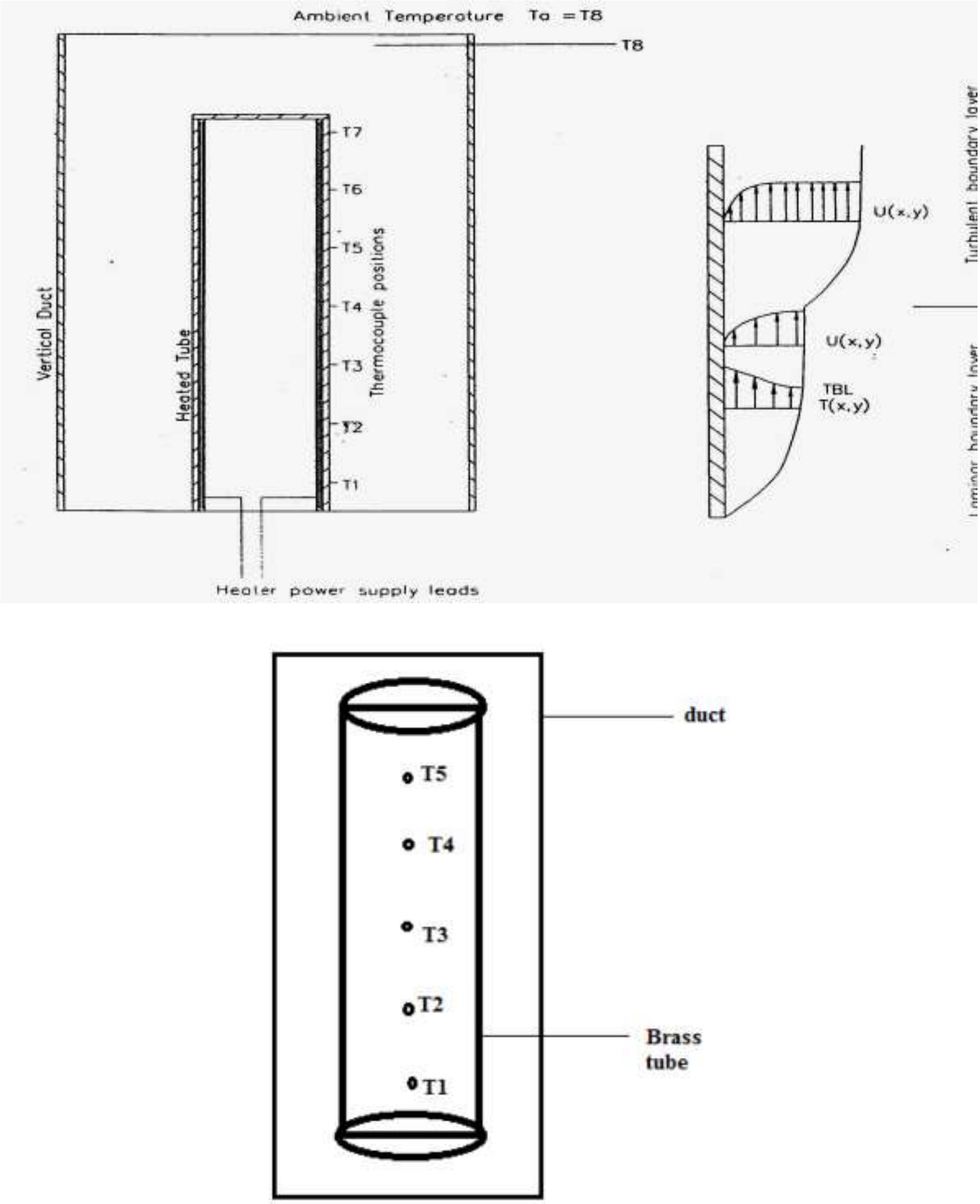
1. Keep the dimmerstat at zero position before starting and increase it slowly.
2. Keep the assembly undisturbed during the test period.
3. Do not increase the voltage above 100 V and the current above 2 amps.
4. Selector switch of the temperature indicator should be operated slowly and gently.

PROCEDURE:

1. Connect the supply and put on the man switch in ON position.
2. Adjust the dimmerstat and set the desired value of heat input.
3. Note down the temperature at different locations on the test surface and the enclosure temperature reading from the temperature display system every 5 minutes until steady state condition is reached (i.e., successive readings are the same).

DESCRIPTION:

The apparatus consists of a brass tube fitted in a rectangular duct in a vertical panel. The duct is kept open at the top and bottom and forms an enclosure for an undisturbed surrounding. Heat loss from the tube to the surrounding air takes place by natural convection. The temperature is measured by means of thermocouples placed at uniform intervals along the length of the tube surface. Heat input is measured by means of a voltmeter and ammeter. The tube surface is polished to minimize radiation loss.



Experimental set up for determining the natural convection heat transfer

TABULATION:

Volts (V) =___________ Amp(I) =____________

SL. No.	Time at which readings taken (min)	Thermo couple readings (^oC)							Ambient air temp
		T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_a (^oC)

TABULATION:

Distance in mm from bottom end of the heated tube (mm)		**Local heat transfer coefficient h_L in W/m^2 K**	
L_1		h_1	
L_2		h_2	
L_3		h_3	
L_4		h_4	
L_5		h_5	
L_6		h_6	
L_7		h_7	

CALCULATIONS:

The heat loss to the surrounding air is obtained by

$q = h\,A\,(T_s - T_a)$ in W

A	Surface area of heat transfer in m^2
T_s	Average surface temperature in K
T_a	Ambient temperature in K

$$h = \frac{q}{A(T_s - T_a)} = \underline{\hspace{5cm}}\ \mathrm{W/m^2\,K}$$

Where,

$q = V\,I$ in W

$A = \pi\,D\,L$ m^2

$T_s = (T_1 + T_2 + \ldots\ldots.. + T_n)/n$

$T_f = (T_s + T_a) / 2$

$\Delta T = T_s - T_a$

Empirical Relations:

The following empirical relation can be used for free convection in a vertical heated cylinder

$Nu = 0.59\,(Gr.\,Pr)^{0.25}$ for $10^4 < Gr.\,Pr < 10^9$

$Nu = 0.10\,(Gr.\,Pr)^{0.33}$ for $10^9 < Gr.\,Pr < 10^{13}$

Where **$Nu = h_{emp}\,L/K$**

$T_f = (T_s + T_a)/2$

Properties of air at this temperature are from HMT data book.

1) $\gamma =$ m^2/s
2) $Pr =$
3) $K =$ W/m K

$\beta = 1 / T_F$ where T_F is in K

$Gr = \beta\,g\,L^3\,\Delta T / \gamma^2$

$Nu = 0.59\,(Gr.\,Pr)^{0.25}$

$h_{emp} = Nu\,K/L$

Where T_i is the local surface temperature ranging from T_1 to T_7. Substituting each temperature, we get the local heat transfer coefficient h_i.

GRAPH:

Plot h_i Vs L where L represents the distance of the thermocouples from the bottom end of the tube.

Scale
In x-axis 1cm =
In y-axis 1 cm =

Pre-Lab Questions	Post Lab Questions
1. Define convection. 2. Define natural convection. 3. State Newton’s law of cooling. 4. Define thermal resistance. 5. Write the applications of convection	1. Distinguish between natural convection and forced convection. 2. Define film temperature. 3. Write the expression of rate of convective heat transfer. 4. Write the significance of the Grashof number. 5. Define heat transfer coefficient.

RESULT:

The average natural convective heat transfer coefficient for a vertical heated tube kept in air is __________________ W/m^2 K experimentally and ________________W/m^2 K empirically.

REPORT:

Particulars	Maximum Marks	Marks Obtained
Pre-Lab Q & A	5	
Post-Lab Q & A	5	
Experimental Performance	10	

Exp. No:

Date:

HEAT TRANSFER BY FORCED CONVECTION

AIM:

To determine the average surface heat transfer coefficient for a pipe, transmitting heat by forced convective flow of air through it, experimentally and empirically.

TEST RIG SPECIFICATION:

Length of the test section L =

Diameter of the test section D =

Diameter of the orifice d =

Max. Heat capacity =

THEORY:

Forced convection heat transfer is widely used in various industrial applications. It is encountered generally in heat exchangers, cryogenic coolant system, heating or cooling of heavy oils etc. Forced convection heat transfer is due to the bulk or macroscopic motion of a fluid over a body. When the fluid flow over a body, the velocity and temperature distribution at the immediate vicinity of the surface strongly influence the heat transfer. So, there are two different kinds of boundary layers, the velocity boundary layer (hydrodynamic boundary layer) and thermal boundary layer.

In the case of a duct or tube as shown in the figure the hydrodynamic boundary layer starts to develop along the wall surface as the flow proceeds. The boundary line continuously thickens until it fills the entire tube. The region from the tube inlet to this section is under developed region. The velocity profile changes from logarithmic to parabolic as the flow enters the under developed region to fully developed region. However, the developing length for both the boundary layers may not be same. Empirical relations have been developed for calculating the heat flow rate in forced convection heat transfer.

PROCEDURE:

1. Connect the supply and put on the heater main switch in ‘ON’ position.
2. Turn the dimmer stat knob clockwise and set the power input to the heater in the desired value.
3. Set the airflow rate to the desire value by adjusting the gate valve.
4. Note down the test surface temperature at different locations on it and air inlet and outlet temperatures looking at temperature display system every five minutes until steady state condition is achieved.
5. Take the manometer reading.

DESCRIPTION:

The apparatus consists of blower unit fitted with the test pipe. The test section is covered with a heater and insulating material. Thermocouples are embedded on the test section and two thermocouples are placed in the air stream at the entrance and the exit of the test section to measure the rise in temperature. An orifice meter is used to measure the flow of air through the test section. Input to the heater is given through the dimmer stat and measured by voltmeter and ammeter.

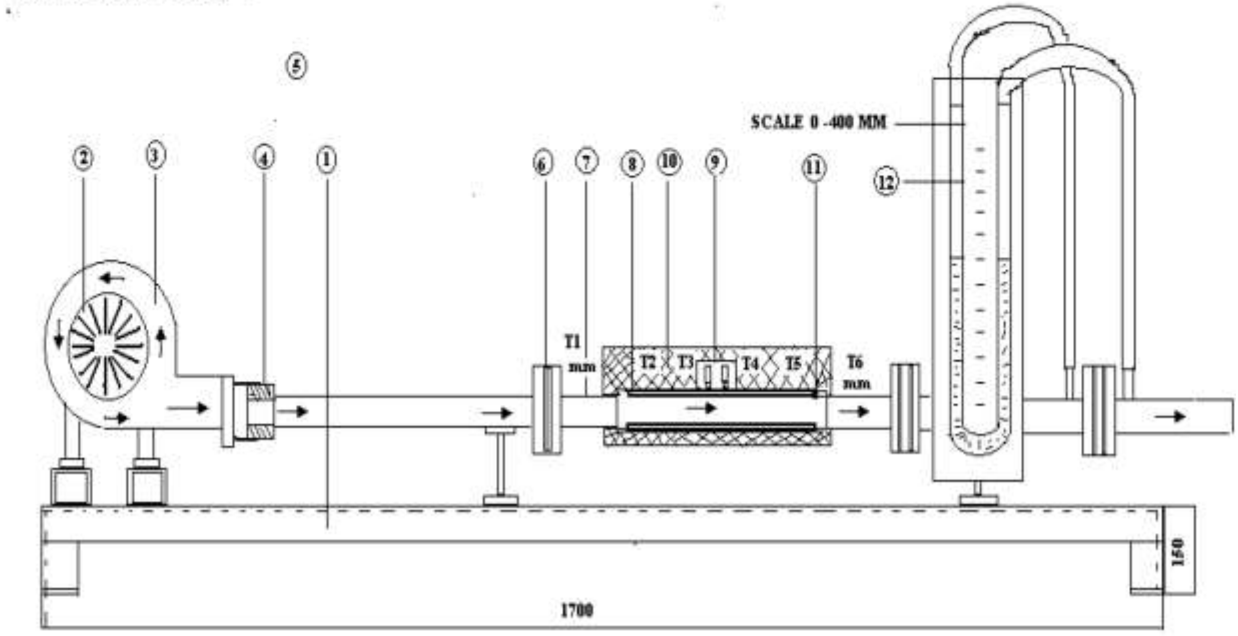
TABULATION:

Manometer Readings, h_1=______ cm; h_2=______ cm

Power input: V =   I =

S. No.	Time at which reading taken (min)	Thermocouple readings (^oC)							
		T_1	T_2	T_3	T_4	T_5	T_6	Inlet air T_i	Outlet air T_o

APPARATUS :



1. "C" Channel	7. Air inlet temperature
2. Motor	8. Mica covered heater
3. Blower	9. Heater socket
4. Adapter	10. Foam packing
5. Air	11. Stainless still cladding
6. Orifice	12. Manometer

Fig. 1 Experimental test rig for forced convection heat transfer

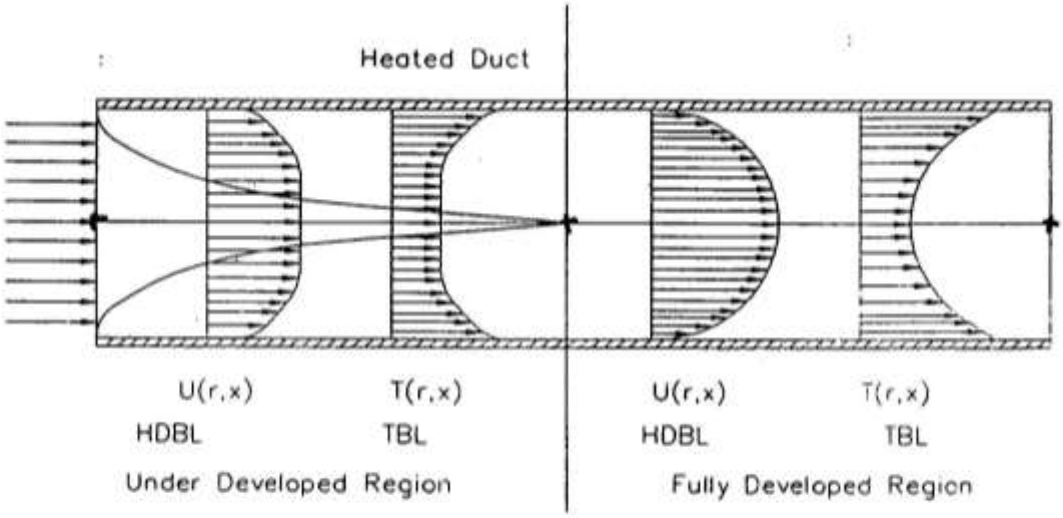


Fig. 2. Schematic diagram for development of boundary layers in forced convection

CALCULATION:

The heat transferred to the air is obtained by the following relations:

$T_s = (T_1 + T_2 + \ldots\ldots. + T_n)/n$

Bulk mean air temperature $T_a = (T_i + T_o)/2$

$q = m\, C_p\, \Delta T$

Where, $\Delta T = (T_o - T_i)\ ^{o}C$

T_o - Outlet temperature of air

T_i - Inlet temperature of air

Mass flow rate of air is given by $m = \rho_a Q$, kg/s

The volume flow rate of air is given by

$$Q = \frac{[(C_d)(a_1)(a_2)\sqrt{2.gh}]}{\sqrt{[(a_1{}^2)-(a_2{}^2)]}}$$

Where,

C_d (Co-efficient of discharge of orifice) = 0.68

$\mathbf{a_1 = \pi.D^2 / 4}$ Cross section area of test section in m^2

$\mathbf{a_2 = \pi.d^2 / 4}$ Area of orifice hole in m^2

Air head causing flow, $\mathbf{h_a = \rho_m. h_m / \rho_a}$

Where, h_m - Manometric level difference in U-tube manometer (m)

ρ_m - Density of fluid in the manometer (kg/m^3)

ρ_a - Density of air at its bulk mean temperature T_a (kg/m^3)

$A = \pi DL$ Surface area of heat transfer in m^2

Log mean temperature difference is given by

$$\text{LMTD} = \frac{((T_S)-(T_o))-((T_S)-(T_i))}{ln\left(\frac{((T_S)-(T_O))}{((T_S)-(T_i))}\right)}$$

$\mathbf{h_{exp} = (m\, C_p\, \Delta T) / A\ LMTD}$

h $_{\mathbf{exp}}$ **=______________W/m^2 K**

Empirical relations:

For forced convection heat transfer

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

Where Nu Nusselt number
Re Reynolds number
Pr Prandtl number

Note: All the fluid properties are taken at the bulk mean temperature T_a from HMT data book

1.Density (ρ) = kg/m^3
2.Absolute viscosity (μ) = N s/m^2
3.Prandtl number (P_r) =
4. Specific heat capacity (C_p) = J/kg K
5.Thermal conductivity (k) = W/m K

$$\mathbf{Re = \rho D u/\mu}$$

Where U is the air velocity in the pipe m/s
D is the pipe diameter m
Air velocity in the pipe (u); = Q/A = m/s

$$\mathbf{h_{(emp)} = Nu\ k/D}$$

$h_{(emp)}$= _____________W/m^2 K

Thus, the average heat transfer coefficient can be calculated using the empirical relation.

Pre-Lab Questions	**Post Lab Questions**
1. Define convection. 2. Define forced convection. 3. State Newton’s law of cooling. 4. Define LMTD. 5. Write the applications of forced convection.	1. Distinguish between natural convection and forced convection. 2. Define bulk mean temperature. 3. Write the expression of Dittus-Boelter equation. 4. Write the significance of Reynolds number. 5. Write the significance of Prandtl number.

RESULTS:

The average surface heat transfer coefficient for a pipe transmitting heat by forced convective flow of air through it is _____________**W/m^2 k** experimentally and____________**W/m^2 k** empirically.

REPORT:

Particulars	**Maximum Marks**	**Marks Obtained**
Pre-Lab Q & A	5	
Post-Lab Q & A	5	
Experimental Performance	10	

Exp. No:

Date:

STEFAN BOLTZMANN APPARATUS

AIM:

To determine Stefan Boltzmann constant of thermal radiation.

EQUIPMENT REQUIRED:

Stefan Boltzmann apparatus

THEORY:

Thermal radiation is the energy emitted by matter that is at a finite temperature. The radiation heat transfer requires no medium and it travels in the form of electromagnetic waves. The radiation is relevant in many industrial heating, cooling and drying processes as well as energy conversion methods that involve combustion of fuels and solar radiation.

The Stefan Boltzmann law states that the thermal radiation heat flux or emissive power of a black surface is proportional to the fourth power of its absolute temperature of the surface.

$Q / A = \sigma \; T^4$

Where σ = Stefan Boltzmann constant = 5.669×10^{-8} W/ m^2 K^4

DESCRIPTION:

The apparatus is centered on a flanged copper hemisphere fixed on a flat insulated material plate. The outer surface of the hemisphere is enclosed in a metal jacket used to heat the hemisphere to certain constant temperature. The hemisphere shape is preferred for easy draining of water bath. Iron – Constantan thermocouples are attached to measure its mean temperature and it is read by a temperature indicator. A disc is mounted on a isolate Bakelite piece fitted on a hole at the center of the base plate. Another similar thermocouple is used to measure the temperature of the disc.

SPECIFICATIONS:

Mass of the test disc	m = 25 g
Specific heat of the disc material	c_p = 0.3768 kJ/kg K
Diameter of the disc	d = 0.025 m
Hemisphere diameter	= 200 mm

PROCEDURE:

1. Switch on the geyser and allow the water temperature to reach 80 °C
2. The window containing the disc is to be opened before letting the hot water into the jacket.
3. The hot water is filled in the jacket and the hemispherical enclosure will reach steady state temperature in a short time.
4. Close the window containing disc and note down the temperature of the disc. Now observe the time by stop watch and temperature of the disc at short temperature rising intervals.
5. Repeat the experiment for different temperatures.

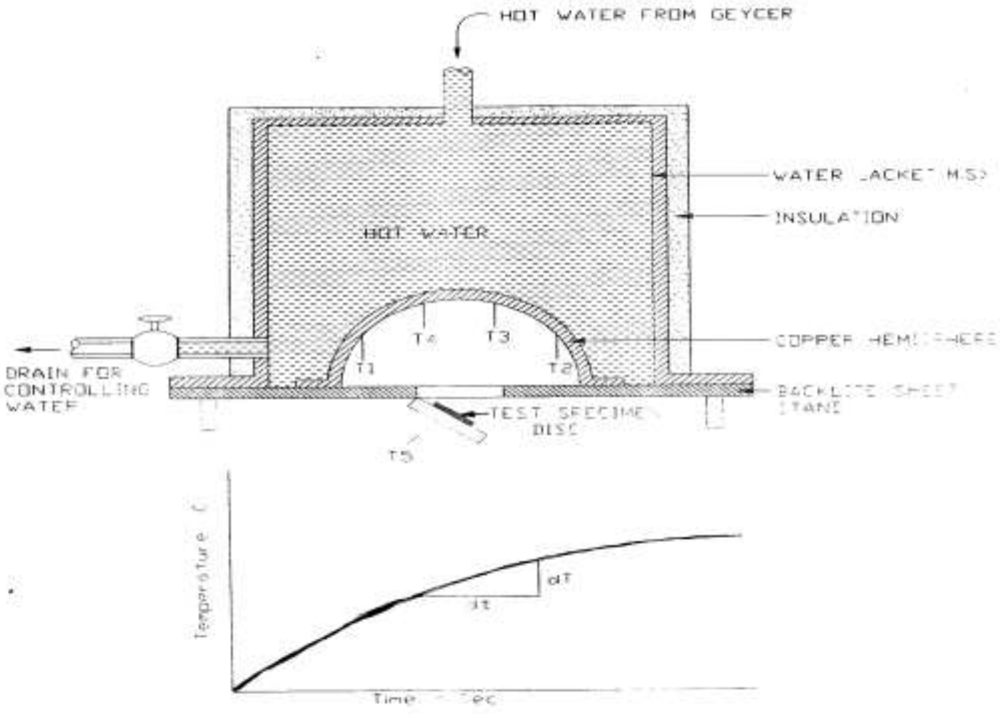


fig 7.1 Experimental set up for determining Stefan Boltsman constant of thermal radiation.

TABULATION A:

S. No.	Time Taken (2 min)	Hemispherical Temp °C			
		T_1	T_2	T_3	T_4

TABULATION B:

S. No.	Time (s)	Test disc Temperature (T_5) (°C)

Scale
In x-axis 1cm =
In y-axis 1 cm =

CALCULATIONS & FORMULAE:

Mass of the test disc = 25 g = 25×10^{-3} kg

Specific heat of the disc material Cp = 0.385 kJ/kg K

Temperature of the enclosure T = $(T_1 + T_2 + T_3 + T_4) / 4$

$T_d = (T_5)$ Steady state temperature of the disc (test section), K

GRAPH: Draw a plot of temperature rise Vs Time and obtain slope from the tangent ($\Delta T/\Delta t$)

A = Area of the disc = $\pi d^2/4$ m^2

$Q = m\, Cp\, (\Delta T/\Delta t)_{disc}$

$Q = \sigma A (T^4 - T_d^4)$

Value of σ can be calculated from,

$Q = m\, C_p\, (\Delta T/\Delta t) = \sigma A (T^4 - T_d^4)$

$$\sigma = \frac{Q}{A [T^4 - T_d^4]} \quad W/ m^2 K^4$$

$\sigma =$ W/ $m^2 K^4$

Pre-Lab Questions	**Post Lab Questions**
1. Define Radiation. 2. State Stefan Boltzmann law. 3. Define black body. 4. Define gray body. 5. Write the applications of radiation.	1. Define emissive power. 2. Define emissivity. 3. Write the expression of the emissive power of a black body. 4. Write the unit of emissive power. 5. Distinguish between black body and gray body.

RESULT:

The Stefan Boltzmann constant was found as σ = _______________**W/ m^2 K^4.**

REPORT:

Particulars	**Maximum Marks**	**Marks Obtained**
Pre-Lab Q & A	5	
Post-Lab Q & A	5	
Experimental Performance	10	

Exp. No:

Date:

SHELL AND TUBE HEAT EXCHANGER

AIM:

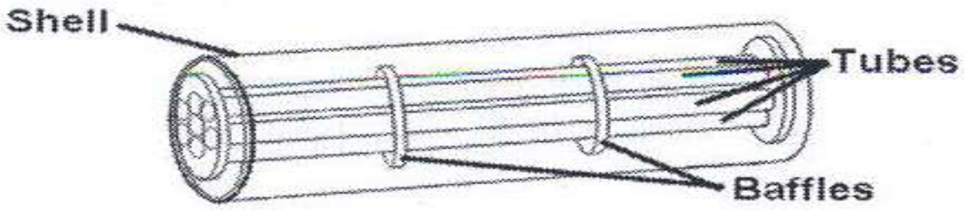
To determine the heat transfer co – efficient, overall thermal efficiency and effectiveness, of the hot and cold fluid for the shell and tube heat exchanger.

APPARATUS REQUIRED:

1. Shell and tube heat exchanger
2. Water container
3. Ammeter
4. Voltmeter
5. Temperature indicator

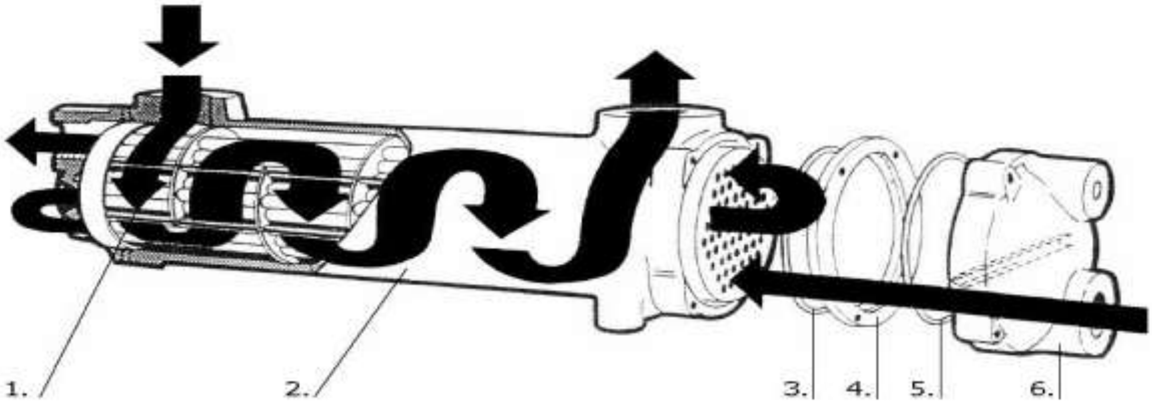
DESCRIPTION:

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 fluids.

LAYOUT DIAGRAM SHELL AND TUBE:



1. Tube stack
2. Body
3. Seal
4. Witness ring
5. Seal
6. Header

METHOD:

By measuring the changes in temperature of the two separate fluid streams in a shell and tube heat exchanger and calculating the heat energy transferred to/from each stream to determine the Overall Efficiency.

PROCEDURE:

1. Set the temperature controller to 60 ^{0}C, and then switch on the hot water circulator.
2. Adjust the hot water control valve setting to give a hot water flow rate of 1L/min.
3. Adjust the cold-water control valve to give 1L/min.
4. Allow the heat exchanger to stabilize.
5. When the temperatures are stable note the values; T_{hi}, T_{ho}, T_{ci}, T_{co}, Q_h, Q_c.

TABULATION:

S. No.	**Hot Water**					**Cold Water**				
	Time for collecting one litre of water t_h (s)	Volumetric flow rate Q_h (m^3/s)	Mass flow rate m_h (kg/s)	Inlet temp. T_{hi} (^{0}C)	Outlet temp. T_{ho} (^{0}C)	Time for collecting one litre of water t_c (s)	Volumetric flow rate Q_c (m^3/s)	Mass flow rate m_c (kg/s)	Inlet temp. T_{ci} (^{0}C)	Outlet temp. T_{co} (^{0}C)

CALCULATIONS:

Reduction in hot fluid temperature $\Delta T_h = T_{hi} – T_{ho}$

Increase in cold fluid temperature $\Delta T_c = T_{co} - T_{ci}$

T_{mean} = $T_{in} + T_{out} / 2$

Mass flow rate (m) kg/s = volume flow rate X density of fluid

Heat power (q) W = Mass flow rate X specific heat

Heat loss q_L W = $q_e – q_a$

For the hot stream (q_e)

$T_{h\,mean} = T_{hi} + T_{ho} / 2$

Hence the power emitted from the hot stream q_e

$q_e = m_h \times c_{ph} \times (T_{hi}-T_{ho})$ **W**

Where m_h = mass flow rate of hot fluid

ρ_h = density of hot fluid

c_{ph} = specific heat of hot fluid

T_{hi} - inlet temperature of hot fluid

T_{ho} - outlet temperature of hot fluid

For the cold stream (q_a)

$T_{c\,mean} = T_{ci} + T_{co} / 2$

The power absorbed by the cold stream

$q_a = m_c \times c_{pc} \times (T_{co}-T_{ci})$ **W**

The overall thermal efficiency

$\eta = q_a / q_e \times 100$

Efficiency of the hot fluid

$\eta = (T_{hi} - T_{ho}) / (T_{hi} - T_{ci}) \times 100$

Efficiency of the cold fluid

$\eta = (T_{co}-T_{ci}) / (T_{hi} – T_{ci}) \times 100$

The mean temperature efficiency

$\eta = \eta_h + \eta_c / 2$

Logarithmic mean temperature difference

$LMTD = (T_{hi}-T_{co})-(T_{ho}-T_{ci}) / \ln((T_{hi}-T_{co})/(T_{ho}-T_{ci}))$

Heat transfer co – efficient

$U = q_e / A \times LMTD$

A – Heat transfer area of heat exchanger (m^2)

q_e – Heat emitted from hot stream in W

LMTD – Logarithmic mean temperature difference X Correction Factor value (F)

Correction factor value consider from HMT data book

(One shell pass two, four or multiple tube passes)

The heat transfer area

$d_m = (d_o + d_i) / 2$

$A = \pi .\ d_m .\ L.\ N$

Specifications:

d_o - Heat transfer tube outside diameter =

d_i - Heat transfer tube inside diameter =

d_m – Heat transfer tube mean diameter =

L - Heat transfer tube effective length =

N - Number of heat transfer tubes =

Effectiveness of heat exchanger:

$$\varepsilon = \frac{q}{\left[C_{\min}.\left(T_{hi} - T_{ci}\right)\right]} = \frac{\textit{Actual}\ \text{heat transfer rate}}{\textit{Maximum possible}\ \text{heat transfer rate}}$$

Where , $C_{\min} = m_h.c_{ph}$ or $m_c.c_{pc}$ whichever is smaller.

Pre-Lab Questions	**Post Lab Questions**
1. List out the various types of heat exchangers 2. Write some practical applications of heat exchanger. 3. Define LMTD. 4. Define overall heat transfer coefficient. 5. What do you mean by 1-1 shell and tube heat exchanger	1. Write the classification of shell and tube heat exchanger. 2. Define efficiency of a heat exchanger. 3. Define effectiveness of a heat exchanger 4. Write the expression of LMTD. 5. Write the flow patterns involved in the heat exchangers.

RESULT:

Thus, the performance test on shell and tube heat exchanger was conducted and the following were calculated.

1. Overall thermal efficiency =

2. Overall heat transfer coefficient =

3. Effectiveness =

REPORT:

Particulars	**Maximum Marks**	**Marks Obtained**
Pre-Lab Q & A	5	
Post-Lab Q & A	5	
Experimental Performance	10	

Exp. No:

Date:

SIMPLE DISTILLATION

AIM:

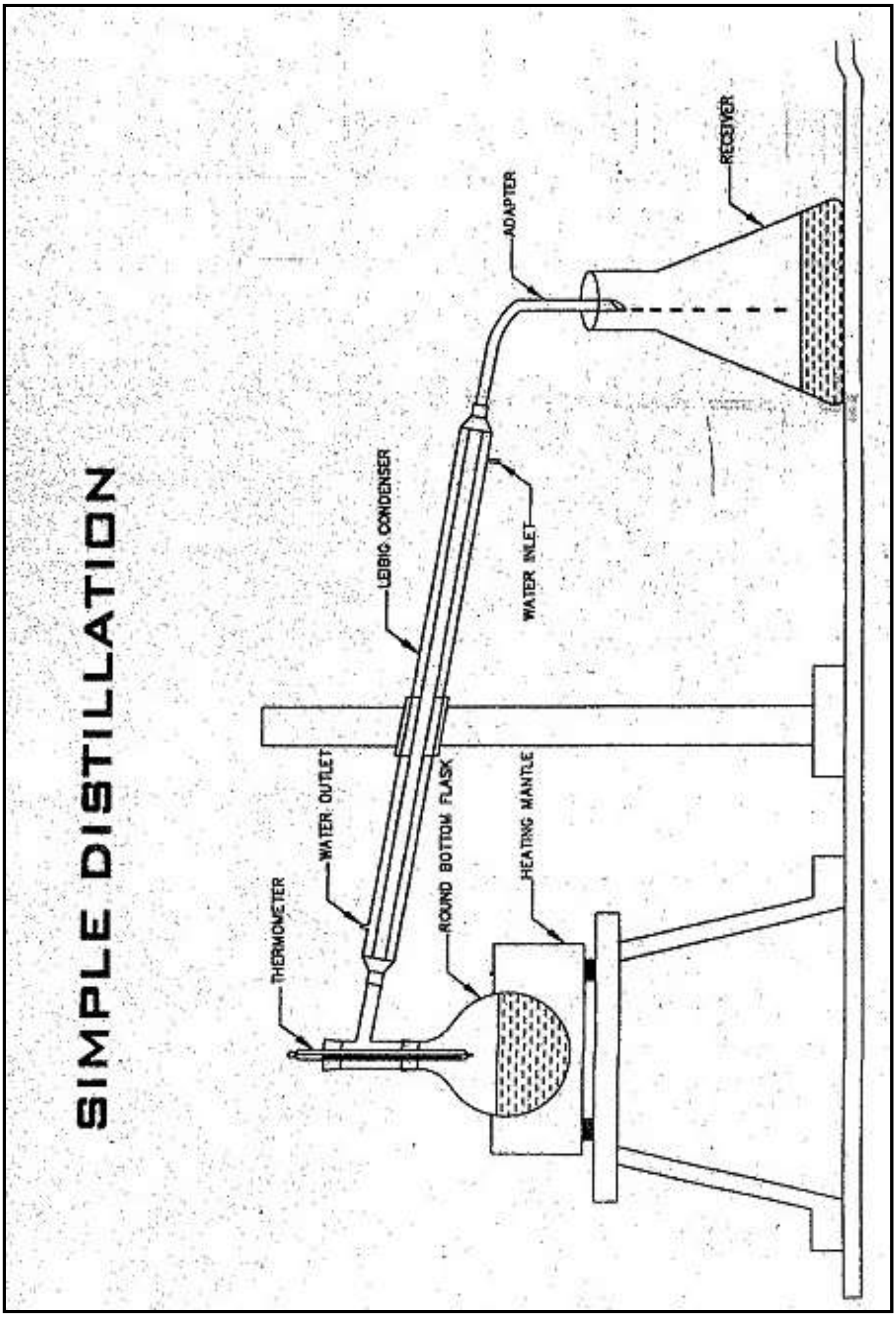
To verify Rayleigh’s equation for simple distillation of a binary mixture.

APPARATUS REQUIRED:

Simple Distillation Assembly, Specific Gravity Bottle, Weighing Balance, Heating Mantle, Measuring Cylinder, Thermometer, Conical Flask.

CHEMICALS REQUIRED:

Acetone (CH_3COCH_3), Water (H_2O).



SIMPLE DISTILLATION SET-UP

THEORY:

The term distillation is employed for operation where vaporization of liquid mixture yield a vapor phase containing more than one constituent and is desired to recover one or more of these constituents in a pure state. The basic requirement for separation of a component by distillation is the difference in composition between vapor and liquid when these two are in equilibrium. If the vapor composition is same as the liquid composition then distillation process will not effect the separation process. Theoretically distillation will never yield a component in absolutely pure form.

In practice distillation is carried out by three main methods

1. Simple or Differential Distillation
2. Flash or Equilibrium distillation
3. Rectification

In simple distillation the vapor generated by boiling the liquid is withdrawn and condensed as fast as it is formed. Since the vapor is rich in the more volatile component than the liquid, the liquid remaining becomes steadily weaken with respect to more volatile component. By condensing the vapor formed the separation of the two components of the binary mixture is possible. The apparatus consists of a round bottomed flask with three way neck. To one of the mouth condenser is attached, so that the vapor comes out while heating may be condensed and collected in a conical flask kept at the end of the condenser. To the other mouth thermometer is inserted to measure the temperature of the vapor. The other mouth can be used for pouring the binary mixture to be distilled.

TABLE 1:

DENSITY COMPOSITION TABLE:

S.No.	Volume of H_2O (ml)	Volume of Acetone (ml)	Volume fraction of Acetone in the mixture (φ_A)	Density of the mixture (ρ) (g/cc)
1	0	25	1.0	0.791
2	5	20	0.8	0.8328
3	10	15	0.6	0.8746
4	15	10	0.4	0.9164
5	20	5	0.2	0.9582
6	25	0	0.0	1.0

TABLE 2:

OBSERVATION:

(1) S.No.	(2) Mixture	(3) Mass of empty specific gravity bottle (g)	(4) Mass of specific gravity bottle + mixture (g)	(5) Mass of the mixture (m) (g) (4-3)	(6) Volume of specific gravity bottle (V) (cc)	(7) Density of the mixture $\left(\rho = \frac{m}{V}\right)$ (g/cc) (5)/(6)	(8) Volume fraction of Acetone in the mixture (φ_A) (from Density Composition graph)
1	Feed (F)					ρ_F	φ_{AF}
2	Distillate (D)					ρ_D	φ_{AD}
3	Residue (W)					ρ_W	φ_{AW}

GRAPH 1:

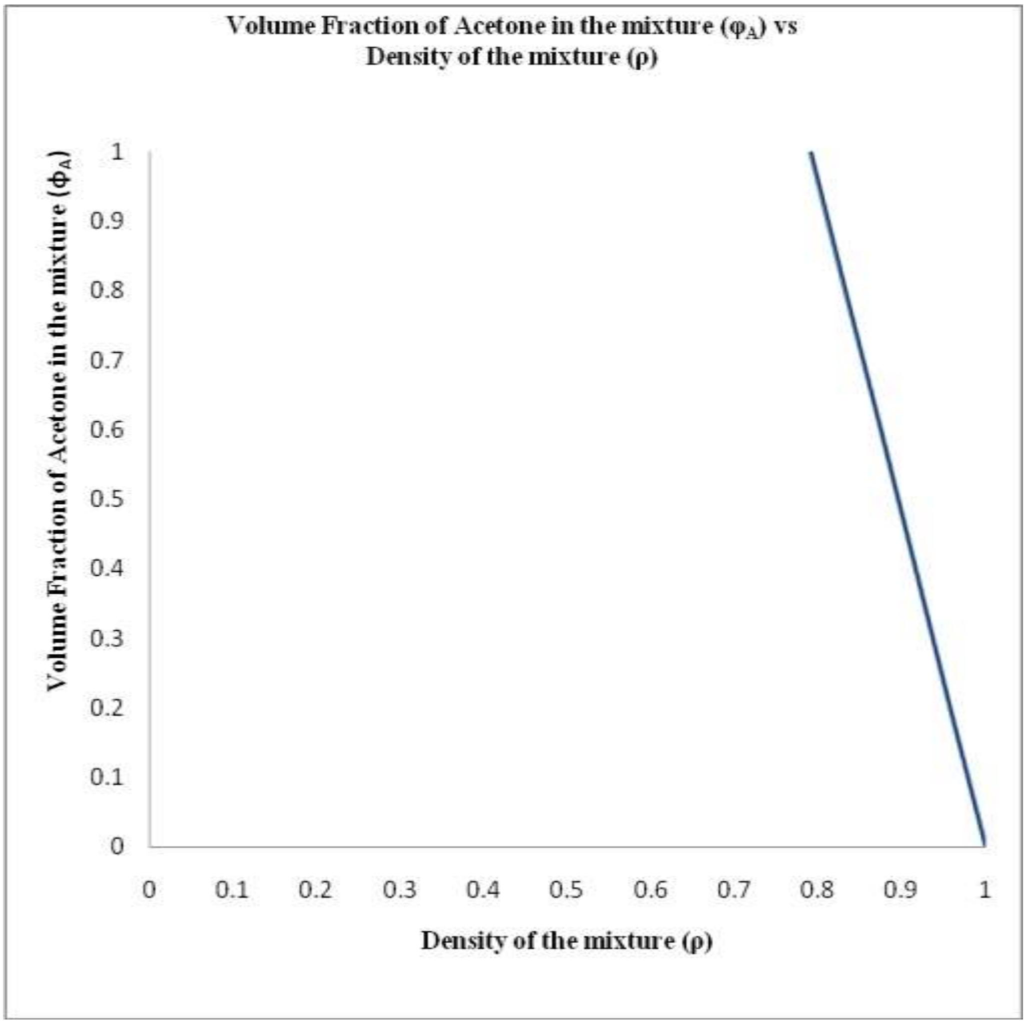
Density Composition Graph for Acetone Water System

Volume Fraction of Acetone in the mixture (φ_A) vs Density of the mixture (ρ)

SCALE:

X Axis 1 cm = 1 Unit= 0.1 g/cc (Density of the mixture (ρ))

Y Axis 1 cm = 1 Unit = 0.1 unit (Volume Fraction of Acetone in the mixture (φ_A))



Scale
In x-axis 1cm =
In y-axis 1 cm =

FORMULAE:

ρ_F, ρ_D, ρ_W - Density of Feed, Distillate, Residue

V_F, V_D, V_W - Volume of Feed, Distillate, Residue

φ_{AF}, φ_{AD}, φ_{AW} - Volume fraction of Acetone in Feed, Distillate, Residue

φ_{BF} - Volume fraction of Water in Feed = $(1- \varphi_{AF})$

φ_{BD} - Volume fraction of Water in Distillate = $(1- \varphi_{AD})$

φ_{BW} - Volume fraction of Water in Residue = $(1- \varphi_{AW})$

ρ_A - Density of Acetone = 0.791 g/cc, ρ_B - Density of Water = 1 g/cc

M_A - Molecular weight of Acetone = 58 g /gmol, M_B- Molecular weight of Water =18 g/gmol

FEED:

$$\text{Number of Moles of Acetone in Feed}, n_{AF} = \frac{V_F\ \varphi_{AF}\ \rho_A}{M_A}$$

$$\text{Number of Moles of Water in Feed}, n_{BF} = \frac{V_F\ \varphi_{BF}\ \rho_B}{M_B} = \frac{V_F(1-\varphi_{AF})\rho_B}{M_B}$$

Total number of Moles of Feed, $F = n_{AF} + n_{BF}$

Mole fraction of Acetone in Feed, $x_F = \frac{n_{AF}}{F}$

DISTILLATE:

$$\text{Number of Moles of Acetone in Distillate}, n_{AD} = \frac{V_D\ \varphi_{AD}\ \rho_A}{M_A}$$

$$\text{Number of Moles of Water in Distillate}, n_{BD} = \frac{V_D\ \varphi_{BD}\ \rho_B}{M_B} = \frac{V_D\ (1-\varphi_{AD})\rho_B}{M_B}$$

Total number of Moles of Distillate, $D = n_{AD} + n_{BD}$

Mole fraction of Acetone in Distillate, $x_D = \frac{n_{AD}}{D}$

RESIDUE:

$$\text{Number of Moles of Acetone in Residue}, n_{AW} = \frac{V_W\ \varphi_{AW}\ \rho_A}{M_A}$$

$$\text{Number of Moles of Water in Residue}, n_{BW} = \frac{V_W\ \varphi_{BW}\ \rho_B}{M_B} = \frac{V_W(1-\varphi_{AW})\rho_B}{M_B}$$

Total number of Moles of Residue, $W = n_{AW} + n_{BW}$

Mole fraction of Acetone in Residue, $x_W = \frac{n_{AW}}{W}$

PROCEDURE:

About 300ml of Acetone and Water is poured (i.e. 50% by Volume of Acetone) in the round bottomed flask which is then closed at the top and the mixture is heated. The vapor formed is condensed and about 150ml is collected. The heating is stopped and the Residue is collected. The densities of the Distillate and Residue are found using specific gravity bottle.

A graph is drawn between $\frac{1}{y^* - x}$ and x where y* and x are equilibrium values of mole fraction of Acetone in vapor and liquid phases respectively. From the graph, the area between the two ranges of mole fraction of Feed and Residue is found out and multiplied by the scale factor. It is seen that the value is approximately equal to $\ln\left(\frac{F}{W}\right)$ where F and W are total number of moles of Acetone and Water in Feed and Residue respectively.

The Rayleigh equation is

$$\ln\left[\frac{F}{W}\right] = \int_{x_W}^{x_F} \frac{dx}{y^* - x}$$

TABLE 3: CALCULATIONS:

Mixture	Volume of mixture (V) (ml)	Volume fraction of Acetone in the mixture (φ_A) (From Density Composition graph)	No. of moles of Acetone in mixture (n_A) (gmol)	No. of moles of water in mixture (n_B) (gmol)	Total No. of moles of mixture (gmol)	Mole fraction of Acetone in mixture (x)
Feed (F)	$V_F =$	$\varphi_{AF} =$	$n_{AF} = \frac{V_F\ \varphi_{AF}\ \rho_A}{M_A}$	$n_{BF} = \frac{V_F(1-\varphi_{AF})\ \rho_B}{M_B}$	$F = n_{AF} + n_{BF}$	$x_F = \frac{n_{AF}}{F}$
Distillate (D)	$V_D =$	$\varphi_{AD} =$	$n_{AD} = \frac{V_D\ \varphi_{AD}\ \rho_A}{M_A}$	$n_{BD} = \frac{V_D(1-\varphi_{AD})\ \rho_B}{M_B}$	$D = n_{AD} + n_{BD}$	$x_D = \frac{n_{AD}}{D}$
Residue (W)	$V_W =$	$\varphi_{AW} =$	$n_{AW} = \frac{V_W\ \varphi_{AW}\ \rho_A}{M_A}$	$n_{Bw} = \frac{V_W(1-\varphi_{AW})\rho_B}{M_B}$	$W = n_{AW} + n_{BW}$	$x_W = \frac{n_{AW}}{W}$

TABLE 4:

VAPOUR LIQUID EQUILIBRIUM DATA FOR ACETONE WATER SYSTEM:

x-y* Data

S.No.	**x**	**y***	**y*-x**	$\frac{1}{y^* - x}$
1	0	0	0	-
2	0.05	0.6381	0.5881	1.700
3	0.1	0.7301	0.6301	1.587
4	0.15	0.7716	0.6216	1.609
5	0.2	0.7916	0.5916	1.690
6	0.25	0.8034	0.5534	1.807
7	0.3	0.8124	0.5124	1.952
8	0.35	0.8201	0.4701	2.127
9	0.4	0.8269	0.4269	2.342
10	0.45	0.8376	0.3876	2.580
11	0.5	0.8387	0.3387	2.952
12	0.55	0.8455	0.2955	3.384
13	0.6	0.8532	0.2532	3.949
14	0.65	0.8615	0.2115	4.728
15	0.7	0.8712	0.1712	5.841
16	0.75	0.8817	0.1317	7.593
17	0.8	0.895	0.095	10.526
18	0.85	0.9118	0.0618	16.181
19	0.9	0.9335	0.0335	29.851
20	0.95	0.9627	0.0127	78.740
21	1	1	0	-

At equilibrium:

x- mole fraction of Acetone in liquid phase

y*-mole fraction of Acetone in vapor phase

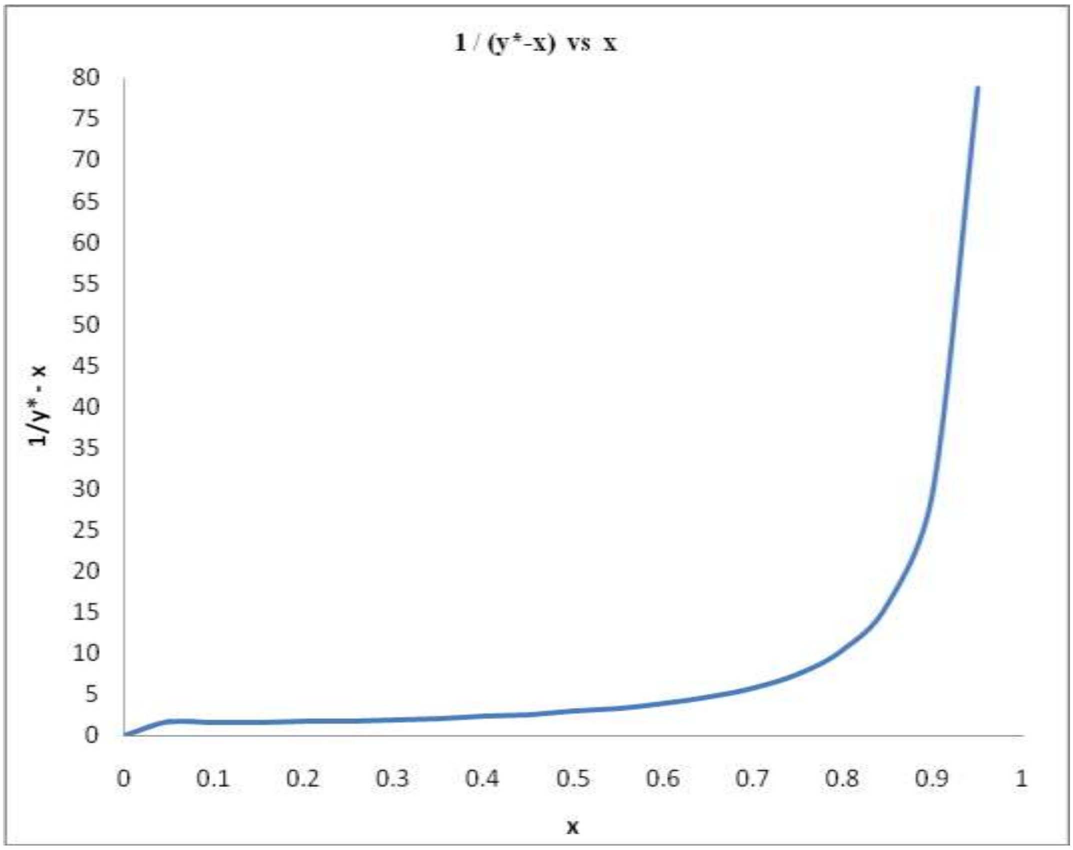
GRAPH 2:

$\frac{1}{y^* - x}$ vs x

SCALE:

X Axis 1 cm = 1 Unit = 0.1 unit (x- mole fraction of Acetone in liquid phase)

Y Axis 1 cm = 1 Unit = $\left(\frac{1}{y^* - x}\right)$



Scale
In x-axis 1cm =
In y-axis 1 cm =

FORMULAE & CALCULATION

RAYLEIGH'S EQUATION

$$ln\left[\frac{F}{W}\right] = \int_{x_W}^{x_F} \frac{dx}{y^* - x}$$

$$ln\left[\frac{F}{W}\right] = \ ln\left[\frac{\ }{\ }\right] =$$

$$\int_{x_W}^{x_F} \frac{dx}{y^* - x} = \text{Area under the curve } \frac{1}{y^* - x} \text{ vs x between the limits } x_W \text{ and } x_F$$

$$= \left(\frac{\text{No. of small boxes}}{100}\right) \text{X (x axis scale) X (y axis scale)}$$

$$=$$

Pre-Lab Questions	**Post Lab Questions**
1. Define distillation. 2. Write the types of distillation. 3. Explain batch distillation. 4. Write the applications of distillation. 5. Write the methods of distillation.	1. Write the significance of Rayleigh's equation. 2. Write the expression of Rayleigh's equation. 3. Define relative volatility. 4. What should be the value of relative volatility for the separation by distillation. 5. What do you mean by distillation with and without reflux.

RESULT:

The Rayleigh's equation was verified for Simple Distillation of a Binary Mixture.

REPORT:

Particulars	**Maximum Marks**	**Marks Obtained**
Pre-Lab Q & A	5	
Post-Lab Q & A	5	
Experimental Performance	10	

Exp. No:

Date:

DRYING CHARACTERISTICS

AIM:

To determine the Rate of drying for a given sample using a tray drier.

APPARATUS REQUIRED:

Tray Drier, Weighing Machine.

CHEMICALS REQUIRED:

Calcium Carbonate ($CaCO_3$), Water (H_2O).

OBSERVATION:

Empty mass of the plate (m_1) =

Mass of the plate + 50 g of $CaCO_3$ (m_2) =

Mass of dry solid (S_s) = (m_2 - m_1) =

Mass of the plate + 50 g of $CaCO_3$ + 50 ml of water (m at $\theta = 0$ min) =

Circumference of the plate = $2 \pi r$ =

Diameter of the plate $D = 2r$

Drying surface area $A = \frac{\pi}{4} D^2 =$

THEORY:

Drying a solid means the removal of relatively small amounts of liquid from the solid to reduce the content of residual liquid to an acceptably low value. The Liquid content of a dried substance varies from product to product. Occasionally the product contains no liquid and is said to be bone dry.

Prediction of mass transfer rates per unit area of dryer requires a knowledge of the mechanism of liquid and vapor motion in and through the solid and of the rather complicated phase equilibrium between a wet solid and a humid gas. The air entering a dryer is seldom completely dry but contains some moisture and has a definite relative humidity. For air of definite humidity, the moisture content of the solid leaving the dryer cannot be less than the equilibrium moisture content corresponding to the humidity of the entering air. That portion of water in the wet solid that cannot be removed by the inlet air, because of the humidity of the inlet air, is called equilibrium moisture. The difference between the total water content of the solid and its equilibrium water content is called the free moisture content.

Drying rate is the rate of removal of moisture content per unit drying area. Rate of drying when plotted against free moisture content, the curve obtained is called drying rate curve. The differences in the shapes of these curves for different materials reflect the differences in the mechanism of internal moisture flow in different materials. For non-porous materials, the curve usually consists of two distinct parts, viz, constant and falling rate periods. Constant rate period is characterized by a drying rate independent of free moisture content. During this period, the solid is so wet that a continuous water film exists over the entire drying surface. In non porous solids, most of the water removed in this period is superficial moisture of the solid surface. As the moisture content decreases, the constant rate period ends at definite moisture content and during further drying the rate decreases.

TABLE 1:

OBSERVATION:

S.No.	**Time θ (min)**	**Time θ (s)**	**Sample mass m (kg)**	**Moisture Content** $X = \frac{m - S_S}{S_S}$ **kg moisture / kg dry solid**
1	0	0		
2	5	300		
3	10	600		
4	15	900		
5	20	1200		
6	25	1500		
7	30	1800		
8	35	2100		
9	40	2400		
10	45	2700		
11	50	3000		
12	55	3300		
13	60	3600		
14	65	3900		
15	70	4200		
16	75	4500		
17	80	4800		
18	85	5100		
19	90	5400		
20	95	5700		
21	100	6000		
22	105	6300		
23	110	6600		
24	115	6900		
25	120	7200		

GRAPH 1:

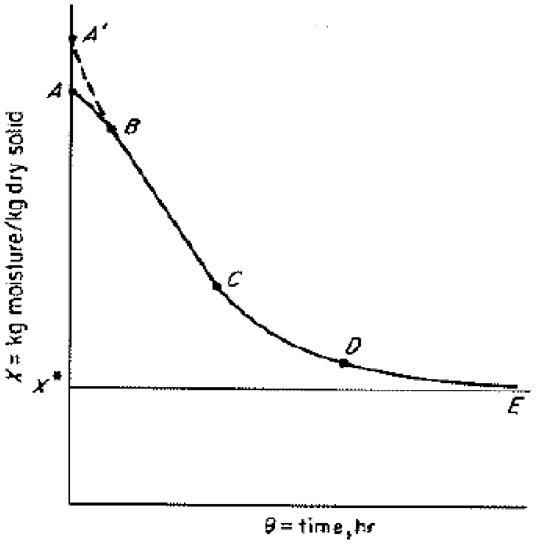
Moisture Content (X) vs Time (θ)

SCALE:

X Axis 1 cm = 1 Unit = s (Time (θ))

Y Axis 1 cm = 1 Unit = $\frac{\text{kg Moisture}}{\text{kg Dry Solid}}$ (Moisture Content (X))

Moisture Content (X) vs Time (θ)



Scale
In x-axis 1cm =
In y-axis 1 cm =

FORMULAE & CALCULATIONS:

m - Mass of sample at time θ

S_s - Mass of dry solid

A - Drying surface area

dX - Change in moisture content of sample

dθ - Corresponding change in time

Free moisture content in the solid $X = \frac{m - S_S}{S_S}$

Drying Flux or Rate of Drying $N = \frac{-S_S}{A}\frac{dX}{d\theta}$

The point terminating the constant rate period is called the critical moisture content. It varies with the thickness of the material and the rate of drying; so it is not a material property. In non-porous solids, critical point occurs at about the time when the superficial moisture evaporates. Constant rate period may not occur if the initial free moisture content of the solid is below its critical moisture content. During the falling rate period, the drying rate drops and when free moisture content of the solid equals its equilibrium moisture content, drying rate becomes zero. The main purpose of conducting Drying test is to determine equilibrium moisture content, critical moisture content and most importantly to determine the drying time to reduce the moisture content of the solid from one value to another.

TABLE 2 :

CALCULATIONS:

S.No.	**Time θ (s)**	**Sample mass (kg)**	$X = \frac{M - S_S}{S_S}$ **kg moisture / kg dry solid**	**dX kg moisture / kg dry solid**	**dθ (s)**	$N = \frac{-S_S}{A}\frac{dX}{d\theta}$ **(kg / m^2 s)**
1	0			0	0	-
2	300					
3	600					
4	900					
5	1200					
6	1500					
7	1800					
8	2100					
9	2400					
10	2700					
11	3000					
12	3300					
13	3600					
14	3900					
15	4200					
16	4500					
17	4800					
18	5100					
19	5400					
20	5700					
21	6000					
22	6300					
23	6600					
24	6900					
25	7200					

GRAPH 2:

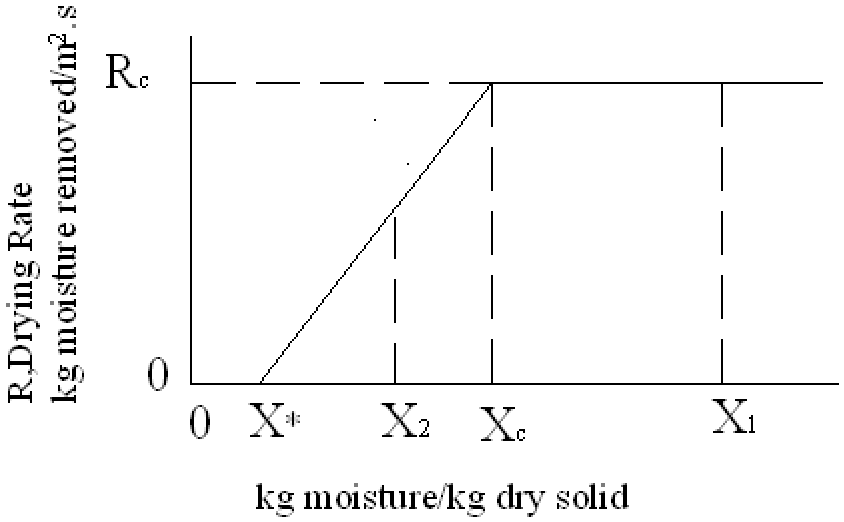
Drying Flux (N) vs Moisture Content (X)

SCALE:

X Axis 1 cm = 1 Unit= $\frac{\text{kg Moisture}}{\text{kg Dry Solid}}$ (Moisture Content (X))

Y Axis 1 cm = 1 Unit = $\frac{\text{kg}}{\text{m}^2\ \text{s}}$ (Drying Flux (N))

Drying Flux (N) vs Moisture Content (X)



Scale
In x-axis 1cm =
In y-axis 1 cm =

PROCEDURE:

About 50g of sample was weighed in a tray. 50ml of water was added to sample and it was made into paste. The tray was weighed and kept in the drier. The tray was taken out after every five minutes, weighed and put back into the drier till 2 consecutive readings were obtained. Then drying was stopped and the observed values were tabulated. The circumference of the plate was measured and drying surface area calculated.

Pre-Lab Questions	**Post Lab Questions**
1. Define drying. 2. Write the classification of dryers. 3. Define equilibrium moisture content of a wet solid. 4. Define bound moisture content of a wet solid. 5. Define unbound moisture content of a wet solid.	1. Write the applications of tray dryer. 2. Define critical moisture content of a wet solid. 3. Define rate of drying. 4. Define constant drying conditions. 5. Write the applications of spray dryer.

RESULT:

The Rate of drying for a given sample was determined using a tray drier.

Drying Characteristics of the given feed was studied and the following graphs were plotted.

Moisture Content in sample vs Time (X vs θ)

Drying Flux vs Free Moisture Content (N vs X)

Initial Moisture Content was found to be (X_1) =

Critical Moisture Content was found to be (X_c) =

Equilibrium Moisture Content was found to be (X^*) =

The Total Time required for Drying is (θ_{Total}) =

The Constant Drying Flux or the Rate of drying was found to be (N_c) =

REPORT:

Particulars	Maximum Marks	Marks Obtained
Pre-Lab Q & A	5	
Post-Lab Q & A	5	
Experimental Performance	10	

Exp. No:

Date:

SIMPLE LEACHING – SINGLE STAGE

AIM:

To find out the Percentage Recovery of Solute by varying the Solvent to Feed Ratio for single Stage Leaching.

APPARATUS REQIRED:

Beaker, Pipette, Burette, Volumetric Flask, Conical Flask, Stirrer.

CHEMICALS REQUIRED:

Sodium Carbonate (Na_2CO_3), Water (H_2O), Hydrochloric acid (HCl), Sand, Methyl Orange Indicator.

OBSERVATION:

Feed:

Mass of Sand = 45 g

Mass of Na_2CO_3 = 5 g

Volume of H_2O = 50 ml

Mass of H_2O = 50 g (Density of water = 1 g /cc)

Total Mass of feed = Mass of Sand + Mass of Na_2CO_3 + Mass of H_2O

= 45 + 5 + 50

= 100 g

Volume of solution used for dilution = 10ml

Made up volume = 100ml

Normality of HCl = 0.1 N

Equivalent weight of Na_2CO_3 = 53

TABLE 1 :

Volume of solution used for titration = 10ml

Indicator - Methyl Orange (1 drop)

End point – Appearance of brick red color

Beaker No.	**Volume of Solvent (H_2O) used for extraction (ml)**	**Mass of Solvent (H_2O) used for extraction (g)**	**Solvent to Feed Ratio**	**Burette Reading**		**Volume of HCl (ml)**
				Initial	**Final**	
1	50	50	50:100 0.5:1			
2	100	100	100:100 1:1			
3	150	150	150:100 1.5:1			
4	200	200	200:100 2:1			
5	250	250	250:100 2.5:1			

THEORY:

Leaching is the extraction of a soluble constituent from a solid mixture using a liquid solvent. It can be used to produce a concentrated solution of a valuable solid material or to remove an insoluble solid, such as a pigment, from a soluble material with which it is contaminated. The method used for the extraction is determined by the proportion of the soluble constituent present, its distribution throughout the solid, the nature of the solid and particle size.

If the solute is uniformly dispersed in the solid, the material near the surface dissolves first, leaving a porous structure in the solid residue. The solvent will then have to penetrate this outer layer before it can further dissolve the solute and the process will become progressively more & more difficult and the extraction rate will fall. If the solute forms a very high proportion of the solid, the porous structure may breakdown to give a fine deposit of insoluble residue and access of solvent to the solute will not be impeded. Generally the process can be considered in three parts. First the change of phase of the solute as it dissolves in the solvent, secondly its diffusion through the solvent in the pores of the solid to the outside of the particle and thirdly the transfer of the solute form the solution in contact with the particle to the main bulk of the solution. Any one of these three processes may be responsible for limiting the extraction rate.

FORMULAE & CALCULATIONS:

$$\text{Normality of dilute extract, } N_{\text{dilute}} = \frac{\text{Volume of HCl X Normality of HCl}}{\text{Volume of solution used for titration}}$$

$$\text{Normality of original extract, } N_{\text{original}} = \frac{\text{Normality of dilute extract X Made up volume}}{\text{Volume of solution used for dilution}}$$

Mass of Na_2CO_3 recovered,

$$m = \frac{\text{Normality of original extract X Equivalent weight of } Na_2CO_3 \text{ X Volume of solvent used for extraction}}{1000}$$

$$\text{Percentage Recovery of } Na_2CO_3 = \frac{\text{Mass of } Na_2CO_3 \text{ recovered}}{\text{Mass of } Na_2CO_3 \text{ taken}} X100$$

PROCEDURE:

PREPARATION OF FEED:

5g of Na_2CO_3 and 45g of Sand were weighed accurately and mixed together. 50ml of distilled water was added to the mixture and this solution was used as Feed.

Different feed samples were prepared in beakers numbered 1 to 5 by adding an additional amount of 50, 100, 150, 200 and 250ml water to beakers 1, 2, 3, 4 and 5 respectively. The mixtures in each of the beakers were well stirred and sand was allowed to settle. 50ml of the clear solution was taken from each bottle. 10ml of the clean solution was pipetted out and made up to 100ml in a standard flask. 10ml of the made up solution was pipetted out and titrated against standard HCl using Methyl Orange as Indicator and the readings were tabulated.

TABLE 2 :

CALCULATIONS:

Beaker No.	**Solvent to Feed Ratio**	**Normality of dilute extract N_{dilute} (N)**	**Normality of original extract $N_{original}$ (N)**	**Mass of Na_2CO_3 Recovered m (g)**	**Percentage Recovery of Na_2CO_3 (%)**
1.	50:100 0.5:1				
2.	100:100 1:1				
3.	150:100 1.5:1				
4.	200:100 2:1				
5.	250:100 2.5:1				

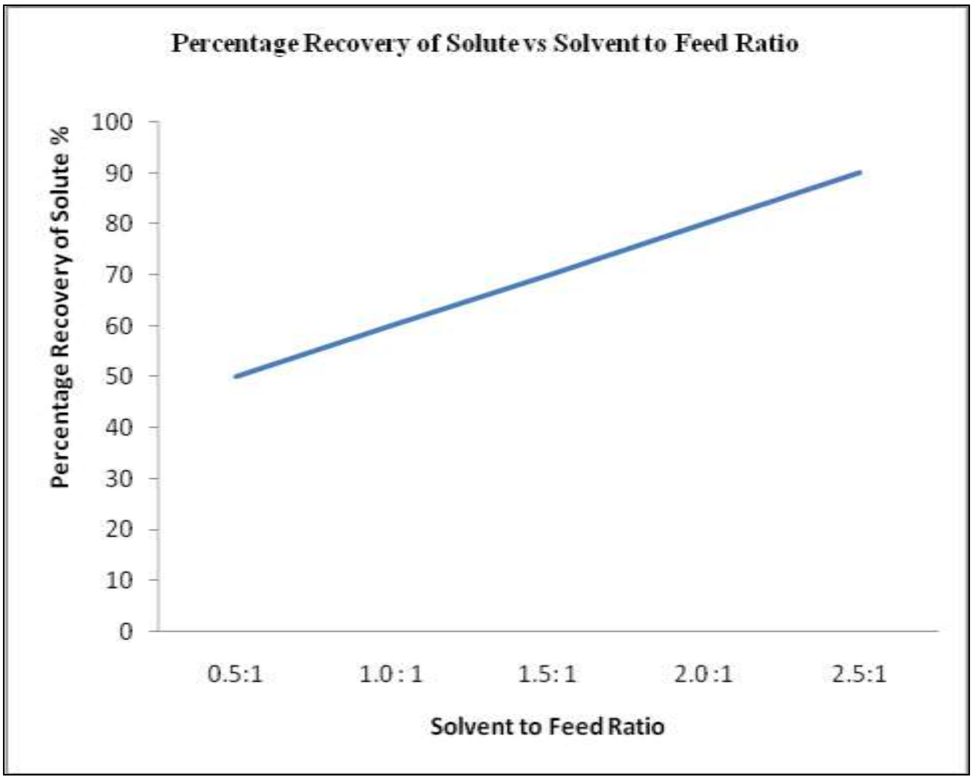
GRAPH :

Percentage Recovery of Solute vs Solvent to Feed Ratio

SCALE:

X Axis 2 cm = 1 Unit = 0.5:1 (Solvent to Feed Ratio)

Y Axis 2 cm = 1 Unit = 10 % (Percentage Recovery of Solute)



Scale
In x-axis 1cm =
In y-axis 1 cm =

Pre-Lab Questions	**Post Lab Questions**
1. Define leaching. 2. Define liquid-liquid extraction. 3. Write the applications of leaching process. 4. Write the applications of liquid-liquid extraction process. 5. Define selectivity of a solvent.	1. Write the effect of solvent to feed ratio on percentage recovery of solute. 2. Write the characteristics of a good solvent. 3. Distinguish between leaching and liquid-liquid extraction. 4. What should be the value of selectivity for a better separation by extraction. 5. Write the difference between distillation and liquid-liquid extraction processes.

RESULT:

The Percentage Recovery of Solute was determined for Single Stage Leaching and a Graph between Percentage Recovery of Solute and Solvent to Feed Ratio was plotted.

Solvent to Feed Ratio	**Percentage Recovery of Na_2CO_3 (%)**
0.5:1	
1:1	
1.5:1	
2:1	
2.5:1	

REPORT:

Particulars	**Maximum Marks**	**Marks Obtained**
Pre-Lab Q & A	5	
Post-Lab Q & A	5	
Experimental Performance	10	

Exp. No:

Date:

SIMPLE LEACHING – MULTI STAGE

AIM:

To find the effect of Number of Stages on Percentage Recovery of Solute by keeping the Solvent to Feed Ratio Constant.

APPARATUS REQUIRED:

Beakers, Pipette, Burette, Volumetric Flask, Conical Flask, Stirrer.

CHEMICALS REQUIRED:

Sodium Carbonate (Na_2CO_3), Water (H_2O), Hydrochloric acid (HCl), Sand, Methyl Orange Indicator.

OBSERVATION:

Feed :

Mass of Sand = 45 g

Mass of Na_2CO_3 = 5 g

Volume of H_2O = 50 ml

Mass of H_2O = 50 g (Density of water = 1 g /cc)

Total Mass of feed = Mass of Sand + Mass of Na_2CO_3 + Mass of H_2O

= 45 + 5 + 50

= 100 g

Volume of solvent (H_2O) used for extraction = 200ml

Mass of solvent (H_2O) used for extraction = 200 g

Solvent to Feed ratio = 200 / 100 = 2 (constant)

Volume of solution used for dilution = 10ml

Made up volume = 100ml

Normality of HCl = 0.1 N

Equivalent weight of Na_2CO_3 = 53

TABLE 1 :

Volume of solution used for titration = 10ml

Indicator - Methyl Orange (1 drop)

End point – Appearance of brick red color

Beaker No.	**No. of Stages**	**Volume of Solvent (H_2O) used per stage (ml)**	**Burette Reading**		**Volume of HCl (ml)**
			Initial	**Final**	
1	1	200			
2	2	100			
3	3	67			
4	4	50			
5	5	40			

THEORY:

Leaching is the preferential separation of one or more constituents of a solid mixture by contacting with a liquid solvent. Metallurgical industries are the largest users of leaching. Most useful minerals occur in mixtures with large proportions of undesirable constituents, and leaching of the valuable material is a separation method which is frequently used. For example copper minerals are preferentially dissolved from certain of their ores by leaching with sulfuric acid or ammoniacal solutions and gold is separated from its ores using sodium cyanide solutions. Pharmaceutical products, tea, coffee and sugar are obtained after leaching operation of their corresponding mixtures.

By contacting the leached solids with a fresh batch of leaching solvent, additional solute may be dissolved or washed away from the insoluble material. The calculations for additional stages are nearly repetitions of the procedure for a single stage, with the leached solids from any stage becoming the feed solids to the next. Determination of numbers of stages may require adjustment by trial of either the amount of solute to be leached or the amount and apportioning of solvent to the stages.

FORMULAE & CALCULATIONS:

$$\text{Normality of dilute extract, } N_{\text{dilute}} = \frac{\text{Volume of HCl X Normality of HCl}}{\text{Volume of solution used for titration}}$$

$$\text{Normality of original extract, } N_{\text{original}} = \frac{\text{Normality of dilute extract X Made up volume}}{\text{Volume of solution used for dilution}}$$

Mass of Na_2CO_3 recovered,

$$m = \frac{\text{Normality of original extract X Equivalent weight of } Na_2CO_3 \text{ X Volume of solvent used for extraction}}{1000}$$

$$\text{Percentage Recovery of } Na_2CO_3 = \frac{\text{Mass of } Na_2CO_3 \text{ recovered}}{\text{Mass of } Na_2CO_3 \text{ taken}} X100$$

PROCEDURE:

PREPARATION OF FEED:

5g of Na_2CO_3 and 45g of Sand was weighed accurately and mixed together. 50ml of distilled water was added to the mixture and this solution was used as feed.

Solute from each beaker was extracted with 200ml of distilled water but the number of stages was varied from 1 to 5.

5 beakers were taken and numbered 1, 2, 3, 4 and 5. To beaker 1, 200ml of water was added and the contents were stirred well. Sand was allowed to settle. The clear solution was poured into another beaker. 10ml of the extracted solution was pipetted and made up to the mark in a 100ml volumetric flask. 10ml of this solution was pipetted into a conical flask. A drop of methyl orange indicator was added and titrated against standard HCl taken in the burette until the end point was reached.

To beaker 2, 100ml of the solvent was added, stirred well and allowed to settle. The clear solution was transferred into another beaker. Again 100ml of pure water was added to beaker 2, stirred well and allowed to settle. Again the clear solution was transferred into the same beaker. 10ml of the extracted solution was pipetted and made upto 100ml in a standard volumetric flask. 10ml of this made up solution was pipetted and titrated against standard HCl using methyl orange as indicator. In beakers 3, 4 and 5 the solutions were extracted 3, 4 and 5 times, each time with 66.7ml, 50ml and 40ml of water respectively.

TABLE 2:

CALCULATIONS:

Beaker No.	**No. of Stages**	**Normality of dilute extract N_{dilute} (N)**	**Normality of original extract $N_{original}$ (N)**	**Mass of Na_2CO_3 Recovered (m) (g)**	**Percentage Recovery of Na_2CO_3 (%)**
1.	1				
2.	2				
3.	3				
4.	4				
5.	5				

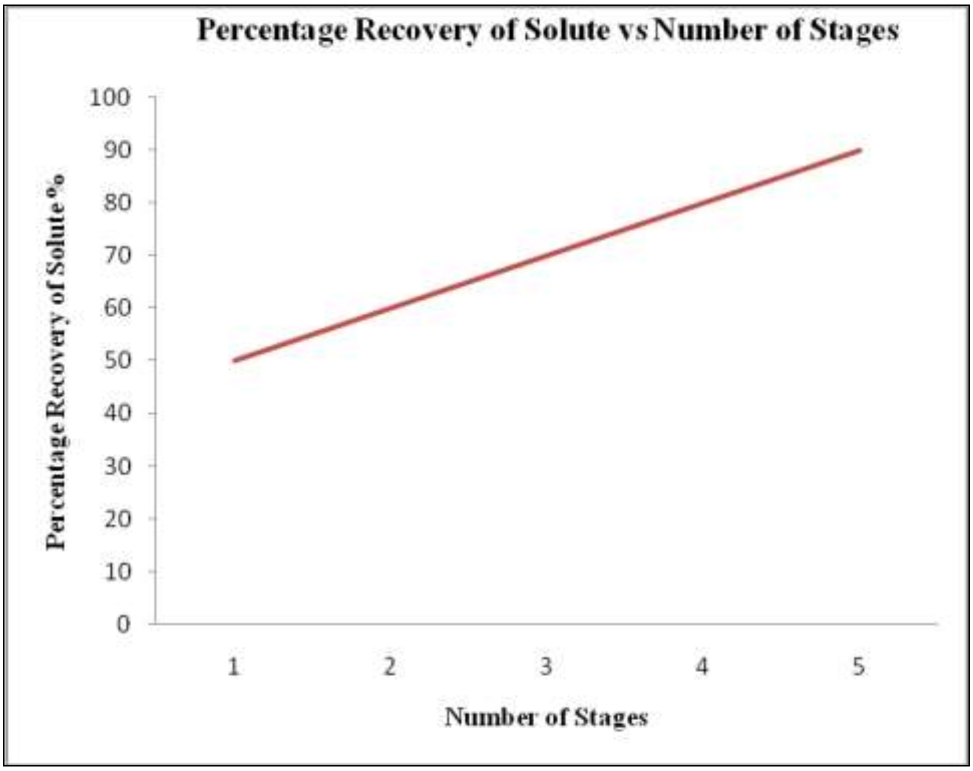
GRAPH:

Percentage Recovery of Solute vs Number of Stages

SCALE:

X Axis 2 cm = 1 Unit = 1 Stage (Number of Stages)

Y Axis 2 cm = 1 Unit = 10 % (Percentage Recovery of Solute)



Scale
In x-axis 1cm =
In y-axis 1 cm =

Pre-Lab Questions	**Post Lab Questions**
1. Define leaching. 2. Define liquid-liquid extraction. 3. Write the applications of leaching process. 4. Write the applications of liquid-liquid extraction process. 5. Define selectivity of a solvent.	1. Write the effect of number of stages on percentage recovery of solute. 2. Write the characteristics of a good solvent. 3. Distinguish between leaching and liquid-liquid extraction. 4. What should be the value of selectivity for a better separation by extraction. 5. Write the difference between distillation and liquid-liquid extraction processes.

RESULT:

The Percentage Recovery of Solute was determined for Multi Stage Leaching and a Graph between Percentage Recovery of Solute and Number of Stages was plotted.

No. of Stages	**Percentage Recovery of Na_2CO_3 (%)**
1	
2	
3	
4	
5	

REPORT:

Particulars	**Maximum Marks**	**Marks Obtained**
Pre-Lab Q & A	5	
Post-Lab Q & A	5	
Experimental Performance	10	

Exp. No:

Date:

ADSORPTION ISOTHERM

AIM:

To verify the applicability of Freundlich adsorption isotherm equation for Adsorption of Acetic Acid on Activated Carbon and to determine the constants k and n for Adsorption at room Temperature and Pressure.

APPARATUS REQUIRED:

Burette, Pipette, Conical Flask, Filter Paper, Reagent Bottle, Bottle Shaker, Volumetric Flask, Weighing Bottle.

CHEMICALS REQUIRED:

Acetic Acid (CH_3COOH), Sodium Hydroxide ($NaOH$), Water (H_2O), Activated Carbon.

PREPARATION OF ACETIC ACID SOLUTION:

25 g of Acetic Acid is dissolved in 250 ml of Water.

Concentration C $= \frac{\text{mass}}{\text{volume}}$

Concentration of Acetic Acid solution $= \frac{25\ \text{g}}{250\ \text{ml}} = 0.1 \frac{\text{g}}{\text{ml}}$

1 ml of solution contains 0.1 g of Acetic Acid

y ml of solution contains (y X 0.1) g of Acetic Acid

TABLE 1:

S.No.	Bottle No.	Volume of Acetic Acid solution used for dilution (y) (ml)	Mass of Acetic Acid present in Acetic Acid solution used for dilution (g)	Made up volume (ml)	Concentration of Acetic Acid in made up volume (Initial Concentration of Acetic Acid in solution) $C_o = \frac{\text{mass}}{\text{volume}} \left(\frac{\text{g}}{\text{ml}}\right)$	Volume of Acetic Acid solution used for adsorption (V) (ml)	mass of adsorbent used for adsorption (m) (g)
1	1	10	10X0.1=1	250	$\frac{1}{250} = 0.004$	200	5
2	2	20	20X0.1=2	250	$\frac{1}{250} = 0.008$	200	5
3	3	30	30X0.1=3	250	$\frac{1}{250} = 0.012$	200	5
4	4	40	40X0.1=4	250	$\frac{1}{250} = 0.016$	200	5
5	5	50	50X0.1=5	250	$\frac{1}{250} = 0.02$	200	5

THEORY:

The Phenomena of concentrating specific molecular species at the surface is called adsorption. The solid that takes up a vapor or solute from a solution is called adsorbent while the solute which is held at the solid surface is called adsorbate. Adsorption is accompanied by a decrease in enthalpy and entropy of the system.

Adsorption is a fluid solid operation. It is a process in which one or more components of a liquid or gaseous mixture adhere to the solid surface with which it is brought in contact, due to force of attraction between the molecules of a solid and the fluid. The component adsorbed is known as adsorbate. Simple system consists of a binary liquid or gaseous mixture and the solid adsorbent.

The ability of solids to adsorb from solution phase is utilized in certain chemical industries. This type of adsorption is influenced appreciably by temperature and concentration. Increase in concentration of the solution causes an increase in the magnitude of adsorption and decreases with rise in temperature.

The amount of substance adsorbed depends on

(i) Concentration of gas and liquid phase

(ii) Temperature

(iii) Pressure

OBSERVATION:

Indicator: Phenolphthalein

End Point: Appearance of pale permanent pink color

Normality of NaOH = 0.1N

Equivalent Weight of Acetic Acid = 60

TABLE 2:

S. No.	Bottle No.	Volume of filtrate (Acetic Acid solution) used for titration (ml)	Burette Reading		Volume of NaOH used for titration (ml)
			Initial	Final	
1	1	10			
2	2	10			
3	3	10			
4	4	10			
5	5	10			

The effect of concentration is represented by Freundlich's equation i.e.,

$$\frac{x}{m} = k\ C_e^{\frac{1}{n}}$$

$$\log\left(\frac{x}{m}\right) = \log k\ + \frac{1}{n}\log\ C_e$$

Where $\frac{x}{m}$ is the amount of solute adsorbed per unit mass of adsorbent from a solution of concentration C at a given temperature. k and n are constants for the given adsorbent and solute. The value of n is less than unity.

Some typical applications of adsorption are listed below. Activated carbon used in gas masks, in which all toxic gases and vapors are adsorbed by charcoal while pure air passes through its pores. Animal charcoal is used as a decolouriser in the manufacture of cane sugar. Adsorption plays an important role in heterogeneous catalysis a phenomenon widely used in chemical industries.

FORMULAE & CALCULATIONS:

Concentration of Acetic Acid in solution at equilibrium

$$C_e = \frac{\text{Volume of NaOH used for titration X Normality of NaOH X Equivalent weight of Acetic Acid}}{\text{Volume of Acetic Acid solution used for titration X 1000}} \left(\frac{g}{ml}\right)$$

mass of solute adsorbed per unit volume of solution = $C_o - C_e \left(\frac{g}{ml}\right)$

V- Volume of solution used for adsorption = 200 ml

mass of solute adsorbed x = $\left(C_o - C_e\right) V$ (g)

m – mass of adsorbent used for adsorption = 5 g

mass of solute adsorbed per unit mass of adsorbent =

$$\frac{x}{m} = \frac{\text{mass of solute adsorbed}}{\text{mass of adsorbent}} = \frac{(C_o - C_e)V}{m} \left(\frac{g}{g}\right)$$

PROCEDURE:

Room temperature was noted. 25g of CH_3COOH was weighed accurately in a weighing bottle and transferred completely by repeated washings into a 250ml volumetric flask F1. The sample was made up to the mark with distilled water. 10ml of this solution was pipette into a 250ml volumetric flask F2 and the volume was made up. About 5g of activated carbon was weighed in a reagent bottle B1. 200ml of the solution from F2 was added to the reagent bottle. The same procedure was repeated with bottles numbered B2, B3, B4 and B5 with the difference that volumes of solutions pipetted out from F1 are 20, 30, 40 & 50ml respectively. The bottles were then placed in a mechanical shaker and shaken well for 20min. In the mean while, a std. oxalic acid solution was prepared and used to standardize NaOH solution. The solutions in the five bottles were filtered. Some of this filtered solution was then titrated against standardized NaOH using phenolphthalein as indicator. This procedure was done for every bottle.

TABLE 3:

CALCULATIONS:

S.No.	Bottle No.	C_O $\left(\frac{g}{ml}\right)$	C_e $\left(\frac{g}{ml}\right)$	C_o - C_e $\left(\frac{g}{ml}\right)$	V (ml)	x= (C_o - C_e)V (g)	m (g)	$\frac{x}{m} = \frac{(C_o - C_e)V}{m}$ $\left(\frac{g}{g}\right)$
1	1	0.004			200		5	
2	2	0.008			200		5	
3	3	0.012			200		5	
4	4	0.016			200		5	
5	5	0.02			200		5	

GRAPH 1:

$\left(\frac{x}{m}\right)$ vs C_e

SCALE:

X Axis 1 cm =1 unit = $\left(\frac{g}{ml}\right)$ (C_e)

Y Axis 1 cm =1 unit = $\left(\frac{g}{g}\right)$ (x/m)

$\left(\frac{x}{m}\right)$ vs C_e

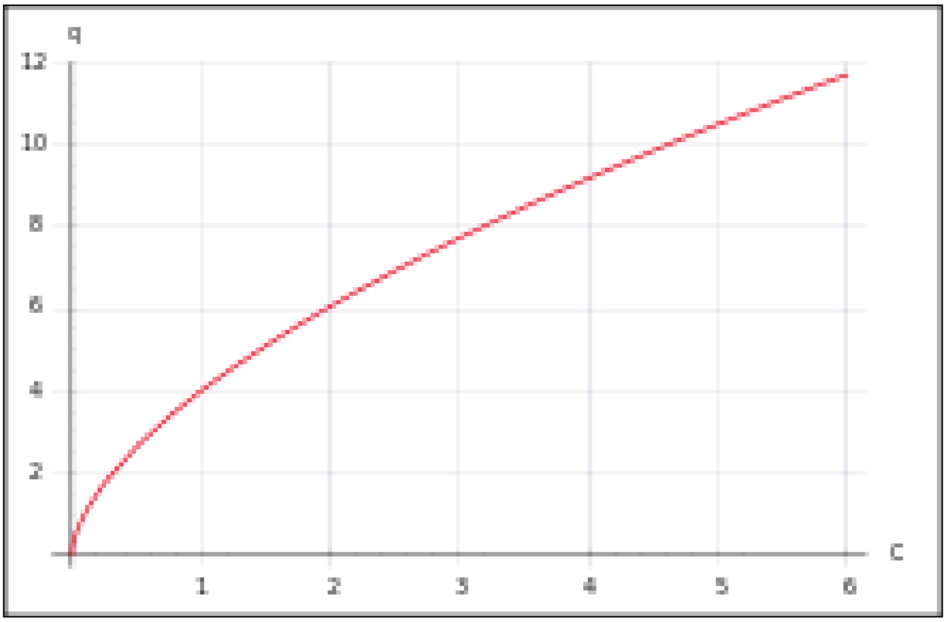


TABLE 4:

CALCULATIONS:

S.No.	Bottle No.	$C_e \left(\frac{g}{ml}\right)$	log C_e	$\frac{x}{m} = \frac{(C_o - C_e)V}{m} \left(\frac{g}{g}\right)$	$\log\left(\frac{x}{m}\right) = \log\left(\frac{(C_o - C_e)V}{m}\right)$
1	1				
2	2				
3	3				
4	4				
5	5				

GRAPH 2:

Freundlich Adsorption Isotherm Equation: $\log\left(\frac{x}{m}\right) = \frac{1}{n}\log C_e + \log k$

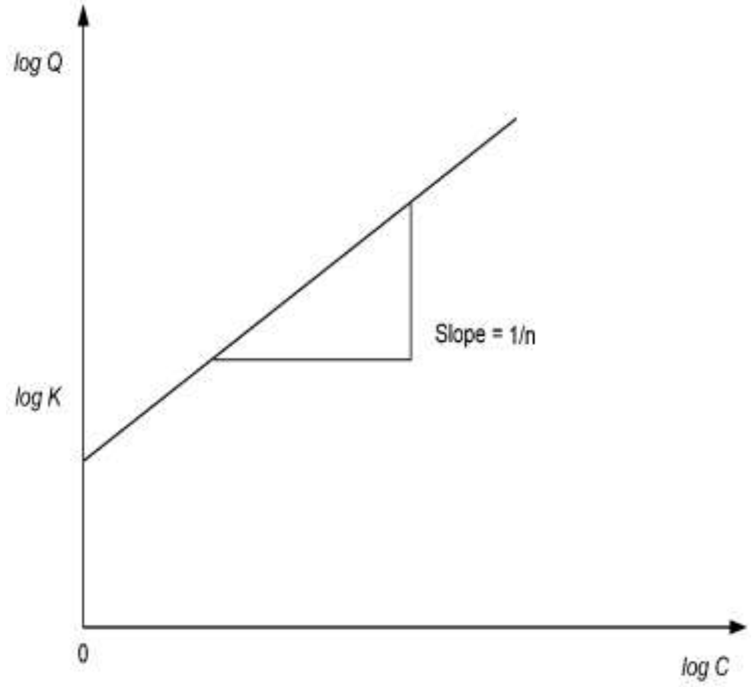
$\log\left(\frac{x}{m}\right)$ vs $\log C_e$

SCALE:

X Axis 1 cm = Unit ($\log C_e$)

Y Axis 1 cm = Unit [log (x/m)]

$\log\left(\frac{x}{m}\right)$ vs $\log C_e$



From graph, slope of the line = $\frac{1}{n}$, from which n can be calculated.

From graph, y intercept of the line = log k, from which k can be calculated.

Pre-Lab Questions	Post Lab Questions
1.Define adsorption. 2.Define adsorbate and adsorbent. 3.Differentiate physisorption and Chemisorption. 4.Name few commercially available adsorbents. 5. Mention any two important adsorption isotherms.	1. Mention few applications of adsorption operation 2. Define regeneration of adsorption process. 3. Differentiate absorption and adsorption. 4. List the important characteristics of adsorbents. 5. List of influencing parameters of adsorption process.

RESULT:

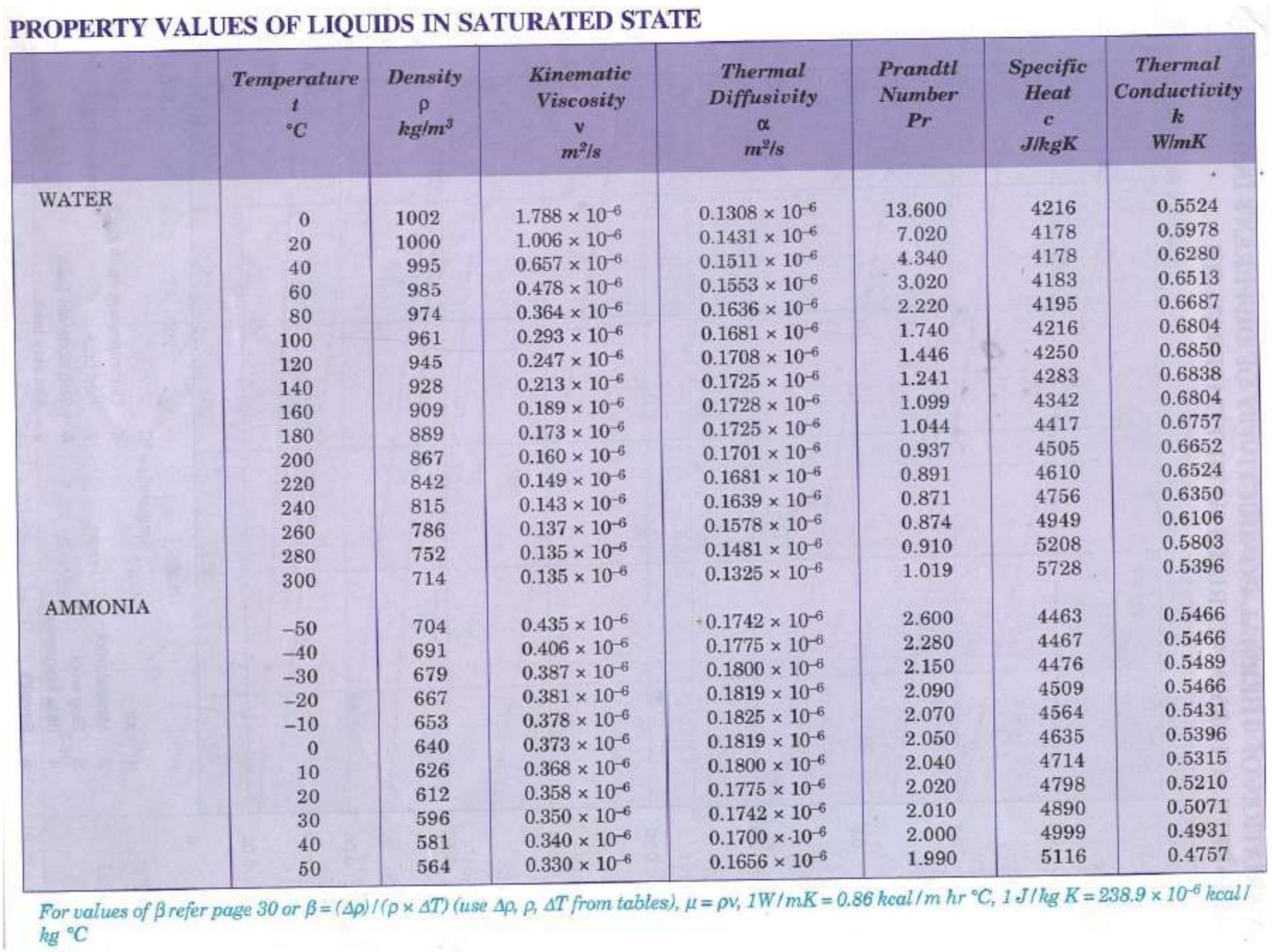
The experiment was conducted and the Freundlich adsorption isotherm for the adsorption of Acetic Acid on Activated Carbon was plotted at room temperature. The values of the parameters in the Freundlich adsorption isotherm equation were determined to be

k = __________

n = __________

REPORT:

Particulars	Maximum Marks	Marks Obtained
Pre-Lab Q & A	5	
Post-Lab Q & A	5	
Experimental Performance	10	

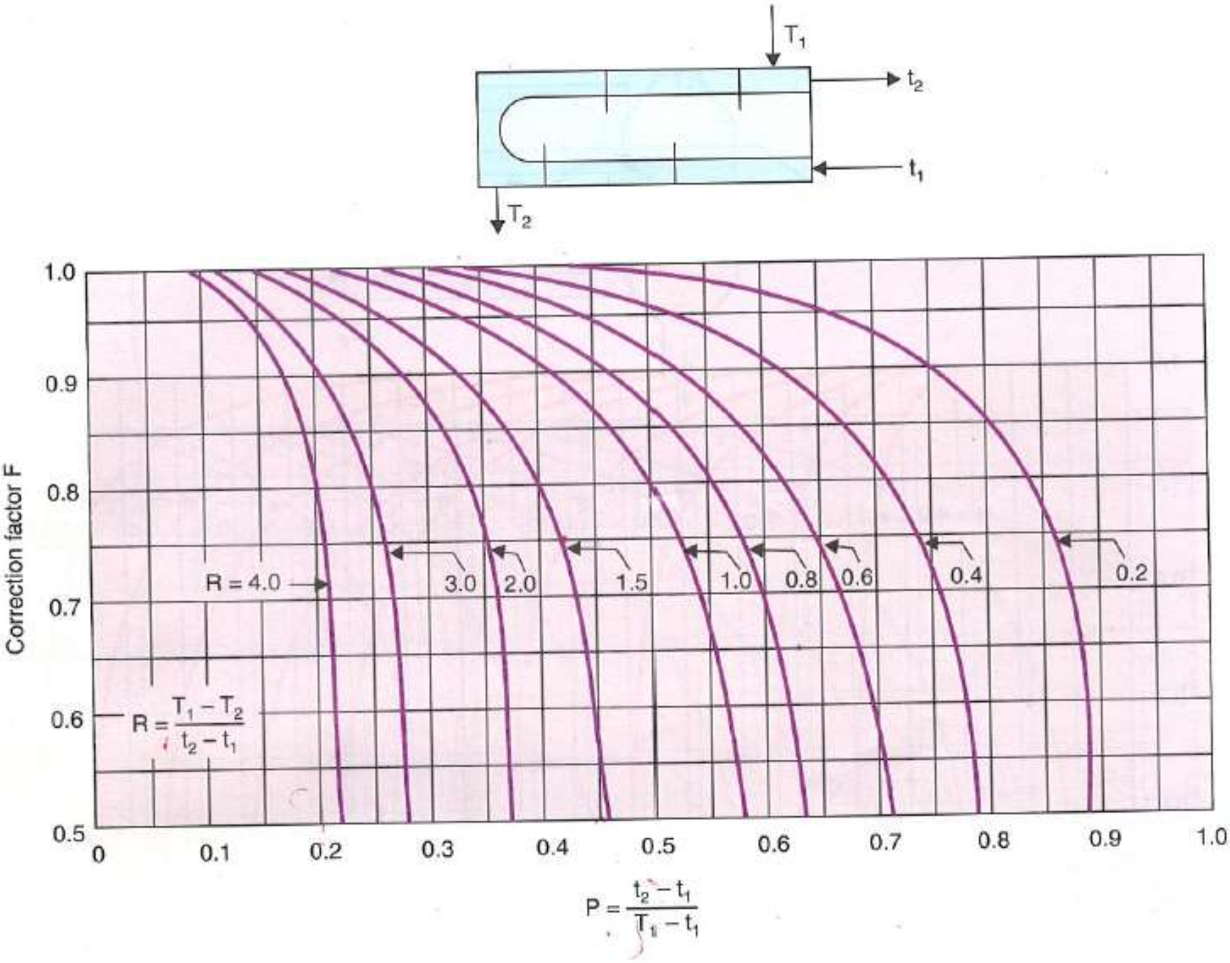


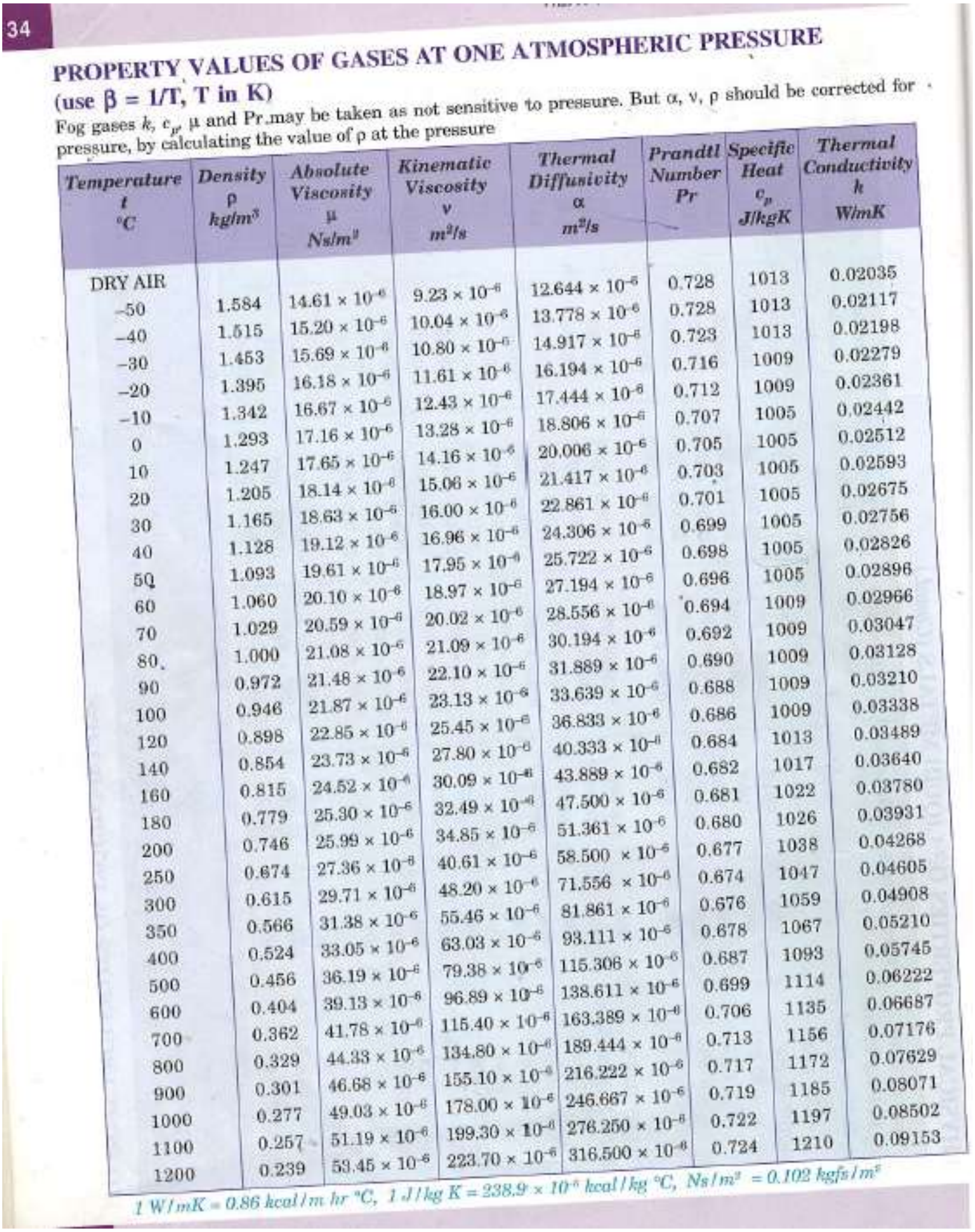
PROPERTY VALUES OF LIQUIDS IN SATURATED STATE

	Temperature t °C	*Density* ρ kg/m^3	*Kinematic Viscosity* ν m^2/s	*Thermal Diffusivity* α m^2/s	*Prandtl Number* Pr	*Specific Heat* c J/kgK	*Thermal Conductivity* k W/mK
WATER							
	0	1002	1.788×10^{-6}	0.1308×10^{-6}	13.600	4216	0.5524
	20	1000	1.006×10^{-6}	0.1431×10^{-6}	7.020	4178	0.5978
	40	995	0.657×10^{-6}	0.1511×10^{-6}	4.340	4178	0.6280
	60	985	0.478×10^{-6}	0.1553×10^{-6}	3.020	4183	0.6513
	80	974	0.364×10^{-6}	0.1636×10^{-6}	2.220	4195	0.6687
	100	961	0.293×10^{-6}	0.1681×10^{-6}	1.740	4216	0.6804
	120	945	0.247×10^{-6}	0.1708×10^{-6}	1.446	4250	0.6850
	140	928	0.213×10^{-6}	0.1725×10^{-6}	1.241	4283	0.6838
	160	909	0.189×10^{-6}	0.1728×10^{-6}	1.099	4342	0.6804
	180	889	0.173×10^{-6}	0.1725×10^{-6}	1.044	4417	0.6757
	200	867	0.160×10^{-6}	0.1701×10^{-6}	0.937	4505	0.6652
	220	842	0.149×10^{-6}	0.1681×10^{-6}	0.891	4610	0.6524
	240	815	0.143×10^{-6}	0.1639×10^{-6}	0.871	4756	0.6350
	260	786	0.137×10^{-6}	0.1578×10^{-6}	0.874	4949	0.6106
	280	752	0.135×10^{-6}	0.1481×10^{-6}	0.910	5208	0.5803
	300	714	0.135×10^{-6}	0.1325×10^{-6}	1.019	5728	0.5396
AMMONIA							
	–50	704	0.435×10^{-6}	0.1742×10^{-6}	2.600	4463	0.5466
	–40	691	0.406×10^{-6}	0.1775×10^{-6}	2.280	4467	0.5466
	–30	679	0.387×10^{-6}	0.1800×10^{-6}	2.150	4476	0.5489
	–20	667	0.381×10^{-6}	0.1819×10^{-6}	2.090	4509	0.5466
	–10	653	0.378×10^{-6}	0.1825×10^{-6}	2.070	4564	0.5431
	0	640	0.373×10^{-6}	0.1819×10^{-6}	2.050	4635	0.5396
	10	626	0.368×10^{-6}	0.1800×10^{-6}	2.040	4714	0.5315
	20	612	0.358×10^{-6}	0.1775×10^{-6}	2.020	4798	0.5210
	30	596	0.350×10^{-6}	0.1742×10^{-6}	2.010	4890	0.5071
	40	581	0.340×10^{-6}	0.1700×10^{-6}	2.000	4999	0.4931
	50	564	0.330×10^{-6}	0.1656×10^{-6}	1.990	5116	0.4757

For values of β refer page 30 or $\beta = (\Delta\rho)/(\rho \times \Delta T)$ (use $\Delta\rho$, ρ, ΔT from tables), $\mu = \rho\nu$, $1 W/mK = 0.86 kcal/m hr °C$, $1 J/kg K = 238.9 \times 10^{-6} kcal/kg °C$

CORRECTION FACTOR PLOT FOR EXCHANGER WITH ONE SHELL PASS AND TWO, FOUR OR MULTIPLE TUBE PASSES





PROPERTY VALUES OF GASES AT ONE ATMOSPHERIC PRESSURE

(use $\beta = 1/T$, T in K)

Fog gases k, c_p, μ and Pr may be taken as not sensitive to pressure. But α, ν, ρ should be corrected for pressure, by calculating the value of ρ at the pressure

Temperature t °C	Density ρ kg/m³	Absolute Viscosity μ Ns/m²	Kinematic Viscosity ν m²/s	Thermal Diffusivity α m²/s	Prandtl Number Pr	Specific Heat c_p J/kgK	Thermal Conductivity k W/mK
DRY AIR							
–50	1.584	14.61×10^{-6}	9.23×10^{-6}	12.644×10^{-6}	0.728	1013	0.02035
–40	1.515	15.20×10^{-6}	10.04×10^{-6}	13.778×10^{-6}	0.728	1013	0.02117
–30	1.453	15.69×10^{-6}	10.80×10^{-6}	14.917×10^{-6}	0.723	1013	0.02198
–20	1.395	16.18×10^{-6}	11.61×10^{-6}	16.194×10^{-6}	0.716	1009	0.02279
–10	1.342	16.67×10^{-6}	12.43×10^{-6}	17.444×10^{-6}	0.712	1009	0.02361
0	1.293	17.16×10^{-6}	13.28×10^{-6}	18.806×10^{-6}	0.707	1005	0.02442
10	1.247	17.65×10^{-6}	14.16×10^{-6}	20.006×10^{-6}	0.705	1005	0.02512
20	1.205	18.14×10^{-6}	15.06×10^{-6}	21.417×10^{-6}	0.703	1005	0.02593
30	1.165	18.63×10^{-6}	16.00×10^{-6}	22.861×10^{-6}	0.701	1005	0.02675
40	1.128	19.12×10^{-6}	16.96×10^{-6}	24.306×10^{-6}	0.699	1005	0.02756
50	1.093	19.61×10^{-6}	17.95×10^{-6}	25.722×10^{-6}	0.698	1005	0.02826
60	1.060	20.10×10^{-6}	18.97×10^{-6}	27.194×10^{-6}	0.696	1005	0.02896
70	1.029	20.59×10^{-6}	20.02×10^{-6}	28.556×10^{-6}	0.694	1009	0.02966
80	1.000	21.08×10^{-6}	21.09×10^{-6}	30.194×10^{-6}	0.692	1009	0.03047
90	0.972	21.48×10^{-6}	22.10×10^{-6}	31.889×10^{-6}	0.690	1009	0.03128
100	0.946	21.87×10^{-6}	23.13×10^{-6}	33.639×10^{-6}	0.688	1009	0.03210
120	0.898	22.85×10^{-6}	25.45×10^{-6}	36.833×10^{-6}	0.686	1009	0.03338
140	0.854	23.73×10^{-6}	27.80×10^{-6}	40.333×10^{-6}	0.684	1013	0.03489
160	0.815	24.52×10^{-6}	30.09×10^{-6}	43.889×10^{-6}	0.682	1017	0.03640
180	0.779	25.30×10^{-6}	32.49×10^{-6}	47.500×10^{-6}	0.681	1022	0.03780
200	0.746	25.99×10^{-6}	34.85×10^{-6}	51.361×10^{-6}	0.680	1026	0.03931
250	0.674	27.36×10^{-6}	40.61×10^{-6}	58.500×10^{-6}	0.677	1038	0.04268
300	0.615	29.71×10^{-6}	48.20×10^{-6}	71.556×10^{-6}	0.674	1047	0.04605
350	0.566	31.38×10^{-6}	55.46×10^{-6}	81.861×10^{-6}	0.676	1059	0.04908
400	0.524	33.05×10^{-6}	63.03×10^{-6}	93.111×10^{-6}	0.678	1067	0.05210
500	0.456	36.19×10^{-6}	79.38×10^{-6}	115.306×10^{-6}	0.687	1093	0.05745
600	0.404	39.13×10^{-6}	96.89×10^{-6}	138.611×10^{-6}	0.699	1114	0.06222
700	0.362	41.78×10^{-6}	115.40×10^{-6}	163.389×10^{-6}	0.706	1135	0.06687
800	0.329	44.33×10^{-6}	134.80×10^{-6}	189.444×10^{-6}	0.713	1156	0.07176
900	0.301	46.68×10^{-6}	155.10×10^{-6}	216.222×10^{-6}	0.717	1172	0.07629
1000	0.277	49.03×10^{-6}	178.00×10^{-6}	246.667×10^{-6}	0.719	1185	0.08071
1100	0.257	51.19×10^{-6}	199.30×10^{-6}	276.250×10^{-6}	0.722	1197	0.08502
1200	0.239	53.45×10^{-6}	223.70×10^{-6}	316.500×10^{-6}	0.724	1210	0.09153

1 W/mK = 0.86 kcal/m hr °C, 1 J/kg K = 238.9×10^{-6} kcal/kg °C, Ns/m² = 0.102 kgfs/m²