FEDERAL POLYTECHNIC NASARAWA
DEPARTMENT OF CHEMICAL ENGINEERING TECHNOLOGY

HND I
LABORATORY MANUAL

CHEMICAL ENGINEERING LABORATORY
III & IV
(CHE 305 & CHE 308)

2024/2025

ADDRESS:
Department of Chemical Engineering Technology
School of Engineering Technology
Federal Polytechnic Nasarawa
PMB 001, Nasarawa
Nasarawa State
www.fpn.edu.ng/chet
www.fpn.edu.ng/set
engineeringtech@fpn.edu.ng
chetfpn@fpn.edu.ng
Tel: 08140976963

MISSION STATEMENT

"Molding students to become disciplined, skilled and innovative for self-actualization and national development"

Goals of Chemical Engineering Department

A Department that is known for academic excellence, highly dynamic staff and a corporate outlook that serves as a world-class centre for the training of Chemical Engineering professionals and academics for Nigerian establishments and beyond.

CHEMICAL ENGINEERING LABORATORY PERSONNEL

Dr. SALIHU S. MAIWALIMA
(MNSChE, MNSE, MSPE, GRADIGEM(UK), COREN)
Head of Department

Tel: 07030699569
Email: ssalihum@gmail.com
suleimansalihum@fedpolynas.edu.ng

ABDULAZEEZ A. ABDULAZEEZ
(Sub Head of Department)

CHIEF LABORATORY COORDINATOR

Tell: 08140976963
Email: azbinbaz@gmail.com
abdulazeezaabdulazeez@fedpolynas.edu.ng

ALIYU ABDULQADIR
MNSChE, MNSE
Assistant Lab Coordinator
Tel: 08069153662
Email:
abdulqadiraliyu@fedpolynas.edu.ng
aliyuabdulqadir@gmail.com

ALIYU S. FATIMA
MNSChE, MNSE,
Assistant Lab Coordinator
Tel: 07062639198
Email: Fatynnhamza@gmail.com

JIBRIL ABUBAKAR AHMAD
Assistant Lab Coordinator
Tel: 08054543261
Email: jibrila02@gmail.com
jibrilabubakarahmad@fedpolynas.edu.ng

MUHAMMAD YASIR
Assistant Lab Coordinator

Tel: 08068684298
Email: yaakzu@gmail.com

SADIQ JOSEPH
Assistant Lab Coordinator

Tel: 08069123122
Email: saddypa247@gmail.com
sadiqjoseph@fedpolynas.edu.ng

IBRAHIM D IBRAHIM
Technician

Tel: 08038331333
Email: ibrahimd.ibrahim65@gmail.com
ibrahimdibrahim@fedpolynas.edu.ng

LABORATORY PERSONNEL

SN	PERSONNEL	DESIGNATION	PR. CODE	PHONE NUMBER
1	ABDULAZEEZ A. ABDULAZEEZ	Chief Coordinator	LAB01	08140976963
2	ALIYU ABDULQADIR	Asst. Coordinator	LAB02	08069153662
3	FATIMA S. ALIYU	Asst. Coordinator	LAB03	07062639198
4	JIBRIL A. AHMAD	Asst. Coordinator	LAB04	08054543261
5	MUHAMMAD YASIR	Asst. Coordinator	LAB05	08035965974
6	SADEEQ JOSEPH	Asst. Coordinator	LAB06	08068684298
	IBRAHIM D IBRAHIM	Technician	LAB07	08038331333
7	ALIYU IBRAHIM	Lab Attendant	LAB08	
8	CORP MEMBER(s)		LAB09	

DEPARTMENTAL LABORATORIES

- Physical Transport Phenomenal (PTP) Laboratory (Fluid Mechanics/ Heat and Mass Transfer
- Unit Operation Laboratory (UOP)/ Chemical Reaction Engineering Laboratory
- Solid Minerals Process Laboratory/Strength of Materials Lab.
- Computer Process Simulation Laboratory

Laboratories according to courses

Name of Laboratory: Mass Transfer Operations

S/No	Name of Equipments
1	Wetted wall column
2	Experimental cooling water tower
3	Fluid bed dryer
4	Liquid-liquid extraction unit
5	Gas absorption in sieve plate column
6	Packed bed distillation column
7	Gas Chromatograph
8	UV-Visible Spectrophotometer
9	Ultrasonic Probe
10	Liquid Diffusion Apparatus
11	Gas Diffusion Apparatus
12	Solid-liquid Extraction Unit
13	Sedimentation Tank
14	Solid conveying system
15	Soxhlet apparatus
16	Batch distillation column
17	Fluid Mixing Apparatus
18	Packed absorption system

Name of Laboratory: Heat Transfer Operations

S/N	Name of Equipment
1	Tray Dryer
2	Heat conduction Apparatus and its service unit
3	Parallel & Counter Current Heat Exchanger
4	Shell and Tube Heat exchanger
6	Fixed and Fluidized bed system
7	Centrifugal Pump Test Rig
8	Convective Heat Transfer
9	Radiative Heat Transfer Apparatus

Name of Laboratory: Fluid and Particles Mechanics

S/N	Name of Equipment
1	Basic Hydraulics Bench
2	Bernoulli's Theorem Apparatus
3	Reynolds Apparatus
4	Thermos Fluid tutor
5	Fluid Friction Apparatus
6	Fluid Mixing Apparatus
7	Model Sedimentation Tank

Name of Laboratory: Instrumentation and Process Control

Sr. N	Name of Equipment
1	Multi Process Control System Pressure Control Trainer Temperature Control Trainer Level Control Trainer Flow Control Trainer
2	Thermocouple
3	PID controller
	Batch Reactor

Name of the Laboratory: Chemical Reaction Engineering

SN	Name of the Equipment
1.	Gas Chromatograph (Thermo Scientific)
2.	UV-Vis Spectrophotometer (Thermo Scientific)
3.	UV-Vis Spectrophotometer (Hach)
4.	Enzyme catalytic reactor
5.	Continuous Stir tank Reactor
6.	Kinematic Viscometer Bath
7.	Incubator
8.	Laboratory Centrifuge

Name of Laboratory: Corrosion and Material Science

Sr. No	Name of the Equipment
1.	Corrosion studies Kit

Name of Laboratory: Computer Simulation Lab

Software available:
- ASPEN HYSYS
- DWSIM
- ProSIM
- CHEMCAD
- MATHCAD
- MATHLAB
- SPRSS Analysis Package
- VISIO
- AutoCAD
- Microsoft Office SUITE

PREFACE

This laboratory manual has been prepared to guide the undergraduate students of the Department of Chemical Engineering at Federal Polytechnic Nasarawa through the laboratory courses of their curriculum. The manual aims to help the students understand how chemical engineers acquire, evaluate, use and report scientific data and design experiments, that they will need in their professional lives. This manual, which covers all the laboratory applications of chemical engineering such as fluid mechanics, heat transfer, reaction engineering, separation processes, process control, raw material and product analyses including instrumental analysis methods, and statistical data analysis.

We wish the students the maximum benefit.

CHAPTER ONE: LABORATORY SAFETY

Safety in the laboratory is one of the highest priorities. It is very important to take all the necessary precautions seriously to ensure your own safety and the safety of other people. In this section, important precautions and rules to be followed by everyone who works in a laboratory, are described.

A.   General Rules

➤ Students must abide the dress code while working in the laboratory.
➤ Laboratory coat must be worn all the time when working in the laboratory.
➤ Only closed toe shoes are allowed in the laboratory. Do not wear sandals, slippers and high heel shoes inside the laboratory.
➤ Students with long hair must get their hair tied up tidily when doing laboratory work.
➤ Bags and other belongings must be kept at the designated places.
➤ Foods, drinks and smoking are strictly prohibited inside the laboratory.
➤ Noise must be kept to the minimum as a courtesy to respect others.
➤ Students are not allowed to work alone without the supervision of laboratory instructor/officer. There must be at least 2 persons present in the laboratory at same time.
➤ Students are not allowed to bring any outsiders (non-registered parties) into the laboratory.
➤ Any unauthorized experiment without the knowledge of laboratory instructor is prohibited.
➤ All instrument and equipment must be handled with care.
➤ Workspace has to be cleaned and tidied up after the experiment completed. Instrument and equipment must be returned orderly after use.
➤ Students are strictly prohibited to take any equipment or any technical manuals out from the laboratory without the permission of laboratory instructor/officer.
➤ Students are required to instill an instinctive awareness towards property value of laboratory equipment and to be responsible when using it. Any damages can cause to jeopardize the success of not only the individual work but also to the university.
➤ Do not attempt to remove and dismantle any parts of the equipment from its original design without permission.
➤ Students shall be liable for damages of equipment caused by individual negligence. If damages occurred, an investigation will take place to identify the causes and the names of the involved students will be recorded for faculty attention.
➤ Please check the notice board regularly and pay attention to laboratory announcements.
➤ Disciplinary action shall be taken against those students who are failed to abide the rules and regulations.

B.   Laboratory Safety Rules

➤ It is always a good practice and the responsibility of an individual to keep a tidy working condition in laboratory.
➤ It is important for each student to follow the procedures given by the laboratory

instructor when conducting laboratory experiment.

- ➤ Before any experiment starts, students must study the information / precaution steps and understand the procedures mentioned in the given laboratory sheet.
- ➤ Students should report immediately to laboratory instructor/officer if the laboratory equipment is suspected to be malfunctioning or faulty.
- ➤ Student should report immediately to the laboratory instructor/officer if discovered any damages on equipment or any hazardous situation and also if any injury occurred.
- ➤ If there is a tingling feel when working with electrical devices, stop and switch off the devices immediately. Place a warning note before reporting to the laboratory instructor/officer and wait for further instruction.
- ➤ Do not work with electricity under wet condition in laboratory. Electric shock is a serious fatal error due to human negligence and may cause death.
- ➤ Students are required to wear goggles, gloves, apron and mask when handling corrosive or active chemical agents.
- ➤ Hazardous chemical agents must be properly stored and labelled in a designated place. Students must acquire and study the material safety data sheet of a particular chemical agent before using it.

C.   Responsibility of Students

- ➤ Attendance is compulsory. Attendance shall be taken during the laboratory session.
- ➤ Please sign your attendance when you attend the laboratory session.
- ➤ Laboratory report can only be accepted for submission if the student has attended the laboratory session.
- ➤ Student must be punctual to attend laboratory session.
- ➤ Students who are **late for more than 30 minutes will be barred from attending the laboratory session**. Only students with valid reason of medical basis or unforeseen circumstances can be considered to apply for laboratory replacement.
- ➤ Students are expected to study the lab sheet before the laboratory session start.
- ➤ Student must understand all the safety measures / precaution steps before starting any experiments.
- ➤ Student must complete the experiment within the allocated duration of laboratory session.
- ➤ Students are responsible for the condition of their working area at the end of each laboratory session. All power to the equipment and instruments should be turned off, and cooling water flows should be shut off. Glassware used should be cleaned and dried.
- ➤ Students have to **pass up** their experiment result to laboratory officer **on the same day** after every experiment.

- ✔ Each student will be designated at least once as a **team leader** and her/his name will be indicated in the Experimental Report and/or -Results. The team leader will accept the full responsibility that all the team members understood the experiment, the results and conclusions, and participated in the Experimental Report and/or -Results preparation.
- ✔ Experimental raw data (measurements) obtained from each experiment should be written in the individual laboratory notebooks. The data should also be written on a separate sheet by the team leader and signed by the supervisor (instructor or

assistant) before leaving the laboratory and **this raw data sheet should be attached to the "Experimental Results"** document.

✓ There are **two types of reports** to be prepared by the teams: **a) Experimental REPORTS** are detailed scientific documents and prepared for a limited number of experiments announced at the beginning of the course (CHE 305, CHE 308, and CHE 409).

✓ All **Experimental REPORTS should be submitted to the supervisor, before the next experimental session of the team.** Reports that are late for any reason will be given 10% reduction of grade per day and will not be accepted after one week.

✓ **The team will be evaluated orally from their reports** by the supervisor at a predetermined date and time. Different report grades can be assessed to each student according to the individual performance and contribution to the work.

✓ **Experimental Reports must be original**. Direct copying of all or part of a report from other reports or sources is a very important ethical issue and will be considered as **cheating**. Such a report will be graded as **zero** and there is **no compensation**. The reports are also subject to random examination by the *Department Ethics Committee*. If an ethical problem is detected by the Committee, the group will also be graded zero regardless of their previous grades given by the instructors.

✓ **Attendance in the laboratory sessions is mandatory**. The students, who do not attend the experiment without notification and approval, will be graded as zero for the performance and Report, and fail the experiment. Unattended students that have valid excuses accepted by the supervisor may compensate the experiment.

✓ **A team may compensate only one experiment** due to an approved excuse**.**

✓ The group members that do not **obtain the "Preparation/Design Questions"** from the supervisor or assistant **at least one week before their experimental session**, cannot perform the experiment.

D.   Assessments

Overall Performance in Laboratory during Experiment Session (10 marks)

This is a group assessment. Each student performance in the laboratory during the experiment session will be observed and marks will be given to the group as a whole.

The performance will be assessed based on the following criteria:

Criteria	Description	Marks
Safety Awareness	➢ Adhere to laboratory safety, rules and regulation. ➢ Abide to dress code (lab coat, shoes, long pants etc.) while working in the laboratory. ➢ Understand all the safety measures / precaution steps before starting any experiments. ➢ Proper safety equipment such as goggles, gloves etc. were used when necessary. ➢ Show precautions when handling chemicals.	
Punctuality	➢ Attend laboratory session on time.	

Criteria	Description	
Preparation	➤ Show understanding in the experiment that are about to carry out.	
Cleanliness and Responsibility	➤ Workspace is clean and tidied up after the experiment completed. ➤ Instrument and equipment are returned orderly after use. ➤ Show instinctive awareness towards property value of laboratory equipment and instruments and their responsibility in handling them.	

E. Laboratory Reports (80 marks)

Laboratory report will be assessed based on the following criteria:
- **Preliminary report 10 marks**
- **Laboratory course work 10 marks**

Criteria	Description	Marks
Overall Presentation of Report	➤ Organisation of report with the correct format and necessary information such as titles, figure explanations. ➤ Report is written in clear and concise English.	20
Observations / Data / Result Presentation	➤ Valid observations, consistent with event and demonstrate attention to detail. ➤ Data are presented in an organised manner. ➤ Quality of data reflects student's ability to perform experiment successfully and utilise computer software in analysis (if applicable). ➤ All calculations and graphs are correct.	30
Discussion	➤ Discussion shows complete understanding of experiment and the significance of data. ➤ Logical explanation for problems in the data.	20
Conclusion	➤ Summary of key findings in a clear statement. ➤ Clearly show relationships between data and conclusion. ➤ Express views on the weakness of the experimental design (if there is any), or what is the implication of the conclusion.	10
	TOTAL	**80**

CHAPTER TWO:

LABORATORY & REPORTS: AN OVERVIEW

All experiments in the **Chemical Engineering Lab III and IV** require either a laboratory report for selective experiments, unless it is stated otherwise. The reports should be simple and clearly written. Laboratory reports are due after all of the experiments are performed, unless it is stated otherwise. **Final reports should be submitted a week after the experiment's day**, unless it is stated otherwise. Any late submission will not be entertained, unless there are concrete and unavoidable reasons.

The laboratory reports should be in hand writing and any graphs needed should be drawn on an appropriate graph paper.

The final laboratory reports should be submitted to the instructor directly or at the instructor's office.
The pre-lab questions in this lab manual should be answered and submitted during the first 5 minutes before you start your experiment accordingly.

Instructions for Preparing Laboratory Reports

For each separate experiment prepare a typed report which, in general, should contain the following sections arranged in the order listed:	
Lab Report Sections	
Subject	**Marks**
1). Title Page	
2). Abstract	
3). Table of Contents	
4). Introduction	
5). Theoretical Background	
6). Equipment and Procedure	
7). Raw Data/Results	
8). Discussion of Results	
9). Conclusions and Recommendations	
10). Literature Cited	
11). Nomenclature	
Appendices	
Calculations	

1. Title Page
The Title page should be separate from the rest of the report. It should contain:
a. The name of the experiment
b. The number of course
c. The date when the experiment was run
d. The name of the writer and his co-workers, Reg. No., and his group number
e. The name of the instructor to whom the report is submitted
f. The date of submission of report

2. Abstract
The abstract should be informative, and should be written in about three to five sentences. It should cover all phases of the investigation. It must include the following:

a. An introductory statement about the subject matter
b. Briefly describe what was done.
c. Present some selected result (numerical values, if possible).
d. If possible, present some percentage errors in experimental results in comparison with theoretical values. While writing the abstract, it should be kept in mind that you should not refer to any graph or table.

3. Introduction
This section should include few sentences discussing the physical and/or chemical principles involved in the experiment.

4. Theoretical Background
This section should include the theory behind the experiment. It should also contain all those equations, which are used to acquire a certain result. Theoretical correlations, which are used for comparison with experimental results, should also be included.

5. Procedure
Here, you should briefly describe the actual step-by-step procedure you followed in running the experiment. It should be written in your own words, e.g. the needle valve was manipulated in order to adjust the liquid flow rate.

6. Results
The results should be presented in the form or Tables or graphs. The Table should contain the results obtain from experiments and from theoretical knowledge. Comparisons should be presented in terms, e.g. percent deviation.

7. Discussion of Results
In this section you should discuss your experimental results. Show how you make comparison with the values obtained theoretically. Also discuss the deviation of experimental results from theoretical values. The possible source of errors should also be mentioned. If the results are obtained in terms of graphs, then interpret them also.

8. Conclusions and Recommendations
Conclusions are the series of numbered sentences which answer the questions posed in the end of each experiment. Conclusions should also include the errors between the experimental and theoretical values. What you have learned from the experiment should be mentioned as well.

Recommendations are the proposals for future work, e.g. suggested changes in equipment, study of new variables, or possible experiments in relative fields.

Like the conclusions, the recommendations are usually listed by numbers, and each consists of only a sentence or two.

9. Literature Cited
Here, you should list the books, Journal's articles, etc. used in writing your report and analyzing the experiment. The reference should be completed (name of the book, author, volume, date of publication, pages, etc.).

References should be arranged alphabetically by author.

10. Nomenclature

The symbols, which are used in the report, should be defined in the nomenclature in alphabetical order. The accompanying definitions must include proper units.

Appendices

All appendices and graphs should be attached at the end of the report.

A1. Raw Data:

It should contain the data on which the experiment was done.

A2. Analysis of Data and Sample Calculations:

This shows how the data is transformed into experimental results by using the appropriate equations. Also, how the theoretical results are obtained using theoretical in terms of percentage error. Sample calculations should contain each step, which is used to acquire certain results.

CHAPTER THREE: CHEMICAL ENGINEERING LABORATORY III (CHE 305)

INDEX OF EXPERIMENTS
HEAT TRANSFER DESIGN LABORATORY

Experiment 1: Determination of overall thermal conductance and temperature distribution profile of a composite wall.

Experiment 2: Determination of thermal conductivity of a liquid.

Experiment 3: Natural and forced convection experiment.

Experiment 4: Concentric tube Heat Exchanger experiment.

EXPERIMENT 5 Parallel Flow Counter Flow Heat Exchanger

Experiment 6: Investigation of the heat transfer in a shell and tube heat exchanger

CHEMICAL ENGINEERING THERMODYNAMICS LAB

Experiment 7: Measurement of specific latent heat of vaporization using electric method

UNIT OPERATION III

Experiment 8: Determination of the effects of temperature on the rate of evaporation of a given solution.

Experiment 9: investigating the Effect of different NaOH concentration during constant pressure and rotation

FILTRATION
Batch Filtration

Experiment 10a: Determination of permeability and investigate porosity of the cake from the filter aid from batch experiment.

Continuous Filtration
Experiment 10b: Predication of dependence of the filtrate flow rate and the rate of the filter cake production.

EXPERIMENT 1

AIM: Study of conduction heat transfer in composite wall.

OBJECTIVE:
1. To determine total thermal resistance and thermal conductivity of composite wall.
2. To calculate thermal conductivity of one material in composite wall.
3. To plot the temperature profile along the composite wall.

INTRODUCTION:
When a temperature gradient exists in a body, there is an energy transfer from the high temperature region to the low temperature region. Energy is transferred by conduction and heat transfer rate per unit area is proportional to the normal temperature gradient:

$$\frac{q}{A} \alpha \frac{\Delta T}{\Delta X}$$

EQ 1

When the proportionality constant is inserted,

$$q = -kA\frac{\Delta T}{\Delta X}$$

EQ 2

Where q is the heat transfer rate and T/ X is the temperature gradient in the direction of heat flow. The positive constant k is called thermal conductivity of the material.

THEORY:
A direct application of Fourier's law is the plane wall. Fourier's equation:

EQ 3

$$q = -\frac{kA}{\Delta X}(T_2 - T_1)$$

Where the thermal conductivity is considered constant. The wall thickness is X, and T1 and T2 are surface temperatures. If more than one material is present, as in the multiplayer
Wall, the analysis would proceed as follows:
The temperature gradients in the three materials (A, B, C), the heat flow may be written

$$q = -k_A A\frac{\Delta T_A}{\Delta X_A} = -k_B A\frac{\Delta T_B}{\Delta X_B} = -k_C A\frac{\Delta T_C}{\Delta X_C}$$

EQ 4

DESCRIPTION:
The Apparatus consists of a heater sandwiched between two asbestos sheets. Three slabs of different material are provided on both sides of heater, which forms a composite structure. A small press- frame is provided to ensure the perfect contact between the slabs. A Variac is provided for varying the input to the heater and measurement of input power is carried out by a Digital Voltmeter & Digital Ammeter. Temperatures Sensors are embedded between inter faces of the slab, to read the temperature at the surface. The experiment can be conducted at various values of power input and calculations can be made accordingly.

EXPERIMENTAL PROCEDURE:
STARTING PROCEDURE:
1. Ensure that Mains ON/OFF switch given on the panel is at OFF position &dimmer-stat is at zero position.
2. Connect electric supply to the set up.
3. Switch ON the Mains ON / OFF switch.
4. Set the heater input by the dimmer-stat, voltmeter in the range 40 to 100 V.
5. After 1 hour. Note down the reading of voltmeter, ampere meter and temperature sensors in the observation table after every 10 minutes interval till observing change inconsecutive readings of temperatures ($\pm$ 0.2 ^{O}C).

CLOSING PROCEDURE:
1. After experiment is over set the dimmer stat to zero position.
2. Switch OFF the Mains ON/OFF switches.
3. Switch OFF electric supply to the set up.

OBSERVATION & CALCULATIONS:
DATA:

d = 0.25 m
X_1 = 0.020 m = 20mm
X_2 = 0.020m = 20 mm X_3 = 0.012m = 12mm K_1=125w/m°C K_2=1.4w/m°C
K_3= --- w/m°C

OBSERVATION TABLE:

S/N	V Volts	A Amps	T1 ^{0}C	T2 ^{0}C	T3 ^{0}C	T4 ^{0}C	T5 ^{0}C	T6 ^{0}C	T7 ^{0}C	T8 ^{0}C

CALCULATIONS:
To plot the temperature profile,

Distance	0	10	20	45
Avg. Temp				

At distance 0, average temp $= \dfrac{(T_1 + T_2)}{2}$ At distance 10, average temp $= \dfrac{(T_3 + T_4)}{2}$

At distance 20, average temp $= \dfrac{(T_5 + T_6)}{2}$

At distance 45, average temp $= \dfrac{(T_7 + T_8)}{2}$

Heat supplied by the heater, $W = 0.86 \times V \times I$, watts

Amount of Heat Transfer, $Q = W$, watts

Where, $A = \dfrac{\pi}{4} d^2$, m^2

Overall Temp. Difference $\Delta T = \dfrac{(T_1 - T_7) + (T_2 - T_8)}{2}$, °C

Total thermal resistance of composite wall $R_t = \dfrac{\Delta T}{q}$, °C m²/W

Total thickness of wall $\Delta X = X_1 + X_2 + X_3$, m

Thermal Conductivity of composite wall $K_{eff} = \dfrac{q \times \Delta X}{\Delta T}$, W/m °C

Thermal Conductivity of press wood $K_3 = \dfrac{X_3}{\left[\dfrac{\Delta T}{q} - \left(\dfrac{X_1}{k_1} + \dfrac{X_2}{k_2} \right) \right]}$, W/m °C

Nomenclature:

A   =   Area of heat transfer, m²

d   =   Diameter, m

I   =   Ammeter reading, amp

Keff   =   Thermal conductivity of composite wall, W/m °C

k1   =   Thermal conductivity of cast iron, W/m °C

K_2 =   Thermal conductivity of Press wood, W/m °C

k3   =   Thermal conductivity of Bakelite, W/m °C

Q   =   Amount of heat transfer, W

q   =   Heat flux, W/m²

Rt   =   Total thermal resistance of composite wall, °C m²/W

ΔT   =   Overall temperature difference, °C

T1   T2   Interface temperature of 1ST slab and heater, °C
&

T3   T4   Interface temperature of 1st and 2nd slab, °C
&

T5   T6   Interface temperature of 2nd and 3rd slab, °C
&

T7   T8   Top surface temperature of press wood, °C
&

V   =   Voltmeter reading, volts

W   =   Heat supplied by the heater, W

ΔX	=	Total thickness of wall, m
X_1	=	MS Slab thickness, m
X_2	=	Bakelite slab thickness, m
X3	=	Press wood thickness, m

EXPERIMENT: 2

AIM: Study of heat transfer through liquid

OBJECTIVE: To determine the thermal conductivity of a liquid

INTRODUCTION:
When temperature gradient exists in a body, there is an energy transfer from the high temperature region to the low temperature region. Energy is transferred by conduction and heat transfer rate per unit area is proportional to the normal temperature gradient:

$$\frac{q}{A} \approx \frac{\partial T}{\partial X}$$

EQ 1

When the proportionality constant is inserted,

EQ 2

$$q = -KA \frac{\partial T}{\partial X}$$

Where q is the heat transfer rate and $\partial T / \partial X$ is the temperature gradient in the direction of heat flow. The positive constant **k** is called is thermal conductivity of the material.

THEORY:
For thermal conductivity of liquids using Fourier's law, the heat flow through the liquid from hot fluid to cold fluid is the heat transfer through conductive fluid medium. Fourier's equation:

EQ 3

$$q = \frac{-KA}{\Delta X}(T_1 - T_2)$$

Fourier's law for the case of liquid
At steady state, the average face temperatures are recorded (T_h and T_c) along with the rate of heat transfer (Q). Knowing, the heat transfer area (A_h) and the thickness of the sample (ΔX) across which the heat transfer takes place, the thermal conductivity of the sample can be
Calculated using Fourier's Law of heat conduction.
$Q = kA_h \Delta T / \Delta X = kA_h (T_h - T_c) / \Delta X$
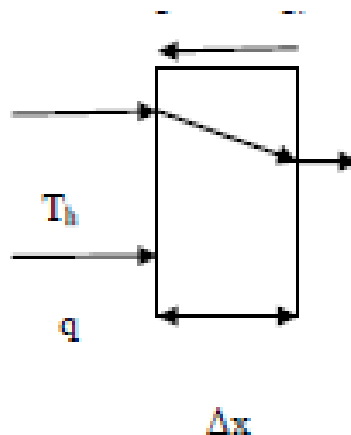
Heat transfer area = A_h (area to direction of heat flow)

DESCRIPTION:

- The apparatus is based on well-established "Guarded Hot Plate" method. It is a steady state absolute method suitable for materials, which can be fixed between two parallel plates and can also be extended to liquids that fill the gap between the plates.

- The essential components of the set-up are the hot plate, the cold plate, and heater to heat the hot plate, cold water supply for the cold plate, RTD PT-100 Sensors and the liquid specimen holder.

- In the set-up, a unidirectional heat flow takes place across the liquid whose two faces are maintained at different temperatures by the hot plate on one end and by the cold plate at the other end.

- A heater heats hot plate and voltage to the heater is varied with the help of variac to conduct the experiment on different voltages as well as different heat inputs. Temperatures are measured by RTD PT-100 sensors attached at three different places on the hot plate as well as on the cold plate. These sensors are provided on the inner surface facing the liquid sample. An average of these sensor readings are used as T_h and T_c at steady state condition.

- Heat is supplied by an electric heater for which, we have to record the voltmeter reading

- (V) and ammeter reading (A) after attaining the steady state condition. The temperature of the cold surface is maintained by circulating cold water at high velocity. The gap between hot plate and cold plate forms the liquid cell, in which liquid sample is filled.

- The depth of the liquid in the direction of flow must be small to ensure the absence of convection currents and a liquid sample of high viscosity and density shall further ensure the absence of convection and the heat transfer can be safely assumed to take place by conduction alone.

EXPERIMENTAL PROCEDURE:

1. Fill the liquid cell with the sample liquid (glycerol) through the inlet port, keeping the apparatus tilted towards upper side so that there is complete removal of air through the outlet port. Liquid filling should be continued till there is complete removal of air and also liquid glycerol comes out of the outlet port. Close the outlet port followed by

inlet port.

2. Allow cold water to flow through the cold-water inlet.

3. Start the electric heater to heat hot plate. Adjust the voltage of hot plate heater in the range of 10 to 50 volts.

4. Adjust the cold-water flow rate such that there is no appreciable change the outlet temperature of cold water (there should be minimum change).

5. Go on recording the thermocouple readings on hot side as well as on cold side, and once steady state is achieved (may be after 30-60 min); (steady state is reached when there no appreciable change in the thermocouple readings, @ 0.1,°C), record the three thermocouple readings (Th1, Th2, Th3 i.e. T1, T2, T3 on Temperature Indicator) on the hot side and three thermocouple readings (Tc1, Tc2, Tc3 i.e. T4, T5, T6 on Temperature Indicator) on the cold side along with the voltmeter (V) and ammeter (A) readings.

6. Stop the electric supply to the heater, and continue with the supply of cold water till there is decrease in temperature of hot plate (may be for another 30-40 min).

7. Open the liquid outlet valve slightly in the downward tilt position and drain the sample liquid in a receiver, keeping liquid inlet port open.

SPECIFICATION:

1.   Hot Plate

	Material =	brass
	Diameter =	180 mm

2.   Cold Plate

	Material =	Aluminum
	Diameter =	180 mm

3.   Sample Liquid depth   =   18 mm

4.   Temp. Sensors   =   RTD PT-100 type.

Type =   RTD PT-100 type

Quantity =   6 Nos.

No. 1 to No. 3 mounted on hot plate.

No. 4 to No. 6 mounted on cold plate.

5. Digital Temperature indicator

Range =   0°C to 199.9°C

Least Count = $0.1^{O}C$

6.   Variance   =   2 Amp, 230VAC

7.	Digital Voltmeter	=	0 to 250 Volts
8.	Digital Ammeter	=	0 to 2.5 Amp.
9.	Main Heater	=	Nichrome heater 300 Watt approximate, ring heater mica held between plates 300-watt, top heater held between plates 300- watt, separate dimmer for heaters, volt and current meter, multi- channel digital temp indicator.

FORMULAE

1. Heat input,

$Q = V*I$ watt

2. Thermal conductivity of liquid,

$$K = Q \frac{\Delta X}{A(T_h - T_c)}, \text{ Watt/m°C}$$

OBSERVATIONS & CALCULATIONS:

DATA: Effective diameter of plate = 0.165 m   Effective area of heat transfer, A = 0.02139 m²

OBSERVATIONS TABLE:

Sl. No.	V	I	W	T_{h1}	T_{h2}	T_{h3}	T_{C1}	T_{C2}	T_{C3}	Cold water flow rate

Record the following at steady state:
Sample liquid:

Heat input,	Q	=	-------------- watt
Hot face average temperature,	Th	=	$(T_{h1} + T_{h2} + T_{h3})/3$
Cold face temperature,	Tc	=	$(T_{c1} + T_{c2} + T_{c3})/3$
Temperature difference,	ΔT	=	$(T_h - T_c)$
Thermal conductivity,	K	=	------------- W/m °C

NOMENCLATURE:

Q = Heat supplied by heater, watt.
A = Heat transfer area, m²
Th = Hot face average temperature, °C
Tc = Cold face average temperature, °C
ΔT = Temperature difference, °C

K = Thermal conductivity of liquid, w/m, °C
ΔX = Thickness of liquid, mm = 18 mm

PRECAUTIONS & MAINTENANCE INSTRUCTIONS:

1. Use the stabilize A.C. Single Phase supply only.
2. Never switch on mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.
3. Voltage to heater starts and increases slowly.
4. Keep all the assembly undisturbed.
5. Never run the apparatus if power supply is less than 180 volts and above than 240 volts.
6. Operate selector switch of temperature indicator gently.
7. Always keep the apparatus free from dust.
8. Testing liquid should be fully filled.

REFERENCES:

1. Holman, J.P., **"Heat Transfer"**,8th ed., McGraw Hill, NY, 1976.
2. Kern, D.Q., **"Process Heat Transfer"**, 1st ed., McGraw Hill, NY, 1965.
3. Perry, R.H., Green, D.(editors), **"Perry's Chemical Engineers' Handbook"**, 6th ed., McGraw Hill, NY, 1985.
4. McCabe, W.L., Smith, J.C., Harriott, P., **"Unit Operations of Chemical Engineering"**, 4th ed. McGraw Hill, NY, 1985.
5. Coulson, J.M., Richardson, J.F., **"Coulson & Richardson's Chemical Engineering Vol. - 1"**, 5th ed., Asian Books ltd., ND, 1996.

EXPERIMENT 3:
NATURAL AND FORCED CONVECTION EXPERIMENT.
AIM: Determination of convective heat transfer coefficient in forced convection.

1. OBJECTIVE

The objective of this experiment is to compare the heat transfer characteristics of free and forced convection.

2. THEORY

Convection is the mechanism of heat transfer through a fluid in the presence of bulk fluid motion. Convection is classified as natural (or free) and forced convection depending on how the fluid motion is initiated. In natural convection, any fluid motion is caused by natural means such as the buoyancy effect, i.e. the rise of warmer fluid and fall the cooler fluid. Whereas in forced convection, the fluid is forced to flow over a surface or in a tube by external means such as a pump or fan.

By applying simple overall energy balance, the heat transfer rate from a heated surface can be calculated as,

EQ 1

$$q = \dot{m}c_p (T_{m,e} - T_{m,i})_c$$

where Cp is the specific heat of the fluid [J / kgK], Tm is the mean temperature, subscript e and i stands for exit and inlet, and m& is the mass flow rate [kg/s] which can be written as,

EQ 2

$$\dot{m} = \rho u_m A_c,$$

where ρ is the density of the fluid [kg/m^3], um is the mean velocity of the fluid [m/s], and Ac is the cross- sectional area of the flow [m^2]. The average heat transfer coefficient of the system, $\bar{h}$[W /m^2 K], can be calculated as,

EQ 3

$$\bar{h} = \frac{q}{A \Delta T_{lm}},$$

where q is the heat transfer rate, A is the area of the heated surface, and ΔT_{lm} is the log-mean temperature difference defined as,

EQ 4

$$\Delta T_{lm} = \frac{T_{m,o} - T_{m,i}}{\ln\left(\dfrac{T_s - T_{m,i}}{T_s - T_{m,o}}\right)},$$

where Ts is the surface temperature. The heat transfer characteristics of a system strongly depends on whether the flow is laminar or turbulent. The dimensionless quantities are Rayleigh number (Ra) (for free convection) and Reynolds number (Re) (for forced convection) that are used to determine the flow characteristics of the system. If they are smaller than a critical value, the flow is assumed to be laminar, otherwise the flow is assumed to be turbulent. The definitions of Ra and Re together with the critical values are given as follows,

EQ 5

$$Ra_L = \frac{g\beta(T_s - T_\infty)L^3}{v\alpha}, \quad Ra_{L,cr} \approx 10^9$$

$$Re = \frac{u_m L}{v}, \quad Re_{L,cr} \approx 5 \times 10^5$$

where g is the gravitational acceleration [m² /s], β is the volumetric thermal expansion coefficient (for an ideal gas, β =1/T), T∞ is the ambient temperature, v is the kinematic viscosity of the fluid [m² /s], α is the thermal diffusivity of the fluid [m² /s], and L is the characteristic length of the flow. The average heat transfer coefficient h can be calculated for a given geometry by using the correlations given in the literature. In the case of free convection from a heated vertical surface, the average value of the Nusselt number $(\overline{Nu})$, which is a dimensionless number and provides a measure of the convective heat transfer, can be determined by using the following correlation,

EQ 6

$$\overline{Nu_L} \equiv \frac{\overline{h}L}{k} = CRa_L^n,$$

$$\overline{Nu_L} \equiv \frac{\overline{h}L}{k} = 0.664\, Re_L^{1/2}\, Pr^{1/3} \text{ (laminar)},$$

where k is the thermal conductivity of the fluid. C and n are the correlation coefficients given as C = 0.59, n=1/4 for laminar flow and C = 0.10, n = 1/3 for turbulent flow case. 3 In the case of a forced convection from a heated surface, the average Nusselt number can be calculated as,

where Pr is the Prandtl number (Pr = v /α).

3. EXPERIMENTS TO BE PERFORMED

$$\overline{Nu_L} \equiv \frac{\overline{h}L}{k} = 0.037\, Re_L^{4/5}\, Pr^{1/3} \text{ (turbulent)},$$

EQ 7

During the experiments, the power input value, the flow speed of the air inside the duct, the inlet and exit temperatures of air and the temperature of the heater surface are recorded.

Procedure
1. Turn on the power and adjust a power input value.
2. Wait until the system reaches the steady-state.
3. Record inlet and exit temperatures of the air.
4. Record the surface temperature of the heater.

5. Turn on the fan.
6. Record the speed of the air, inlet and exit temperatures of the air.
7. Record the surface temperature of the heater.

For natural convection,

	Inlet Temperature (K)	Exit Temperature (K)	Surface Temperature (K)
Plate			

For forced convection,

Plate /Speed of Air (m/s)	Inlet Temperature (K)	Exit Temperature (K)	Surface Temperature (K)
5 m/s			
10 m/s			
15 m/s			
20 m/S			

Analysis For free convection:
1. Calculate the mass flow rate of the air and the heat transfer rate.
2. Calculate the efficiency (η) of the heat transfer, which is the measure of what fraction of energy input is transferred to the fluid ($\eta = q/Pel$).
3. Calculate the log-mean temperature difference and the average heat transfer coefficient.
4. Calculate Ra and the corresponding Nu and the average heat transfer coefficient.
5. Compare the measured heat transfer coefficient with the theoretical value.

For forced convection:
1. Calculate the mass flow rate of the air and the heat transfer rate.
2. Calculate the efficiency ($\eta = q/Pel$).
3. Calculate the log-mean temperature difference and the average heat transfer coefficient
4. Calculate Re and the corresponding Nu and the average heat transfer coefficient.
5. Compare the measured heat transfer coefficient with the theoretical value.

Report Questions

• Compare the heat transfer coefficients for free and forced convection. Comment on the results.
• Compare the efficiency values for free and forced convection. Are they different? Is it expected?
• Are the flows for free and forced convection laminar or turbulent? What would be the case if otherwise?
• Compare your results with the theoretical results available in the literature. Comment on the discrepancy between the results if any.

TROUBLE SHOOTING:
1. If electric panel is not showing the input on the mains light. Check the main supply.

REFERENCES:

1. Holman, J.P., "Heat Transfer", 9th ed., McGraw Hill, ND, 2008, Page 39-46.
2. D.S Kumar, "Heat & Mass Transfer", 7th ed, S.K Kataria & Sons, ND, 2008, Page 233- 239, 253-256, 260-262.

<div align="center">

EXPERIMENT 4
CONCENTRIC TUBE HEAT EXCHANGER

</div>

EXPERIMENT 4

AIM: determination of rate of flow of heat transfer, Logarithmic mean temperature difference (LMTD) of parallel and counter flow heat exchanger.

OBJECTIVE:
To know heat exchanger working and how to increase the cold-water temperature and how to reduce the hot water temperature

APPARATUS REQUIRED:
1. Thermocouple with thermal indicator
2. Stop watch

OBSERVATION:
1. Length of heat exchanger = 1000 mm
2. Inner Tube material: Copper
Outer diameter, d_o = 12.5 mm   Inner diameter, d_i = 9.5 mm
   3. Outer Tube material: GI pipe
Outer diameter, D_o = 32.5 mm Inner diameter, D_i = 28.5 mm

   4. Specific Heat of Water   = 4186 J/kg K

PROCEDURE:
1. Note the initial temperature of water
2. Start the flow of heat in hot water side
3. Arrange the parallel flow arrangement
4. Switch "ON" the electric heater.
5. adjust the flow rate of hot water side with help of valve
6. Keep the flow rate same way, wait for the steady state condition is reached
7. Record the temperature of the hot water side and cold-water side and also know flow rate accurately
8. Repeat the experiment in counter flow condition
DIAGRAM:
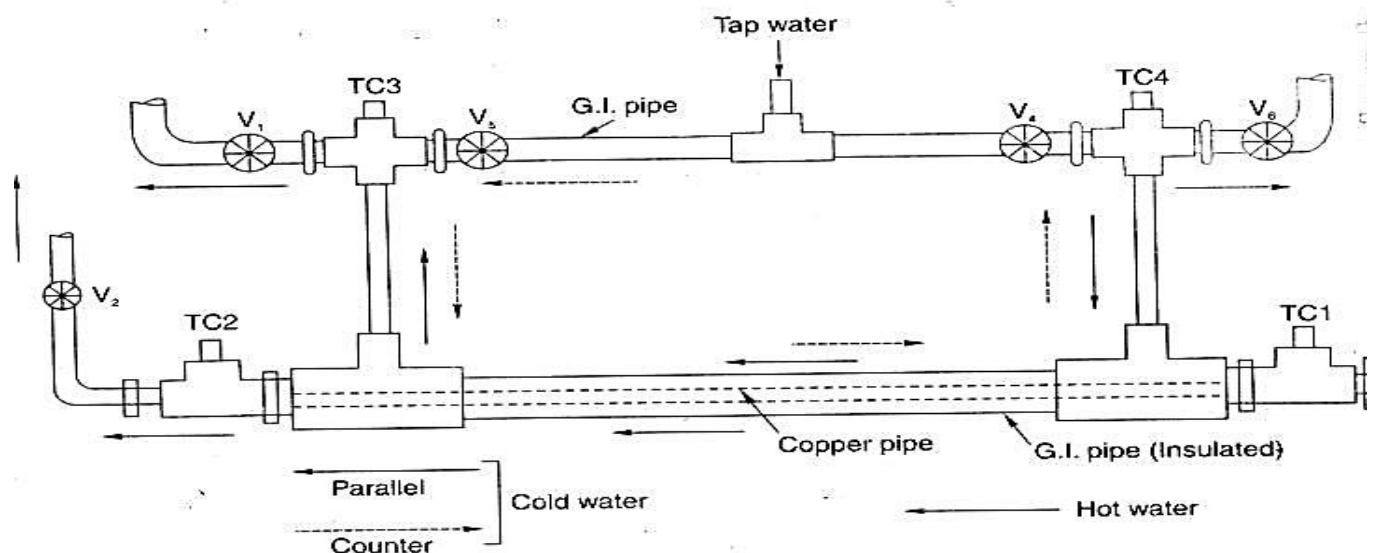
OBSERVATION TABLE:

Parallel Flow

Hot Water Side			Cold Water Side		
Time taken for 1 litre of water In sec	Temperature ⁰C		Time taken for 1 litre of water In sec	Temperature ⁰C	
	Inlet (Thi)	Outlet (Tho)		Inlet (Tci)	Outlet (Tco)

Counter Flow

Hot Water Side			Cold Water Side		
Time taken for 1 litre of water In sec	Temperature ⁰C		Time taken for 1 litre of water In sec	Temperature ⁰C	
	Inlet (Thi)	Outlet (Tho)		Inlet (Tci)	Outlet (Tco)

FORMULA USED

Parallel flow operation

1. Heat transfer rate from cold water, $Q_c = \dot{m}_c\, c_c (T_{co} - T_{ci}) = C_c (T_{co} - T_{ci})$

2. Heat transfer rate from hot water, $Q_h = \dot{m}_h\, c_h (T_{hi} - T_{ho}) = C_h (T_{hi} - T_{ho})$, where $\dot{m}$ and c are the mass flow rate and specific heat respectively.

3. $Q_{\text{average}}, Q_a = \dfrac{Q_c + Q_h}{2}$ (W)

4. $LMTD = \dfrac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \dfrac{(T_{hi} - T_{ci}) - (T_{ho} - T_{co})}{\ln\left[\dfrac{T_{hi} - T_{ci}}{T_{ho} - T_{co}}\right]}$ (°C)

5. The overall heat transfer coefficient U_0 can be calculated from Eqn. (10B).

$$U_o = \dfrac{Q}{A_o \cdot LMTD} \quad (\text{W/m}^2\,{}^\circ\text{C})$$

where $A_o = \pi D_o L$ (m²)

D_o = outer diameter of the inner tube in m

L = length of the heat exchanger in m.

6. $C_{\min}$ = smaller of C_c and C_h

7. Calculate the effectiveness $\in$ of the heat exchanger by using either of Eqns. (10C) and (10D).

(b) Counter flow operation

1. Proceed as in steps 1, 2 and 3 of parallel flow operation

2. $LMTD = \dfrac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \dfrac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{\ln\left[\dfrac{T_{hi} - T_{co})}{T_{ho} - T_{ci})}\right]}$

3. Calculate U_o and ε as outlined in (a) above.

RESULT:

Thus the heat transfers rates, Logarithmic mean temperature difference (LMTD) of the parallel and counter flow heat exchanger were determined.

EXPERIMENT 5 PARALLEL FLOW COUNTER FLOW HEAT EXCHANGER

Aim: To determine the values of effectiveness of heat exchanger for parallel and counter flow.

Apparatus required:
(i)   Experimental Setup,   Stop watch and Thermometer

Theory:
Heat exchangers are classified in three categories: Transfer type,   Storage   type and Direct contact type.

A transfer type of heat exchanger is one which both fluids pass simultaneously through the device and heat is transferred through separating walls. In practice, most of the heat exchangers used are transfer type one.

The transfer type exchangers are further classified accordant to flow arrangements as:
i.   PARALLEL FLOW in which fluids flow in the same direction.
ii.   COUNTER FLOW in which fluids flow in opposite direction.
iii.   CROSS FLOW in which fluids flow at right angles to each other.

The apparatus consists of a tube in tube type concentric tube heat exchanger. The hot fluid is not water which is obtained from an electric geyser and it flows through the inner tube while the cold fluid is cold water flowing through the annulus. The hot water flows always in one direction and the flow rate is controlled by means of a gate vale. The cold water can be admitted at one of the ends enabling the heat exchanger to run as a parallel flow apparatus or a counter flow apparatus. This is done by valve operations.

Specifications:

1. Inner tube material – copper Internal diameter (I.D) =

2. Inner tube material – copper Internal diameter (O.D) =

2. Outer tube material – G.I Internal diameter (I.D) =

3. Outer tube material – G.I Internal diameter (O.D) =

4. Length of the heat exchanger (L) =

5. Thermocouples (for cold water & hot water)

6. Measuring flask

7. Geyser: single phase type to obtain hot water supply

Precautions:

1. Start the cooling circuit before switching ON the heaters (geyser) and adjust the flow rate so that practically there is no temperature rise in the circuiting fluid.

Formulae Used: (Parralle flow & Counter flow)

1.   Area of the pipe   A = p (D – d) L

         Where, D = inlet diameter of the outer tube

         d = outlet diameter of the inner tube L =

Length of the tube

2.   Heat transferred from hot water $Q_a = m_{cp}(T_{hi} - T_{ho})$

w Where, m = mass flow rate   kg/ sec.

    $m = rv/t$, r = density of water and t = time taken for hot water
    C_p = Specific heat of capacity 4.187 kJ/kg -k
    T_{hi} = Temperature of hot water inlet T_{ho} =
    Temperature of hot water outlet

3.   Heat transfer from cold water $Q_c = m_{cp}(T_{co} - T_{ci})$ w
    Where, m = mass flow rate
    C_p = Specific heat of capacity
    T_{co} = Temperature of cold-water inlet T_{ci} =
    Temperature of cold-water outlet

4.   Effectiveness, $E = Q_a / \{m_{cp}(T_{hi} - T_{ci})\}$ w

    Where, $Q_a = (Q_a + Q_c) / 2$

5. Logarithmic mean temperature difference (L M T D)
    $\Delta T_{(LMTD)} = (\Delta T_i - \Delta T_o) / \ln(\Delta T_i / \Delta T_o)$
    Where, $\Delta T_o = T_{ho} - T_{co}$
        $\Delta T_i = T_{hi} - T_{ci}$

6. Over all heat transfer coefficient
    $h = Q_a / \Delta T_{(LMTD)} A$ $w/m^2 k$ where Q_a =
    $(Q_a + Q_c) / 2$

Procedure:
1. Place the thermocouples in position and note down their readings when they are at room temperature and no water is flowing at either side. This is required to correct the temperature.
2. Start the flow on hot water side.
3. Start the flow through annulus and run the exchanger as parallel flow unit.
4. Put ON the geyser.
5. Adjust the flow rate on hot water side, between the ranges of 1.5 to 4 L/min.
6. Adjust the flow rate on cold water side between ranges of 3 to 8 L/min.
7. Keeping the flow rates same, wait till the steady state conditions are reached.
8. Record the temperatures on hot water and cold-water side and also the flow rates accurately.
9. Repeat the experiment with a counter flow under identical flow conditions.
10. Correct the temperatures by suitable correction obtained from initial readings of thermometers.

Tabulations:

S. No	Flow	Ho Fluid ^{0} C. t		Col Fluid C d ^{0}		Time for collection of hot fluid kg/sec	Time for collection of cold fluid kg/sec
1	Parallel flow	T_{hi} ( )	T_{ho} ( )	T_{ci} ( )	T_{co}( )		
2	Counter flow						

Result:

1. The values of effectiveness of heat exchanger were found as
        (i)   Parallel flow = _____ .
        (ii)   Counter flow = _____ .

2. Over all heat exchanger (heat transfer coefficient)
        (i)   Parallel flow = _____ .
        (ii)   Counter flow = _____ .

Precautions & Maintenance Instructions:

1. Never run the apparatus if power supply is less than 180 volts and above than 230 volts.
2. Never switch ON mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.
3. Operator selectors switch off temperature indicator gently.
4. Always keep the apparatus free from dust.

References:

1. Arora. Domukundwar, "A **course in Heat & Mass Transfer",** 6th ed., Dhanpat Rai & Co. (P) LTD., NY, 2003, Page A.6
2. Holman, J.P., **"Heat Transfer"**, 8th ed., McGraw Hill, NY, 1976.
3. Kern, D.Q., **"Process Heat Transfer"**, 1st ed., McGraw Hill, NY, 1965.
4. McCabe, W.L., Smith, J.C., Harriott, P., **"Unit Operations of Chemical Engineering"**, 4th ed. McGraw Hill, NY, 1985.
5. Coulson, J.M., Richardson, J.F., **"Coulson & Richardson's Chemical Engineering Vol. - 1"**, 5th ed.Asian Books ltd., ND, 1996.

EXPERIMENT 6:

AIM: Investigation of the heat transfer in a shell and tube heat exchanger

Objective

- To evaluate and study the heat load and head balance, LMTD and overall heat transfer coefficient.
- To calculate the Reynolds numbers at the shell and tubes sides.
- To measure and determine the shell and tube sides pressure drop

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.

Equipment Required

HT30X/HT30XC Heat Exchanger Service Unit   HT33 Shell and Tube Heat Exchanger

Equipment set-up

Before proceeding with the exercise ensure that the equipment has been set up and the accessory installed as described in this manual, with a cold-water supply connected and the pressure regulator adjusted. The apparatus should be switched on, and if using the HT30XC the service unit should be connected to a suitable PC on which the software has been installed. Computer operation is optional with the HT30X.

Prime the hot and cold-water circuits using the cold water supply (Refer to the Operation section if you need details on how to prime the equipment).

If using the HT30XC, or the HT30X with the optional software, run the HT33 software for the service unit used (HT30XC software must be used with the HT30XC and HT30X software with the HT30X, as the calibration for the sensors differs between the two service units). If using the HT30XC, select the Countercurrent exercise. If using the HT30X, select Exercise A and then select Countercurrent Operation on the software display option box.

Theory/Background

Note: For this demonstration the heat exchanger is configured for countercurrent flow (the two fluid streams flowing in opposite directions).
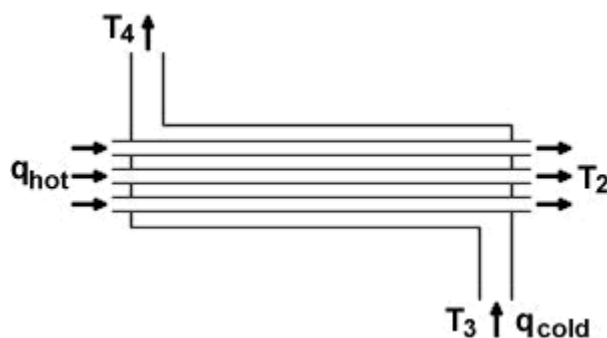
Mass flowrate (qm)   =   Volume flowrate (qv)
                             x Density of fluid (ρ) (kg/s)

Heat power (Q)   =   Mass flowrate (qm) x specific heat (Cp)
                         x change in temperature (ΔT) (W)

Therefore:

Heat power emitted from hot fluid Q_e =

qm_h. Cp_h (T1 - T2) (W) Heat power absorbed by cold fluid

Q_a = qm_c . Cp_c (T4 - T3) (W) Heat power lost (or gained)

$$Q_f = Q_e - Q_a \qquad (W)$$

$$\eta = \frac{Q_a}{Q_e} \times 100 \ (\%)$$

Overall Efficiency   (%)

Theoretically Q_e and Q_a should be equal. In practice these differ due to heat losses or gains to/from the environment.

Note: In this exercise the cold fluid is circulated through the outer shell, if the average cold fluid temperature is above the ambient air temperature then heat will be lost to the surroundings resulting in ŋ <100%. If the average cold fluid temperature is below the ambient temperature, then heat will be gained resulting in ŋ>100%.

Procedure
1. Set the temperature controller to 60ºC. If using the HT30X then switch on the hot water circulator.
2. Adjust the cold-water control valve setting to give a cold-water flow rate of 1 litre/min.
3. If using HT30X, adjust the hot water control valve setting Vhot to give a hot water flow of 3 litres/min. If using HT30XC, click on the button for the hot water flow rate controller, set the controller to Automatic and enter a Set Point value of 3 litres/min. Apply and click 'OK'.
4. Allow the temperatures to stabilise (monitor the temperatures using the sensor display on the software screen or control console).
5. When the temperatures are stable select the   icon to record the following, or manually note the values: T1, T2, T3, T4, F_{hot}, F_{cold}.

6. Adjust the cold-water control valve to give 2 litres/min.
7. Allow the heat exchanger to stabilize then repeat the above readings.

Results and Calculations

The software records all sensor outputs and also calculates several derived figures, and presents the recorded data in tabular form. The following columns are relevant to this exercise, and are suggested as suitable column headings if recording values manually:

Hot fluid volume flowrate	qvhot	(m³/s)	Multiply F_{hot} (litres/min) by 1.667x10⁻⁵
Hot fluid inlet temperature	T1	(°C)	

Hot fluid outlet temperature	T2	(°C)	
Cold fluid volume flowrate	qv$_{COld}$	(m³/s)	Multiply F$_{cold}$ (litres/min) by 1.667x10^{-5}
Cold fluid inlet temperature	T3	(°C)	
Cold fluid outlet temperature	T4	(°C)	

You should also estimate and record the experimental errors for these measurements.

For each set of readings, the software calculates the average hot fluid temperature (from T1 and T2) and the average cold fluid temperature (from T3 and T4) and then automatically provides values for the following variables. If recording data manually, calculate these values and obtain the variables from the Reference Tables

Specific heat of hot fluid	Cp_h	kJ/kg°K (From table 1)
Specific heat of cold fluid	Cp_c	kJ/kg°K (From table 1)
Density of hot fluid	ρ_h	kg/m³ (From table 2)
Density of cold fluid	ρ_c	kg/m³ (From table 2)

Table 1: Counter-current Shell and Tube Heat Exchanger at constant FT1

FT 1 (LPM)	FT 2 (LPM)	TT 1 (⁰C)	TT 2 (⁰C)	TT 3 (⁰C)	TT 4 (⁰C)	DPT 1 (mmH$_2$O)	DPT 2 (mmH$_2$O)
10	2						
10	4						
10	6						
10	8						
10	10						

Table 2: Counter-current and Tube Heat Exchanger at constant FT2

FT 1 (LPM)	FT 2 (LPM)	TT 1 (⁰C)	TT 2 (⁰C)	TT 3 (⁰C)	TT 4 (⁰C)	DPT 1 (mmH$_2$O)	DPT 1 (mmH$_2$O)
2	10						
4	10						
6	10						
8	10						
10	10						

For each set of readings, the relevant derived results are calculated and presented with the following headings:

Mass flowrate (hot fluid)	qm_h	(kg/s)
Mass flowrate (cold fluid)	qm_c	(kg/s)
Heat power emitted	Q_e	(W)
Heat power absorbed	Q_a	(W)
Heat power lost	Q_f	(W)
Overall Efficiency	η	(%)

Conclusions

Explain any difference between Q_e and Q_a in your results. Comment on the effects of the increase in the cold fluid flowrate.

Reference Tables

Table 1: Specific Heat Capacity of Water (Cp kJ/kg°K)

°C	0	1	2	3	4	5	6	7	8	9
0	4.1274	4.2138	4.2104	4.2074	4.2045	4.2019	4.1996	4.1974	4.1954	4.1936
10	4.1919	4.1904	4.1890	4.1877	4.1866	4.1855	4.1846	4.1837	4.1829	4.1822
20	4.1816	4.1810	4.1805	4.1801	4.1797	4.1793	4.1790	4.1787	4.1785	4.1783
30	4.1782	4.1781	4.1780	4.1780	4.1779	4.1779	4.1780	4.1780	4.1781	4.1782
40	4.1783	4.1784	4.1786	4.1788	4.1789	4.1792	4.1794	4.1796	4.1799	4.1801
50	4.1804	4.1807	4.1811	4.1814	4.1817	4.1821	4.1825	4.1829	4.1833	4.1837
60	4.1841	4.1846	4.1850	4.1855	4.1860	4.1865	4.1871	4.1876	4.1882	4.1887
70	4.1893	4.1899	4.1905	4.1912	4.1918	4.1925	4.1932	4.1939	4.1946	4.1954

Table 2: Density of Water (ρ kg/m³)

°C	0	2	4	6	8
0	999.8	999.9	999.9	999.9	999.9
10	999.7	999.5	999.2	998.9	998.6
20	998.2	997.8	997.3	996.8	996.2
30	995.7	995.0	994.4	993.7	993.0
40	992.2	991.4	990.6	989.8	988.9
50	988.0	987.1	986.2	985.2	984.2
60	983.2	982.2	981.1	980.0	978.9
70	977.8	976.6	975.4	974.2	973.0
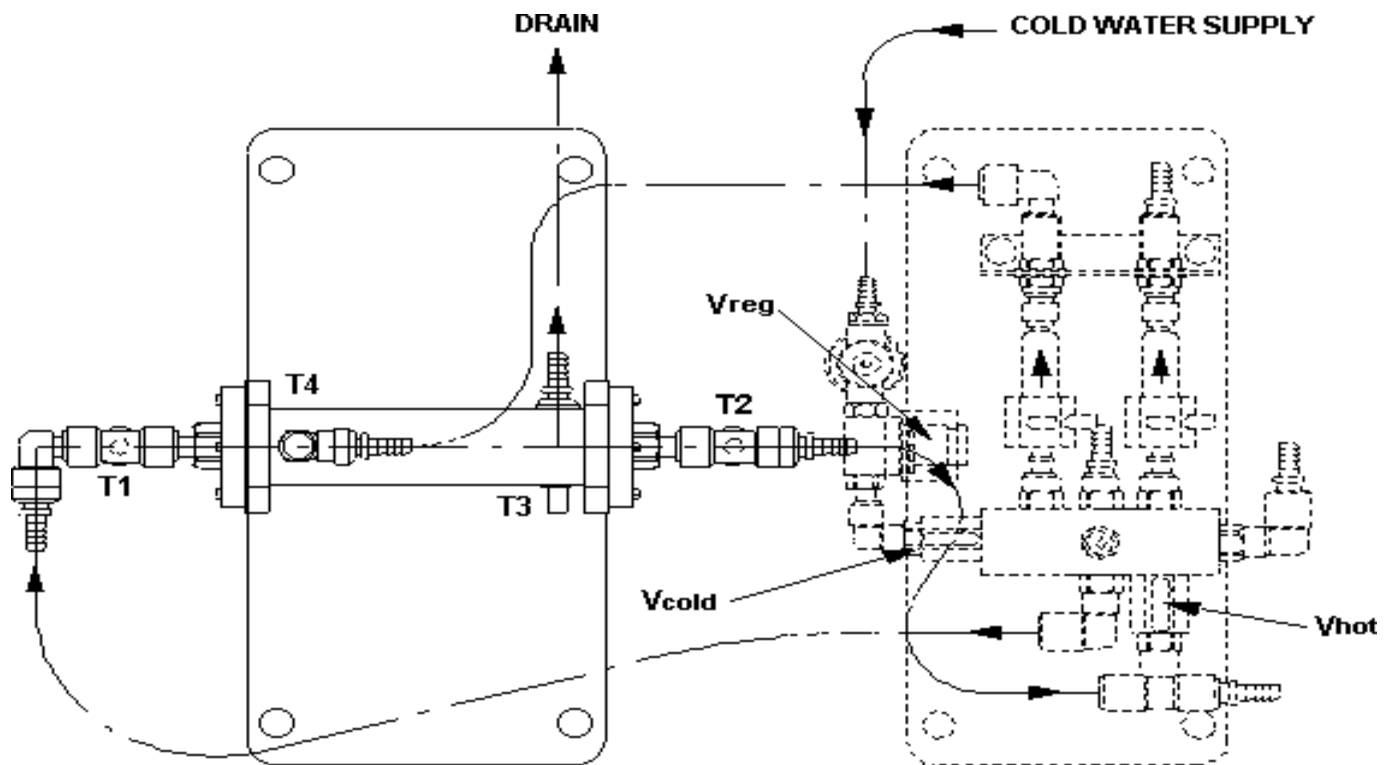
**HT33 SHELL & TUBE HEAT EXCHANGER
(CONNECTED IN COCURRENT OPERATION)**

Counter-Current Flow

Hot Water	
Density:	988.18 kg/m³
Heat Capacity:	4175.00
Thermal condition:	J/kg.K
Viscosity:	0.6436 W/m.K
	0.0005494
	Pa.s
Cold Water	
Density:	995.67 kg/m³
Heat Capacity:	4183.00
	J/kg.K
Thermal condition:	0.6155 W/m.K
Viscosity:	0.0008007
	Pa.s

1. Calculation of heat transfer and heat lost

Hot Water Flowrate = 10.0 LPM   Cold water flowrate = 2, 4, 6, 8 & 10 LPM

1)

$$Q_{hot}(W) = m_h C_p \Delta T$$

$$= 10.0 \frac{L}{min} \times \frac{1m^3}{1000L} \times \frac{1\ min}{60\ s} \times 988.18 \frac{kg}{m^3} \times 4175 \frac{J}{kg \cdot °C} \times (48.8 - 47.5)°C$$

$$= 893.89W$$

$$Q_{cold}(W) = m_h C_p \Delta T$$

$$= 2.0 \frac{L}{min} \times \frac{1m^3}{1000L} \times \frac{1\ min}{60\ s} \times 995.67 \frac{kg}{m^3} \times 4183 \frac{J}{kg \cdot °C} \times (44.7 - 29.5)°C$$

$$= 2110.21W$$

$$Heat\ Lost\ Rate = Q_{hot} - Q_{cold} = (893.89 - 2110.21)W = -1216.32W$$

$$\varepsilon = \frac{Q}{Q_{max}} = \frac{893.89}{2110.21} \times 100\% = 42.36\%$$

2)

$$Q_{hot}(W) = m_h C_p \Delta$$

$$= 10.0 \frac{L}{min} \times \frac{1m^3}{1000L} \times \frac{1\ min}{60\ s} \times 988.18 \frac{kg}{m^3} \times 4175 \frac{J}{kg \cdot °C} \times (50.0 - 46.9)°C$$

$$= 2131.59W$$

$$Q_{cold}(W) = m_h C_p \Delta T$$

$$= 4.0 \frac{L}{min} \times \frac{1m^3}{1000L} \times \frac{1\ min}{60\ s} \times 995.67 \frac{kg}{m^3} \times 4183 \frac{J}{kg \cdot °C} \times (37.5 - 27.5)°C$$

$$= 2776.59W$$

$$Heat\ Lost\ Rate = Q_{hot} - Q_{cold} = (2131.59 - 2776.59)W = -645W$$

$$\varepsilon = \frac{Q}{Q_{max}} = \frac{2131.59}{2776.59} \times 100\% = 76.77\%$$

3)

$$Q_{hot}(W) = m_h C_p \Delta$$

$$= 10.0 \frac{L}{min} \times \frac{1m^3}{1000L} \times \frac{1\ min}{60\ s} \times 988.18 \frac{kg}{m^3} \times 4175 \frac{J}{kg \cdot °C} \times (49.1 - 45.3)°C$$

$$= 2612.91W$$

$$Q_{cold}(W) = m_h C_p \Delta = 6.0 \frac{L}{min} \times \frac{1m^3}{1000L} \times \frac{1\ min}{60\ s} \times 995.67 \frac{kg}{m^3} \times 4183 \frac{J}{kg \cdot °C} \times (34.9 - 28.6)°C$$

$$= 2623.88W$$

$$Heat\ Lost\ Rate = Q_{hot} - Q_{cold} = (2162.91 - 2623.88)W = -10.97W$$

$$\varepsilon = \frac{Q}{Q_{max}} = \frac{2612.91}{2623.88} \times 100\% = 99.58\%$$

$$Q_{hot}(W) = m_h C_p \Delta$$

$$= 10.0\,\frac{L}{min} \times \frac{1m^3}{1000L} \times \frac{1\,min}{60\,s} \times 988.18\,\frac{kg}{m^3} \times 4175\,\frac{J}{kg \cdot {}^\circ C} \times (49.5 - 44.8){}^\circ C$$

$$= 3231.76\,W$$

$$Q_{cold}(W) = m_h C_p \Delta T$$

$$= 8.0\,\frac{L}{min} \times \frac{1m^3}{1000L} \times \frac{1\,min}{60\,s} \times 995.67\,\frac{kg}{m^3} \times 4183\,\frac{J}{kg \cdot {}^\circ C} \times (33.8 - 28.5){}^\circ C$$

$$= 2943.19\,W$$

$$\text{Heat Lost Rate} = Q_{hot} - Q_{cold} = (3231.76 - 2943.19)W = 288.57\,W$$

5)
$$\varepsilon = \frac{Q}{Q_{max}} = \frac{2943.19}{3231.76} \times 100\% = 91.07\%$$

$$Q_{hot}(W) = m_h C_p \Delta$$

$$= 10.0\,\frac{L}{min} \times \frac{1m^3}{1000L} \times \frac{1\,min}{60\,s} \times 988.18\,\frac{kg}{m^3} \times 4175\,\frac{J}{kg \cdot {}^\circ C} \times (49.5 - 44.2){}^\circ C$$

$$= 3644.33\,W$$

$$Q_{cold}(W) = m_h C_p \Delta T$$

$$= 10.0\,\frac{L}{min} \times \frac{1m^3}{1000L} \times \frac{1\,min}{60\,s} \times 995.67\,\frac{kg}{m^3} \times 4183\,\frac{J}{kg \cdot {}^\circ C} \times (33.2 - 29.2){}^\circ C$$

$$= 2766.59\,W$$

$$\text{Heat Lost Rate} = Q_{hot} - Q_{cold} = (3644.33 - 2766.59)W = 877.74\,W$$

$$\varepsilon = \frac{Q}{Q_{max}} = \frac{2766.59}{3644.33} \times 100\% = 75.91\%$$

2. Calculation of Log Mean Temperature Difference (LMTD)

$$\Delta T_{lm} = \frac{[(Th_{,in} - Tc_{,out}) - (Th_{,out} - Tc_{,in})]}{\ln[\frac{(Th_{,in} - Tc_{,out})}{(Th_{,out} - Tc_{,in})}]}$$

1)

$$\Delta T_{lm} = \frac{[(48.8 - 44.7) - (47.5 - 29.5)]}{\ln[\frac{(48.8 - 44.7)}{(47.5 - 29.5)}]} = 9.40{}^\circ C$$

$$\Delta T_{lm} = \frac{[(49.1 - 34.9) - (45.3 - 28.6)]}{\ln[\frac{(49.1 - 34.9)}{(45.3 - 28.6)}]} = 15.42{}^\circ C$$

$$\Delta T_{lm} = \frac{[(49.5 - 33.8) - (44.8 - 28.5)]}{\ln[\frac{(49.5 - 33.8)}{(44.8 - 28.5)}]} = 16.00\ {}^\circ C$$

3. Calculate of the tube and shell heat transfer coefficient

At tube side (hot water-cooling process): $Nu = 0.023 \times Re^{0.8} \times Pr^{0.33}$

$$\dot{V} = 10 \frac{L}{min} \times \frac{1m^3}{1000L} \times \frac{1min}{60s} = 1.67 \times 10^{-4} \frac{m^3}{s}$$

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (0.02664)^2}{4} = 0.000557 m^2$$

$$v = \frac{\dot{V}}{A} = \frac{1.67 \times 10^{-4}}{0.000557} = 0.299 \frac{m}{s}$$

$$Re = \frac{\rho v d}{\mu} = \frac{988.18 \frac{kg}{m^3} \times 0.299 \frac{m}{s} \times 0.02664 m}{0.0005494 Pa \cdot s} = 14327 \ (turbulent\ flow)$$

$$Pr = \frac{\mu C_p}{k} = \frac{(0.0005494 Pa \cdot s) \times (4175 \frac{J}{kg \cdot K})}{0.6436 \frac{W}{m \cdot K}} = 3.564$$

$$Nu = 0.023 \times Re^{0.8} \times Pr^{0.33} = 0.023 \times 14327^{0.8} \times 3.564^{0.33} = 73.55$$

$$h = \frac{Nuk}{d} = \frac{73.55 \times 0.6436 \frac{W}{m \cdot K}}{0.02664 m} = 1776.91 \frac{W}{m^2 \cdot K}$$

At shell side (cold water-heating process): $Nu = 0.023 \times Re^{0.8} \times Pr^{0.4}$

At the shell side: 2 LPM

$$\dot{V} = 2 \frac{L}{min} \times \frac{1m^3}{1000L} \times \frac{1min}{60s} = 3.33 \times 10^{-5} \frac{m^3}{s}$$

$$A = \frac{\pi(d_s^2 - d_o^2)}{4} = \frac{\pi \times ((0.085)^2 - (0.0334)^2)}{4} = 0.0048 m^2$$

$$v = \frac{\dot{V}}{A} = \frac{3.33 \times 10^{-5}}{0.0048} = 0.0069 \frac{m}{s}$$

$$Re = \frac{\rho v (d_s - d_o)}{\mu} = \frac{955.67 \frac{kg}{m^3} \times 0.0069 \frac{m}{s} \times (0.085 - 0.0334 m)}{0.0008007 Pa \cdot s}$$

$$= 425 \ (laminar\ flow)$$

$$Pr = \frac{\mu C_p}{k} = \frac{(0.0008007 Pa \cdot s) \times (4183 \frac{J}{kg \cdot K})}{0.6155 \frac{W}{m \cdot K}} = 5.49$$

$$Nu = 0.023 \times Re^{0.8} \times Pr^{0.4} = 0.023 \times 425^{0.8} \times 5.49^{0.4} = 5.76$$

$$h = \frac{Nuk}{d} = \frac{5.76 \times 0.6155 \frac{W}{m \cdot K}}{(0.085 m - 0.0334 m)} = 68.68 \frac{W}{m^2 \cdot K}$$

Overall heat transfer coefficient:

Total exchange area, $A = \pi \times tube\ od \times length = \pi \times 0.02664m \times 0.5m = 0.05m^2$

$$U = \frac{Q_{hot}}{A\Delta T_{lm}} = \frac{893.89W}{0.05m^2 \times 9.40°C} = 1901.89 \frac{W}{m^2 \cdot K}$$

$$U = \frac{Q_{hot}}{A\Delta T_{lm}} = \frac{2131.59W}{0.05m^2 \times 15.70°C} = 2715.40 \frac{W}{m^2 \cdot K}$$

$$U = \frac{Q_{hot}}{A\Delta T_{lm}} = \frac{2612.91W}{0.05m^2 \times 15.42°C} = 3388.99 \frac{W}{m^2 \cdot K}$$

$$U = \frac{Q_{hot}}{A\Delta T_{lm}} = \frac{3231.76W}{0.05m^2 \times 16.00°C} = 4039.7 \frac{W}{m^2 \cdot K}$$

$$U = \frac{Q_{hot}}{A\Delta T_{lm}} = \frac{3644.44W}{0.05m^2 \times 15.64°C} = 4660.41 \frac{W}{m^2 \cdot K}$$

CHEMICAL ENGINEERING THERMODYNAMICS LAB

Experiment 7: Measurement of specific latent heat of vaporization using electric method

AIM: -
To measure the specific latent heat of vaporization of water by an electric method

APPARATUS REQUIRED: -
Container to hold water, Water to measure its specific latent heat of fusion Electric heater, Stop watch, Balance

THEORY: -
The specific latent heat of vaporization is the amount of heat that is needed change 1 kg of the substance in the liquid state into the gaseous state at the boiling point. When an electric heater is immersed in water, the electrical energy flowing in heater will be totally converted into heat energy. The electrical energy is given by E=pt where p is the heater power in watts and t is the time in seconds E is electrical energy in joules. The heat gained by water is given by H=mc (T1-T2), where heat energy is in joules is water mass in kg and c is the specific heat in J/kg°c and T1 and T2 are initial and final temperatures.

Assuming there is no loss of heat to the surroundings, we can say that heat gained by water is equal to electrical energy, i.e.pt=mLᵥ.

Hence Lᵥ=pt/m

DIAGRAM: -
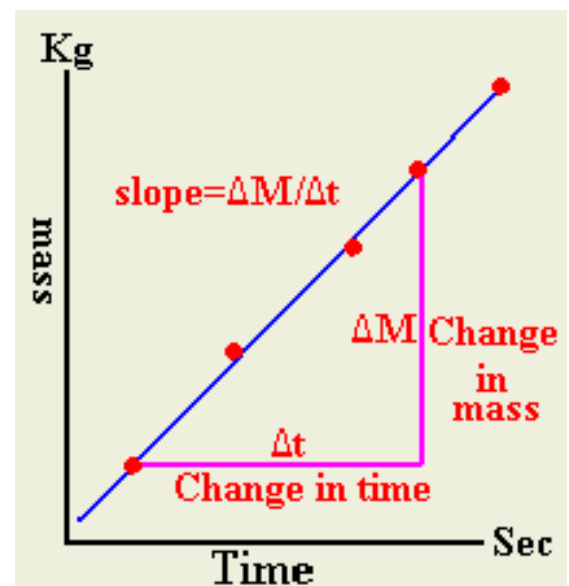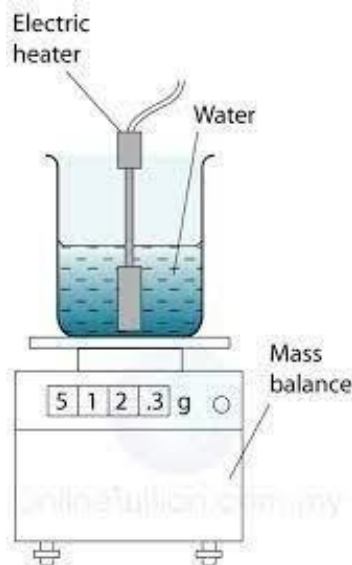
Method-1:-
1. Prepare all he needed tools and equipment. .
2. Assemble the experiment as shown
3. Place a quality of water in the container

4. Measure the mass of the water and container and record it as M.

5. Place the electric heater in water placed in container.

6. Switch on the heater.

7. Turn on the stop was when the water is boiling.

8. After several minutes, switch off the heater and
   stop watch and record the mass of water as "M"

9. Record the time of the watch as "t"

10. Find the mass of the evaporated water and record
    it as "m".

11. Evaluate the latent heat of vaporization from
    $Lv = pt/m$

12. Repeat steps 7-11 and record three readings in
    the table.

13. Calculate the avg. of the three values obtained.

Heater power's (p) = --------- watts

Mass of water (M_1) = ---------- kg

TABLE-1

SL NO	STOP WATCH TIME(t)	MASS OF CONTAINER + LIQUID(M_2)	MASS OF EVAPORATED WATER $M=M_1+M_2$	CALCULATED $Lv=pt/m$

Method: -2

1. Prepare all he needed tools and equipment.

2. Assemble the experiment as shown

3. Place a quality of water in the container

4. Measure the mass of the water and container and record it as M.

5. Place the electric heater in water placed in container.

6. Switch on the heater.

7. Turn on the stop was when the water is boiling.

8. After each 5 minutes, record the mass of water

and container as "M2".

9. Record the time of the watch as "t"

10. Find the mass of the evaporated water and record it as "m".

11.   Repeat step 8-10 for five times.

12. Plot mass of evaporated vs time.
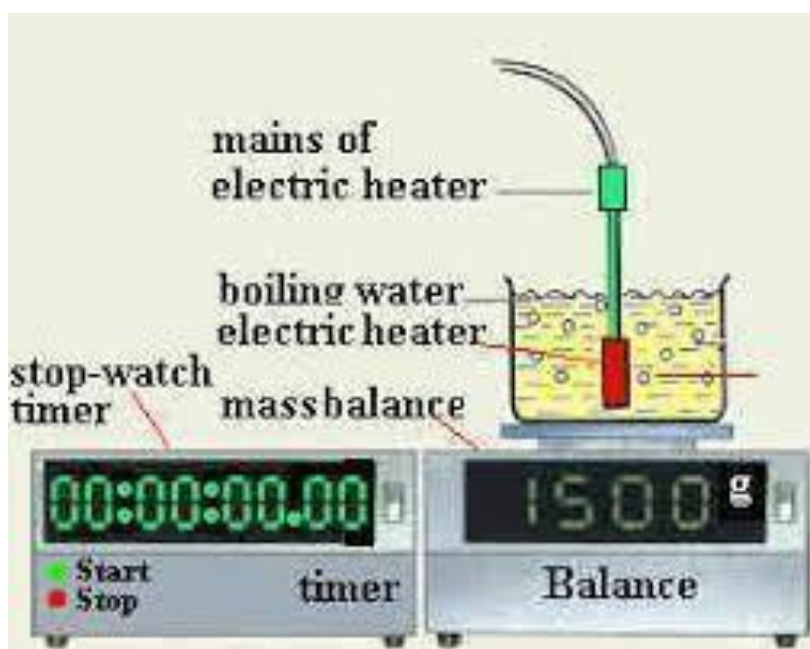13.   Evaluate the slop from the graph.
14.   Calculate the heat of vaporization from $m=(p/Lv)t$ where slope$=p/Lv$.
        Heater power's (p) = ------- watts
        Mass of water and container (M1) =---------- kg

Table-2

S/NO	STOP WATCH TIME(t)	MASS OF CONTAINER + LIQUID(M2)	MASS OF EVAPORATED WATER M=M1-M2

EXPERIMENT 8:

AIM: Determination of the effects of temperature on the rate of evaporation of a given solution.

Objective:
To study the effects of temperature on the rate of evaporation of orange juice solution.

Theory
In evaporation the vapor from a boiling liquid solution is removed a more concentrated solution remains. In the majority of cases the separation process called evaporation refers to the removal of water from an aqueous solution.
Typical example of aqueous solution of sugar, sodium chloride, sodium hydroxide, glycerol, glue, milk, an orange juice. In these cases, the concentration solution is the desired product and the evaporated water is normally discarded. In a few cases, water, which contains a small amount of mineral, is evaporated to give a solid-free water to be used as boiler feed, for special chemical process, or for other purposes. In some cases, the primary purpose of evaporation is to concentrates a solution so that upon cooling, salt crystals will form and be separated. It's called crystallization.

Rotary Evaporator

Heat and Material Balances for evaporators

The basic equation for solving for the capacity of a single-effect evaporator is Eq (1)

$$q = UA \, \Delta T \qquad (1)$$

where

q , W (btu/h)   = capacity of a single-effect evaporator

ΔT , $K(^0F)$ = difference in temperature between the condensing steam and the

boiling liquid in the evaporator

FIGURE 8.4-1. *Heat and mass balance for single-effect evaporator.*

vapor V

feed F

T_F, x_F, h_F

T_1, y_V, H_V

P_1

T_1

condensate S

steam S

T_S, H_S

T_S, h_S

concentrated liquid L

T_1, x_L, h_L
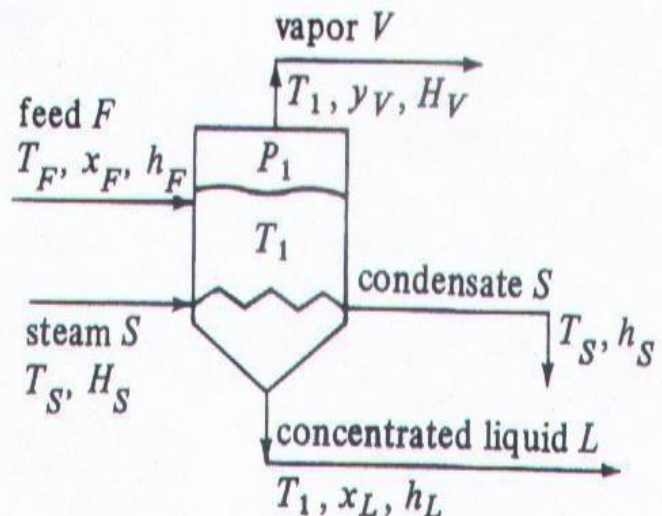
TF , K (^{0}F) = temperature

F , kg/h (lbm/h) = feed to the evaporator

XF = mass fraction

hF, J/kg (btu/lbm) = enthalphy

L, kg/h (lbm/h) = concentrated liquid that coming out

XL = solids content T1 =

temperature hL

=enthalphy

V, kg/h (lbm/h) = vapor

Y_v *=0, pure solvent having a solids content*

H_v = enthalphy

S kg/h (lbm/h) = saturated steam

entering T_S = temperature

H_S = enthalphy

Latent heat λ, = H_S − h_S (2)

Total balance, F = L+V (3)

Balance solute (solids) alone, FXF = LXL

Heat q transferred in the evaporator then q = S(H_S *−* h_S *) = Sλ*   (4)

Procedure:

1) Measure 50 mL of orange juice solution using measuring cylinder and poured in the evaporator flask.

2) Clamp the flask to the rotary evaporator and turn on the equipment.

3) Fix the speed of rotation to 100 rpm and keep constant throughout the experiment.

4) Set the temperature to 30°C. After the temperature is stabilized, take reading after 10 minutes.

5) Record the volume of the condensate.

6) Repeat the Step 4 using different temperature 50°C and 100°C and record your data.

7) **Plot the graph of temperature against the rate of evaporation of orange juice solution**

Figure 1 : Rotary Evaporator Equipment

No	Apparatus	Function
1	Condenser	Provide cool water to turn the vapor into condensate
2	Coupling clamp duct	Hold the receiving flask on the condenser
3	Receiving flask	Collect the condensate for the product
4	Control panel	Control the change for the condition of the rotary evaporator
5	Evaporator flask	Contain the solution that is going to be heated
6	Heating bath	As the heat source and heat up the evaporator flask

Other **Apparatus**: Measuring cylinder   **Material**: Orange Juice solution or milk solution

Data /Results /Calculation:

Amount of solution used : 50 mL

Controlled variable   : 100 rpm,

Time: 10 minutes

Manipulated variable: Temperature of the water bath

$$\text{Rate of Evaporation} = \frac{Volume\ of\ Condensate\ (mL)}{Time\ (min)}$$

Data and results for the experiment

Temperature (°C)	Volume of Condensate (mL)	Rate of Evaporation (m^3/mL)

EXPERIMENT 9:

AIM: Investigating the Effect of different NaOH concentration during constant pressure and rotation

OBJECT OF EXPERIMENT:
To determine effects of different concentration of NaOH during evaporation

Procedures:
1. Prepare a sodium hydroxide solution by adding 20 gram of sodium hydroxide into 100 ml of water. Weight this solution.
2. Set the water bath temperature to 100^OC
3. Set the vacuum pressure to 119mBar
4. Set the rotation at 60rpm.
5. Run the process for 30 minutes.
6. After 30 minutes, determine the RI and weight the liquid and vapor.
7. Repeat the experiment with 40g and 60g of sodium hydroxide in 100ml of water.

Discussion:
1. Perform overall material balance of total liquid left and vapor produce.
2. Calculate the heat transfer area, a.
3. State your comments on the calculation and experimental results

References:
What is The Boiling Point of Orange Juice.

http://science.blurtit.com/2770672/what-is-the-boiling-point-of-orange-juice

Rotavap.http://www.chem.ucla.edu/~bacher/Specialtopics/rotavap.html
Rotary Evaporator: http://www.heidolph-instruments.com/products/rotary-evaporators/tabnavi/hei-vap-rotary- evaporators/

FILTRATION

PLATE AND FRAME FILTER PRESS EXPERIMENTS

Experiment 10

1. To be able to identify the basic parts and function of a plate and frame filter press.
2. To determine the optimum filtration time and optimum cake thickness
3. To develop the operation and maintenance of a plate and frame filter press
4. To identify the variation in time of filtrate quantity and solid concentration in filtrate
5. To study the mass of filter cake dependent on filtrate quantity

INTRODUCTION

The purpose of Plate and Frame Filter Press experiments is to study the operation of filter press for filtration of calcium carbonate slurry and to determine filter medium resistance and specific cake resistance from filtration data obtained.

PROCEDURE:

1. weigh 5kg of calcium carbonate powder, dissolve it in 100 L of water in a container and transfers it to the slurry tank.

2. Once the pump being switch on, the RUN light will light green, this indicates that the process of feeding the slurry into the filter press has started.

3. Record the time to collect 5L of filtrate volume, V until there is no filtrate coming out.

4. Weigh the wet cake and dry cake and record the values.

5. Calculate the filter medium resistance Rm for each trays

6. Plot the graphs of t/V versus V

DATA

Weight fraction of calcium carbonate in slurry = 5 wt%

Weight of wet cake,

      Tray 1 = kg Tray 2 =

      kg Tray 3 = kg

Weight of dry cake,

      Tray 1 = kg Tray 2 =

      kg Tray 3 = kg

Weight ratio of wet cake to dry cake (m_F/ m_C) = 0.787

Density of calcium carbonate (ρ) = 2.93 g/cm^3

Total active filter area = 0.47 m x 4.7 m

= 2.209 m^2

Pressure drop = 50 Psi = kPa Total filtration time = s

Total volume of filtrate = L

Filtrate volume, V (L)	Time, t (s)	Time /Volume, t/V (s/ L)
		undefined

REFERENCES

1. C.v.s subrahmanyam et al., Pharmaceutical Engineering Principles and Practices- Filtration, 2001, pg260-266
2. Filtration, 1998-2009, Lentech Water treatment & purification Holding B.V, [Online]. [Accessed 29th March 2016]. Available from World Wide Web: http://lenntech.com/chemistry/filtration.htm
3. Cebu Institute of Technology, Chemical Engineering Department, Juphil A. Lamanilao, 2010, p239
4. Filtration, 2014, Ritu R. Kudarha and M. Pharm, [Online]. [Accessed 30th March 2016]. Available from World Wide Web: http://slideshare.net/ritukudarha/filtration- 39038033

APPENDICES

SAMPLE CALCULATION

From graph of t/ V against V plotted in figure 1, the equation of the line obtained is y = - 0.0197x + 12.368.

Slope, $\dfrac{Kc}{2}$ = - 0.0197 s/L

$\qquad$ Kc = - 0.0394 s/L

y-intercept, $\dfrac{1}{qo}$ = 12.368

Equations provided to calculate filter medium resistance (Rm) and cake resistance (α) are as follows,

$$\dfrac{1}{q_o} = \dfrac{\mu\, Rm}{A\,(\Delta P)} \qquad\qquad Kc = \dfrac{\mu\, c\, \alpha}{A^2\, \Delta P}$$

To calculate filter medium resistance (Rm),

i. For Tray at 10 L,

$$R_m = \dfrac{1}{q_o} \; x \; \dfrac{A\,(\Delta P)}{\mu}$$

$$Rm = \dfrac{(12368 \; s/m3)\;(2.209\;m2)\;(34474\;Pa)}{0.0128 \; Pa.s}$$

$$= -7.3583 \text{x} 10^{10}\,m^{-1}$$

ii. For Tray at 50 L,

$$R_m = \dfrac{1}{q_o} \; x \; \dfrac{A\,(\Delta P)}{\mu}$$

$$Rm = \dfrac{(12368 \; s/m3)\;(2.209\;m2)\;(34474\;Pa)}{0.02 \; Pa.s}$$

$$= -4.7093 \text{x} 10^{10}\,m^{-1}$$

iii. For Tray at 70 L,

$$R_m = \dfrac{1}{q_o} \; x \; \dfrac{A\,(\Delta P)}{\mu}$$

$$Rm = \frac{(12368 \text{ s/m3}) (2.209 \text{ m2}) (34474 \text{ Pa})}{0.02 \text{ } Pa.s}$$

$$= -4.7093 \times 10^{10} \text{ m}^{-1}$$

To calculate cake resistance (α).

i. For Tray at 10 L,

$$\alpha = \frac{Kc \, A^2 \, \Delta P}{\mu \, c}$$

$$\alpha = \frac{(-0.0394 \text{ s/L}) (4.8797 \text{ m4}) (34474 \text{ Pa})}{(0.0128 \text{ } Pa.s)(0.05\frac{kg}{L})}$$

$$= 10356214.76 \text{ (m}^4\text{/kg)}$$

ii. For Tray at 50 L,

$$\alpha = \frac{Kc \, A^2 \, \Delta P}{\mu \, c}$$

$$\alpha = \frac{(-0.0394 \text{ s/L}) (4.8797 \text{ m4}) (34474 \text{ Pa})}{(0.02 \text{ } Pa.s)(0.05\frac{kg}{L})}$$

$$= 6627977.45 \text{ (m}^4\text{/kg)}$$

iii. For Tray at 70 L,

$$\alpha = \frac{Kc \, A^2 \, \Delta P}{\mu \, c}$$

$$\alpha = \frac{(-0.0394 \text{ s/L}) (4.8797 \text{ m4}) (34474 \text{ Pa})}{(0.02 \text{ } Pa.s)(0.05\frac{kg}{L})}$$

$$= 6627977.45 \text{ (m}^4\text{/kg)}$$

SECOND SEMESTER

CHEMICAL ENGINEERING LABORATORY IV (CHE 308)

EXPERIMENT INDEX

DRYING OPERATION:
MODE OF OPERATION OF DRYING EQUIPMENT

EXPERIMENT 1: DETERMINATION OF OVERALL DRYING RATE OF A TRAY DRYER, PNEUMATIC DRYER AND ROTARY DRYER

AIM:
1. Mode of operation of drying equipment, Tray dryer, Rotary dryer and vertical pneumatic dryer

OBJECTIVES:
1. To produce drying and drying rate curves for a wet solid being dried with air of fixed temperature and humidity.
2. To determine the critical and equilibrium moisture contents, bound and unbound moisture of the wet solid being dried.

Apparatus: Weighing balance, tray dryer, fluidized bed dryer and stop watch.

Sample: Wet sand, Rice, Banana Peel e.t.c.

INTRODUCTION
Technically, drying is a mass transfer process resulting in the removal of water moisture or moisture from another solvent, by evaporation from a solid, semi-solid or liquid to end in a solid state. To achieve this, there must be a source of heat, and a sink of the vapor thus produced. In the most common case, a gas stream, e.g., air, applies the heat by convection and carries away the vapor as humidity. Other possibilities are vacuum drying, where the source of heat may be by conduction or radiation and the vapor is removed by the vacuum system. Another possibility is drum drying, where a heated surface is used in connection with aspirators to draw the vapor outside the site.

THEORY
Drying refers to an operation in which a volatile liquid is removed from a solid or semi-solid material by means of thermal energy. Tray dryers are used mostly for lumpy or pasty solids. During drying, mass and heat transfer occur simultaneously. Heat is transferred from the bulk gas phase to the solid phase, where part of it is utilized for vaporization and the remainder is taken up by the solid phase as sensible heat. Mass is transferred in the form of liquid and vapour through various resistances, first from the interior of the solid to the surface, then through vaporization at or near the surface and finally in the transport of the vapour into the bulk gas phase. Free moisture content can be obtained from the total average moisture content minus the equilibrium moisture content for the prevailing conditions of drying.

Drying rate is the ratio of free moisture content to time with respect to surface area of material under drying.

$$\text{Drying rate} = -\frac{1}{A}\frac{dm}{dt} \qquad\qquad \text{EQ 1}$$

The moisture in a solid is retained in two forms as shown in Figure 1. These comprise:

(a) Bound moisture, which exerts an equilibrium vapor pressure less than that of free water at the same temperature. How this moisture is retained depends upon the nature of the solid; it may be retained in fine capillaries, or adsorbed onto surfaces, or within a cell or fibre walls, or in physical/chemical combination with the solid.

(b) Unbound moisture which exerts an equilibrium vapor pressure equal to that of water
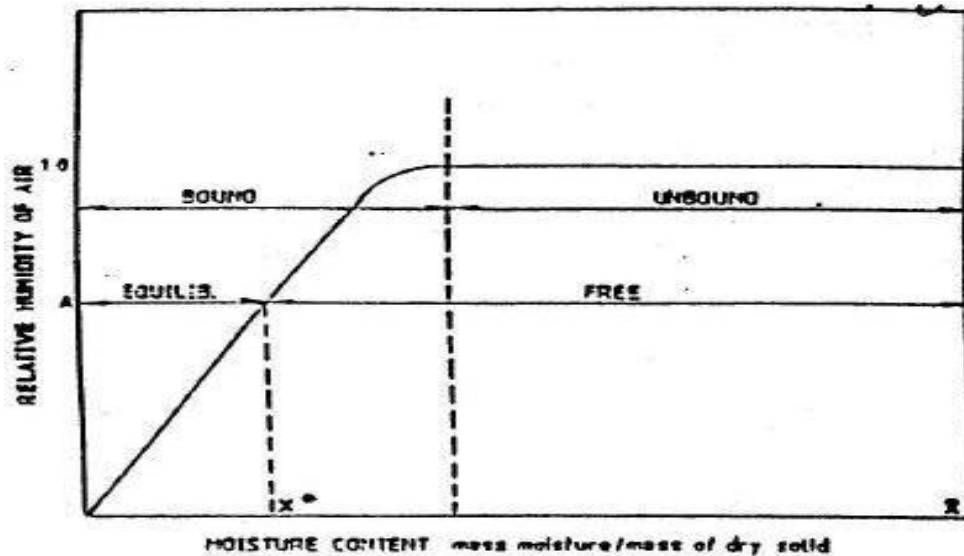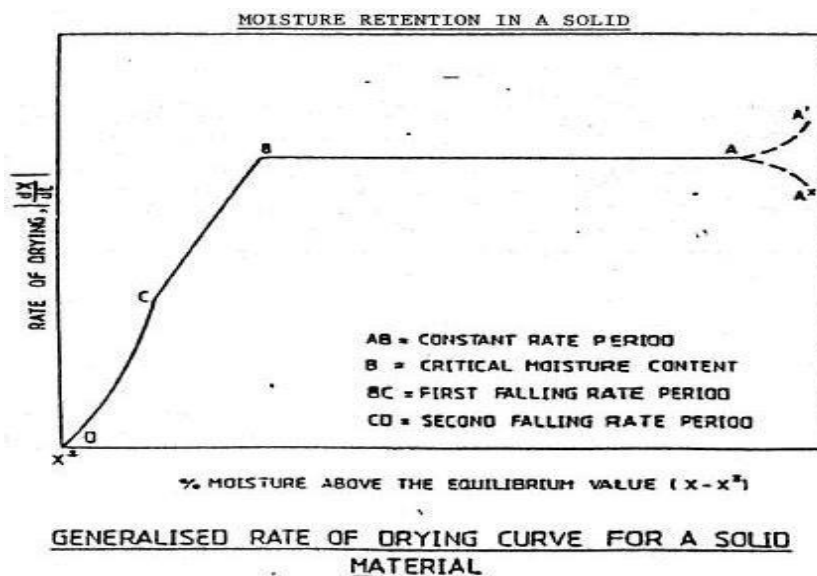
Figure 1

The distinction between bound and unbound moisture is a property of the specific solid under consideration. If the solid represented in Figure 1 is dried in air of relative humidity 'A', then all of the unbound and part of the bound moisture can be removed. This will comprise the 'free' moisture above the equilibrium moisture content corresponding to the air condition. Hence the 'free' moisture = $(X-X^*)$. Note that the distinction between 'equilibrium' and 'free' moisture contents depends both upon the nature of the solid and the conditions. Also, the bound moisture represents the equilibrium moisture content of the solid in contact with air that is saturated -- that is, air with a relative humidity of 1.0.

Drying Rate Behavior

A typical drying rate curve is shown in Figure 2. The rate of drying, dX/dt, is plotted as the ordinate against the % moisture above the equilibrium value, $X-X^*$. Clearly, as drying proceeds, X decreases and dX/dt would be a negative number.

MOISTURE RETENTION IN A SOLID

AB = CONSTANT RATE PERIOD
B = CRITICAL MOISTURE CONTENT
BC = FIRST FALLING RATE PERIOD
CD = SECOND FALLING RATE PERIOD

GENERALISED RATE OF DRYING CURVE FOR A SOLID MATERIAL

PROCEDURE
OPTION A
1. Screen sufficient dry sand (bone dry) to approximately 500 mesh using sieve shaker to fill the four drying trays to a depth of about 10 mm each.
2. Weigh the empty tray and record
3. Take the dimension of the tray with sample to calculate its surface area.
4. Weigh the given sample on tray and record before drying.
5. Spread the sample uniformly to a depth of 10 to 100 mm on metal tray and introduce into the dryer
6. Connect the dryer to the wall socket and switch on to observe for 10 minutes.
7. Record the free moisture content by taking the difference of initial weight and the final weight of sample after drying at designated time.
8. Repeat the experiment for 20 minutes, 30 minutes, 40 minutes and 50 minutes.

OPTION B:
 i. Load the pre-weighed tray with solid (e.g., saw dust or sand).
 ii. Place it over the weighing balance.
 iii. Record the weight of sand & tray.
 iv. Set the temperature of chamber with the help of temp. controller.
 v. Keep the tray gentle in the drying chamber and start the stopwatch.
 vi. Record the balance reading with time at about 3-5 min interval.
 vii. Similarly note down the readings in every 5-minute interval.
 viii. Drying is assumed to be complete when at least 3 consecutive readings are same.
 ix. Switch off the main power supply.

OBSERVATION & CALCULATIONS:
Solid dry wt. = S,kg   Initial moisture content = x

RESULT: Tabulate the results obtained as below:

Time (mins)	Time (sec)	Mass of Sand (g)	Free moisture content (Kg H_2O/kg solution)	Drying rate (kg/hrm^2)
10				
20				
30				
40				
50				

Graph
1. Plot free moisture content against time and determine the overall drying rate.
2. Plot drying rate against free moisture content and determine constant rate of drying.

Reference
- S.K. Ghosal *et. al*, Introduction to Chemical Engineering.
- http://www.eng.auburn.edu/users/tplacek/courses/4860/Lab%20Notes%20for%20Drying.pdf

CENTRIFUGAL PUMP TEST RIG

EXPERIMENT NO 2: DETERMINATION OF PUMP EFFICIENCY
AIM: Study of Centrifugal pumps characteristics.

Objectives:
To Determine Pump Efficiency and Overall Efficiency of centrifugal pump

2. To Plot the Following Performance
a) Head vs. Discharge
b) Pump Efficiency vs. Discharge
c) Overall Efficiency vs. Discharge

INTRODUCTION
A centrifugal pump is a rotating machine in which flow and pressure are generated dynamically. The inlet is not walled off from the outlet as is the case with positive displacement pumps, whether they are reciprocating or rotary in configuration. Rather, a centrifugal pump delivers useful energy to the fluid or "pumpage" largely through velocity changes that occur as this fluid flows through the impeller and the associated fixed passageways of the pump; that is, it is a "rotodynamic" pump. All impeller pumps are roto-dynamic, including those with radial-flow, mixed-flow, and axial-flow impellers: the term "centrifugal pump" tends to encompass all rotodynamic pumps.

THEORY
The centrifugal pump works on the principle of forced vortex flow, which means that an external torque rotates a certain mass of liquid, rise in pressure head of the rotating liquid takes place. The rise in pressure head at any point of the rotating liquid is proportional to the square of the tangential velocity of the liquid at that point. Thus, at the outlet of the impeller where radius is more, the rise in pressure head will be more and liquid will be discharged at the outlet with a high-pressure head. Due to this high-pressure head, the liquid can be lifted to a high level. The centrifugal pump acts as a reversed of an inward radial flow reaction turbine. This means that the flow in centrifugal pump is in the radial outward direction.

Component of Centrifugal Pump
Heads and Efficiencies of a Centrifugal Pump
Suction Head (h_s): It is the vertical height of the centre line of the centrifugal pump above the water surface in the tank or pump from which is to lifted. This height is also called suction lift.
- **Delivery Head (h_d):** The vertical distance between the centre line of the pump and the water surface in the tank to which the water is delivered is known as delivery head.
- **Static head (H_s):** The sum of suction head and delivery head is known as static head. This is written as $H_5 = h_S + h_d$
- **Manometrlc Head (H_m):** The manometric head is defined as the head against which a centrifugal pump has to work.
H_m = Head imparted by the impeller — loss of head in the pump
H_m = Total head at outlet of the pump — Total head at inlet of pump
H_m = $h_s + h_d + h_{f5} + h_{fd} + V_d 2/2g$
H_f = frictional head loss in suction pipe, h_{fd} = frictional head loss in delivery pipe
- **Efficiencies of a Centrifugal Pump:** In case of centrifugal pump, the power is

the impeller. From the impeller, the power is given to the water. Thus power is decreasing from the shaft of the pump to the impeller to the impeller and then to the water. The following are the important efficiencies of a centrifugal pump:

1. Manometric efficiencies, η_{man}
2. Mechanical efficiency, η_m
3. Overall efficiency, η_0

Experimental Setup

Set up consists of a Centrifugal Pump coupled with Electrical Motor, Supply Tank, Measuring Tank & Pipe Fitting for closed loop Water Circulation. Pressure and Vacuum Gauges are connected on Delivery and Suction side of Pump for purpose of measurement of Pressure. The Flow rate of water is measured by using measuring Tank and Stop Watch provided.

Experimental Procedure

1. Clean the apparatus and make all tanks free from dust.
2. Close the drain valves provided.
3. Open the valves of Sump and Delivery.
4. Ensure that all On/Off Switches given on the Panel are at off position.
5. Now switch on the Main Power Supply (220 V AC, 50Hz) and switch on the pump.
6. Switch on the power supply.
7. Fix Speed with minimum head i.e. all valves in the line fully open.
8. Allow the water to pass to collection tank till 10-50 liter of water is collected in the reservoir and note the time taken for lifting this volume of water.
9. Slowly reduce the speed of rotation of pump and note down the flow rate as in the previous step.
10. Tabulate the results and plot the graph for the Characteristics of the Pump.

Specification

Pump   :   Centrifugal Type, 1HP Speed 2900 RPM (max.), Head 12m (max.), Make Kirloskar

Drive   :   AC motor with step cone pulley

Arrangement for 3 prefixed Speed for Variation of RPM/DC motor with variable speed drive

Supply Tank   :   Capacity 50 Liters.

Measuring Tank :   Capacity 20 Liters. Fitted with Piezometer tube & scale.

Stop Watch   :   Electronic

Control Panel   :   With required electrical instrumentation.

Piping   :   GI/PVC

Tank Material   :   Stainless Steel

Standard Data

Pipe Diameter at Suction Side   25 mm

Pipe Diameter at Delivery Side   40 mm

Energy Meter Constant EMC   6400 imp/kW-hr

Acceleration due to Gravity g   9.81 rn/sec²

Density of Water ρ 1000 kg/rn³

Motor Efficiency η_{Motor} 80%

Transmission Efficiency $\eta_{Transmission}$ 65%

Conversion Factor   1 kg/cm² = 0.104 m of Water

Tank	400 mm x 250 mm

Observation Table
For Centrifugal Pump Efficiency

S/N	P_d (kg/cm^2)	P_s (mm)	Pulses of Energy Meter P	t' (sec)	R Rise in Tank (m)	t Time Taken for R (sec)

Formulae
Total Head, H
$$H = 10.3 \ x \ (P_d + \frac{P_d}{760}) \ \text{m of Water.}$$

Actual Discharge (Qa)
$$P_d = \frac{A \ x \ R}{t} \quad m^3/s$$

Electrical Input (HP)
$$Electrical \ Input = \frac{P \ x \ 3600 \ x \ 1000}{t \ x \ EMC \ x \ 746} \ HP$$

Pump Output
$$PumpOutput = \frac{g \ x \ \rho \ x \ Q \ x \ H}{746} \ HP$$

Shaft HP

$$Shaft \ Power = \ Electrical \ Input \ x \ \eta_{motor} \ x \ \eta_{Transmission}$$
Pump Efficiency η_p

$$\eta_p\% = \frac{PumpOutput}{ShaftPower} \ x \ 100$$

Overall Efficiency η_0

$$\eta_0\% = \frac{PumpOutput}{ElectricalInput} \ x \ 100$$

CALCULATION TABLE

For Centrifugal Pump Efficiency

S/N	Q (m^3/sec)	H (m)	Electrical Input, (HP)	Pump Output, (HP)	Pump Efficiency,η_p%	Overall Efficiency, η_0%

Nomenclature

η_0 = Overall Efficiency

η_p = Pump Efficiency

A = Area of Measuring Tank EMC = Energy Meter Constant

H = Head produced by the pump, meter.

N = RPM of pump.

Q = Discharge, m3/sec.

t' = Time for P pulses, sec.

g = Acceleration due to gravity = 9.81 rn/sec2

ρ = Density of Water = 1000 kg/rn3 P_d = Delivery side Pressure Head

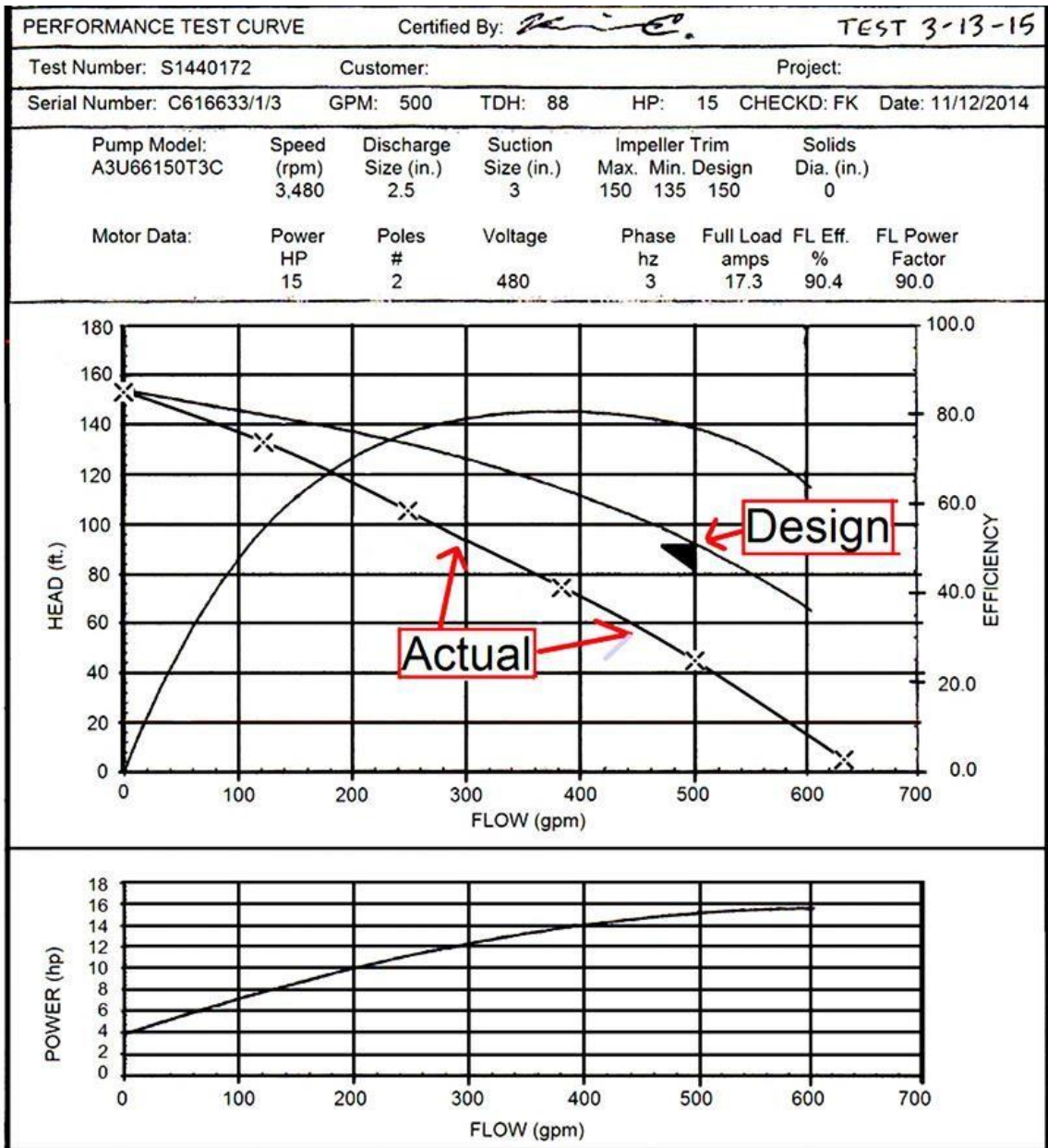P_s = Suction side Pressure Head R = Rise in the level of Tank

Result
Plot the Following Performance
A. Head vs. Discharge
B. Pump Efficiency vs. Discharge
C. Overall Efficiency vs. Discharge

Precautions
1) Frequently grease/oil the rotating parts, once in three months.
2) If apparatus is not in use for more than one month, drain the apparatus completely, and fill pump with cutting oil with help of priming valve.
3) Do not run the pump with high heads and less discharge for any time longer than required for obtaining the required reading. During this time motor starts heating and if run for longer intervals may cause the insulating failure of motor winding and subsequently short circuiting or other severe, dangerous conditions.

PERFORMANCE TEST CURVE   Certified By: _____   TEST 3-13-15

Test Number: S1440172	Customer:		Project:

Serial Number: C616633/1/3	GPM: 500	TDH: 88	HP: 15	CHECKD: FK	Date: 11/12/2014

Pump Model: A3U66150T3C	Speed (rpm) 3,480	Discharge Size (in.) 2.5	Suction Size (in.) 3	Impeller Trim Max. Min. Design 150 135 150	Solids Dia. (in.) 0

Motor Data:	Power HP 15	Poles # 2	Voltage 480	Phase hz 3	Full Load amps 17.3	FL Eff. % 90.4	FL Power Factor 90.0

FIXED AND FLUIDIZED BED SYSTEM

EXPERIMENT NO: 3A

AIM: DETERMINATION OF PRESSURE DROP THROUGH PACKED AND FLUIDIZED BEDS FOR BOTH AIR AND WATER SYSTEMS.

OBJECTIVES:
a) To determine the head loss (pressure drop)
b) To verify the equation.
c) To observe the unset of fluidization and differentiate between the characteristics of a fixed bed and a fluidized bed.
d) To compare the predicted onset of fluidization with the measured head loss.

INTRODUCTION
A **fluidized bed** is a physical phenomenon occurring when a quantity of a solid particulate substance (usually present in a holding vessel) is placed under appropriate conditions to cause a solid/fluid mixture to behave as a fluid. This is usually achieved by the introduction of pressurized fluid through the particulate medium. This results in the medium then having many properties and characteristics of normal fluids, such as the ability to free-flow under gravity, or to be pumped using fluid type technologies. The resulting phenomenon is called fluidization. Fluidized beds are used for several purposes, such as fluidized bed reactors (types of chemical reactors), solids separation, fluid catalytic cracking, fluidized bed combustion, heat or mass transfer or interface modification, such as applying a coating onto solid items. This technique is also becoming more common in aquaculture for the production of shellfish in integrated multi-trophic aquaculture systems.

Packed and fluidized beds play a major role in many chemical engineering processes. Packed bed situations include such diverse processes as filtration, wastewater treatment, and the flow of crude oil in a petroleum reservoir. In these cases, the interest centers on the pressure drop through the bed as a function the volumetric flow rate or superficial velocity.

THEORY
The flow of a fluid, either liquid or gas, through a static packed bed of particles is a situation encountered both in nature and industry. Natural occurrences include the movement of ground water, the movement of crude petroleum or the movement of natural gas through process media. Industrial occurrences include operations of backwashing filters, ion exchange processes, extraction of soluble components from raw material and certain type of chemical reactors. The theory for this experiment is covered in Chapter 7 of McCabe, Smith, and Harriott (M,S&H). The following material is a condensation of that chapter as it relates to the experiment at hand. As an aid to you, some specific equations in M,S,&H are referred to. There are three areas of interest to us:
(1) Relationship between the pressure drop and the flow rate;
(2) Minimum fluidization velocity, and;
(3) Behavior of the expanded bed.

Relationship between pressure drop and flow rate.
The flow of a fluid, either liquid or gas, through a static packed bed can be described in a quantitative manner by defining a bed friction factor, fp, and a particle Reynolds

number, NRe,p, as follows: Note that this equation cannot be derived directly by extrapolating the case of flow through a circular conduit since friction factor defined in both cases is different (see McCabe and Smith 4th edition, pg. 137).

Where ΔP = pressure drop across the bed
L = bed depth or length
gc = conversion constant (= unity if SI units are used)
Dp = particle diameter
ρ = fluid density
ε = bed porosity or void fraction
Vo = superficial fluid velocity
μ = fluid viscosity
φ_s = sphericity

The friction factor and the Reynolds number are dimensionless. Some typical sphericity factors are given in McCabe, Smith and Harriott (p. 928, Table 28.1).
 When a fluid is admitted at the bottom of a packed bed of solids at a low flow rate, it passes upward through bed without causing any particle motion. If the particles are quite small, flow in the channels between the particles will be laminar and the pressure drop across the bed will be proportional to the superficial velocity Vo and for turbulent situations, pressure drop across the bed increase nonlinearly with the increase in the superficial velocity. As the velocity is gradually increased, the pressure drop increases, but particles do not move and the bed height remains the same. At a certain velocity, the pressure drop across the bed counterbalances the force of gravity on the particles or the weight of the bed,and any other further increase in velocity causes the particles to move and the true fluidization begins. For a high enough fluid velocity, the friction force is large enough to lift the particles. This represents the onset of fluidization Once the bed is fluidized pressure drop across the bed remains constant,but the bed height continues to increase with increasing flow.
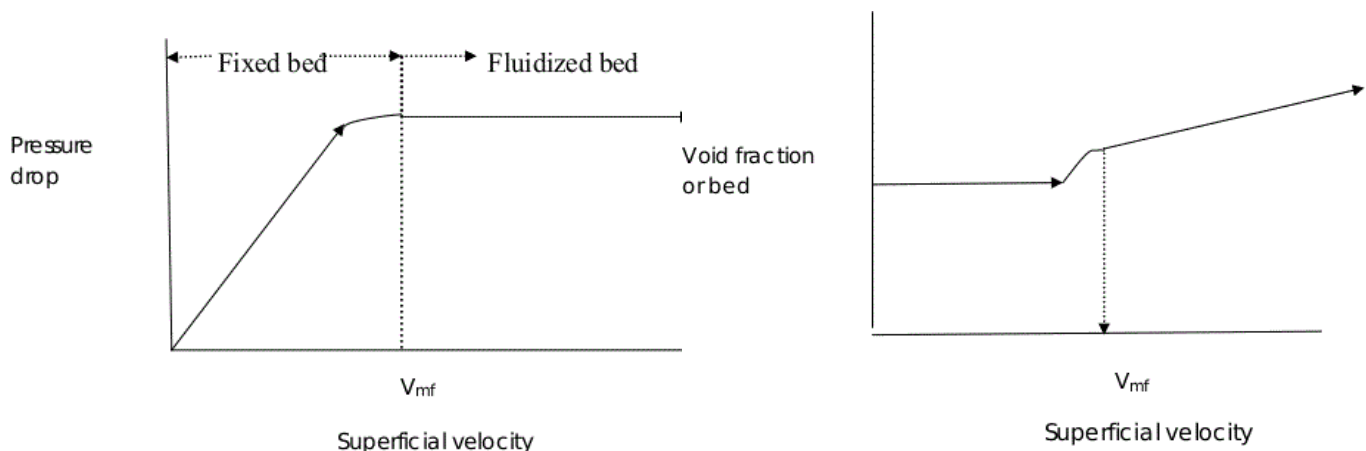
2) Minimum fluidization velocity
At a sufficiently high flow rate, the total drag force on the solid particles constituting the bed becomes equal to the net gravitational force and the bed becomes fluidized. For this situation a force balance yields: $(-\Delta p)A = LA (1-\varepsilon M)(\rho p - \rho)g/gc = M (\rho p - \rho)g/ (gc\rho p)$ (6)
where εM = void fraction at the minimum fluidization velocity
A = cross-sectional area of the bed
ρp = particle density   g = gravitational constant   M = total mass of packing.

DESCRIPTION OF APPARATUS

All numerical references relate to figure 1

The equipment consists of a water circuit and an air circuit main field on a support frame (1) and back board (2). The water circuit is located at the left-hand side and the air circuit is located at the right-hand side when looking from the front. The two circuits are independent of each other and therefore may be operated separately or together according to choose. Water is drawn from a plastic sump tank (3) by a centrifugal pump (4), both Situated at the rear of equipment. The pump delivers water to the base of the water test column (7) via a flow control value (5) and a direct reading variable-area flowmeter (6). Having passed vertically upwards through the test column, the water discharges rearwards from the top of the column and return via a flexible overflow pipe {I.S) to the sump tank for recycling. A drain lap (22) at the base of the sump tank allows the tank to be emptied. A lid on the sump tank keeps the contents clean. The water pump is switched on or off using the mains switch (23) that is located above the water flowmeter.

1. CONTROL SWITCH: used to turn on the air circuit.
2. DIFFERENTIAL WATER MANOMETER: used to measure pressure drop.
3. VARIABLE AREA FLOWMETER: used for measuring flow rate.
4. BED FLOW CONTROL VALVE: used to alter the flow rate.
5. BRASS DISK: supports the particle inside the test column and helps to distribute water uniformly across the section of the test column.

DESCRIPTION OF APARATUS
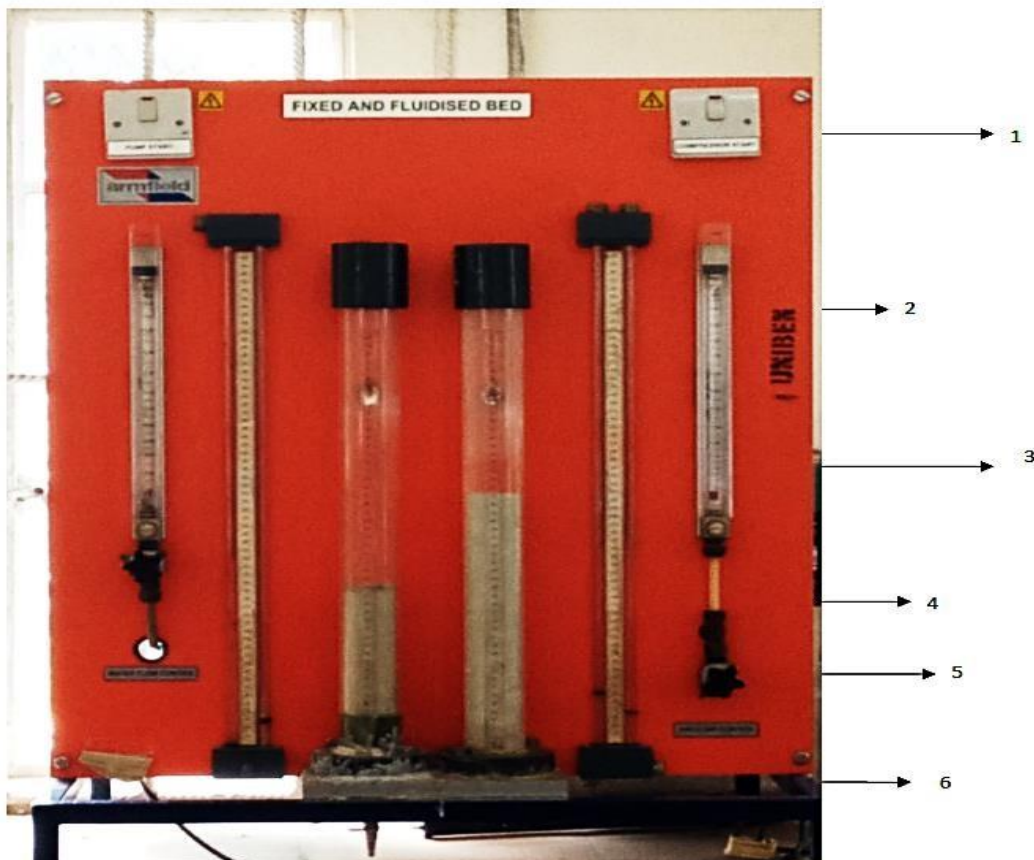
PROCEDURES

i.   fill the air column to a height of 310 mm, then close the air flow control
ii. check the water manometer for air bubbles.
iii. Switch on the air compressor and adjust the air flow rate to an increment of 1L/min
iv. At each setting observe the conditions and allow to stabilize and the height of the bed, record differential reading of the manometer and the state of bed.
v.   Continue this process until the flow rate got to 20L/min, and take records accordingly.
vi. Tabulate your data on the table below and pressure drop against flowrate:
vii. Plot graph of Pressure drop against bed Hight.
viii. Discuss your findings

Bed height (mm)	Flow Rate (L/min)	P_1 (mmH$_2$O)	P_2 (mmH$_2$O)	Pressure drop in bed ΔP (mmH2O)	Bed state
					fixed
					fixed
					fixed
					fixed
					Fluidized
					Fluidized
					Fluidized
					Fluidized

REFERENCES

- Chapter 7 of McCabe, Smith, and Harriott (M,S&H). unit operations for chemical engineering
- R.h. perry and C.H chiliton, chemical engineering handbook, seventh edtion

FIXED AND FLUIDIZED BED SYSTEM
EXPERIMENT NO: 3B: DRYING CHARACTERISTICS OF A GIVEN MATERIAL

AIM: determination of drying characteristics of a given material in a fluidized bed system.

THEORY:
The term drying usually infer removal of relatively small amounts of water from solid or nearly solid material. The water is usually removed by circulation of air or some other gas gives the material in order to carry away the water vapor. There are many types of equipment used in industries for drying operation. The most recent method is fluidized bed drying, which could be operated batch-wise as well as continuously. Drying is a process of simultaneous heat and mass transfer. The heat transfer rate is between five to twenty-five times that for the gas alone. Because of rapid equalization of temperature in fluidized bed, temperature control can be accomplished.
Fluidized bed units for drying solids, particularly coal, cement, fertilizers, limestone etc are in general acceptance. One of the major advantages of this type of dryer is the close control of conditions so that a predetermined amount of free moisture may be left with the solids to prevent dusting of the product during subsequent material handling. In order to set up drying schedules and to determine the size of the equipment, it is necessary to know the time which will be required to dry a substance from one moisture content to another under specified conditions. Our knowledge of the mechanism of drying is so incomplete that it is necessary with few exceptions to rely upon at-least some experimental measurements for this purpose.

EXPERIMENTAL SETUP:
The experimental setup consists of a vertical glass tube in which arrangement for filling and taking out the sample is made. A heater controlled by dimmer-stat regulates the temperature of air as desired. An air compressor supplies the air and the Rota meter measures the flow rate of this air. The air inlet and outlet conditions can be obtained from the dry and wet bulb temperatures recorded at the inner and outlet of the bed.

PROCEDURE:
Select the material for this test such that at the end the drying operation it will be in the fluidized state. Materials such as light particles of thermocol, asbestos, foam, silica gel, wood saw etc should be tried before the actual experiment.
➢ Take a known weight of this material and moist it around 25 to 30% of moisture dry basis.
➢ Adjust the air flow rate you have already tested to bring this material in fluidized conditions.
➢ Select some heater conditions such that the material is dried in a desired time approximately.
➢ Note the steady state temperature of inlet and outlet air before the material has been added to the bed.
➢ Add the known weight of the wet material to the bed and record the outlet dry and wet bulb temperatures of the air at the intervals of 2 minutes.
➢ Also record the inlet humidity of air by noting the dry and wet bulb temperature of the inlet the temperature recordings till the initial conditions are observed.

OBSERVATIONS:
1. Weight of dry material   =   46.6 – 29   =   20.6 g

2. Weight of wet material $\qquad$ = 68.4 – 29 = 39.4 g
3. Drying temperature = 60.4 °C
4. Surface area of the material (A) = 52281 x 10^{-3} m^2
5. Inlet air
      a) Dry bulb temp = 29^{0}C
      b) Wet bulb temp = 28.7^{0}C
6. Air flow rate
      (G) = 1.78 x 10^{-4} Kgs
7. Weight of final sample= 48.4 gm

CALCULATIONS:

Rate of drying, = $G (H_2 – H_1)$ eq. (1)

Where:
      H_2 is the outlet humidity of air = kg water/kg dry air
      H_1 is the inlet humidity of air = kg water/kg dry air

The average moisture content of the material w = $(w_1 + w_2)/2$

Where W_1 is moisture content at time t_1 and w_2 is the moisture content at time t_2.

OBSERVATIONS:

1) Initial dry bulb temperature = 60.4 ^{0}C
2) Initial wet bulb temperature = 53.9 ^{0}C
3) LPM = 6
4) W1 of petri dish = 29 g
5) W2 of dry material = 49.6 g
6) W3 of wet material = 68.4 g
7) Diameter = 4.5 cm
8) Bed height = 3.7 cm
9) V = 230 v
10) I = 054 mA

TEMPERATURE AFTER EVERY 1 MINUTE

S/N	Dry bulb ^{0}C	Wet Bulb ^{0}C
1	59	48.4
2	46.7	45.8
3	45.3	44.2
4	44.8	44.5
5	45	43.9
6	45.1	43.4
7	44.4	42.6
8	44.8	42.6
9	46.3	42.7
10	48.2	43.7
11	50.2	44.9
12	52	46.9

13	54.2	48.3
14	56.4	50.7
15	58.7	53.2
16	60.7	55.2

CALCULATIONS

1) A = $2Brh$ = $2 \times 3.14 \times 2.25 \times 10^{-2} \times (3.7 \times 10^{-2})$

$\therefore A$ = $5.2281 \times 10^{-3} \ m^2$

2) $\frac{dw}{dt}$ = $6(H_2 - H_1)$

Q = $6LPM$ = $\frac{6 \times 10^{-3} m^3}{60}$ = $10^{-4} \ m^3/sec$

$$u \ = \ \frac{Q}{A} \quad \frac{10^{-4} m^3/sec}{5.2281 \times 10^{-3} \ m^2} \ = \ 0.019 \ m/sec$$

$$G = USA = 0.019 \frac{m}{s} \ 8 \frac{kg}{m^3} \times 5.2281 \times 10^{-3} \ m^2$$

$$G = 1.78 \times 10^{-4} \ kg/sec$$

$$\frac{dw}{dt} = 1.78 \ 10^{-4} \ (0.08 - 0.002) = 1.032 \times 10^{-5} \ kg/sec$$

$$\frac{dw}{\Delta dt} = \frac{1.03 \times 10^{-5}}{5.2281 \ x 10^{-3}} = 1.9730 \times 10^{-3} \ \frac{kg}{m^3} = 1.973 \ \frac{g}{m^3}$$

Moisture content after 2 minutes $= \dfrac{(wt\ of\ wet\ material - wt\ of\ dry\ material)}{(wt\ of\ dry\ material)} x\ 100$

$$= \dfrac{(68.4 - 1.032\ x\ 10^2 x\ 60) - 49.6}{(49.6)} x\ 10$$

$$= \quad 36.65\%$$

Moisture content after 1 minute $= \dfrac{(68.4 - 0.0137) - 49.6}{(49.6)}\ x\ 100$

$$= \dfrac{(68.4 - 1.032\ x\ 10^2 x\ 60)}{(49.6)} x\ 10$$

$$= \quad 37.8\%$$

Average moisture content $\quad = \quad \dfrac{36.65\ +\ 37.8}{2} = 37.22\ g/g$

RESULT:

Equilibrium moisture $\qquad = \qquad 20\%$

Critical Moisture $\qquad\qquad = \qquad 34.2\%$

Eqn for falling rate period $\qquad = \qquad 8.88\ x\ 10^{-4}\ w - 0.0011 \quad = \qquad \dfrac{dw}{dt}$

Eqn for Constant rate period $\quad = \qquad 0.0082 \qquad\qquad\qquad = \qquad \dfrac{dw}{t}$

Experimental Observation

S/N	Time (min)	DBT	WBT (°C)	H_2	dw/dt (gm)	dw/Δdt (gm/m²s)	W (gm/gm)
1	0	60.4	53.9	0.099	0.0137	2.62	37.85
2	1	57	48.4	0.68	0.01032	1.973	37.22
3	2	46.7	45.8	0.066	0.0078	1.49	35.22
4	3	45.3	44.2	0.064	0.0075	1.43	33.4
5	4	44.8	44.5	0.062	0.0071	1.36	32.63
6	5	45	43.9	0.06	0.0068	1.29	32.38
7	6	45.1	43.4	0.58	0.0064	1.22	31.58
8	7	44.4	42.6	0.056	0.006	1.15	30.32
9	8	44.8	42.6	0.055	0.0058	1.12	29.62
10	9	46.3	42.7	0.053	0.0055	1.05	28.82
11	10	48.2	43.7	0.057	0.0062	1.19	28.12
12	11	50.2	44.9	0.066	0.0078	1.49	27.32
13	12	52	46.9	0.076	0.0096	1.84	26.2

| 14 | 13 | 54.2 | 48.3 | 0.08 | 0.01032 | 1.97 | 25 |
| 15 | 14 | 56.4 | 50.7 | 0.087 | 0.0157 | 2.21 | 23.52 |

RESULTS:

Plot the graph of drying rate vs moisture content indicates the drying characteristics of the material. Its critical moisture content is = °h an its equilibrium moisture content is °k.

The equation for constant drying rate period is dw/dt = 8.88 x 10w-O.0011 and that for falling rate period is dw/dt = 0.0082.

GAS ABSORPTION

EXPERIMENT 4:
To study the performance of packed bed during absorption process.

OBJECTIVE:
      (a) To estimate, N_{oy}, Numbers of transfer unit, (NTU).
      (b) To estimate, H_{oy}, Height of transfer unit, (HTU).
      (c) To plot $K_{G}a$ (kgmolels/m³-h-atm) vs. mass velocity of liquid.

APPARATUS:
      Packed bed column, CO_2 cylinder, 4% NaOH Sol., Rota meters for CO_2, air & NaOH Sol. flow rates, Air compressor, Titration apparatus.

THEORY:
      In absorption, a gas mixture is contacted with a liquid for preferential dissolution of one or more components of the gas in the liquid. Such operations require transfer of mass from gas stream to liquid. In case of absorption wit chemical reaction, (Here CO_2 absorption in NaOH solution). Reaction of absorbed solute provides higher absorption rates due to:

1. Destruction of the absorbed solute as it forms a compound reduces the equilibrium partial pressure of the solute that in turn increases the concentration difference between the bulk phase & the interface.

2. Increase in liquid phase mass transfer co-efficient.

The equilibrium partial pressure is zero ($Y^* = 0$) (If reaction is reversible).

$$N_{oy} = \int_{a}^{b} \frac{dy}{y} = \ln y_b/y_a$$

$$H_{oy} = Z_T/N_{oy}$$

But

$$H_{oy} = \frac{V'/S}{K_y a} = \frac{V}{K_y a}$$

$$K_y a = \frac{V'/S}{H_{oy}} = \frac{V}{H_{oy}}$$

And $K_G a = K_y a/P$

Where

$K_G a$ = Gas phase mass transfer co-efficient.
$K_y a$ = Overall mass transfer co-efficient.

N0 Number of transfer unit (NTU).
H0 = Height of transfer unit (HTU).
Ya Mole fraction of C02 in inlet gas.
Ya Mole fraction of C02 in outlet gas.
ZT = Total packed height.
V = Gas mass velocity, kgmollh-m2.

V' Molal gas flow rate. kgmollh.

PROCEDURE:

1. Record column diameter, packed height.
2. Calibrate NaOH Rota meter (using 4% NaOH Sol.).
3. Select the flow rate of CO_2 & Air (V) & record it.
4. Select one flow rate of NAOH aqueous solution, L.
5. Measure the inlet concentration of CO_2 in gas stream y_a.
6. Run the experiment at the selected value of L for 15-20 Mining. Measure the concentration of CO_2 in outlet gas stream, y_b.
7. Select another liquid flow rate (L) & repeat steps 5 & 6.
8. Repeat step 8 for at least 5 liquid rates.

OBSERVATIONS:

Room Temperature	=	T	=	--------°C
Atmospheric pressure	=	P	=	--------
Column diameter	=	D_c	=	-------
Cross sectional area of column	=	S	=	-------
Total packed height	=	Z_T	=	-------

W

TABLE-1:

S.No.	Gas flow rate, Q	Gas density (at P_T & T) ρ	Gas av. mol wt., M	Gas mass Velocity, V	Mole fraction of CO_2	
					In inlet gas y_a	In outlet gas y_b [NaOH]i-[NaOH]o

TABLE-2:

S.No.	Liquid flow rate, 1	Liquid density ρ_L	Liquid mol. wt. M_L	Liquid mass velocity L=1 $\rho_l/M_L S$
1.				
2.				
3.				
4.				

TITRATIONS:

Vol. of feed sample $=$ $V_{[NaOH]i}$ $=$ HCL used $=$ V_{HCL} $=$

$$[NaOH]l = \frac{N_{HCL} * V_{HCL}}{V_{[NaOH]i}}$$

S.No.	Vol. of outlet sample, V ml.	Vol of HCL used				
		using phenolphthalein V_2	using methyl orange V_1	for Na_2CO_3 $2(V_1\text{-}V_2)$	for NaOH $2V_1\text{-}V_2$	$[NaOH]_o$ $\dfrac{2V_2 - V_1 * N}{V}$

FLUID FLOW CIRCUIT SYSTEM (FLUID FRICTION APPARATUS)

EXPERIMENT 5: DETERMINATION OF ENERGY LOSSES, WHICH OCCUR WHEN FLUID FLOWS THROUGH PIPEFITTINGS.

OBJECTIVES:
(1) To determine the loss of head due to friction in incompressible flow in a horizontal pipe.
(2) To compare the losses of energy (head losses) in different configuration of pipes.
(3) To determine the head loss associated with flow of water through standard fittings used in plumbing installations.

COURSE OUTCOME:
✓ Ability to analyze the essential parameters describing a fluid system and recognize the common devices used in measuring pressure and flow rates, and turbo machineries.

INTRODUCTION

Fluid friction apparatus is designed to allow the detailed study of the fluid friction head losses which occur when an incompressible fluid flows through pipes, bends, valves and pipe flow metering devices. Friction head losses in straight pipes of different sizes can be investigated over a range of Reynolds' numbers from 10^3 to nearly 10^5, thereby covering the laminar, transitional and turbulent flow regimes in smooth pipes. In addition, an artificially roughened pipe is supplied which, at the higher Reynolds' numbers, shows a clear departure from the typical smooth bore pipe characteristics. Pipe friction is one of the classic laboratory experiments and has always found a place in the practical teaching of fluid mechanics. The results and underlying principles are of the greatest importance to engineers in the aeronautical, civil, mechanical, marine, agricultural and hydraulic fields.

THEORY
1. Fluid Friction in a Smooth Bore Pipe
Professor Osborne Reynolds demonstrated that two types of flow may exist in a pipe.
i. Laminar flow at low velocities where head loss, h α velocity, u
ii. Turbulent flow at higher velocities where h α un

2. Head Loss due to Friction Through Pipes
For a circular pipe flowing full, the head loss due to friction (mH_2O) may be calculated from the formula:

$$h = \frac{4f\,Lu^2}{2gd} \text{ or } \frac{\lambda Lu^2}{2gd} \qquad (3.1)$$

were,
L = length of pipe between tapping's (m) = 1 m for all pipes
d = internal diameter of the pipe (m)
u = mean velocity of water through the pipe (m/s)
g = 9.81 (acceleration due to gravity, m/s2)
f = pipe friction coefficient (British)
4f = λ (American)

Having established the value of Reynolds number Re for flow in the pipe, the value of f may be determined from a Moody diagram.

$$Re = \frac{\rho u d}{\mu} \qquad (3.2)$$

μ = molecular viscosity = 1.15 x 10-3 Ns/m² at 15⁰C   ρ = density = 999 kg/m3
at 15⁰C
A simplified Moody diagram is included in **Appendix.**

3. Head Loss Through Fittings
A piping installation consists of various fittings such as bends, elbows, tees and valves that form obstructions to flow. Head loss in a pipe fitting is proportional to the velocity head of the fluid flowing through the fittings.

$$H = \frac{K u^2}{2g} \qquad (3.3)$$

where,
H = Head loss across fittings (mH2O)   K = Fittings Factor   u = Mean velocity of water through the pipe (m/s)
g = 9.81 (acceleration due to gravity m/s²)

4. Flow Measurement Using Differential Head
The Pitot tube (named after Henri Pitot in 1732) measures fluid velocity by converting the kinetic energy of the flow into potential energy. The conversion takes place at the stagnation point, located at the Pitot tube entrance (Figure 1). A pressure higher than the free-stream (i.e. dynamic) pressure results from the kinematics to potential conversion. This "static" pressure is measured by comparing it to the flow's dynamic pressure with a differential manometer.

Equipment Description
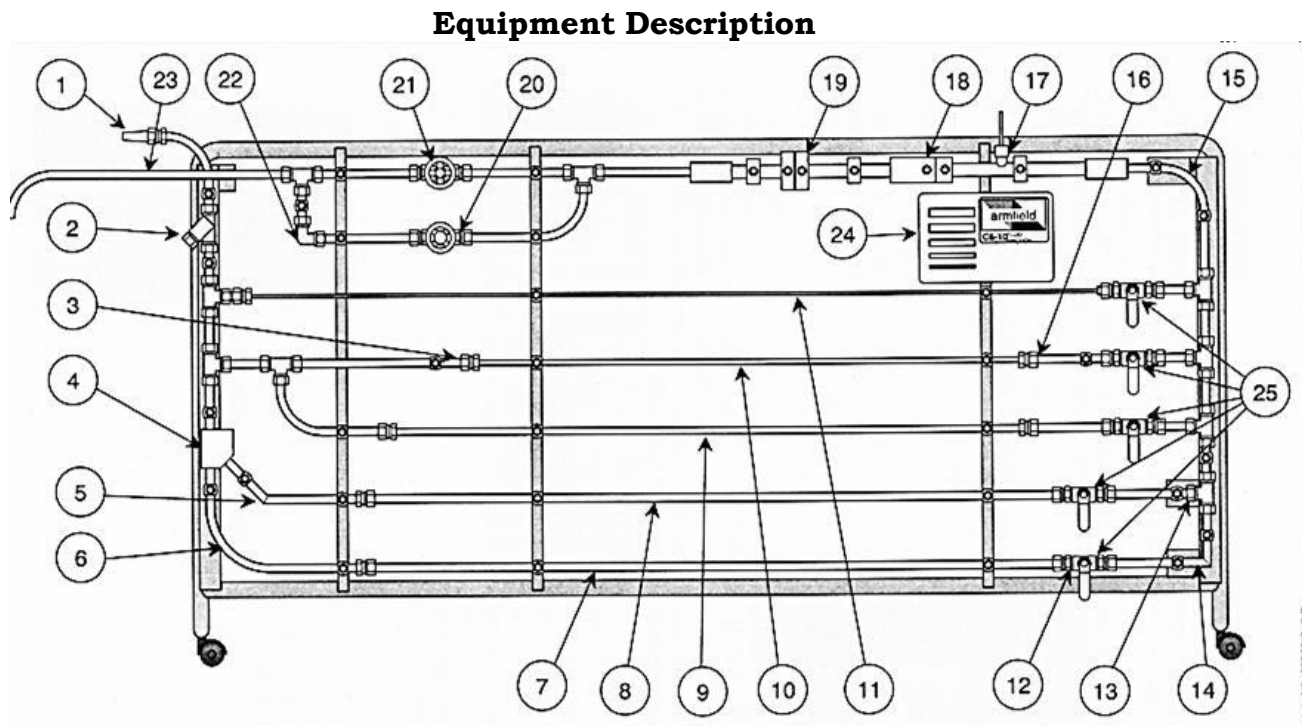
Fig 5 - Labeled Diagram of apparatus

Parts

- Water is fed in from the hydraulics bench via the barbed connector (1)
- An in-line strainer (2)
- A sudden contraction (3)
- A 45° "Y" (4)
- A 45° elbow (5)
- A long radius 90° bend (6)
- An artificially roughened pipe (7)
- Smooth bore pipes of 4 different diameters (8), (9), (10) and (11)
- A 90° "T" (13)
- A 90° miter (14)
- A short radius 90° bend (15)
- A sudden enlargement (16)

Note:

Diameter $\frac{D2}{D_1}$ or $\frac{D0}{D_1}$.

Where c, = discharge coefficient for venture =0.98, Re> 10,000. C_0 = discharge coefficient for orifice = 0.62, Re≥ 30,000

g =acceleration due to gravity $9.8 n/s^2$ D_1 diameter of the pipe (24 mm)

D_2 diameter for the venture (14 mm), D_2 =diameter for the orifice (20 mm)

A pipe section made of clear acrylic with a Pitot static tube (17)
- A Venturi meter made of clear acrylic (18)
- An orifice meter made of clear acrylic (19)
- Ball valve (20), (21)
- A 90° elbow (22)
- exit tube (23)
- Short samples of each size test pipe
  (24) are provided loose so that you can measure the exact diameter
- isolating valves (25)

EXPERIMENTAL PROCEDURE

Experiment: Fluid Friction in Pipes and Head Loss due to Pipe Friction

2. Start-up the apparatus according to general procedures stated in the Standard Operating Procedure (SOP).
3. Open and close the appropriate valves to obtain flow of water through the required test pipe.
4. Measure flow rates using the volumetric tank in conjunction with flow control valve.
5. For small flow rates use the measuring cylinder in conjunction with flow control.
6. Measure head loss between the tapping using the mercury manometer or pressurised water manometer as appropriate.
7. Repeat the testing with different flow rate and obtain readings on test section.
8. Record your data.

RESULTS AND QUESTIONS

1. Complete your data in an organize table. Show your calculations.
2. Plot a graph h versus u for each size of pipe. Identify the laminar, transition and turbulent zones on the graphs. Confirm that the graph is a straight line for the zone of laminar flow (h α u).
3. Plot a graph of log h versus log u for each size of pipe. Confirm that the graph is a

straight line for the zone of turbulent flow (h α un). Determine the slope of the straight line to find n.
4. Estimate the value of Reynolds number (Re = ρud/μ) at the start and finish of the transition phase. These two values of Re are called the upper and lower critical velocities.
2. μ is the molecular viscosity = 1.15 x 10⁻³ Ns/m² at 15°C.
3. ρ is the density = 999 kg/m³ at 15°C.

5. Compare the values of head loss determined by calculation with those measured using the manometer.
6. Confirm that the head loss can be predicted using the pipe friction equation provided the velocity of the fluid and the pipe dimensions are known.

RESULT TABLE

	a	b	a/b	C (Head Loss)		d	e
Measurement	Volume measured	Time observed	Q	h_1	h_2	v	v^2
No	(litres)	(s)	(ltr)	(m³/s)	(mm)	(mm)	(m/s)	(m²/s²)
1							
2							
3							
4							
5							
6							

SAMPLE CALCULATION
Pipe cross-sectional area
A= πr^2
A= π (0.0085)²
A= 0.00022698 m^2

To find Q (m^3/s)
$$Q = \frac{\text{Volume measured}}{\text{Time observed}}$$

Q= 5 ltr/138.07s
Q = 0.036 (lires/s)
Q = 0.000036 (m^3/s)

To find V (m/s)
V= Q/A
V= $\frac{0.000036 \ m^3/s}{0.00022698 \ m^2}$
V= 0.160 m/s
To find hf (m)
$hf = h_1(mm) - h_2(mm)$
$hf = 633 \ mm - 623 \ mm$
$hf = 10 \ mm$
$hf = 0.01 \ m$

Print : Moody Diagram

PRE-LAB QUESTIONS
1. Explain the phenomena that occur at a bend that lead to a loss.
2. State Darcy-Weisbach Equation for head loss, hL..
3. What is minor loss?

DRAG COEFFICIENT

EXPERIMENT 6

OBJECTIVE
To analyze and determine the drag coefficient or the resistance of an object that move in a fluid environment.

THEORY
The drag force or the drag coefficient measurement is called as a force that is happen in phenomena when any surface in contact with a flowing fluid is subject to a force exerted by the fluid. The drag force on a sphere immersed in a flowing fluid is easily derived by using dimensional analysis. The principal variables that give the impacts of the drag force is commonly;
9. F_D the drag force in the sphere
10. D the diameter of the sphere
11. U_∞ the free stream velocity of the fluid
12. P the density of the fluid
13. μ the viscosity of the fluid

Drag is the component of force on a body acting parallel to the direction of the relative motion. The drag force, F_D, was written in the functional form;

$$F_D = f(D, u_\infty, \rho, \mu),$$

This physical variable gives the important in drag coefficient measurement. Hence, the equation of the drag force on the sphere gives the new expression when supplying some constants.

$$F_D = CD^a u_\infty^b \rho^c \mu^d.$$

By using the same equation as the above, the dimension of the mass, length, time system of units is using and also is substituted the proper dimensions.

$$\frac{ML}{T^2} = L^a \left(\frac{L}{T}\right)^b \left(\frac{M}{L^3}\right)^c \left(\frac{M}{LT}\right)^d.$$

$$a = 2 - d; b = 2 - d; c = 1 - d.$$

$$F_D = CD^{2-d} u_\infty^{2-d} \rho^{1-d} \mu^d.$$

This formula is substituted with that variable and it could be as;

$$F_D = CD^2 u_\infty^2 \rho \left(\frac{u_\infty D \rho}{\mu}\right)^{-d},$$

$$\frac{u_\infty D \rho}{\mu} = \text{Reynolds number}$$

The Reynolds number is called the dimensionless group. This formula also can be as below equation;

$$\frac{F_D}{\rho D^2 u_\infty^2} = f'(\text{Re}),$$

An expression for the drag force on a body commonly in form;

$$F_D = C_D A \frac{\rho u_\infty^2}{2g_c}$$

14. C_D is a dimensionless drag coefficient,
15. A is the frontal area of the body exposed to the flow ($\pi D^2/4$ for a sphere),
16. g_c is the gravitational constant which allows the left-hand side to be expressed in units of force.
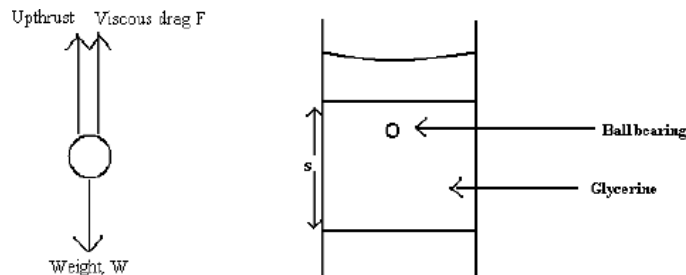
The drag equation is essentially a statement that the drag force on any object is proportional to the density of the fluid and proportional to the square of the relative speed between the object and the fluid. C_D is not constant but varies as a function of speed, flow reaction, object position, object size, fluid density and fluid viscosity.
The drag coefficient can be calculated by this form;

$$C_D = \frac{F_D 2g_c}{A\rho u_\infty^2} = \frac{8}{\pi}\left(\frac{F_D g_c}{D^2 \rho u_\infty^2}\right) = f''(\text{Re}).$$

Therefore, the drag coefficient itself is a function of the Reynolds number.

EXPERIMENTAL SETUP

PROCEDURE
1. Fill the three tubes with; glycerin, water and engine oil respectively.
2. Put a sphere (released) from the top of the tube by an assistant.

3. Record the time as the sphere dropped through the liquid, and passed the upper timing mark and stop immediately as the sphere reached the mark at the bottom of the tube.
4. Repeat the steps using the different fluids and different size of bearings. Record the time.

Object shape	Material	Length/dia meter (mm)	Mass (kg)	Time taken (s)				Drag coefficie nt CD oil	Reyno l ds No Re oil	Viscosit y (kg/sm)
				1	2	3	Average			
	White Ball									
	Silver Ball									

REFERENCES

Lehman, D. A. (2005). Viscosity Mesurment Technique By Merging Liquid Drops Aboard The International Space Station. Masters Thesis, The University Of Tennessee

Novikov, V. N., & Sokolov, A. P. (2004, October 21). Pissan's ratio and the fragility of glass- forming liquids. Nature , 431, pp. 961-963.

Happel, B. J. (1965). Low Reynolds Number Hydrodynamics. Englewood Cliffs, NJ: Prentice Hall.

PROCESS CONTROL – LEVEL CONTROL TRAINER

VPL-PLC-MPCT MULTIFUNCTION PROCESS CONTROL SYSTEM

System Parts Details

System Front View
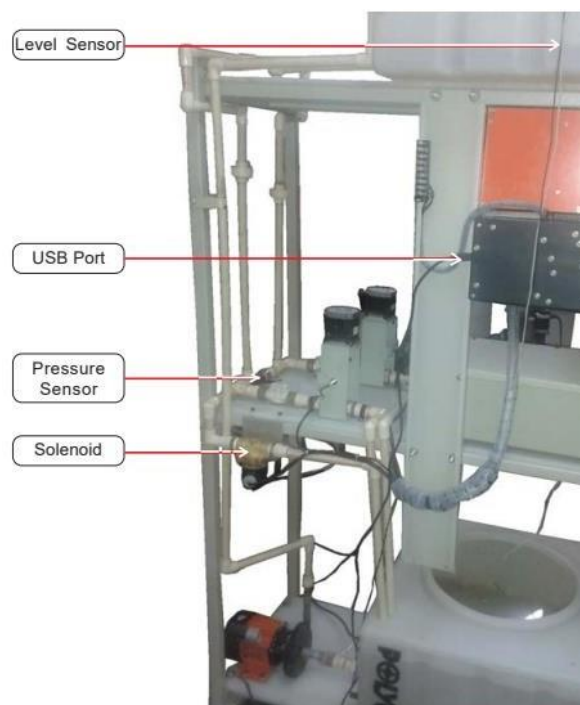
System Rear View

SYSTEM DESCRIPTION

The process control trainer helps us to study the dynamics and control of multi process system.

This system consists of two tanks. The lower tanks have a heater unit and RTD which helps us to control the temperature. There is a PID control box with RTD as input and heater control to maintain the temperature according to the set point.

The upper tank has a level indicator to measure the level. The upper tank and lower tank are connected by pump and solenoid valve.

The motor pump is used to pump water from lower tank to upper tank. There is a safety switch in the lower tank which prevents the motor to run dry. The solenoid valve when switched ON descends the water from the upper tank to the lower tank.

There are two proportional valves which also delivers water from upper tank to the lower tank. The positions of these valves are controlled by valve controller.

An impeller type Flowmeter is included in the flow circuit of each proportional valve to measure the flow and provide a calibrated output signal for display or control purposes. Water flowing in the flow circuit causes the impeller to rotate. Optical sensing of the impeller produces a series of pulses. These pulses are proportional to the flow rate. A frequency-to- voltage converter produces a D.C. signal proportional to the flow rate that can be used for display or control purposes.

There is a pressure sensor in the flow circuit of Proportional valve 1. It measures the

pressure in the flow line connecting the upper tank to lower tank via Proportional valve 1.

There is a main controller unit called System controller. It has all the inputs of sensor and a communication block which connects to PC via USB. This controller block is also linked o valve controller and provides the appropriate signal to position the Valves at desired location.
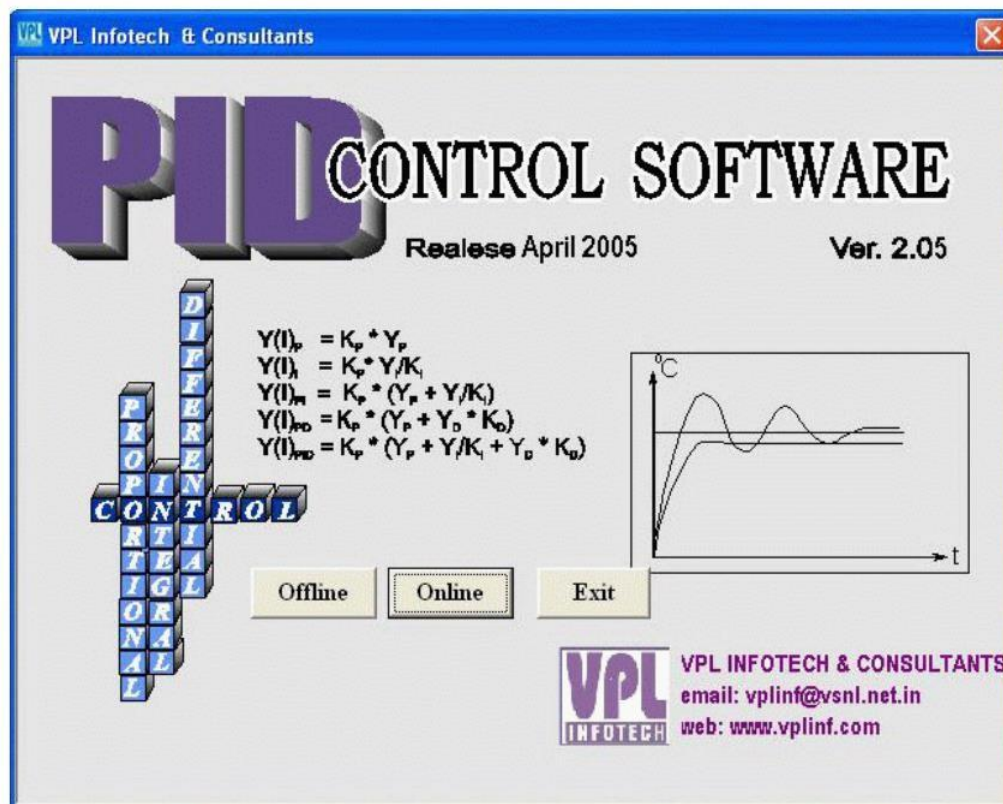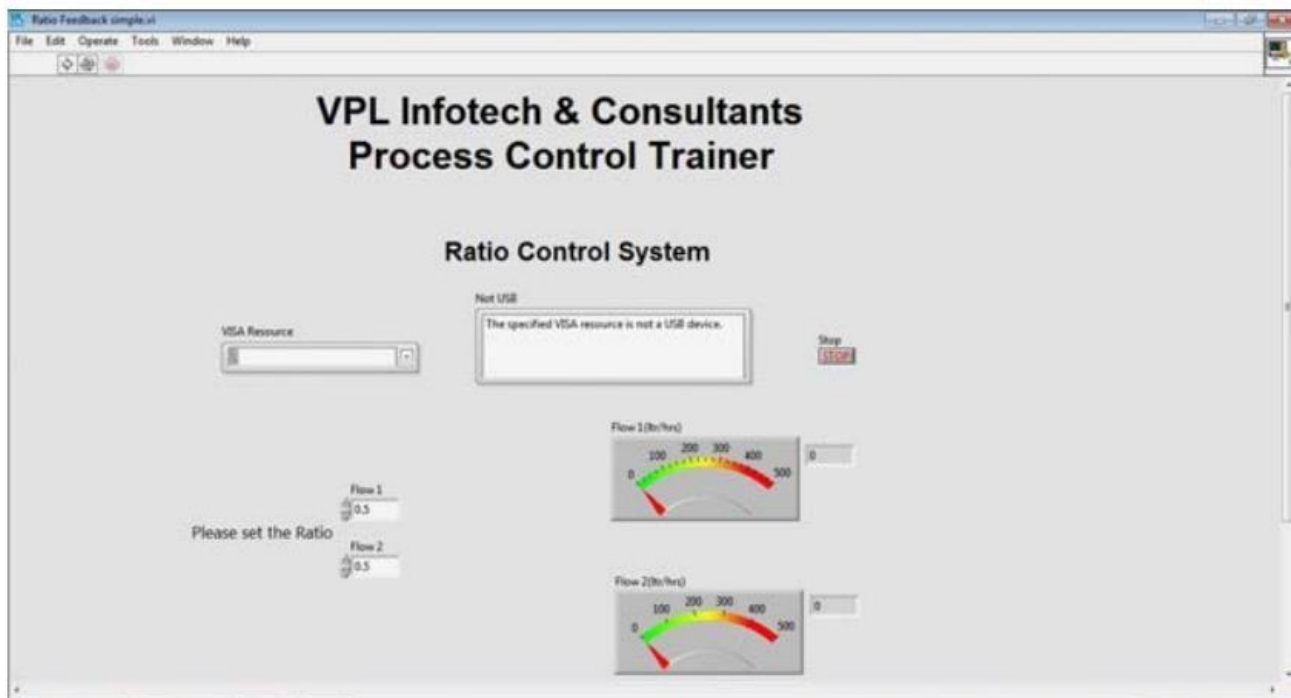
The Monitoring panel of the whole processes:

Level Control System   Flow 1 Control System   Flow 2 Control System

Pressure level Controller Temperature level controller
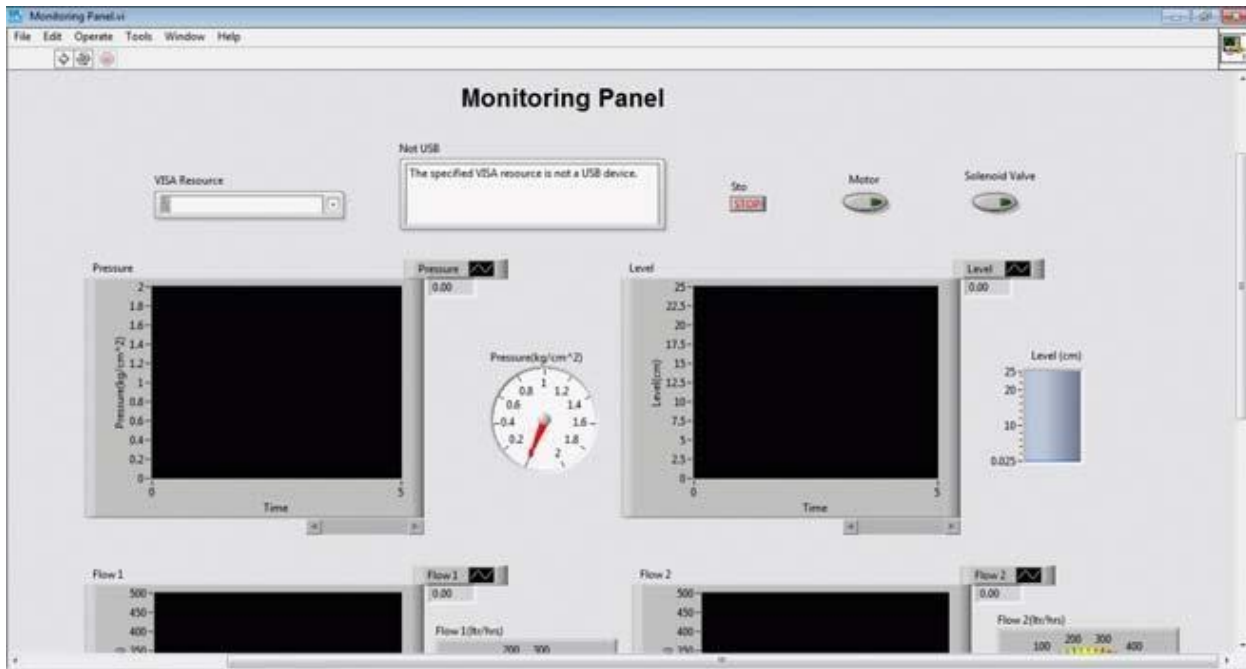
Multi-Process Control System Trainer
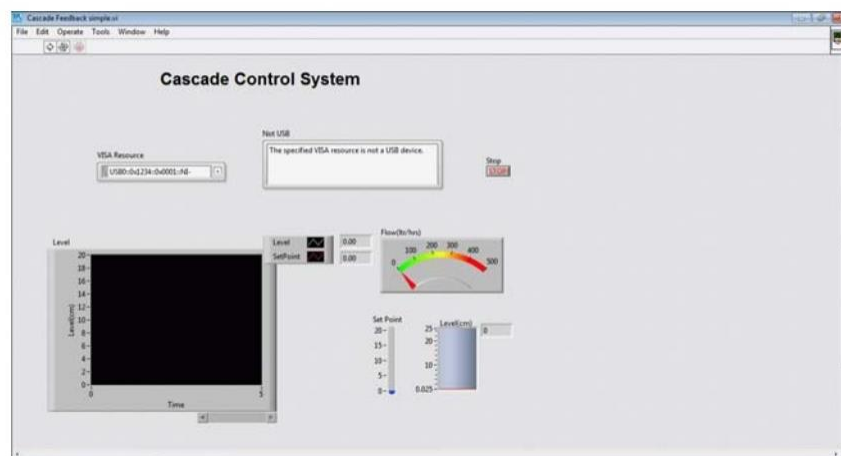
PID controller interface

EXPERIMENTS EXPERIMENT 7, 8,

AIM: determination of System response of different control systems.

OBJECTIVE:
1. To control the water level in the process vessel tank by using the different control systems.
2. To control the liquid level with the use and programming of a feedback control system.

THEORIES

PRESSURE PROCESS CONTROLLER

Theory: - Pressure control trainer is designed for understanding the basic principles of pressure control. The process set up consists of pressure vessel fitted with pneumatic control valve. Pressure transmitter is used for pressure sensing. The process parameter (Pressure) is controlled by microprocessor based digital indicating controller which manipulates pneumatic control valve fitted at Outlet of pressure tank outlet through I/P converter. These units along with necessary piping are fitted on support housing designed for tabletop mounting.

LEVEL PROCESS CONTROLLER

The level process controller is used to perform the control action of level process and study the characteristics of I/P converter. The RF capacitance level transmitter is used to measure the level of the process tank. In level control action, a pump sucks the air from reservoir and gives it to control valve. Every internal transaction is in voltage. Here, IBM-PC acts as error detector and controller. According to error signal, corresponding control signal is given to the I/P converter. It controls the flow of the liquid in pipeline by varying stem position of the control valve. For maintaining the level of the process tank, flow is manipulated level signal is given to the data acquisition card. By pass line is provided to avoid the pump overloading.

From this controller also study the characteristics of the level transmitter, I/P converter, control valve and justify the various control actions.

FLOW PROCESS CONTROLLER

Flow process controller is used to perform the control action on Flow process. In this unit flow is the process variable and is sensed and given to controller. A Differential Pressure Transmitter is used to measure the Flow of the fluid through orifice plate.

In this unit, pump sucks the water from the reservoir tank and gives it to the control valve. Every internal transaction are in voltage. Here, PC acts as error detector and controller. According to the error signal, computer develops a control signal.

This control signal is given to I/P Converter which operates the control valve

Control valves act here as final control element which controls the flow of the fluid in pipe line by varying stem position of the control valve.

Flow is the manipulated level signal here and is given to the Data acquisition card. By pass line is provided to avoid the pump over loading.

TEMPERATURE PROCESS CONTROLLER

Temperature process controller is used to perform the control action on temperature process. In this unit, temperature is the process variable. An RTD sensor is being used to measure the temperature of the process and is transmitted by RTD transmitter.

In this unit, water is stored up in the overhead tank by pumping water from reservoir tank through pump. Water from overhead tank is allowed to heater through a rota meter.

Rota meter is being provided for giving disturbance to the process and for operational safety of the heater. For conducting experiment flow rate in minimum value (say 30 Lph). In the outlet of heater, an RTD is provided for sensing the temperature and is transmitted by RTD transmitter. Every internal transaction are ion voltage. Here PC acts as error detector and controller. According to the error signal, computer develops a control signal. This control signal is given to the SCR power driver circuit by which firing angle varies. Accordingly, the supply delivered to heater varies and thus process gets controlled.

Data acquisition card has the ADC and DAC so that it acts as an effective link between the process and controller.

TYPES OF CONTROL

ON/OFF Control

One of the most widely used type of control is the ON/OFF control. ON/OFF control is also referred as "TWO POSITION" control or "OPEN AND CLOSE" control. Two position controls is a position type of controller action in which the manipulated variable is quickly changed to either a maximum or minimum value depending upon the controlled variable is greater or less than the set point.

If the controlled variable is below the set point, the controller output is 100% (i.e. control valve is fully closed). If the controlled variable is above the set point, the controller output is 0% (i.e. control valve is fully opened), when the differential gap is zero. The tuning parameter for ON/OFF control are differential gap and time delay.

Differential Gap

Differential gap is the region in which the control causes the manipulated variable to maintain its previous until the controlled variable has moved slightly beyond the set point. Small differential gap is not preferred. Because it introduces oscillations and reduces the life of final control element.

Proportional Control

Two position control applied to a process results in a continuous oscillation in the quantity to be controlled. This drawback was overcome by a continuous control action which could maintain the continuous balance of input and output mode of control which will accomplish this is known as "PROPORTIONAL CONTROL"

Proportional control is defined as follows.

"It is a controller action is which there is a continuous linear relationship between value of the controlled variable and position of the final control element within the proportional band".

The tuning parameters for proportional control are,

Proportional Gain [Kp],

Time   Delay   [Td]

Proportional Band [Pb]

Proportional band is defined as the percent deviation in measurement of its full scale required to give 100% valve deviation. Narrow band proportional control gives a comparatively large corrective action to the valve for a small change in the measurement. For wide band proportional the corrective action to the valve is small band therefore the offset will be large. Usually, narrow proportional band is preferred. If proportional band is zero, the controller behaves as two position control.

i. Time Delay

Time required to take the successive samples of process variable.

Proportional + Integral (P+I)

The proportional control mode provides a stabilizing influence while the integral mode will help to overcome OFFSET. Integral controller will provide corrective action as long as there is deviation in the controlled variable from the set point value.

Integral control has a phase lag of 90 degrees over proportional control. This lagging feature of reset will result in a slow response and oscillation will come into picture.

This is suitable for flow control and pressure control where the process has little lag. But a wide proportional band is required for stability. The small process lag permits the use of a large amount of integral action.

Proportional derivative (P+D)

Derivative control action combined with proportional gives a controller which is good on process containing appreciable lag. Because the process lag can be compensated by the anticipatory nature of derivative action (i.e.) derivative action provides the boost necessary to counter at the time delay associated with such control by 90 degree.

Since this controller combination is most effective where the system lags are high, lit could be used on most multi capacity process applications. Where the process lag is short, this combination could not be used. This controller combination does not eliminate OFFSET after a sustained load disturbance. It does reduce the magnitude of OFFSET because of narrow proportional band.

A Proportional plus derivative controller properly fitted and adjusted to the process acts to prevent the controlled variable from deviating excessively and reduces time required to stabilize.

Proportional + Integral derivative (P+I+D)

This controller offers the benefit of each control action and moreover the effect duplicates the action of good human operator of the process. A three mode controller contains the "stability "of ability to provide an immediate correction for the magnitude of a disturbance because of rate control.

Pre-Lab Questions:
Pressure controller
1. Name some pressure transducer.
2. Define PB.

3. What is two position control/
4. Define offset.
5. What is integral windup?

Post Lab Questions:
i.   Why derivative mode is nor used alone?
ii.   What are the advantages of pi controller?
iii.   What are the drawbacks of p controller?
iv.   Comment on the responsed of P, PI, PID controllers.
v.   What is differential gap?

Level Controller

Pre-Lab Questions:

1. Name some level transducer.
2. Define PB.
3. What is two position control/
4. Define offset.
5. What is integral windup?

Post Lab Questions:

1. Why derivative mode is nor used alone?
2. What are the advantages of pi controller?
3. What are the drawbacks of p controller?
4. Comment on the responsed of P, PI, PID controllers.
5. What is differential gap?
FLOW PROCESS CONTROLLER

1. Name some flow transducer.
2. Define PB.
3. What is two position control/
4. Define offset.
5. What is integral windup?

Post Lab Questions:

1. Why derivative mode is nor used alone?
2. What are the advantages of pi controller?
3. What are the drawbacks of p controller?
4. Comment on the responsed of P, PI, PID controllers.
5. What is differential gap?

Temperature Controller

Pre-Lab Questions:

1. List out some temperature transducers.
2. What is the principle of RTD?
3. Write the equation of RTD.

4. What are the different types of RTD?
5. Mention some of the safety factors to be followed before starting the experiment?

Post Lab question:

1. What is the purpose of using rotameter?
2. Which component is used as FCE in this process?
3. What is controller tuning?
4. What are the different tuning methods of controller?
5. What is the principle of SCR?

EXPERIMENT 9:

PID CONTROLLER

AIM: To be familiar with PID controller.

- how changing PID controller parameter effect on system response.

THEORY:
The basic function of a controller is to execute an algorithm (electronic controller) based on the control engineer's input (tuning constants), the operators desired operating value (set-point) and the current plant process value. In most cases, the requirement is for the controller to act so that the process value is as close to the set-point as possible. In a basic process control loop, the control engineer utilises the PID algorithms to achieve this.

The PID control algorithm is used for the control of almost all loops in the process industries, and is also the basis for many advanced control algorithms and strategies, In order for control loops to work properly.
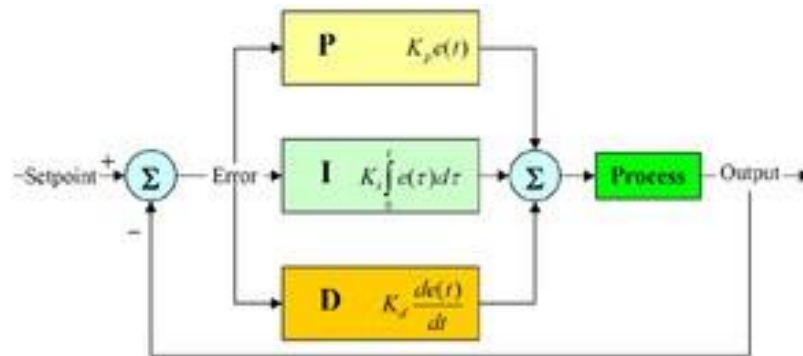
Figure 1 A block diagram of a PID controller

As an example, considers a heating tank in which some liquid is heated to a desired temperature by burning fuel gas. The process variable y is the temperature of the liquid, and the manipulated variable u is the flow of fuel gas. The mission of controller is to control the flow of fuel and PID controller control how the gas will flow, that will appear as an output response.
In our experiment we will note by changing PID parameter how we can change either the transient or the force response.

PROPORTIONAL TERM
The proportional term (sometimes called *gain*) makes a change to the output that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant *Kp*, called the proportional gain.
The proportional term is given by:

$P_{out} = K_p e(t)$

Where;
*P*out: Proportional term of output parameter

Kp: Proportional gain, a tuning

SP: Setpoint, the desired value

PV: Process value (or process variable), the measured value

e: Error = *SP − PV*

t: Time or instantaneous time (the present)

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable. In contrast, a small gain results in a small output response to a large input error, and a less responsive (or sensitive) controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances.
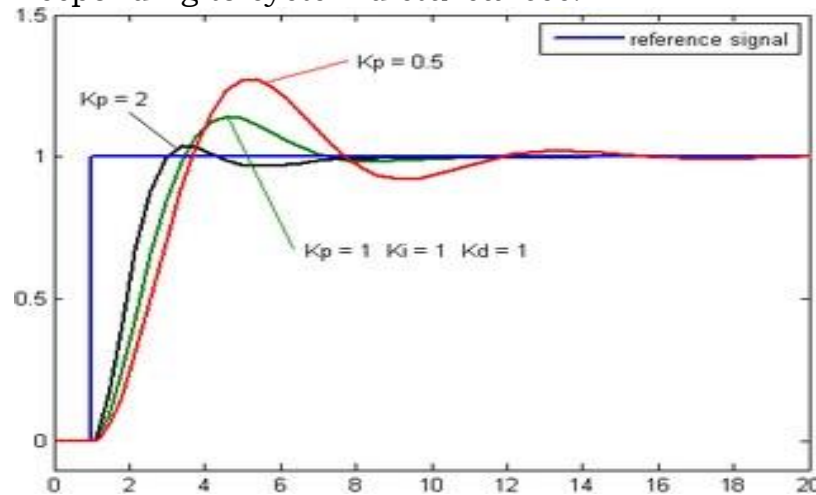

Figure (2): Plot of step response vs time, For three values of K_p (K_i and K_d held constant) Integral term

Derivative term

The rate of change of the process error is calculated by determining the slope of the error over time (i.e., its first derivative with respect to time) and multiplying this rate of change by the derivative gain K_d. The magnitude of the contribution of the derivative term (sometimes called *rate*) to the overall control action is termed the derivative gain, K_d.

The derivative term is given by:

$$D_{out} = K_d \frac{d}{dt} e(t)$$

Where,
D_{out}: Derivative term of output parameter
SP: Setpoint, the desired value the measured value
e: Error = $SP - PV$

K_d: Derivative gain, a tuning

PV: Process value (or process variable),

t: Time or instantaneous time (the present)

The derivative term slows the rate of change of the controller output and this effect is most noticeable close to the controller setpoint. Hence, derivative control is used to reduce the magnitude of the overshoot produced by the integral component and improve the combined controller-process stability. However, differentiation of a signal amplifies noise and thus this term in the controller is highly sensitive to noise in the error term, and can cause a process to become unstable if the noise and the derivative gain are sufficiently large. Hence an approximation to a differentiator with a limited bandwidth is more commonly used.
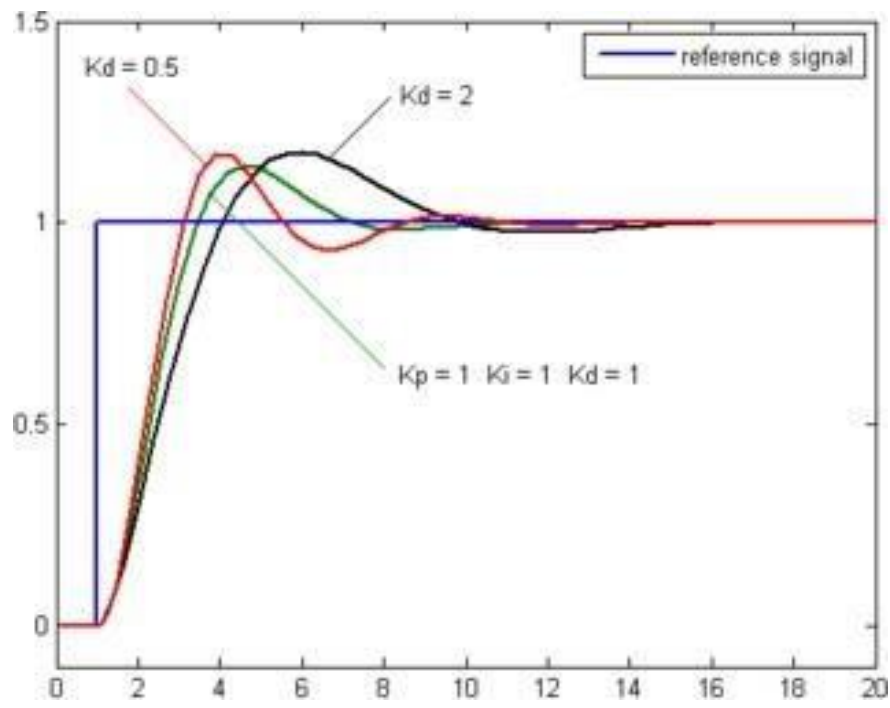
Figure (3): Plot of step response vs time, For three values of K_d (K_i and K_p held constant)

SUMMARY

The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Defining $u(t)$ as the controller output, the final form of the PID algorithm is:

$$u(t) = \mathrm{MV}(t) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{d}{dt} e(t)$$

where the tuning parameters are:

Proportional gain, K_p
Larger values typically mean faster response since the larger the error, the larger the proportional term compensation. An excessively large proportional gain will lead to process instability and oscillation.

Integral gain, K_i
Larger values imply steady state errors are eliminated more quickly. The trade-off is larger overshoot: any negative error integrated during transient response must be integrated away by positive error before reaching steady state.

Derivative gain, K_d
Larger values decrease overshoot, but slow down transient response and may lead to instability due to signal noise amplification in the differentiation of the error.

LAB WORK:
17. download control simulation and design tool box to lab view.
18. Construct the block diagram shown in figure 4, use the following transfer function

19. change PID controller parameters K_d, K_i and K_p and note the change on system transient response.
20. Fill table 1 with one of the following options
3. Decrease

4.   Increase
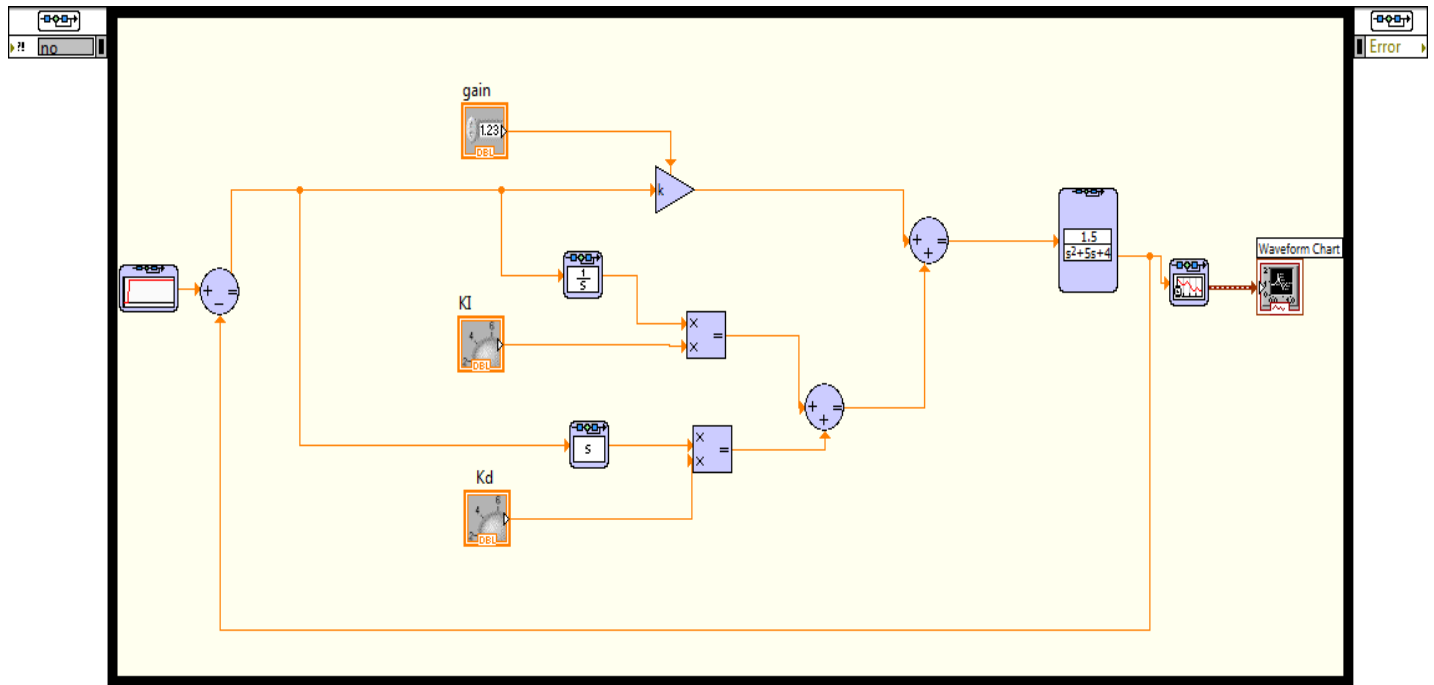5.   Eliminate
6.   No change.

Figure (4): close loop system with PID controller

Parameter	Rise time	Overshoot	Settling time	Steady-state error	Stability
K_p					
K_i					
K_d					--

Table (1) Effect of increasing parameter independently

REFERENCES
Abdul Aziz Ishak (2018). PID Tuning: Self-Study Tutorials & Exercises

SEDIMENTATION

EXPERIMENT 10
AIM: DETERMINATION OF HYDRAULIC CHARACTERISTICS OF A MODEL SEDIMENTATION TANK
OBJECTIVE

- Determination of hydraulic characteristics of a model sedimentation tank, including short-circuiting, average retention times, holdback and flow profiles as a function of flow rate
- Determination of the efficiency of sedimentation of calcium carbonate suspensions at various flowrates.

INTRODUCTION

In most industrial chemical processes, the desired product formed is usually in a mixture with other components. These components can be excess reactants, by-products, catalysts and components of solvents or reaction media. To obtain the products in the desired purity and form separation must be undertaken. The most common separation processes include evaporation, distillation, absorption, crystallization, filtration, centrifugation, drying and membrane processes. Separation processes are mainly based on physical and physio-chemical means (Chapter 3 Separation Processes 2009).

THEORY

Sedimentation Principles

As already explained, sedimentation is the process by which particles settle to the bottom of a liquid and form a sediment. Particles that experience a force, either due to gravity or due to centrifugal motion will tend to move in a uniform manner in the direction exerted by that force. For gravity settling, this means that the particles will tend to fall to the bottom of the vessel, forming a slurry at the vessel base. For settling particles, there are two main forces enacting upon any particle. The primary force is an applied force, such as gravity, and a drag force that is due to the motion of the particle through the fluid. The force applied is usually not affected by the particle's velocity, whereas the drag force is the function of the particle velocity. As the particles increase in the velocity, eventually the forces will approximately equate, causing no further change in the particle's velocity. This velocity is known as the settling velocity (Backhurst, Harker & Richardson 2002).

For each of the batch settling tests the settling velocity can be determined from the slope of the height-time graph.

$$U = \frac{y_2 - y_1}{x_2 - x_1}$$

eq 1

The rate of sedimentation can be calculated as follows:

$$\dot{Q}_s = \frac{V}{t}$$

eq 2

The removal efficiency can be defined as the ratio of the amount of solid material that settles/sediments per amount of solids fed. This ratio can also be expressed as a percentage as follows:

$$\% E = \frac{Solids\ Settled}{Solids\ in\ Feed} \times 100$$

eq 3

The solids settled can be expressed as the difference between the mass of solids fed and the mass of solids in the overflow. Therefore equation 3 becomes:
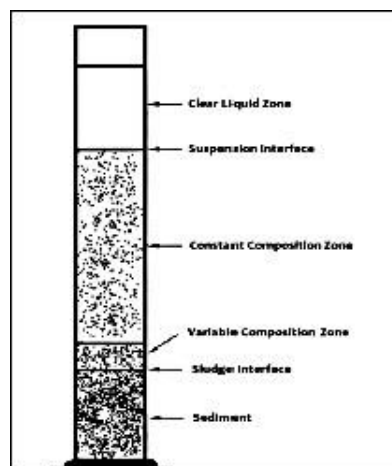
$$\% E = \frac{m_F - m_o}{m_F}$$

Principles of Momentum and Sedimentation

An object's momentum is the product of its mass and velocity. An object can have a large momentum by having a large mass or a large velocity. It can have a large momentum by having either a small mass but a large velocity or a small velocity but a large mass. The same principles of momentum apply for the particles is suspension (Impulse and Momentum).

Sedimentation is achieved by decreasing the velocity of the mixture to a point which the solid particles will no longer remain in suspension. When the velocity no longer supports the particles, gravity will remove them from the fluid (Sedimentation).

Fig 1: Batch Settling Test Apparatus   **Fig 2: Sedimentation Zones**

EXPERIMENTAL METHOD

Process Descriptions: Batch Sedimentation

a) Pre-Prepare three sedimentation cylinders, containing unknown masses and sample types of calcium carbonate in water, and dislodge from the sedimentation apparatus, shaken thoroughly. Do this until the mixture became homogenous.

b) Set your stop watch and the moment you put back the mixture onto the apparatus start the timer and record the heights of the three suspensions.

c) Observe after two-minute intervals the heights of the suspension interfaces, the separation between the zone of clear liquid and the zone of constant composition, and record your observation.

d) When there is no further settling the test is complete.

Continuous Sedimentation

1. Prepare the slurry of calcium carbonate suspension and water, stir until it becomes a homogenous mixture. Open pump to ensure through mixing, take a sample of 250 ml from the storage tank.

2. Set a stopper in the settling tank to ensure that no fluid is passing out. Open the valve and adjust the rotameter to 5 litre/min. set the stop watch to determine the time it takes to fill the tank. Stop the watch once its full and record the time. Take the sample of 250 ml when the settling tank overflows.

3. Turn off the valve and also the rotameter. Take stopper out to empty the settling tank via the outlet tap.
4. Repeat the same procedure for rotameter readings of 10, 15, and 20 L/min
5. Weigh and mark the filter paper and petri dishes. Filter the samples using vacuum filter.
6. Place the samples in an oven for approximately 24 hours to ensure through evaporation. Weigh the samples again and discard.
7. Plot the graph of Removal Efficiency against Volumetric Flowrate and the graph of Sedimentation Rate against Volumetric Flowrate Graph for Continuous Sedimentation Apparatus
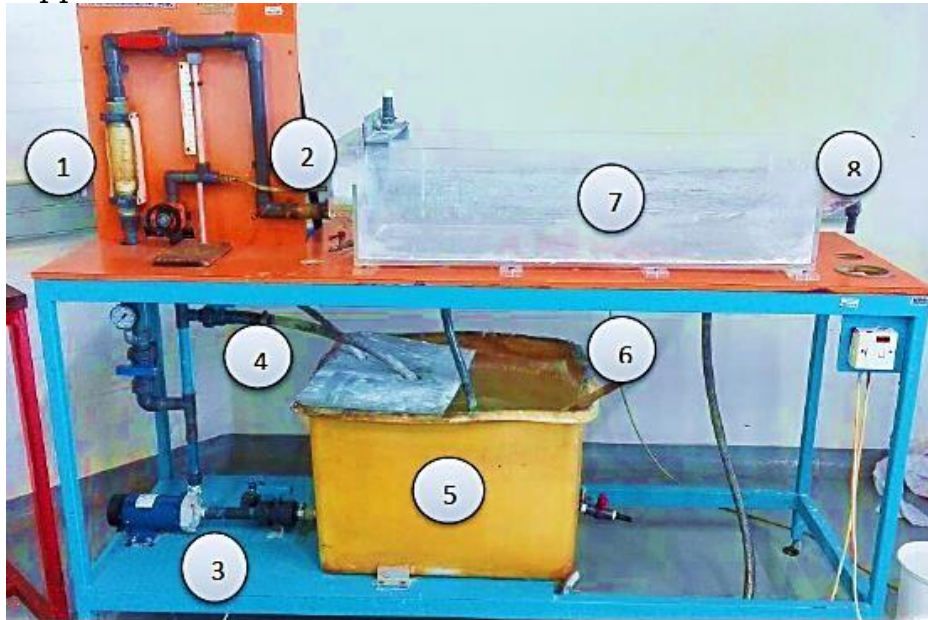

Fig. 3: The Continuous Sedimentation Apparatus

Number	Description
1	Flow Meter
2	Feed Stream
3	Pump
4	Recycle Stream
5	Storage Tank
6	Drain
7	Settling Tank
8	Overflow

TABULATION OF RESULT

Table 1: Continuous Sedimentation Test

Volumetric Flowrate (l/min)	Time (min)	Mass of petri dish, filter paper and solids (g)	Mass of petri dish and filter paper (g)	Mass of solids (g)
Feed				
5				
10				
15				
20				

Table 2: Batch Sedimentation Test

Time (min)	Cylinder A heights (mm)	Cylinder B heights (mm)	Cylinder C heights (mm)
0			
2			
4			
6			
8			
10			
12			
14			
16			
18			
20			

Technical Data

Quantity	Amount
Volume of tank	0.6 x 0.5 x1.9 m
Pump Capacity	6 l/mm

Tabulation of Results

Settling Velocities for the Batch Sedimentation Test

Cylinder	Settling velocity (mm/min)
A	
B	
C	

Continuous Sedimentation Test

Volumetric Flowrate (l/min)	Removal efficiency (%)	Rate of sedimentation (m³/min)
5		
10		
15		
20		

REFERENCES

- *Momentum and Impulse,* Available from: <https://www.pearson.com/content/dam/onedot-com/one-dot-com/us/en/higher-ed/en/products-services/course-products/knightphysics-4e-info/pdf/chapter11.pdf>. [29 August 2017].

- *Chapter 3 Separation Processes,* Available: from:<http://www.polyu.edu.hk/edc/tdg/userfiles/file/490Q_ABCT/ICBPT_cht3Se

p.pdf>[30August 2017].

Appendix
Sample of calculation

Continuous Sedimentation

Mass of the Feed Stream

$$m_F = 37.2969 - 33.6577$$

$$= 3.6392 \ g$$

Overflow at Volumetric Flowrate of 5 L/min

$$m_{01} = 34.7078 - 33.7536$$

$$= 0.9542 \ g$$

$$\% \ E_1 = \frac{m_F - m_{01}}{m_F} \times 100$$

$$= \frac{3.6392 - 0.9542}{3.6392} \times 100$$

$$= 73.78 \ \%$$

$$\dot{Q}_{s1} = \frac{0.6 \times 0.5 \times 1.9}{9.3}$$

$$= 0.0613 \ m^3/min$$

Efficiency and sedimentation rate calculations were performed in the similar fashion for all the other volumetric flowrates.
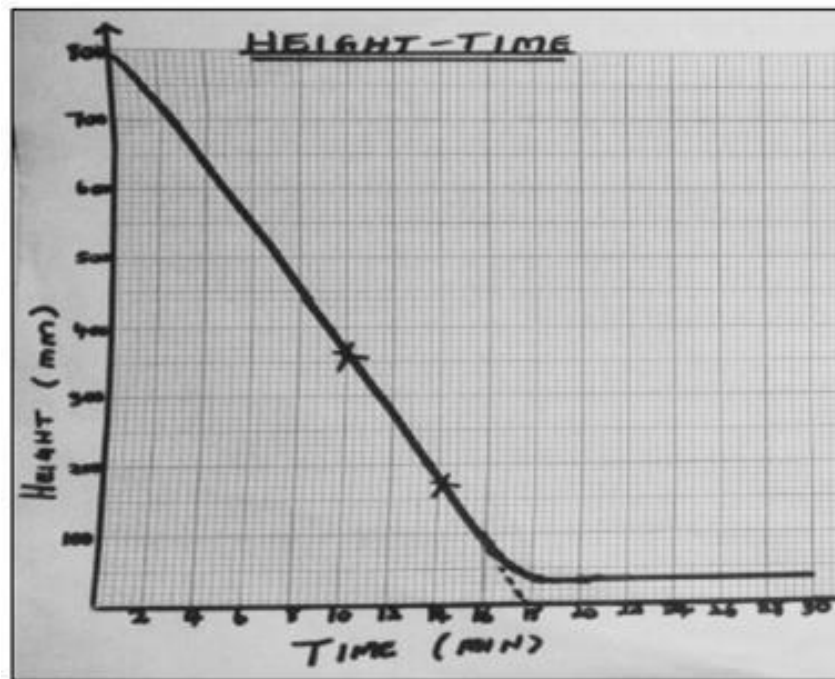
Batch sedimentation

Figure 4. Hand Drawn Batch Sedimentation Graph for Cylinder B

As explained in the theoretical section the settling velocity of a batch settling test is determined by finding the gradient of the graph. In figure above there are two points marked with an x sign. From these points the settling velocity for Cylinder B can be calculated as ff.:

$$U = \frac{y_2 - y_1}{x_2 - x_1}$$

$$U_B = \frac{265 - 460}{12 - 8}$$

$$= 48.750 \; mm/min \; downwards$$

LEARNING RESOURCES (EQUIPMENT):
1. Tray dryer, Rotary dryer, vertical pneumatic dryer
2. Packed Distillation Column, Plate Distillation Column,
3. Process Control Training Unit,
4. Temperature Control Apparatus,
5. Sedimentation Tank.
6. Gas absorption equipment
7. Fluidized bed systems,
8. Centrifugal pumps