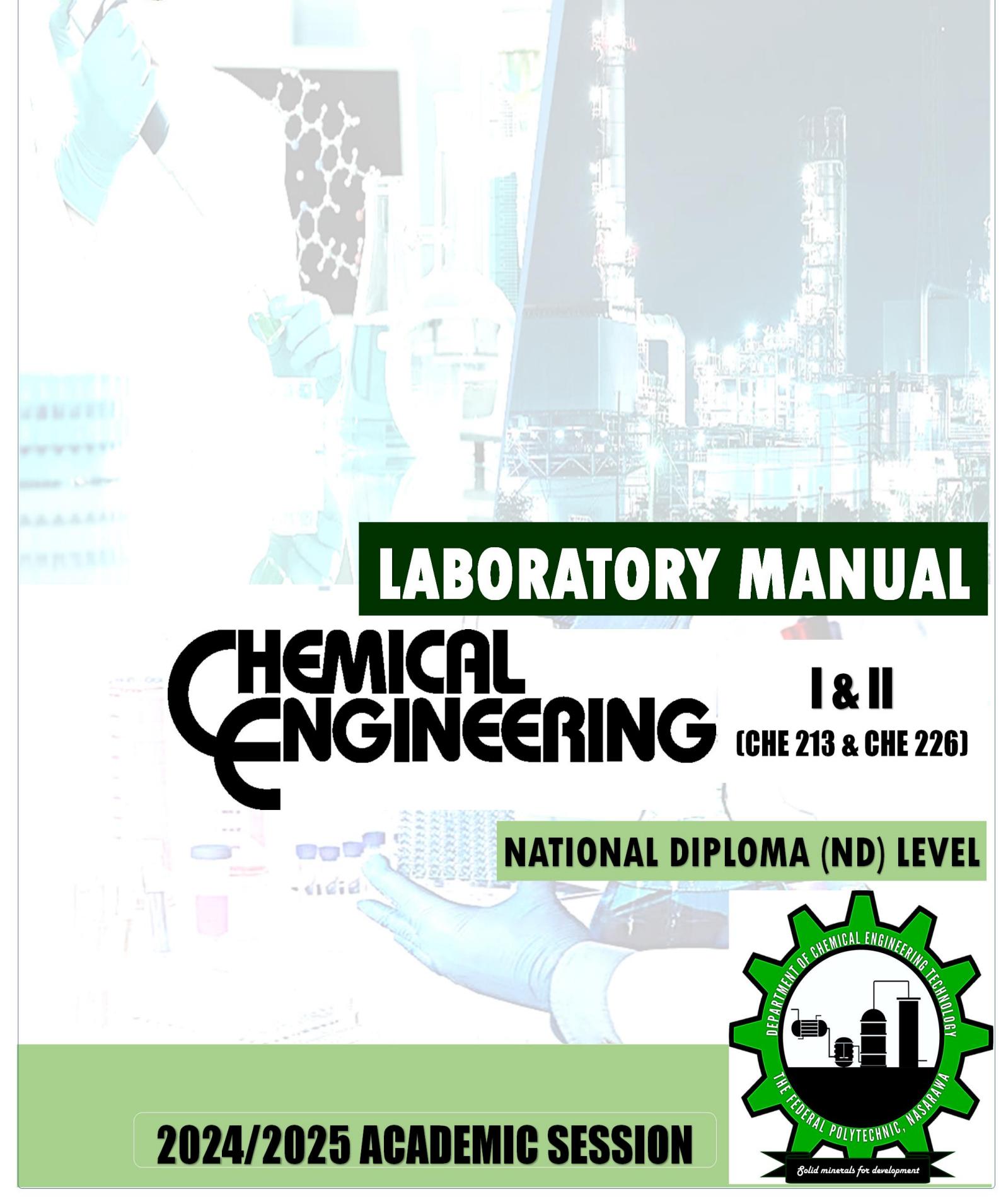




FEDERAL POLYTECHNIC NASARAWA

DEPARTMENT OF CHEMICAL ENGINEERING



LABORATORY MANUAL

CHEMICAL ENGINEERING

I & II

[CHE 213 & CHE 226]

NATIONAL DIPLOMA (ND) LEVEL

2024/2025 ACADEMIC SESSION



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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.

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7	CORP MEMBER(s)		LAB08	
8	LAB ATTENDANT		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

17	Fluid Mixing Apparatus
18	Packed absorption system

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
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

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

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
- MATLAB
- SPSS Analysis Package
- VISIO
- AutoCAD

Microsoft Office SUITE

PREFACE

This laboratory manual is prepared for Chemical Engineering Laboratory I & II (CHE 213 and CHE 226). The purpose of this manual is to serve as instructional book for students, technical staff and instructors to assist in performing and understanding the experiments in chemical engineering.

This manual two laboratory courses sequence covering the application of principles of chemical and process engineering: Thermodynamics; Fluid mechanics; Heat Transfer; Experimental planning, data acquisition and safety considerations.

This manual is divided into 3 sections. The first section comprises the importance and objectives of Chemical Engineering Laboratory. Section two; Safety and Chemical Engineering Lab Report writing. The last section is a collection of experiments; covering the application of principles of chemical and process engineering: Thermodynamics, Fluid mechanics, Heat Transfer, Process Control & Instrumentation, Corrosion and materials Science.

This manual will be updated over time. In addition, some experiments will undergo modification and updating.

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- ❖ Cover page
- ❖ Preface
- ❖ Table of content
- ❖ SAFETY IN THE LABORATORY
- ❖ LABORATORY & REPORTS: An overview
- ❖ Instructions for Preparing Laboratory Reports

Experiment No	Title	Page No:
Fluid Mechanics		
	Basic Hydraulics Bench	
Experiment No: 1	Flow rate Measurement	
Experiment No. 2	Bernoulli's Theorem	
Experiment No. 3(a)	Study of Reynolds Apparatus	
Experiment No. 3(b)	Observation of Laminar, Transitional and Turbulent flow through a circular pipe	
	Fluid Friction Apparatus	
Experiment No. 4	Determination of Head Loss At Different Flow rates through an Orifice And Venturi meter	
Experiment No. 5	Measurement of Velocity Head distribution along a Venturi meter and Orifice meter	
Experiment No. 6	Determination of Pressure Drop in Orifice and Venture meter as a result of Sudden Contraction and Expansion	
	Fluid Mixing Apparatus	
Experiment No. 7	Observation of various Flow patterns induced by different Impellers with and without baffles	
Experiment No. 8	Determination of Power consumption of Fluid mixing machine	
Heat Transfer (Transport Phenomena II)		
	Tray Dryer	
Experiment No. 9	Determination of overall Drying rate of a Tray dryer	
Experiment No. 10	Determination of Conductivity of Metal Specimens	
Experiment No. 11	Calibration and uses of basic types of Temperature Measuring Instruments	

	Heat Exchanger
Experiment No 12	Parallel flow and Counter flow Heat Exchanger
	Fixed and Fluidized bed system
Experiment No: 13	Drying Characteristics of a given Material
	Centrifugal Pump test rig
experiment No 14	Determination of Pump efficiency
	Screening Analysis
Experiment No: 15	Separation of Solid particles into sizes and determination of its surface mean diameter
	Mass Transfer (Transport Phenomena III)
Experiment No. 16 (a and b)	Determination of Diffusivity of Volatile liquid (Acetone) into air.
Experiment No. 17	Determination of Diffusion Coefficient of 2m Sodium Chloride solution in distilled water
	Instrumentation and Process Control
	Response of the First Order System
Experiment No. 18	Determination of the Actual Temperature Response of a Temperature measuring instrument
	PID controller
Experiment No. 19	Determination of Temperature and Pressure of a System with ON-OFF Controller
	Corrosion and Material Science
	corrosion studies
Experiment No. 20	Determination of the Effect of pH level on Corrosion rate
	Thermodynamics
	Heat of reaction and Heat of combustion
Experiment No. 21	Determination of heat of reaction
Experiment 22	Determination of heat of combustion

SAFETY IN THE LABORATORY

GOAL/OBJECTIVE

This laboratory manual is designed to enable the students acquire the ability to operate and obtain data from equipment and instruments relevant to a particular chemical engineering principle and analyze the data, in a comprehensive report.

Safety, according to oxford advance leaner's dictionary, it is defined as the state of being safe and protected from danger or harm.

Hazard is a thing that can be dangerous or cause damage. It could be chemical, electrical and biological in nature. As a researcher, it is required of him/her to put necessary measures in place to safe guide his/her body from injury or harm. The below safety measures are to be taken while in the laboratory:

Preparation

Before starting any laboratory, operation ask and answer the following questions by yourself:

1. Have I done this before?
2. Do I have the proper equipment?
3. Does anything look wrong?
4. What are the hazards?
5. Should I work in a fume hood?
6. Do I need goggles or other safety equipment?
7. Do I need additional help?
8. Should I check further with my instructor?
9. Have I planned this experiment or exercise?
10. Do I know what to do, if there is an accident?
11. Do I know where the fire extinguishers are located?

LABORATORY SAFETY RULES

- 1) No smoking in the laboratory;
- 2) Safety glasses will be worn at all times where applicable during laboratory periods.
These glasses will be kept between laboratory sessions in the racks provided.
- 3) Suitable clothing like laboratory coat should be worn in the laboratory. Loose garments can cause serious injury if caught in rotating machine.
- 4) Wear apron (lab overall) in the lab when running apparatus and handling liquids.
- 5) Wear rubber gloves when handling liquids.
- 6) When dangerous chemicals are in use, a second person should be within call.
- 7) Find out the location of First Aid Box.
- 8) Before operating any valve, switch, etc., know precisely what the effect of your manipulation will be. Turn off all the valves on cylinders of compressed or liquefied gases when not in use.
- 9) A researcher, Student must not eat in the laboratory, to avoid contamination with some volatile chemicals i.e. mercury that can easily vapourized.
- 10)Lightening where necessary should be carefully done when dealing with flammable gas! liquid to source for energy.
- 11)Equipment must not be tampered with except with directive and thorough supervision by the officer in charge of the laboratory.
- 12)Water and electricity are not compatible and can cause serious injury if they come in contact. Never operate portable electrical appliances adjacent to equipment involving water unless some forms of constraints or barriers is incorporated to prevent accidental contact.
- 13)Always disconnect equipment from the electrical supply when not in use.
- 14)Take care when handling sharp edged components. Do not exert undue force on glass or fragile items.
- 15)Goggles must be worn whenever there is a risk to the eyes. Alkaline solution is particularly dangerous to the eyes.
- 16)Concentrated acid should not be diluted by pouring water into the beaker containing acid, to avoid splash.

- 17) In case, acid or corrosive chemical spills on you, wash it off immediately with water.
- 18) Report to the instructor any conditions that are safety hazards.
- 19) All power wiring is to be installed by an approved electrician.
- 20) All forms of asbestos should be treated as dangerous.
- 21) Keep the lab tidy.
- 22) Always remember: **SAFETY IS GOOD TECHNIQUE!**

Above all, instructions given in an equipment manual or practical manual should be strictly adhered to.

TECHNICAL REPORT APPROACH

(LABORATORY & REPORTS)

LABORATORY DETAILS

Course: Chem. Eng'g Laboratory I Chem. Eng'g Laboratory II	Code: CHE 213 (First Semester) Code: CHE 226 (Second Semester)	Unit: 3 Unit: 3
Level & Semester	ND II	
Laboratory Name:	Chemical Engineering Lab I and II Room(s) PTP Lab, UOP Lab, & C/SM lab	
Objectives	To understand, operate and acquire hands on experience on experiments such as Bernoulli principles, Fluid Flow Measurement Devices, Friction in pipes, Head Conduction, Heat convection, Heat Exchangers, Temperature Measurement Bench.	

Technical Report Approach

Technical report writing is a written composition that provides an account or descriptions of special task that has been learnt by experience, observation or investigation. It provides information on subject matter in a manner that will make it clear and meaningful for whom it is intended.

For a good technical report, it is written with the use of passive, nominalization, past tense, past participle where necessary and third person singular. Though, it is preferable to use impersonal when presenting your own research work.

It is mostly written based on fact findings and at times to add value to the research work that has already been carried out, by acting on its recommendations. A report should be concise and coherent with chosen words, in such that a layman can appraise and take challenges without thorough supervision.

All experiments in the **Chemical Engineering Lab I & II** 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 in 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:

Table of Content

	Page(s)
i. Title Page	1
ii. Abstract	1
iii. Table of Contents	1
iv. Introduction	2-3
v. Theoretical Background	4 - 5
vi. Experimental procedure	6
vii. Diagram of equipment	7
viii. Precautions	8
ix. Result and calculation	9 - 11
x. Graph	
xi. Discussion of Result	
xii. Conclusions and Recommendation	
xiii. Reference (cited literature)	
xiv. Appendices	
xv. Raw Data	
xvi. Sample Calculations	

1. Title Page

The Title page should be separate from the rest of the report. It should contain:

- The name of the experiment
- The number of course
- The date when the experiment was run
- The name of the writer and his co-workers, ID number, and his group number
- The name of the instructor to whom the report is submitted
- 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:

- An introductory statement about the subject matter
- Briefly describe what was done.

- Present some selected result (numerical values, if possible).
- 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 and It should not be misconstrued with procedure undertook involved in an experiment

3. Table of content

Table of contents is to be arranged according to the number of sheets of paper used in each of the contents that a report or any writing, composition consists. If a particular research work takes one sheet of paper to present abstract, two sheets of paper for presentation of introduction, e.t.c. the table of contents of such report will be drawn as shown below.

4. Introduction

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

5. 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.

6. Diagram of Equipment Set Up

A neat diagram should be drawn as a replica of the equipment/apparatus set up for the experiment. For every drawing, it must be designated with number that denotes its nature. For example, if the first diagram is a mechanical vibrator for screen analysis, it should be written beneath it, Fig. I: Mechanical Vibrator. Refer to the diagrams of mechanical vibrator 2nd weighing balance below as a guide.



Figure 1: Mechanical vibrator and weighing balance

7. 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. Experimental Observation/Result and Calculation

The results should be presented in the form of Tables or graphs. The Table should contain the results obtained from experiments and from theoretical knowledge. Comparisons should be presented in terms, e.g. percent deviation. The observation made during the experiment or in the course of research work is to be stated legibly. The table culled from a text or thesis work, its source must be written beneath it, to avoid plagiarism. It is expected that, where slope of a graph is to be determined, it should be under calculation and to be presented as appendix.

Calculation can be exercised based on data generated from experiment and at times with the formula/equations stated in the theory of the subject matter as a revolving factor. Where necessary to calculate and generate results, such calculation should be presented for clarification.

The tables below are examples on how to present results in a tabular form and table

Culled from a literature cited.

Table I: The production of cottonseeds in different continents

Continents/country	Production Unit
Africa	147,000
North & central America	3,003,000
Asia	6,325,000
South America	1,037,000
Europe	174,000
USSR	116,000
Oceania	2,894,000
World total	14,697,000

Source: Kochhar, (1982)

Conventionally, the number to be assigned to table of results must align with the preceding one and importantly the numbering pattern of the research work.

Table 2: Result obtained from the experiment

Time (s)	Distance (m)	Velocity (m/s)
5	10	2.00
10	15	1.50
15	25	1.67
20	30	1.50
25	40	1.60

7. Graph

Plotting of graph in some research works is the pivot that facts lies on. As such, it is necessary to abide by the mathematical rules of plotting a graph. For example, a convenient scale that suits the generated data must be chosen for both the ordinate and abscissa. And if it is a straight-line graph, best align points should be joined. At least three out of five points is acceptable.

The graph must be properly defined via heading. If slope of a graph is to be determined, the nature of the graph matters. When dealing with straight line graph two lines perpendicular to each other are to be drawn by chosen two points corresponding to ordinate and abscissa respectively. Then find the slope as the tangent.

$$\text{Mathematically, slope } \frac{Y_2 - Y_1}{x_2 - x_1}$$

Where Y denotes the points correspond to ordinate and X for points correspond to abscissa.

But if it is dome shape, a tangent should be drawn to the curve and calculate as above. Intercept of a graph is the value at a point where the straight-line cuts either the ordinate or abscissa and at times on both axes.

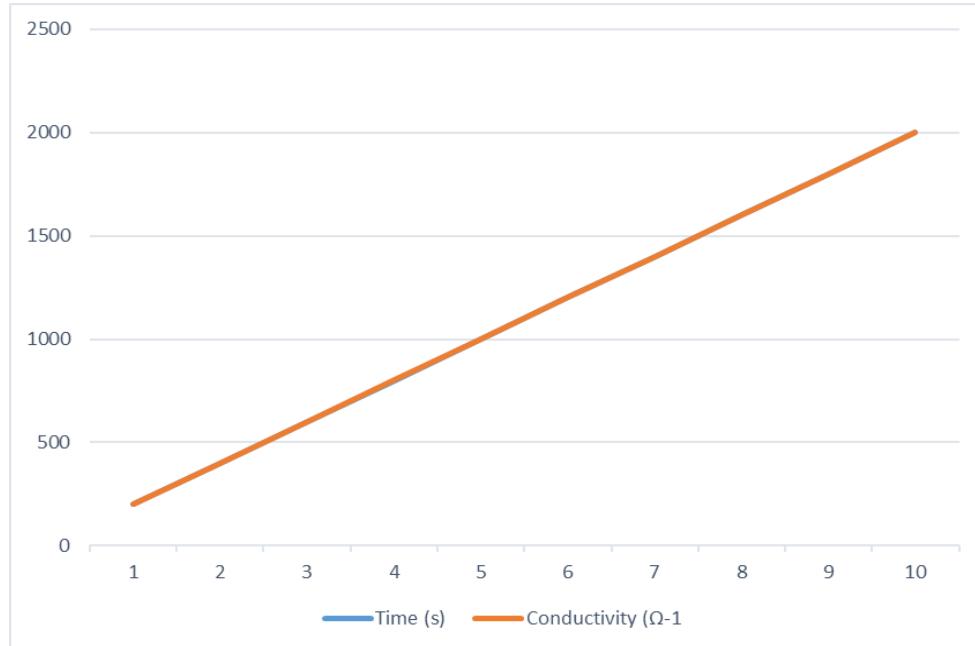


Figure 2: Graph of Conductivity against Time

8. Discussion of Results

Results obtained are to be discussed extensively with respect to accepted theory and promulgated scientific law. Discussion of results could be based on table of results, graph plotted and relatively to the facts in the literature survey of the concept under review. As part of discussion of results, facts should be established regarding the

conformity of results of such research work with the standard values. It is different from the procedure on how results were obtained in a research work.

9. 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.

10. Reference (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.

There are two formats of writing a reference, namely, APA format and numbering type. But the department recommends APA format for any research to be undertaken by the students.

As for APA format, the names of authors of the text books cited are to be arranged alphabetically. Surname of the author is to be written in full and other names abbreviated, followed by year of publication, title of the book, edition, place of publication, publisher and page reference. If it is journal, the order for presentation of references is the author, date, title of article, text of journal, issue information (volume, issue number) and page reference. Even lecture note, information from the internet, their details must be presented.

For example:

Aderele, A.O. (1996). Effect of Weeding Depth, Blades Speed and Weed Density on Performance of a Motorized Mechanical Weeder. *Journal of Agriculture Technology*, 4, 1, 19.

Galadima, M. S. (2005). Extraction of Eucalyptus Oil. M. Sc. Thesis, Department of Chemical Engineering, Ahmadu Bello University, Zaria, pp 14-15.

Isah AN. (2009/2010). Lecture Note on Polymer Science and Technology, Department of Chemical Engineering Technology, Federal Polytechnic Nasarawa, pp 15-18.

Mc Cabe,M.L., Smith, J.C., and P.Hariott (1985). Unit Operations of Chemical Engineering, 3" Edition. New York: Mc Graw-Hill,265

<http://www.wikipedia.org/standardvalueandcharacterizationofNeemseed oil.htm>,
cited on November 15,2010 @ 12pm

11. 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.

Organization and Neatness

The students must organize their reports in a manner as mentioned earlier. The neatness will include how the student has written the report.

Important notes:

- Be concise to the point in writing your report. Extra words actually distract from the sought meaning.
- Use visual aids. Writing a technical report is more than common prose writing.
- Each graph, figure, or table should have a title and a number.
- All pages should be numbered except the cover page.
- All reports should be typed and checked for spelling and grammatical errors.
- Use the past tense at all times unless it's truly awkward.
- Avoid using I, we, you, etc. while writing the report.

Disciplinary actions:

- ✓ Any absent student cannot re-do the experiment without an acceptable reason. Private hospitals/clinics sick leave is not acceptable.
- ✓ Any delay or late submission of the reports will be punished (5% reduction for every day of delay).
- ✓ Students may be refused entry to the lab if he/she is late by more than 5 minutes.
- ✓ Copying or forging of report materials is strictly prohibited and will be severely punished.

INDEX OF EXPERIMENTS

Fluid Mechanics

(Transport Phenomena I)

The Hydraulics Bench

The standard Hydraulics Bench is used for all the laboratory experiments carried out during this course. The Bench has a closed water circulating system to facilitate mobility. Water is stored in an enclosed tank at the bottom of the bench then pumped up to the experimental setup situated on top of the bench from which water flows into the upper tank. The upper tank has a drain controlled by a plug to collect and gauge the water in the upper tank after which water is drained to the bottom tank. The volume of water collected in the upper tank (in liters) can be measured using the graduated scale fixed at the side of the Hydraulics Bench. The switch of the water pump and the control valve that regulates the amount of water that flows to the experimental setup are at the front side of the Hydraulics Bench.

1. Technical description

The Basic Hydraulics Bench HM 150 and the various ancillary modules available form a comprehensive laboratory facility which enables a detailed Mechanics of Fluids Laboratory.

The hydraulics bench unit provides the basic services for the pumping and volumetric measurement of the water supply with which all the additional accessories and experiments are used.

The working surface of the unit is in fibreglass, moulded to provide a recessed area on which to mount experiments. An integral weir tank is provided along with a volumetric measuring tank.

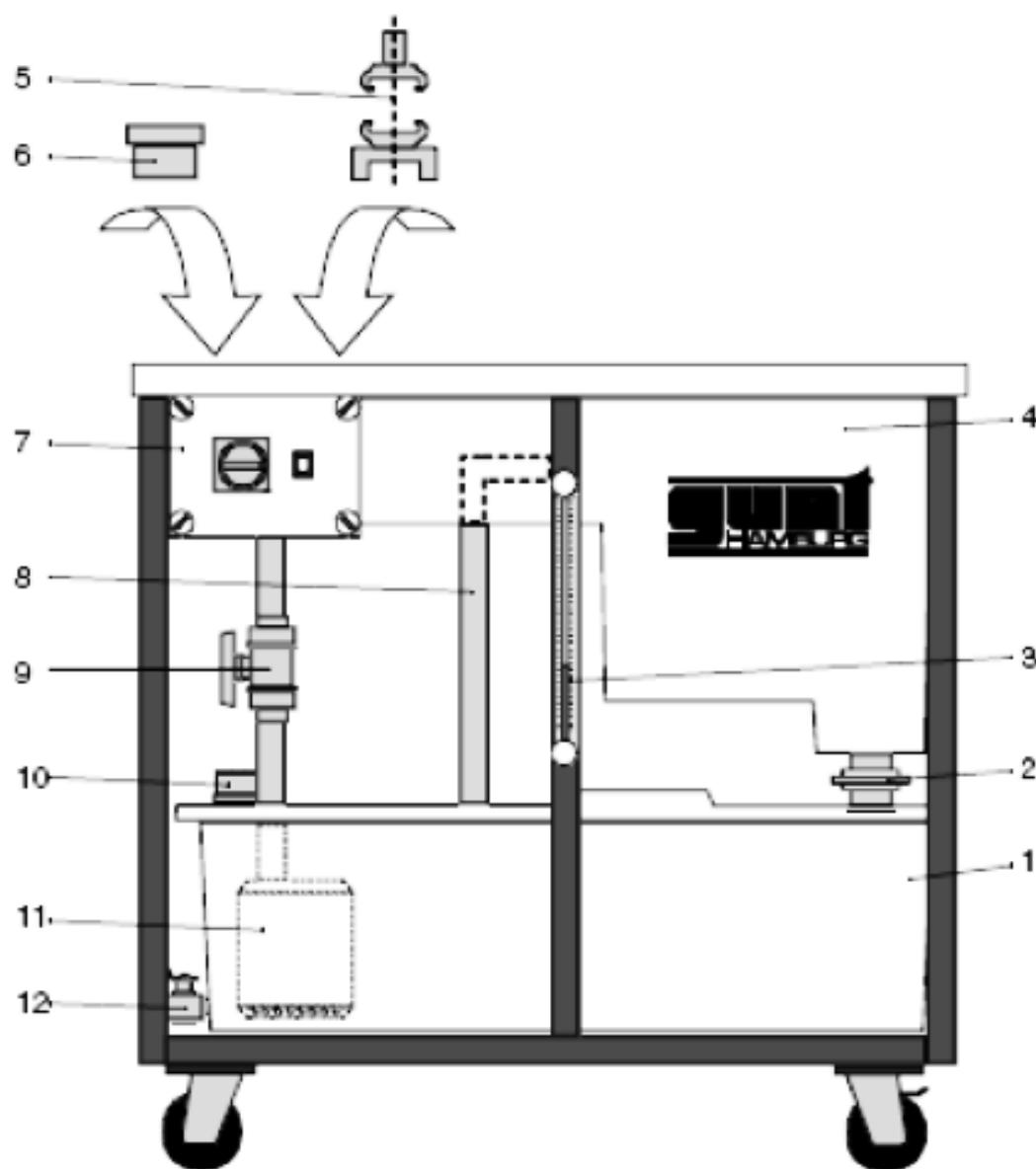
The measuring tank is stepped to enable for accurate measuring of both high and low flow rates. A level indicator allows convenient read out of the flow.

The measuring tank discharges into a fiberglass sump tank via a valve. Overflow pipe is provided.

An electric motor drives a submersible motor driven pump which delivers water to the outlet at the working surface for connection to the individual experiments. Materials used in the bench construction and its modules have been carefully selected in order to minimise corrosion problems.

The entire unit is self-contained and mobile.

For low volumetric measurement use the 2 ltr measuring cup.



Pos.	Item	Pos.	Item
1	Sump tank	7	Switch box
2	Sliding valve	8	Overflow pipe
3	Remote sight gauge	9	Flow control valve
4	Volumetric measuring tank with channel	10	Water supply connection for accessories with pump
5	Water supply connection for accessories without pump	11	Submersible motor driven pump
6	Discharge cap	12	Drain cock

Fig. 1.1 Basic bench

2. Determine Volumetric Flow Rate

To do so, use stopwatch to establish time t required for raising the level in the volumetric tank of the HM 150 from 20ltr to 30ltr.

- Close the outlet valve.
- Read the actual volume at the remote sight gauge.

The volume flow-rate is calculated as: $\dot{V} = \frac{\Delta V}{\Delta t}$

3. List of Experiments

The experimental topics covered include, together with the individual experimental set-ups:

- Bernoulli's Principle Demonstrator
- Fluid Friction Apparatus
- Methods of Flow Measurement
- Osborne Reynolds Demonstrator

4. Technical Data

Overall dimension

(L x W x H) 1220 x 760 x 1200 mm

Weight : 125 kg

Pump

Head : $H = 11$ m

Flow : $Q = 230$ ltr/min

Electrical supply 230V, ~ 50Hz; 0,55 kW

Alternatives optional, see name plate

Sump tank 180 ltr

Volumetric tanks

High flow : 40 ltr

Low flow : 10 ltr

Beaker : 2 ltr

Stop watch: 1/100 s

EXPERIMENT NO: 1

FLOW RATE MEASUREMENT

Aim & Objectives:

The objectives of the experiment are:

1. To show the measurement of flow rate
2. To determine the co-efficient of discharge through Venturimeter & Orifice meter.
3. To calibrate the Rotameter

Learning outcomes

It is expected by completing the experiment, the students will be able:

1. To determine flow rate by using orifice meter, Venturi meter and rotameter
2. To explain how to calculate ideal flow rate by using Bernoulli equation
3. To determine the correction factor for by using an elbow and a sudden expansion
4. To measure pressure by using piezometer

Theory/Background

There are various ways of measuring volumetric flow rate. Some flow meters measure the flow rate directly by discharging and recharging a measuring chamber of known volume continuously and keeping track of the number of discharges per unit time. However, most flow meters measure the flow rate indirectly – they measure the average velocity V or a quantity related to average velocity such as pressure and drag, and determine volume flow rate, Q from $Q = AV$, where A is cross sectional area of flow.

Obstruction Flow Meters: Venturi Meter and Orifice Meter

One way to measure flow rate is to put obstruction in a pipe flow such as a throat (Venturi Meter) and simple obstruction that reduced the cross sectional area (Orifice Meter).

Theoretical ideas behind these flow meters are the conservation of mass and the Bernoulli equation. From conservation of mass we know that reduce of cross sectional area will contribute to an increase of velocity.

Thus, from Bernoulli equation, this will lead to a decrease of static pressure. These kinds of flow meters did not measure the flow rate or velocity directly but it

measures the drop of static pressure. Then the velocity can be calculated from Bernoulli equation and conservation of mass.

The same idea can be applied for sudden expansion and elbow meter.

Rotameter

Rotameter is also known as variable-area flow meter or float meter. A rotameter consists of a vertical tapered conical transparent tube made of glass or plastic with a float inside that is free to move. As fluid flows through tapered tube, the float rises within the tube to a location where the float weight, drag force and buoyancy force are balance each other and the net force acting on the float is zero. The flow rate is determined by simply matching the position of the float against the graduated flow scale outside the tapered transparent tube.

Coefficient of Discharge

For Rotameter the flow rate can be read directly from scale at tapered tube. However, for obstruction flow meter, we need to consider a loss due to viscous (frictional) effects. As we know the Bernoulli equation did not include the viscous effects. Therefore, any calculation that calculated from the conservation of mass and Bernoulli equation is an ideal volumetric flow rate, not an actual one. Thus, to determine an actual volumetric flow rate a correction factor need to be introduced to the ideal flow rate equation. This correction factor is called as coefficient of discharge. The coefficient of discharge can be defined as the ratio of actual flow rate to the ideal flow rate.

Loss coefficient

Due to viscous effects, there are losses at the obstruction. The losses at the obstruction can be considered as minor losses. If the pressure drop and average velocity is known, then the loss coefficient can be determined since the pressure drop is proportional to velocity.

This experiment is to demonstrate flow rate measurements.

Venturi meter:

A Venturimeter consists of;

1. An inlet section followed by a convergent cone.
2. A Cylindrical Throat.
3. A gradually divergent cone.

The inlet section of the Venturimeter is of the same diameter as that of the pipe, which is followed by a convergent cone. The convergent cone is a short pipe, which tapers from the original size of the pipe to that of the Throat of the Venturimeter. The Throat of the Venturimeter is a short parallel side tube having its cross-sectional area smaller than that of the pipe. The divergent cone of the Venturimeter is gradually diverging pipe with its cross-sectional area increasing from that of the Throat to the original size of the pipe. At inlet section & Throat of the Venturimeter, pressure taps are provided.

Orifice meter:

An Orifice meter consists of a flat circular plate with a circular hole called Orifice, which is concentric with the pipe axis. An orifice plate is a thin plate with a hole in the middle. It is usually placed in a pipe in which fluid flows. When the fluid reaches the orifice plate, the fluid is forced to converge to go through the small hole; the point of maximum convergence actually occurs shortly downstream of the physical orifice, at the so-called vena contracta point. As it does so, the velocity and the pressure changes. Beyond the vena contracta, the fluid expands and the velocity and pressure change once again. By measuring the difference in fluid pressure between the normal pipe section and at the vena contracta, the volumetric and mass flow rates can be obtained from Bernoulli's equation.

For Orifice meter, Venturi meter,

1. Measure pressure drop (in term of head) as a function of valve opening.
2. Determine ideal flow rate and actual flow rate.
3. Determine Reynolds number
4. Determine coefficient of discharge, C_d
5. Prepare the following graph
 - a. On the same set of axes, plot actual volume flow rate vs. pressure head drop and ideal flow rate vs. pressure head drop with flow rate on the vertical axis for obstruction flow meter
 - b. Plot actual volumetric flow rate vs. ideal flow rate for Rotameter
 - c. Plot coefficient of discharge vs. Reynolds number on log-log grid for obstruction flow meter

Pre-lab questions

1. Explain briefly the following terms:
 - i. Pressure Head
 - ii. Velocity Head
 - iii. Elevation Head
2. Define Loss Coefficient
3. Define Coefficient of Discharge and what its significance in flow rate measurement.

Experimental set up

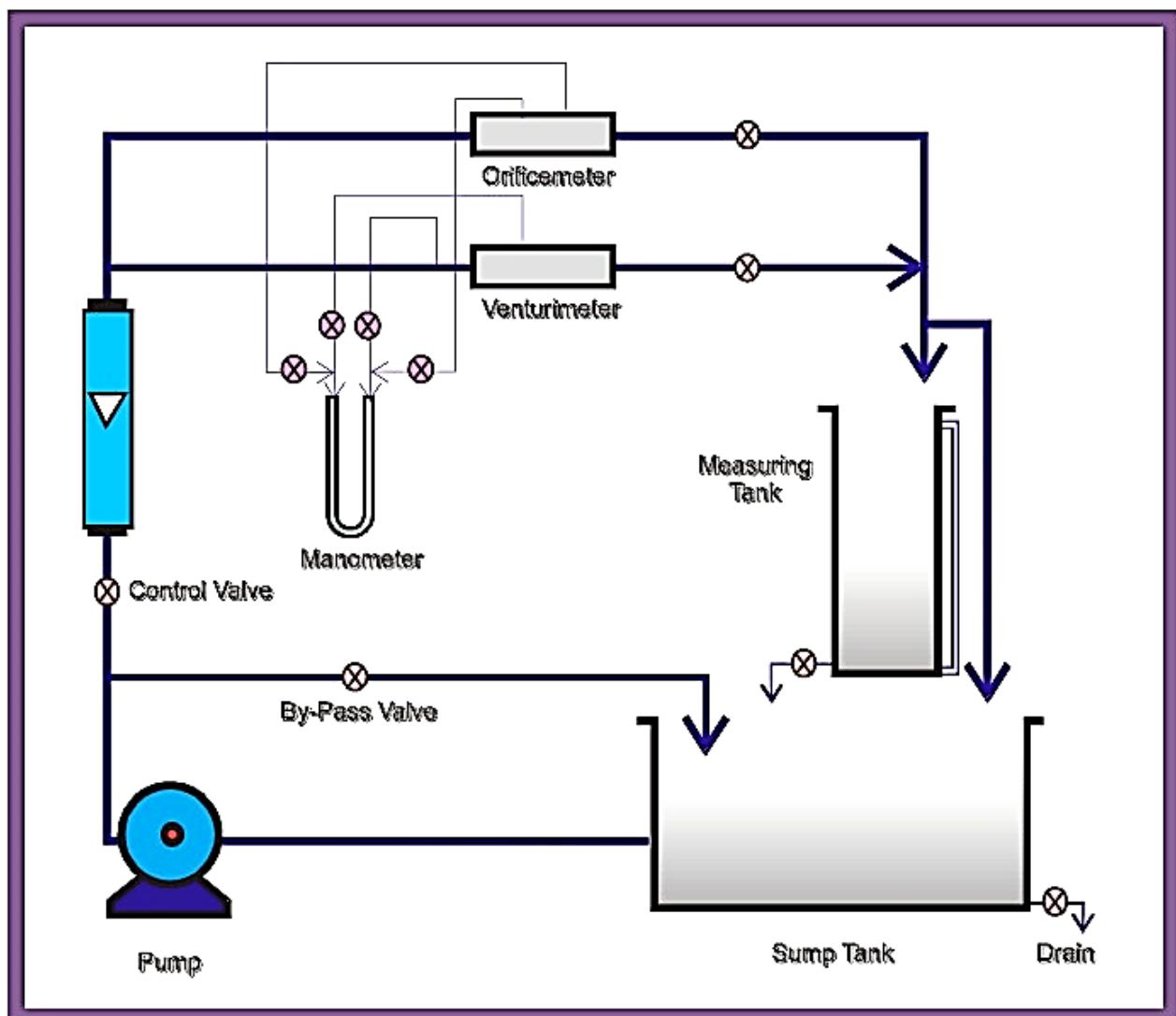


Fig. 1: Schematic Diagram for Venturi meter, Orifice meter & Rotameter Apparatus

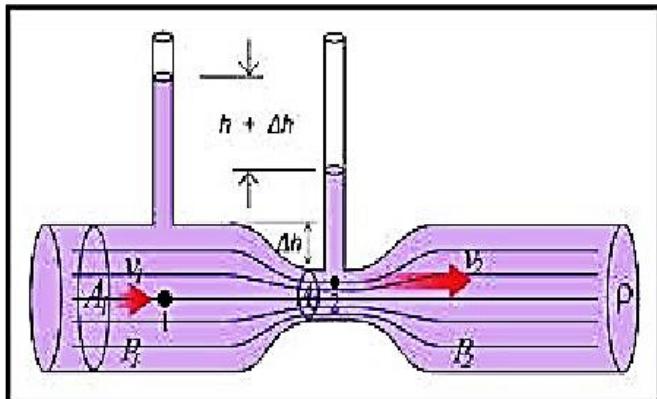


Fig.2: Flow Diagram of Venturi meter

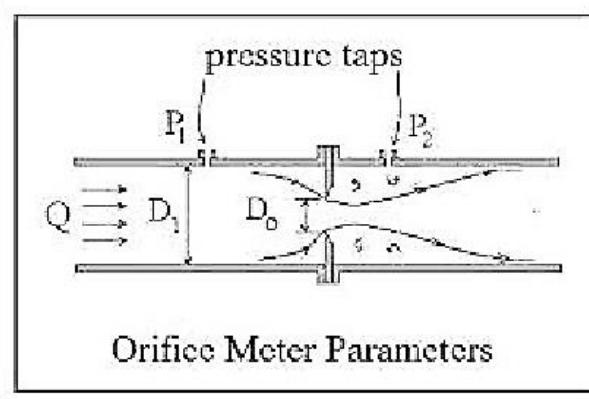


Fig. 3: Flow Diagram of Orifice meter

Experimental procedure

Venturi meter & orifice meter:

Starting Procedure:

- Clean the apparatus and make All Tanks free from Dust.
- Close the drain valves provided.
- Fill Sump tank $\frac{3}{4}$ with Clean Water and ensure that no foreign particles are there.
- Close all Flow Control Valves given on the water line and open By-Pass Valve.
- Close all Pressure Taps of Manometer connected to Venturi meter & Orifice meter.
- Ensure that On/Off Switch given on the Panel is at OFF position.
- Now switch on the Main Power Supply (220 Volts AC, 50 Hz).
- Switch on the Pump.
- Operate the Flow Control Valve to regulate the flow of water in the desired Test Section.
- Open the Pressure Taps of Manometer of related Test section, very slowly to avoid the blow of water on manometer fluid.
- Now open the Air Release Valve provided on the Manometer, slowly to release the air in manometer.
- When there is no air in the manometer, close the Air release valves.
- Adjust water flow rate in desired section with the help of Control Valve.
- Record the Manometer reading.
- Measure the flow of water, discharged through desired test section, using Stop Watch and Measuring Tank.
- Repeat Steps the same procedure for different flow rates of water, operating Control Valve and By-Pass valve.
- When experiment is over for one desired test section, open the By-Pass Valve fully. Then close the flow control valve of running test section and open the Control valve of secondly desired test section.

Calibration of Rotameter:

- a. Close the ball valves provided in the Venturimeter and Orifice meter pipelines.
- b. Open the ball valve provided in the Rotameter pipeline.
- c. Now switch on the main power supply and switch on the pump.
- d) Set the flow rate with the help of by pass and flow control valves provided in Rotameter pipeline.
- e. Measure the discharge with the help of measuring tank and stopwatch.
- f. The actual discharge, verify the set value of Rotameter.
- g. Repeat the same procedure for different flow rates.

Closing Procedure:

- b) When experiment is over, close all Manometers Pressure Taps first.
- c) Switch off Pump.
- d) Switch off Power Supply to Panel.

Observation Table

For venture meter & Orifice meter

S.No	Pressure difference, h (cm)	Rise of Water level in Measuring Tank, R (cm)	Time taken for R, t (sec.)
------	--------------------------------	--	-------------------------------

Average Co-efficient of Discharge:

Formulae:

1. Head Losses

$$H = \frac{h}{100} \left(\frac{\rho_m}{\rho_w} - 1 \right), \text{ m of water} \quad \text{e.q. (1)}$$

2. Theoretical discharge (Q_t)

$$Q_t = \frac{a_1 a_2 \sqrt{2gH}}{\sqrt{a_1^2 - a_2^2}}, \text{ m}^3/\text{s} \quad \text{e.q. (2)}$$

3. Actual discharge (Q_a)

$$Q_a = \frac{AxR}{t*100}, \text{ m}^3/\text{s} \quad \text{e.q. (3)}$$

4. Co – efficient of discharge (C_d)

$$C_d = \frac{Q_a}{Q_t} \quad \text{e.q. (4)}$$

Data

H= Head loss

h = Pressure difference (m)

A = 0.1 m²

ρ_m = Density of manometric fluid = 13600 kg/ m

ρ_w = Density of working fluid = 1000 kg/ m³

g = Acceleration due to Gravity = 9.81 m/sec²

For Venturi meter:

d_1 = Dia. at inlet of the venturi meter = 28mm = 0.028m

d_2 = Dia. at throat of the Venturi meter = 14mm = 0.014m

a_1 = $\pi d_1^2/4$ cm² Area at inlet of Venturi meter = $6.157 * 10^{-4}$ m²

a_2 = $\pi d_2^2/4$ cm² Area at throat of Venturi meter = $1.539 * 10^{-4}$ m²

For Orifice meter:

d_1 = Dia. at inlet of Orifice meter = 28 mm. = 0.028 m

d_2 = Dia. of Orifice Plate = 14 mm. = 0.014 m

a_1 = $\pi d_1^2/4$ Area at inlet of Orifice meter = $6.157 * 10^{-4}$ m²

a_2 = $\pi d_2^2/4$ m² Area of Orifice Plate = $1.539 * 10^{-4}$ m²

Result and discussion

For Venturi meter and Orifice meter

S/N	Actual discharge Q_a , m ³ /s	Theo. Discharge Q_t , m ³ /s	$C_d = Q_a/Q_t$

Precaution

1. Do not run the pump at low voltage i.e. less than 180 Volts.
2. Never fully close the Delivery line and By-Pass Line Valves simultaneously.
3. Always keep apparatus free from dust.
4. To prevent clogging of moving parts, Run Pump at least once in a fortnight

EXPERIMENT NO. 2

BERNOULLI'S THEOREM

Aim & Objective

To experimentally verify Bernoulli equation for fluid flow in horizontal pipe.

Apparatus

FHP pump run setup consisting of 4 rectangular tanks, horizontal pipe section, 8 piezometric tubes with measuring scales, stopwatch.

Theory

Energy of a Liquid in Motion

The energy, in general, may be defined as the capacity to do work. Though the energy exists in many forms, yet the following are important from the subject point of view:

- a) Potential Energy
- b) Kinetic Energy, and
- c) Pressure Energy.

Potential Energy of a Liquid in Motion

It is the energy possessed by a liquid particle, by virtue of its position. If a liquid particle is Z meters above the horizontal datum (arbitrarily chosen), the potential energy of the particle will be Z meter-kilogram per kg of liquid. Potential head of the liquid, at that point, will be Z meters of the liquid.

Kinetic Energy of a Liquid Particle in Motion:

It is the energy, possessed by a liquid particle, by virtue of its motion or velocity. If a liquid particle is flowing with a mean velocity of v meter per second, then the kinetic energy of the particle will be $v^2/ 2g$ m-kg per kg of liquid. Velocity head of the liquid, at that velocity, will be $v^2/ 2g$ meter of the liquid.

Pressure Energy of a Liquid Particle in Motion:

It is the energy, possessed by a liquid particle, by virtue of its existing pressure. If a liquid particle is under a pressure of p kg/m², then the pressure energy of the particle will be p/w m-kg per kg of liquid, where w is the specific weight of the liquid.

Total Energy of a Liquid Particle in Motion:

The total energy of a liquid particle, in motion, is the sum of its potential energy, kinetic energy and pressure energy. Mathematically,

Total Energy:

$$E = Z + \frac{V^2}{2g} + \frac{P}{W} \quad \frac{\text{m.kg}}{\text{kg}} \text{ of of liquid}$$

Bernoulli's Equation:

It states, "For a perfect incompressible liquid, flowing in a continuous stream, the total energy of a particle remains the same; while the particle moves from one point to another." This statement assumes that there are no losses due to friction in pipe.

Mathematically,

$$E = Z + \frac{V^2}{2g} + \frac{P}{W} \quad \frac{\text{m.kg}}{\text{kg}} \text{ Constant} \quad (\text{eq. 1})$$

Bernoulli Equation:

$$\frac{P}{\rho g} + \frac{V^2}{2g} + z = \text{constant} \quad (\text{eq. 2})$$

This is the basic form of Bernoulli equation for steady incompressible inviscid flows. It may be written for any two points 1 and 2 on the same streamline as

$$\frac{P_1}{\rho_1 g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho_2 g} + \frac{V_2^2}{2g} + z_2 \quad (\text{eq. 3})$$

The constant of Bernoulli equation, can be named as total head (h_o) has different values on different streamlines.

$$h_o = \frac{P}{\rho g} + \frac{V^2}{2g} + z \quad (\text{eq. 4})$$

The total head may be regarded as the sum of the piezometric head $h^* = \frac{P}{\rho g} + z + z$ and the kinetic head $V^2/2g$.

Bernoulli equation is arrived from the following assumptions:

- Steady flow - common assumption applicable to many flows.
- Incompressible flow - acceptable if the flow Mach number is less than 0.3.
- Frictionless flow - very restrictive; solid walls introduce friction effects.
- Valid for flow along a single streamline; i.e., different streamlines may have different h_o .
- No shaft work - no pump or turbines on the streamline.
- No transfer of heat - either added or removed.

Range of validity of the Bernoulli Equation:

Bernoulli equation is valid along any streamline in any steady, inviscid, incompressible flow. There are no restrictions on the shape of the streamline or on the geometry of the overall flow. The equation is valid for flow in one, two or three dimensions.

Modifications on Bernoulli equation:

Bernoulli equation can be corrected and used in the following form for real cases.

$$\frac{p_1}{\rho_1 g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho_2 g} + \frac{v_2^2}{2g} + z_2 + h + w - q$$

Where 'q' is the work done by pump and 'w' is the work done by the fluid and h is the head loss by friction.

Experimental Set-Up

The apparatus is made from transparent acrylic and has both the convergent and divergent sections. Water is supplied from the constant head tank attached to the test section. Constant level is maintained in the supply tank. Piezometric tubes are attached at different distance on the test section. Water discharges to the discharge tank attached at the far end of the test section and from there it goes to the measuring tank through valve. The entire setup is mounted on a stand.

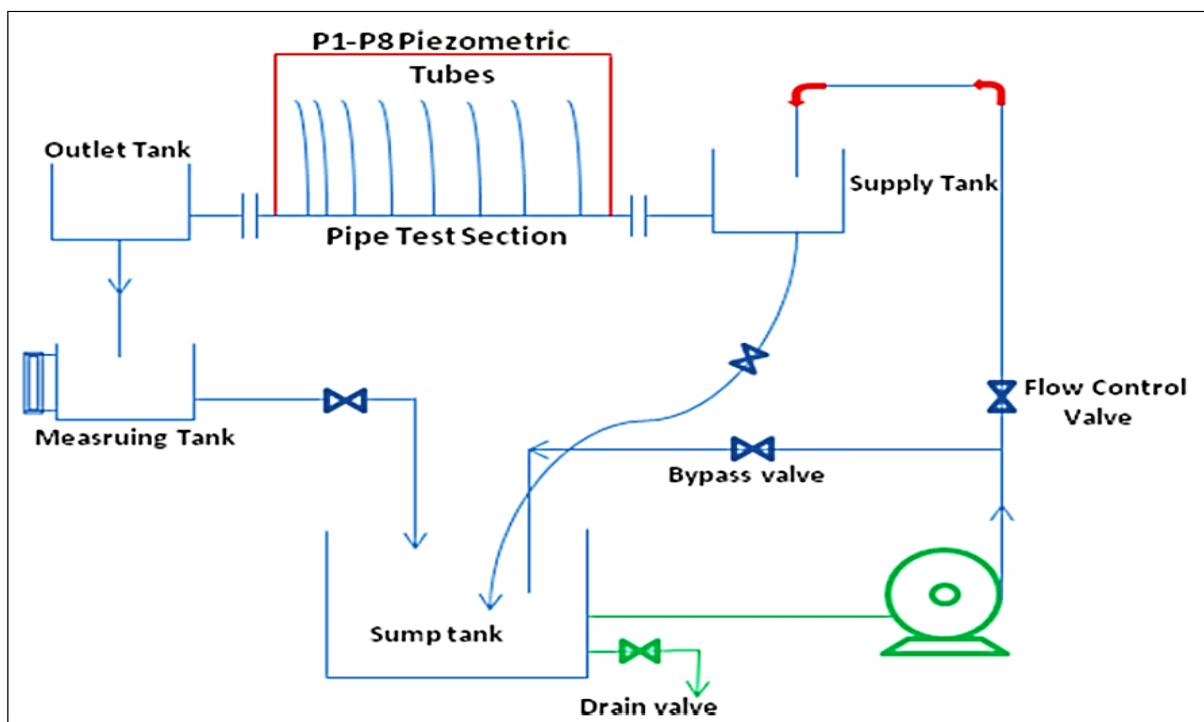


Figure 1: Schematic diagram of experimental setup

Experimental Procedure

- 1) Fill the sump tank with water.
- 2) Before starting the pump, make sure that the bypass valve is fully open and the discharge valve is closed.
- 3) Switch ON the Pump.
- 4) Flow control valve to the supply tank is opened and bypass valve is closed slowly and simultaneously. Keep drain valve of the discharge tank fully open.
- 5) After we get steady height of liquid in the supply tank adjust the drain valve on the discharge tank so as to get steady level there also.
- 6) Collect the predetermined quantity of water in the measuring tank and measure the time required for the same.
- 7) Also record the height of liquid in each of the piezometric tube.

Observations

Sr. No.				
Height. diff. in measuring tank (m)	H ₁			
	H ₂			
	ΔH			
Volume (m ³)	V			
Time (sec)	T			
Vol. Flow rate (m ³ /sec)	Q			
Tric tube	1	H ₁ =P ₁ /w(m)		
		v ₁ = Q/A ₁		
		v ₂ ¹ / 2g (m)		
		Total Head		
	2	H ₂ =P ₂ /w(m)		
		v ₂ = Q/A ₂		
		v ₂ ² / 2g (m)		
		Total Head		
	3	H ₃ =P ₃ /w(m)		
		v ₃ = Q/A ₃		
		v ₃ ² / 2g (m)		
		Total Head		
	4	H ₄ =P ₄ /w(m)		
		v ₄ = Q/A ₄		
		v ₄ ² / 2g (m)		
		Total Head		
	5	H ₅ =P ₅ /w(m)		
		v ₅ = Q/A ₅		
		v ₅ ² / 2g (m)		
		Total Head		
	6	H ₆ =P ₆ /w(m)		
		v ₆ = Q/A ₆		
		v ₆ ² / 2g (m)		

	Total Head				
7	$H_7 = P_7/w(m)$				
	$v_7 = Q/A_7$				
	$v_7^2/2g (m)$				
	Total Head				
8	$H_8 = P_8/w(m)$				
	$v_8 = Q/A_8$				
	$v_8^2/2g (m)$				
	Total Head				

Calculations:

Length of the test section

$$= 0.4 \text{ m}$$

Piezo tube 1 at 0.05 m

$$\text{c/s area } A_1 = 0.000961 \text{ m}^2$$

Piezo tube 2 at 0.085 m

$$\text{c/s area } A_2 = 0.00053 \text{ m}^2$$

Piezo tube 3 at 0.115 m

$$\text{c/s area } A_3 = 0.000314 \text{ m}^2$$

Piezo tube 4 at 0.18 m

$$\text{c/s area } A_4 = 0.000572 \text{ m}^2$$

Piezo tube 5 at 0.240 m

$$\text{c/s area } A_5 = 0.000854 \text{ m}^2$$

Piezo tube 6 at 0.300 m

$$\text{c/s area } A_6 = 0.001256 \text{ m}^2$$

Piezo tube 7 at 0.355 m

$$\text{c/s area } A_7 = 0.00166 \text{ m}^2$$

Piezo tube 8 at 0.40 m

$$\text{c/s area } A_8 = 0.00215 \text{ m}^2$$

Cross Sectional Area of Measuring Tank (A_m) = 0.09 m²

$$\text{Height Difference in measuring tank } (\Delta H) = H_1 - H_2 \text{ (m)}$$

$$\text{Volume Collected } (V) = \Delta H * A_m \text{ m}^3$$

$$\text{Volumetric Flow rate } (Q) = V / T \text{ (m}^3/\text{s)}$$

$$\text{Linear Point Velocity } (v_i) = Q/A_i \text{ (m/sec)}$$

$$\text{Velocity head at point -1} = [v_{i2} / (2*g)] \text{ (m)}$$

$$\text{Total Head at point -1} = \text{Static Head + Velocity Head}$$

$$= H_i + v_{i2} / (2*g) \text{ (m)}$$

Check for all the points that sum of velocity head and pressure head is almost constant. Here potential energy is not being considered as the test section lies in one horizontal plane only.

Result:

Draw graph of static head, velocity head, and total head Vs distance of the piezometric tubes.

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EXPERIMENT NO. 3(a)

STUDY OF REYNOLDS APPARATUS

Aim

To study the flow regime for liquid flow in a pipe, and to find the critical Reynolds's number.

Objective

- 1) To find the volumetric flow rate corresponding to various flow regimes.
- 2) Demonstrate visually the laminar (or streamline) flow and its transition to turbulent flow.
- 3) Calculate Reynolds' number.

Theory

Osborne Reynolds (1883) demonstrated different flow regimes when a fluid flows through a pipe. These regimes are: laminar, turbulent and transition or intermediate regimes. For a given pipe and fluid, laminar flow exists at low velocity characterized by ordered sliding past of liquid layer over one another without lateral mixing; while turbulent flow is found at high velocity in which the flow pattern is random and there is intense lateral mixing in the fluid. In between these two extremes, a transition flow regime is observed in which the flow alters between laminar and turbulent flows. Reynolds's found that the nature of flow depends on the diameter of the pipe, and viscosity, density and average velocity of the fluid; and these factors can be combined into one dimensionless group, called the Reynolds's number, the magnitude of which would indicate the flow regime. The Reynolds number, Re is defined as

$$Re = Du/\mu = Du/v$$

Where D = pipe diameter, u = fluid velocity, ρ = fluid density, μ = fluid viscosity, and v = kinematic viscosity.

Physically, Reynolds number is interpreted as the ratio of the inertial force to viscous force acting on the fluid. In general, D and v represent some characteristic dimension of the flow domain and characteristic velocity of the fluid. Thus, laminar flow exists at small Reynolds number, and turbulent flow at large Reynolds number.

The minimum Reynolds number at which laminar flow disappears is called the critical

Reynolds number. The value of critical Reynolds number depends on the geometry of the flow domain (circular or rectangular pipe, open or closed channel, flat plate etc.) and flow configuration (flow around a bluff body, in packed bed etc.)

The flow changes from laminar to turbulent when:

$$Re = 2300$$

$Re < 2300$ means laminar flow

$Re_{Turb} > 2300$ means turbulent flow

The diagram shown in Fig. 3 shows the three flow states

Requirements

Reynolds apparatus, water source, dye, measuring cylinder, stop watch.

Equipment

The schematic for the (Reynolds' apparatus) is shown in Fig. 1.

The unit essentially comprises:

- a) Base plate [1] with the necessary connections for water supply [10] with control valve [13] and waste water discharge [11].
- b) Water reservoir [2] with a ball block to stem the flow [9].
- c) Overflow section [7] to generate a constant pressure level in the reservoir.
- d) Aluminum well [4] for ink with metering tap [5] and brass inflow tip [6].
- e) Test pipe section [8] of plexiglass with flow-optimized inflow [3].
- f) Drain cock [12] to adjust the flow through the test pipe section.

Procedure

- 1) Fill in the tank with water, and the dye- chamber with dye.
- 2) Note the water temperature.
- 3) Start the water flow and maintain a small flow rate, enough to fill the whole pipe cross section.
- 4) Once the flow stabilizes, start the dye injection. The injection rate should be just enough to give a clear visible streak of the dye.
- 5) Observe the pattern of the dye streak. The dye should flow in a straight line.
- 6) Increase the water in small and equal increments, and observe the dye streak.
- 7) Repeat step 6 until some undulations commence in the streak. Note the

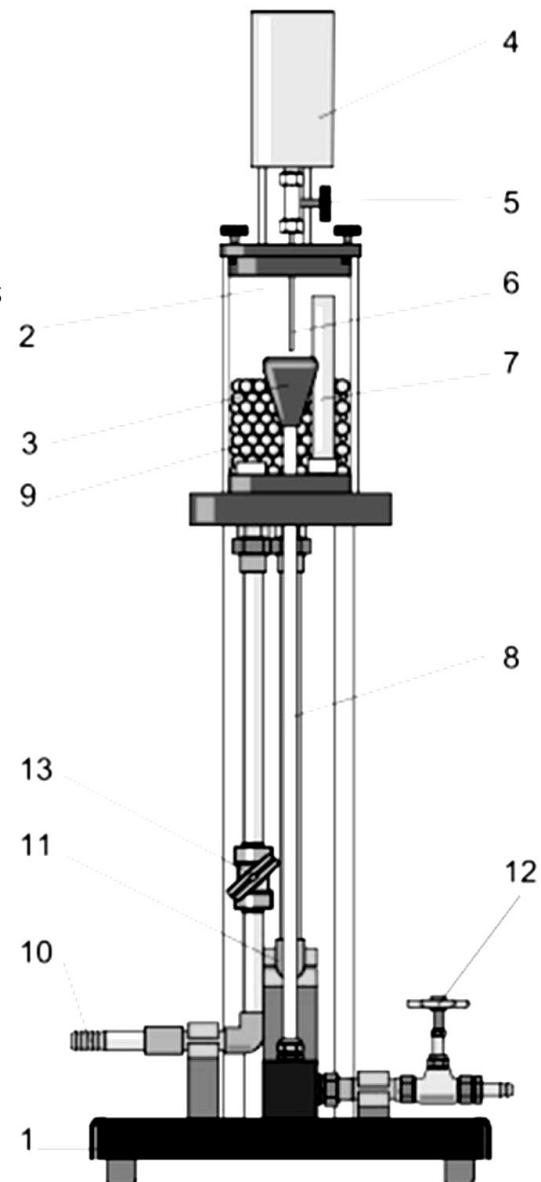


Fig. 1. Reynolds' apparatus

corresponding volumetric flow rate of water, which is the critical Reynolds number. Appearance of the undulations signify the initiation of the intermediate or transition flow.

Note at this point the undulations will be unstable so that there will be some portion of the dye streak which will be undulating and some portion which will not.

- 8) Keep increasing the flow rate of the liquid further until at one point there is found a complete dispersion of the dye (indicated by the liquid getting colour through the cross section) just as it comes out of the injection needle. This point shows the conversion to a fully turbulent regime.
- 9) Note the corresponding the volumetric flow rate.

Observations

Temperature of the liquid =

Pipe diameter = m

S.No	Flow Regime	Volume of water collected	Time taken
1	Laminar		
2	Transition		
3	Fully Turbulent		

Volumetric flow rate corresponding to start of the Laminar flow = m³/s

Volumetric flow rate corresponding to start of the transition flow m³/s

Volumetric flow rate corresponding to fully turbulent flow = m³/s

Liquid density at observed temperature = kg/m³

Liquid viscosity at the observed temperature = kg/m.s

Calculations

The Reynolds number is calculated from

$$Re = \frac{u \cdot d}{\nu}$$

where

d = inside diameter of pipe section [m]

u = flow rate (velocity) [m/s]

v = kinematic viscosity of the medium (m²/s)

For water, v= 10⁻⁶ m²/s

The flow rate can be calculated from the volume flow, which is determined with a measuring vessel and a stopwatch.

$$u = \frac{V}{A}; A = \frac{\pi \cdot d^2}{4} \text{ where}$$

d is the diameter of pipe = 10 mm

V is the volume flow rate

A is the cross-sectional area of the pipe

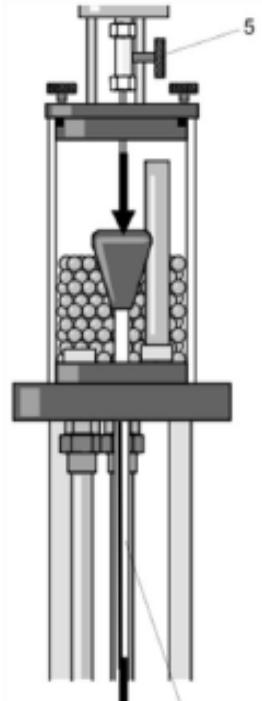


Fig. 2. Blue stream thread.

Results

- Calculate the average volumetric flow rate V , the velocity u and Reynolds' number Re for both laminar and turbulent flow conditions and record them in Tables.
- Calculated average volume flow rate V , velocity u and Reynolds' number. Also the liquid velocity can be calculate using $u = 4Q/\pi D^2$, Where Q is the volumetric flow rate.
- Compare the critical Reynolds number and the Reynolds number for transition to fully turbulent flow observed with those reported in the literature. Discuss the possible sources of discrepancy, if any.

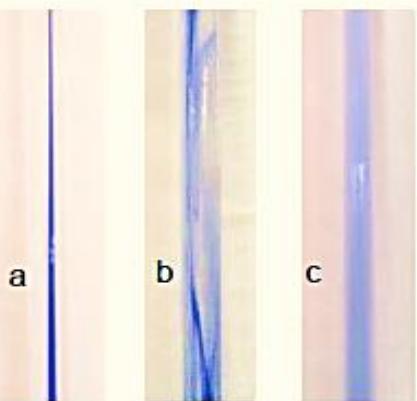


Fig. 3. The three states of flow: (a) laminar, (b) transition, and (c) turbulent.

Technical Data:

Main dimensions:

Length x Width x Height: Approx. 400 x 400 x 1140 mm

Weight: Approx. 16 kg

Reservoir: Approx. 2.2 litres

Test pipe section:

Inside diameter: 10 mm

Length: 675 mm

Ink well: 265 ml

Kinematic viscosity of water at atmospheric pressure

Temperature, (°C)	Kinematic viscosity (ν), ($\nu \times 10^5$ m ² /s)
10	1.307
11	1.270
12	1.235
13	1.201
14	1.169
15	1.138
16	1.108
17	1.080
18	1.053
19	1.027
20	1.002
21	0.978
22	0.955
23	0.933
24	0.911

FLUID FRICTION APPARATUS

EXPERIMENT NO. 4

DETERMINATION OF HEAD LOSS AT DIFFERENT FLOW RATES THROUGH AN ORIFICE AND VENTURI METER

Apparatus: Hydraulic bench connected to fluid friction apparatus, u-tube manometer.

Reagent: water

Theory

The rate of flow of fluids into process equipment is another important variable and may be measured by inferential or direct means. Inferential method determines the rate of flow by measuring related variables such as the differential pressure. In an orifice meter the fluid is accelerated by causing it flow through a constriction (orifice plate). The kinetic energy is thereby increased and the pressure head decreases. The flow rate is obtained by measuring the pressure difference across the orifice plate.

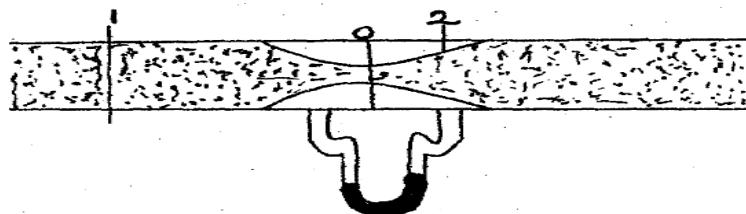


Fig. I and illustration of orifice meter

Applying Bernoulli's theorem for steady flow between section 1 and the vena contracta section 2, assuming horizontal flow in the absence of both external work effect and friction and negligible variation of fluid density between the sections.

$$\frac{U_2^2}{2\alpha_2} - \frac{U_1^2}{2\alpha_1} + \frac{1}{\rho}(P_2 - P_1) = 0 \quad \text{EQ 1}$$

After the evaluation of equation (1), it becomes

$$U_o = \frac{c_o \sqrt{2g\Delta H}}{\sqrt{1 - (\frac{D_0}{D_1})^4}} \quad \text{EQ 2}$$

Similarly, venture meter consists of two tapered sections inserted in the pipeline, with the tapering parts made smooth and gradual to minimize the frictional head loss.

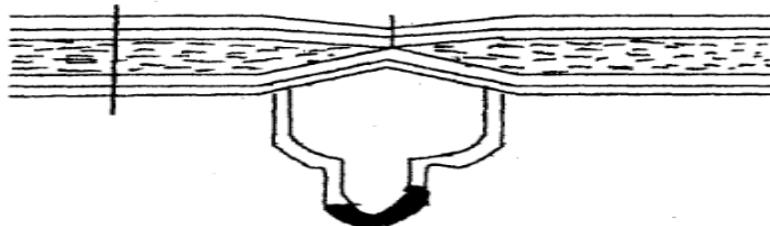


Fig. 2 An illustration of venture meter

The mean velocity of fluid through venture is denoted with U_v ,

$$U_v = \frac{c_v \sqrt{2g\Delta H}}{\sqrt{1 - (\frac{D_0}{D_1})^4}} \quad \text{EQ 3}$$

The discharge coefficient, c , depends on the upstream Reynolds number and the ratio of through to the pipe

Diameter $\frac{D_2}{D_1}$ or $\frac{D_0}{D_1}$.

Where c = discharge coefficient for venture = 0.98, $Re > 10,000$

C_0 = discharge coefficient for orifice = 0.62, $Re \geq 30,000$

g = acceleration due to gravity 9.8 m/s^2

D_1 diameter of the pipe (24 mm)

D_2 diameter for the venture (14 mm), D_0 = diameter for the orifice (20 mm)

Procedure

1. Ensure that adequate fluid to be used is poured into the hydraulic bench connected to fluid friction apparatus. Switch on the hydraulic system via the socket and prime with the fluid in order to avoid bubbles in the orifice meter and venture meter- by opening appropriate valve at convenient degree and close other valves.
2. Cover the round hole in the hydraulic bench with round bail suspended on it and observe the operation for 25 seconds. Before using the u-tube manometer, blow off the water it contains.
3. After then, measure and record the head loss in each of the meters by connecting u-Tube Manometer on selected part of the meters and volume of water should be recorded as well.
4. Observe the experiment for 35 secs. 45 secs. 55 secs. 65 secs and tabulate the results as below.

Reading

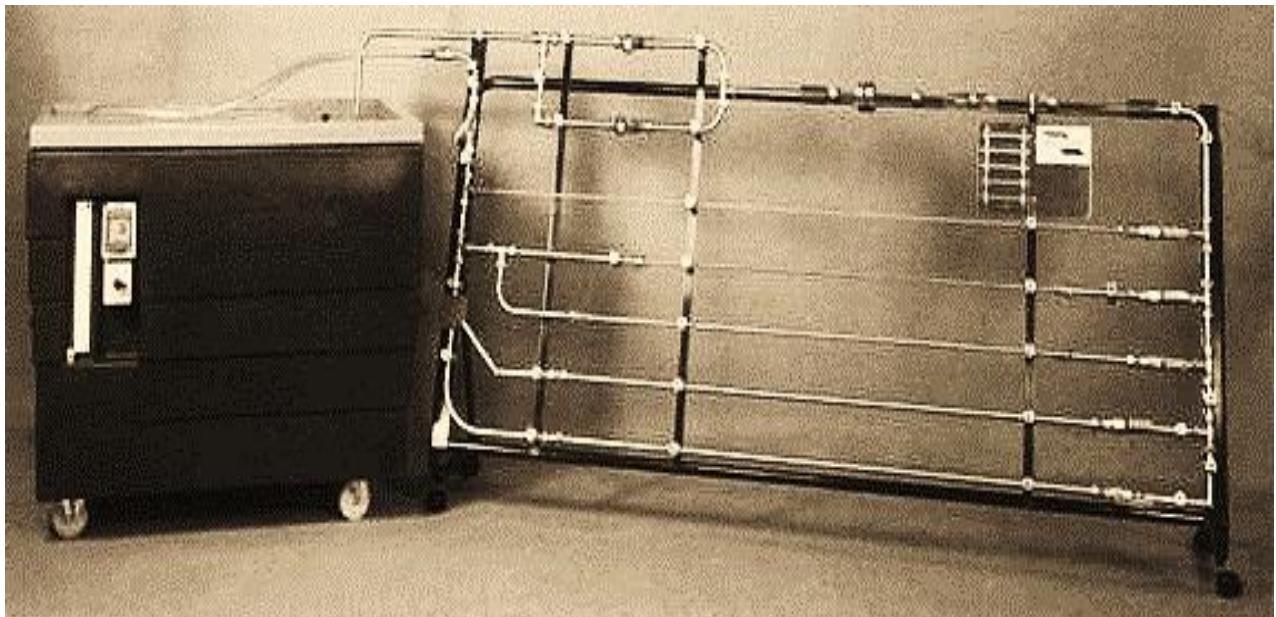
Time (s)	Head loss (m)	Volume of H ₂ O (m ³)	Flow rate (m ³ /s)	U_0^2	U_v^2
25					
35					
45					
55					
65					

Graph

- Plot a graph of ΔH against U_0^2 and All against U_v^2
- Calculate the respective slope and intercept.

References

- ✓ W.J.Beek etal, Transport phenomena
- ✓ S.K.Ghosal etal, Introduction to Chemical Engineering.



**Fig 1- Hydraulic bench and fluid friction apparatus
Equipment Description**

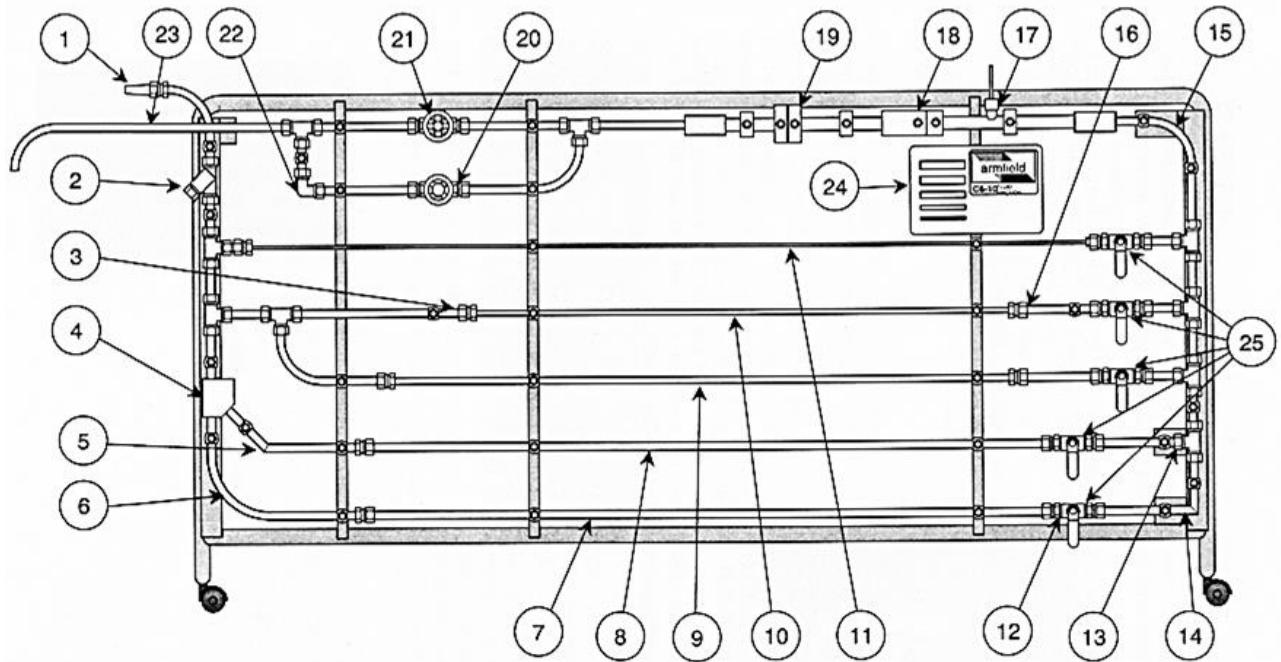


Figure 2.1: General Arrangement of C6-MKII-10 Fluid Friction Apparatus

Fig 2 - 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)
- 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)

EXPERIMENT NO. 5

MEASUREMENT OF VELOCITY HEAD DISTRIBUTION ALONG A VENTURI METER AND ORIFICE METER

Apparatus: Hydraulic benchh connected to fluid friction apparatus, u-tube manometer.

Reagent: water

Theory

In an orifice meter, the fluid is accelerated by causing in to flow through a constriction (orifice plate).

The kinetic energy is thereby increased and the pressure head decreases. The flow rate is obtained by measuring the pressure difference across the orifice plate

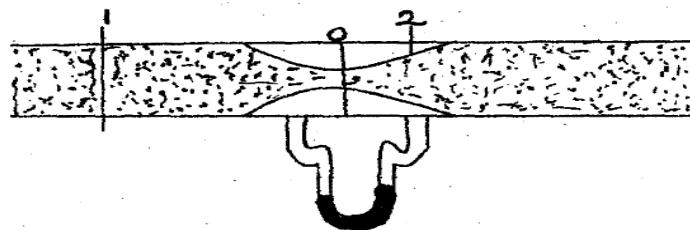


Fig. 1 An illustration of orificee meter

The linear average velocity of fluid through orifice is denoted with U

$$U_o = \frac{c_o \sqrt{2g\Delta H}}{\sqrt{1 - (\frac{D_2}{D_1})^4}} \quad \text{EQ 1}$$

Similarly, venturimeter consist of two tapered sections inserted in a pipe made smooth and gradual to minimize the frictional head loss.

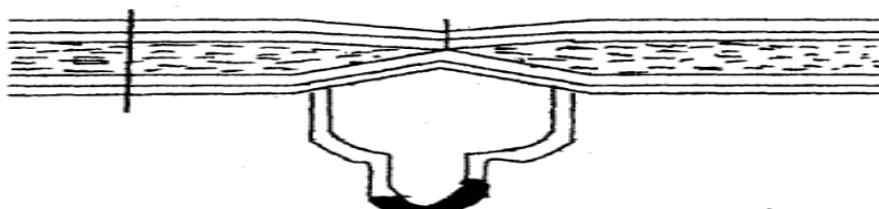


Fig. 2 An illustration of venture meter

The mean velocity of fluid through venture is denoted with V_v

$$U_v = \frac{C_v \sqrt{2g\Delta H}}{\sqrt{1 - (\frac{D_2}{D_1})^4}} \quad \text{EQ 2}$$

The velocity head of water along the two meters is

$$h = \frac{U^2}{2g}$$

Where u is the linear average velocity of fluid through the two meters. g is the acceleration due to gravity,

C_1 is the discharge coefficient for venture = 0.98, $Re > 10,000$

C_0 is the discharge coefficient for orifice = 0.62, $Re \approx 30,000$

D_1 is diameter of the pipe 24mm

D_2 is diameter for the venture = 14mm, 2 is diameter for the orifice = 20 mm

Procedure

1. Ensure that adequate fluid to be used is poured. In to the hydraulic bench connected to fluid friction apparatus. Switch on the hydraulic system via the socket and prime with the fluid in order to avoid bubbles in the orifice meter and venture meter- by opening appropriate valve at convenient degree and close other valves.
2. Cover the round hole in the hydraulic bench with round ball suspended on it and observe the operation for 30 seconds. Before using the u-tube manometer, blow off the water it contains. After then, measure and record the head loss in each of the meters by connecting u-tube manometer on selected part of the meters and volume of water should be recorded as well.
3. Observe the experiment for 40 secs. 50 secs. 60 sec. 70 secs and tabulate the results as below.

Time (s)	Head loss ΔH (m)	Volume of H_2O (m^3)	$U_v^2 (m^2/s^2)$	$U_0^2 (m^2/s^2)$	$h_{vv}(m)$	$h_{vo}(m)$
30						
40						
50						
60						
70						

Graph

Plot h_{vv} against U_v^2 and h_{vo} against U_0^2 . Find the respective slope and the value of g.

Question

- Calculate the average linear velocity of H₂O at the throat of venture meter, if the flow rate is 15 m³/s and diameter of venture is 14 mm.
- Determine from the graph of h_{vv} against U_v^2 , the value of U_v^2 when h_{vv} is 0.05m.

References

- ✓ W.J. Beck; Transport Phenomena
- ✓ S.K.Ghosal; Introduction to Chemical Engineering

EXPERIMENT NO. 6

DETERMINATION OF PRESSURE DROP IN ORIFICE AND VENTURE METER AS A RESULT OF SUDDEN CONTRACTION AND EXPANSION.

Apparatus: Hydraulic bench connected to fluid friction apparatus, u-tube manometer.

Reagent: water

Theory:

The pressure drops in pipelines containing valves and fittings, flow meters occurs because of frictional viscous forces. The loss in pressure due to sudden expansion from a diameter d_1 to a larger diameter d_2 is given by the equation;

$$\Delta P_e = \rho \frac{(U_1 - U_2)^2}{2} = \frac{\rho U_1^2}{2} \left[1 - \left(\frac{d_1}{d_2} \right)^2 \right]^2 \quad \text{eq. 1}$$

Where U_1 and U_2 are the mean linear velocities in the smaller entrance pipe and the larger exit pipe respectively.

The loss in pressure due to sudden contraction from a diameter d_1 to a smaller diameter d_2 is given by the equation

$$\Delta P_e = K \frac{\rho U_2^2}{2} \quad \text{eq. 2}$$

Where $k = 0.4 \left[1.25 - \frac{d_2}{d_1} \right] \text{ when } \frac{d_2^2}{d_1^2} < 0.715 \text{ & } k = 0.75 \left[1.00 - \left(\frac{d_2}{d_1} \right)^2 \right] \text{ when } \frac{d_2^2}{d_1^2} > 0.715$

U_2 is the mean linear velocity in the smaller exit pipe. Applying Bernoulli's theorem for steady flow between upstream section and the vena contracta section, assuming horizontal flow in the 'absence of both external work effects and friction and negligible variation of fluid density between the sections, the mean linear velocity of the fluid through the orifice is

$$U_0 = \frac{C_0 \sqrt{2g\Delta h}}{\sqrt{1 - \left(\frac{D_0}{D_1} \right)^4}} \quad \text{eq. 3}$$

Where D_0 is the diameter of orifice in mm, D_1 is the diameter of pipe upstream, Δh is the average differential head in meters of water, g is the acceleration due to gravity in m/s^2 ,

C_0 is the orifice discharge coefficient = 0.62.

Similarly, the mean linear velocity of the fluid through the venture meter is

$$U_v = \frac{C_v \sqrt{2g\Delta h}}{\sqrt{1 - \left(\frac{D_v}{D_1} \right)^4}} \quad \text{eq. 4}$$

Where C_v is the venture discharge coefficient = 0.98, D_v is the diameter of the venture in mm.

$$\Delta h = \frac{\Delta h_1 + \Delta h_2 + \Delta h_3 + \Delta h_4 + \Delta h_5}{5} \quad \text{eq. 5}$$

Procedure

1. Ensure that adequate fluid to be used is poured into the hydraulic bench connected to fluid friction apparatus.
2. Switch on the hydraulic system via the socket and prime with the fluid in order to avoid bubbles in the orifice meter and venture meter by opening appropriate valve at convenient degree and close other valves.
3. Cover the round hole in the hydraulic bench with round ball suspended on it and observe the operation for 30 seconds. Before using the u-tube manometer, blow off the water it contains.
4. After then, measure and record the head loss in each of the meters by connecting u – tube manometer on selected part of the meters and volume of water should be recorded as well.
5. Observe the experiment for 40 sees, 50 secs, 60 secs, 70 secs and tabulate the results as below.

Time(s)	Differential Head Δh (m)
40	Δh_1
50	Δh_2
60	Δh_3
70	Δh_4
80	Δh_5

References

- a) F.A. Holland; Fluid Flow for Chemical Engineers.
- b) Warren L. McCabe et. al; Unit Operations of Chemical Engineering.

FLUID MIXING APPARATUS

EXPERIMENT NO. 7

OBSERVATION OF VARIOUS FLOW PATTERNS INDUCED BY DIFFERENT IMPELLERS WITH AND WITHOUT BAFFLES.

Equipment: Fluid mixing apparatus filled with water up to a depth of 0.3m, flat paddle and turbine impellers, screw propeller, set of baffles, plastic pellets and dye

Introduction

This Liquid Mixing Equipment (Model: FM 103) is a bench-top unit designed for laboratory experiments on solid/liquid and liquid/liquid mixing. Student will be able to study the factors affecting mixing using visualization and measurement techniques.

Theory

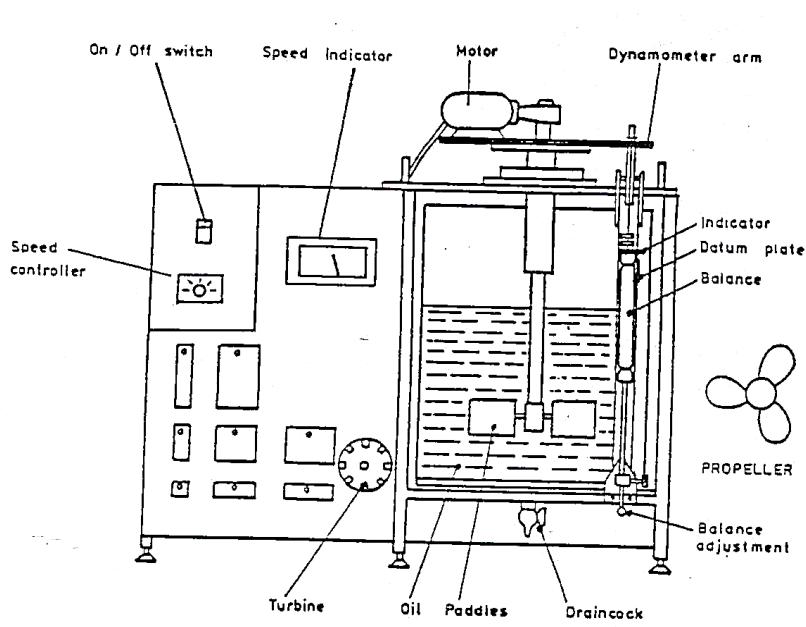
Mixing is a common operation in the process industries and is generally performed by a rotating impeller in a vessel. Products obtained from food, petroleum, mining, pharmaceutical, pulp and paper, and chemical industries would not be available without fluid mixing equipment and technology. Mixing also plays a vital role in industries waste treatment and in environmental cleaning, such as in sulfur dioxide absorption for treatment of acid rain.

Mixing implies taking two or more separate phases, such as two fluids, or a fluid and a powdered solid, and causing them to be randomly distributed through one another. While agitation usually refers to forcing a fluid by mechanical means to flow in a circulatory pattern inside a tank. Selection of the type of agitator depends on the viscosity of the fluid. Propellers are used for viscosities below about 3pas, turbines can be used below about 100pas, an anchor agitator can be used above 50pas to about 500pas, while helical and ribbon-type agitators are often used above the range. Mixing may involve single phase liquid, immiscible liquids and gas- liquid operation.

Procedure

- Attach flat paddle impeller with base of level with the end of the shaft. Add a small quantity of plastic pellets and make such that the torque and clamp is fixed.
- Turn up the speed of the impeller in small increments, say 25 r.p.m, until the pellets are seen to swirl around in the water.
- A vortex will be seen to form on the surface of the water. A small quantity of dye added to the water shows the mixing pattern of the liquid. As the speed is increased air is entrained and bubbles become dispersed through the 'water. Care should be taken to make sure that water does not spill over the sides of the tank by increasing the speed too much.
- Repeat the procedure with each impeller and again with the four baffles in position with each of the impellers.
- Observe the movement of dye and pellets in each case. When the concentration of dye becomes too high tank should be drained and refilled with fresh water.

Apparatus



Results

Discuss the various flow pattern of each of the impeller, with and without baffles.

Table 1: Different impeller + without baffles (water)

Types of impeller	Speed (rpm)	Torque, τ (Nm $^{-2}$)	Observation (Flow pattern)
Flat paddle	25	2.40	
	45	2.42	
	65	2.44	
	85	2.48	
Turbine impeller	25	2.30	
	45	2.33	
	65	2.37	
	85	2.42	
Screw propeller	25	3.20	
	45	3.24	
	65	3.28	
	85	3.33	

Plot

- i. Graph of Power against speed without baffle by using water and
- ii. Graph of Power against speed with baffle by using water

References

- a) Aubin, J., Mavros, P., Fletcher, D.F., Bertrand, J., Xuereb, C., 2001. Effect of axial agitator configuration (up-pumping, down-pumping, reverse rotation) on flow patterns generated in stirred vessels. Chemical Engineering Research Design 79, 845–856.
- b) Instruction Manual on Fluid Mixing Apparatus, issue 10, July 2005
- c) Mak, A.T.C. Solid-Liquid Mixing in Mechanically Agitated Vessels. Ph.D. Thesis, University of London, London, UK, 1992.

EXPERIMENT NO. 8

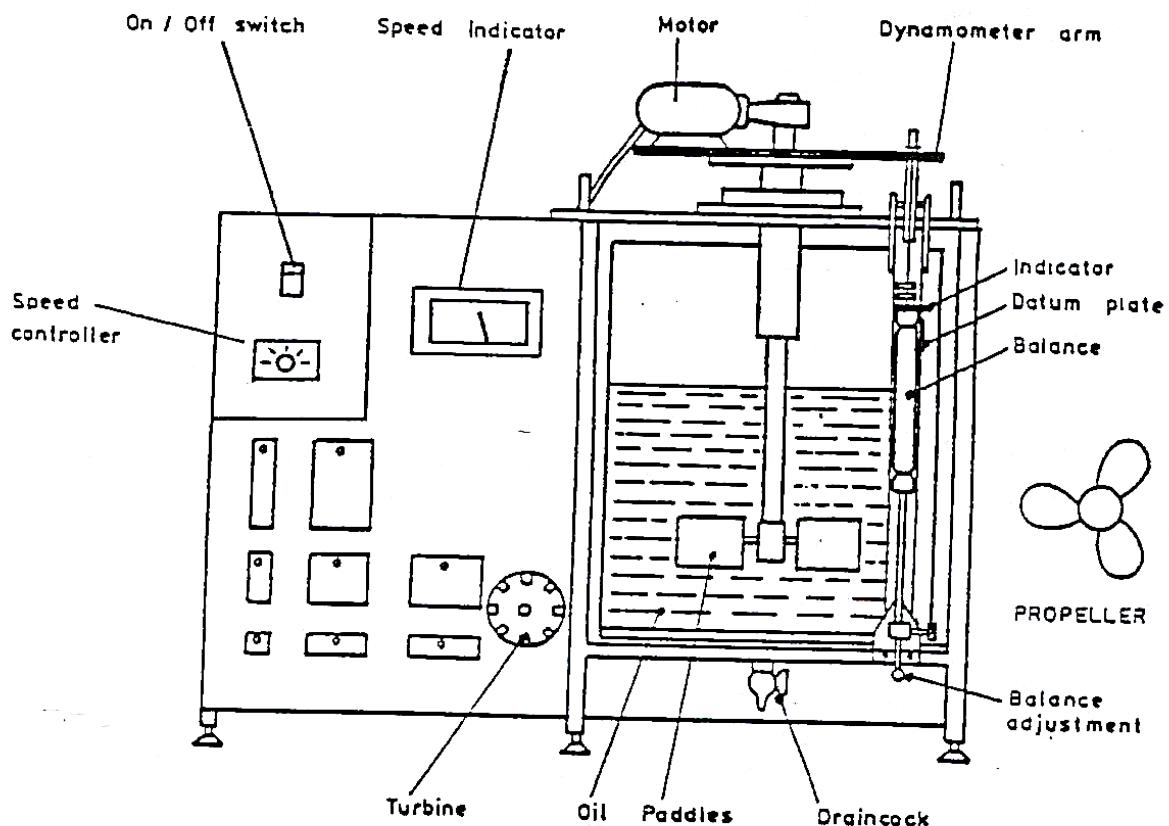
DETERMINATION OF POWER CONSUMPTION OF FLUID MIXING MACHINE

Objective

To show how the power consumed by a mixer varies with speed, type of impeller, and with the inclusion of baffles.

Equipment Set-up

Fluid Mixing Apparatus filled with medium or light oil up to a depth of 0.3m, flat paddle and turbine impellers, screw propeller; sets of baffles.



Summary of Theory

$$\text{Power (W)} = \text{Torque (T)} \times \text{Angular Speed } \omega \text{ (rad/s)}$$

$$\text{Torque (T)} = \text{Force recorded on spring balance} \times \text{length of torque arm (0.11 m)} (r)$$

Procedure:

- 1) Fill the tank up to a depth of 0.3m with light oil or water and attach the flat paddle impeller, 0.09m x 0.06m with the base of the bush level with the end of the shaft.

Release the balance adjustment clamp, and allow the dynamometer arm to move freely.

- 2) To set the dynamometer to a neutral position use the setting bar and adjust the tension spring as necessary. Adjust the length of the cord so that the indicator aligns with the mark on the datum plate in the neutral position.
- 3) Increase the speed control knob in gradual increments and record the speed on the speed indicator and the force on the balance at each speed of the mixer.
- 4) Repeat using the turbine impeller and other flat bladed paddles. The experiment can be repeated using angled rather than vertical paddles.
- 5) Repeat with the baffles fitted with each flat paddle and the turbine impeller.

Results:

Types impeller	Speed, rpm	Angular speed, ω (rad/s)	Force, F (N)	Torque, T (Nm ⁻²)	Power, P (watts)
Flat paddle	25				
	45				
	65				
	85				
Screw	25				
propeller	45				
	65				
	85				
Turbine	25				
impeller	45				
	65				
	85				

Formula:

$$\begin{aligned}\text{Area of flat paddle impeller} &= 0.09\text{m} \times 0.06\text{m} \\ &= 0.0054 \text{ m}^2\end{aligned}$$

Torque arm radius = 0.11m

$$\begin{aligned}\text{Torque (T)} &= \text{Balance reading} \times 9.81 \text{ (Newton's)} \times \text{torque arm radius (m)} \\ &= 3.23 \times 9.81 \times 0.11 \\ &= 3.49 \text{ N/m}^{-2}\end{aligned}$$

Angular speed = rpm x (2π / 60)

$$\begin{aligned}&= 100 \text{ rpm} \times 2 (3.142) / 60 \\ &= 10.47 \text{ rad/s}\end{aligned}$$

Force (N) = N/m² (torque) x m² (area of flat paddle)

$$\begin{aligned}&= 3.49 \times 0.0054 \\ &= 0.0188 \text{ N}\end{aligned}$$

Power (W) = Torque (T) x Angular Speed ω (rad/s)

$$\begin{aligned}&= 3.23 \times 10.47 \\ &= 6.79 \text{ watts}\end{aligned}$$

Torque arm (r) = 0.11 m

Angular speed (ω) = r.p.m. x 2π/60 = rad/s

Result

- Plot the power consumed vs. area at different speed values without baffles only.
- Plot the power consumed vs. area at different torque values without baffles only.
- Discuss the shape of the curves.

HEAT TRANSFER

(Transport Phenomena II)

TRAY DRYER

EXPERIMENT NO. 9

DETERMINATION OF OVERALL DRYING RATE OF A TRAY 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 and stop watch.

Sample: wet sand or any lumpy solid

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.

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

Procedure

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.

RESULT

Tabulate the results obtained as below:

Time (mins)	Mass of Sand (g)	Free moisture content (Kg H ₂ O/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>

EXPERIMENT NO. 10

DETERMINATION OF CONDUCTIVITY OF METAL SPECIMENS

Apparatus: HR10X Heat transfer unit and HT11 Linear conduction accessory.

Theory and Principles

The heated, intermediate and cooled sections are clamped tightly together, so that the end faces are in full thermal contact, and create a composite bar with a metal specimens of unknown thermal conductivities sandwiched between two specimens.

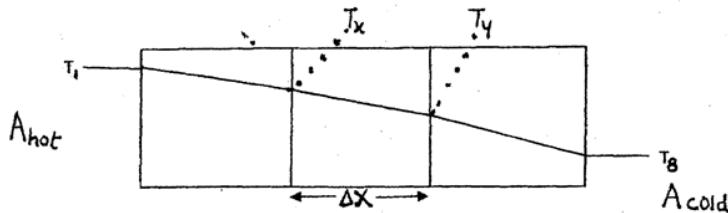


Fig. II an illustration of heat transfers through conduction

From Fourier's law,

$$Q = KA \frac{dT}{dx} \text{ Where } dT = T_x - T_y \text{ and } T_x = T_3 - \left(\frac{T_2 - T_3}{2} \right), T_y = T_6 + \left(\frac{T_7 - T_6}{2} \right)$$

K = is the thermal conductivity of specimen, T_x is the temperature at the hot face

A = is the cross-sectional area, T_y is the temperature at the cold face

dT = is the temperature difference

dX = is the length of the specimen

$$\text{Heat flow (Q)} = VI \text{ (w)}$$

$$A = \frac{\pi D^2}{4} \text{ (m}^2\text{)}$$

$$\text{Temperature difference in heated section } \Delta T_{hot} = T_1 - T_3 \text{ (}^\circ\text{C)}$$

$$\text{Conductivity in heated section } K_{hot} = \frac{X_{13}Q}{\Delta T_{hot}A_{hot}} \quad \left(\frac{W}{m \cdot ^\circ C} \right)$$

$$\text{Temperature difference in intermediate section } (\Delta T_{int}) = \Delta T_{int} = T_4 - T_3$$

$$\text{Conductivity in intermediate section } (K_{int}) = \frac{X_{45}Q}{\Delta T_{int}A_{int}} \quad \left(\frac{W}{m \cdot ^\circ C} \right)$$

$$\text{Temperature difference in cooled section } (\Delta t_{cold}) = T_6 - T_8 \text{ (}^\circ\text{C)}$$

$$\text{Conductivity in cooled section } (K_{cold}) = \frac{X_{68}Q}{\Delta T_{cold}A_{cold}} \quad \left(\frac{W}{m \cdot ^\circ C} \right)$$

Procedure

- Clamp the intermediate specimen section between the heated and cooled section of the HT111 having lightly coated the mating faces with thermal paste.
- Connect the eight thermocouples on the HT11 to the appropriate sockets on the front of the service unit. Ensure that the labels on the thermocouple leads (T_1-T_8) match the labels on the sockets.
- Set the voltage control potentiometer to minimum (anticlockwise) and the selector switch to manual, then connect the heater lead from the HT11 to the socket marked O/P_3 at the rear of service unit.
- Ensure that a cold-water supply is connected to the inlet of the pressure regulating valve on HT11.
- Ensure that the flexible cooling water outlet tube is directed to a suitable drain. Switch on the front mains switch. (if the panel meters do not illuminate check the RCD and circuit breakers at the rear of the service unit, all switches at the rear should be up.)
- Turn on the cooling water and adjust the flow control valve to give approximately 1.5 litres/min.
- Set the heater voltage to 9 volts — via voltage control potentiometer with the selector switch set to position V.
- Allow the HT11 to stabilize and when the temperatures are stable record the following $T_1, T_2, T_3, T_6, T_7, T_8, V, I$ and F_w if sensor SFT2 is fitted. Set the heater voltage to 12 volts.
- Allow the HT11 to stabilize, then repeat the above readings and tabulate your result as below;

S/NO	Voltage (V)	Amp (A)	$T_1 (^{\circ}C)$	$T_2 (^{\circ}C)$	$T_3 (^{\circ}C)$	$T_6 (^{\circ}C)$	$T_7 (^{\circ}C)$	$T_8 (^{\circ}C)$	I	F_w
1	9 volts									
2	12 volts									

Graph:

Plot a graph of temperature against position along the bar and draw the best straight line through the points for the heated section and cooled section.

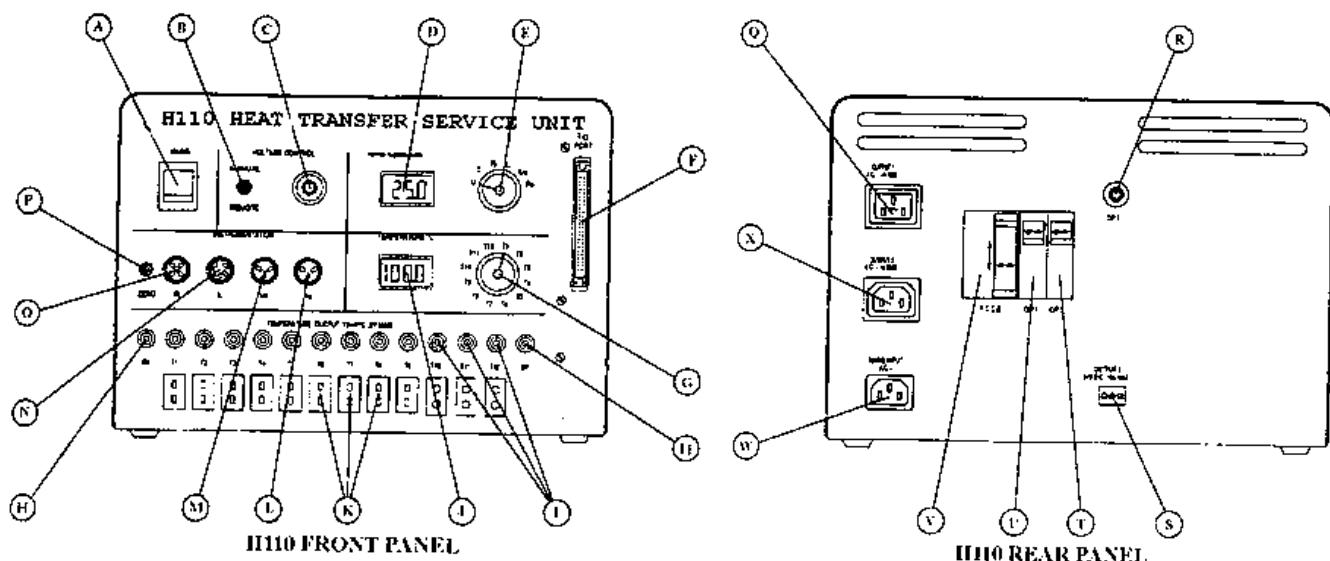
Questions:

- 1) Compare the values obtained for the thermal conductivity at the different settings of heat flow through the specimen.
- 2) Measure the temperature gradient through the aluminum section from the graph. Then calculate the thermal conductivity using the average gradient.

References:

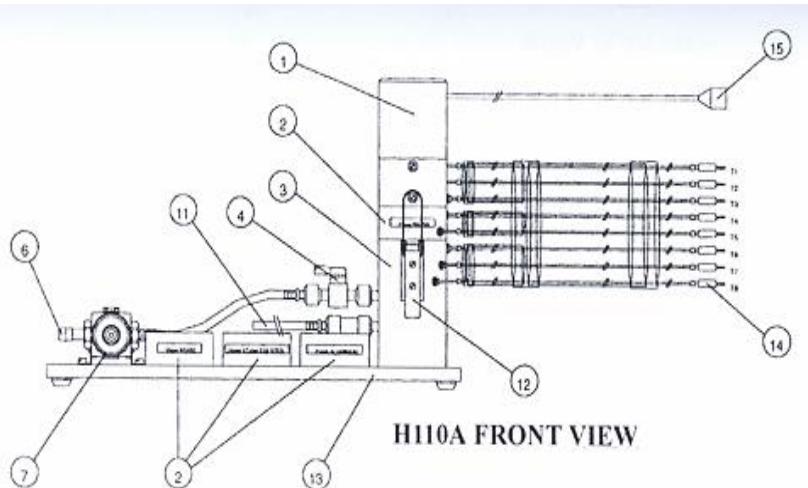
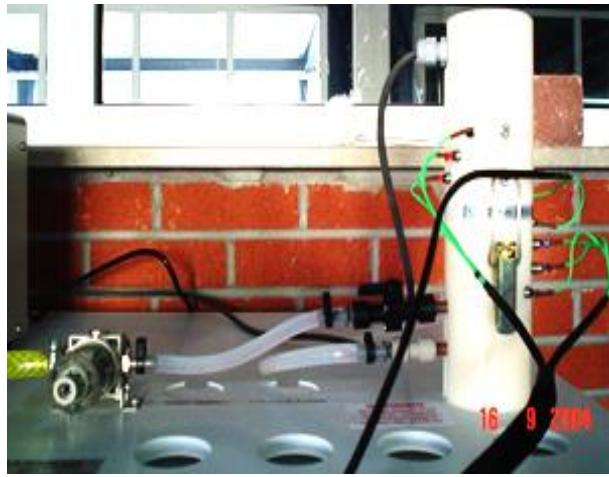
- ✓ Introduction Manual on Linear Heat Conduction, Issue 3, July 2005.
- ✓ Perry H.P et, al. Chemical Engineer's Handbook

CONFIGURATION OF CONTROL PANEL

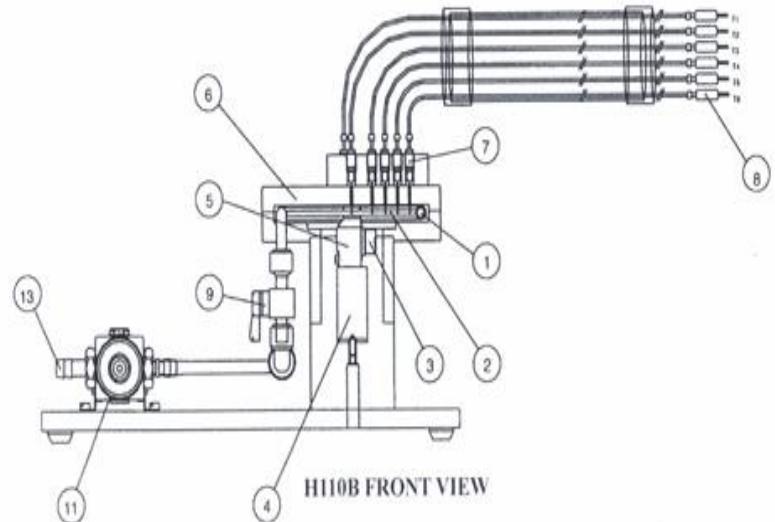


- | | |
|----------|--|
| A | on/off switch |
| B | Manual/Remote control |
| C | Voltage control potentiometer |
| D | Display Volts (V), Current (I), Thermal radiation (R), Light illumination (L), air velocity (Ua), Cooling water flow rate (Fw) |
| E | Rotary selector switch for V, I, R, L, Ua, and Fw |
| F | IO port |

LINEAR HEAT CONDUCTION UNIT



1 heating section, 2 intermediate section, 3 cooling section, 4 manual control valve, 6 hose coupling pressure regulator, 11 outlet hose, 12 toggle clamps, 13 PVC base plate, 14 thermocouple plugs (extreme right), 15 plug and lead



RADIAL HEAT CONDUCTION UNIT

1 brass disc, 2 solid disc of brass (110mm diameter), 3 heating section, 4 central heater, 5 solid copper core (14mm diameter), 6 insulation material, 7 six fixed thermocouples, 8 miniature plug, 9 manual control valve 11 pressure regulator, 13 hose coupling, 15 plug and lead.

EXPERIMENT NO. 11

CALIBRATION AND USES OF BASIC TYPES OF TEMPERATURE MEASURING INSTRUMENTS

Apparatus: stop watch, thermocouple with probe, beaker, and tripod stand, Bunsen burner with its fitting s and wire gauze.

Reagent: Water

Theory:

Temperature is the degree of coldness or hotness of a body as a result of heat flow. It can be measured by means of a thermocouple and other related temperature measuring instrument such as liquid in glass thermometer, clinical thermometer, pyrometer, gas thermometer e.t.c.

Thermometers use some physical properties of a substance which changes as proportion to temperature changes. Having chosen a thermometric property x , we can construct a scale.

A measurement of x at the two fixed points is made and the scale is constructed as illustrated below.

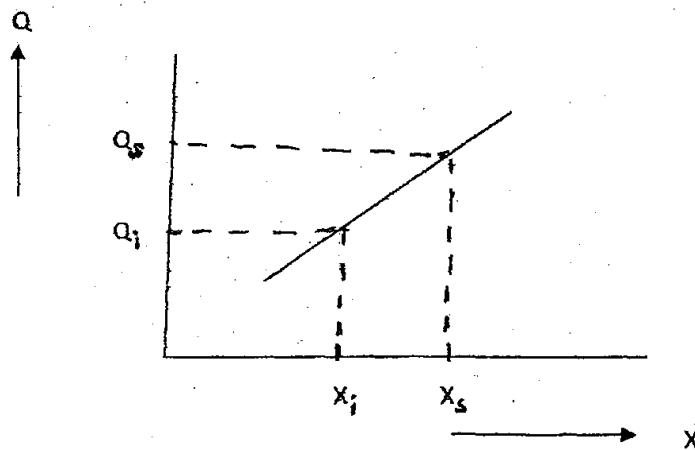


Fig 1 illustration of temperature measurement with respect to thermometric property
 The values of temperature Q and Q_s are defined as the steam and ice points respectively, and are measured at these points to construct a straight line.

Conversion:

Temperature measured in Celsius can be converted to Kelvin with the relation of $X^{\circ}\text{K} = X^{\circ}\text{C} + 273$, where x is the value.

Conversion from degree Celsius to Fahrenheit conform with mathematical relation of $\frac{5}{9} (Y^{\circ}\text{F} - 32) = X^{\circ}\text{C}$

From degree Fahrenheit to Rankine $T^{\circ}\text{R} = T^{\circ}\text{F} + 459.67$

Procedure

Switch the given thermocouple on by holding down the 1:0 key for 1-2 seconds and at the same time press the hold key.

Place the temperature probe into an ice bath and allow the reading to stabilize. Press mode key to calibrate the reading to 0°C .

The instrument has now performed the probe offset calibration and is ready for use.

1. Set the Bunsen burner to produce light blue flame and wire gauze should be placed over the tripod stand.
2. Place a beaker with known volume of water on the tripod stand.
3. Insert the probe of thermocouple in the beaker containing water and heat for 2 minutes, while recording the temperature and volume of water that remain
4. Repeat the experiment for 4 mins., 6 mins, 8 mins, and 10 mins.

Tabulate results obtained as below:

Time (s)	Temperature ($^{\circ}\text{C}$)	Volume of water (remain) (m^3)

Graph:

Plot temperature against time and volume remain against temperature.

References

- ✓ John E.W; Modern physics
- ✓ Perry et. al; Chemical Engineering Handbook

EXPERIMENT NO 12

PARALLEL FLOW AND COUNTER FLOW HEAT EXCHANGER

Aim

- a) To calculate the overall Heat transfer coefficient of the heat exchanger.
- b) To calculate the local heat transfer coefficient of the heat exchanger using Seider Tate Equation and Dittus-Boelter Equation.

Objective

To study the heat transfer phenomena in parallel and counter flow arrangements.

Introduction

Heat Exchanger is a device in which heat is transferred from one fluid to another. The necessity for doing this arises in a multitude of industrial applications. Common examples of heat exchangers are the radiator of a car, the condenser at the back of a domestic refrigerator and the steam boiler of a thermal power plant.

Theory

The double-pipe heat exchanger is one of the simplest types of heat exchangers. It is called a double-pipe exchanger because one fluid flows inside a pipe and the other fluid flows between that pipe and another pipe that surrounds the first. This is a concentric tube construction. Flow in a double-pipe heat exchanger can be co-current or counter-current. There are two flow configurations: co-current is when the flow of the two streams is in the same direction, counter current is when the flow of the streams is in opposite directions.

As conditions in the pipes change: inlet temperatures, flow rates, fluid properties, fluid composition, etc., the amount of heat transferred also changes. This transient behaviour leads to change in process temperatures, which will lead to a point where the temperature distribution becomes steady. When heat is beginning to be transferred, this changes the temperature of the fluids. Until these temperatures reach a steady state their behaviour is dependent on time.

In this double-pipe heat exchanger a hot process fluid flowing through the inner pipe transfers its heat to cooling water flowing in the outer pipe. The system is in steady state until conditions change, such as flow rate or inlet temperature. These changes in conditions cause the temperature distribution to change with time until a new steady state is reached. The new steady state will be observed once the inlet and outlet temperatures for the process and coolant fluid become stable. In reality, the temperatures will never be completely stable, but with large enough changes in inlet temperatures or flow rates a relative steady state can be experimentally observed.

As with any process the analysis of a heat exchanger begins with an energy and material balance. Before doing a complete energy balance a few assumptions can be made. The first assumption is that the energy lost to the surroundings from the cooling water or from the U-bends in the inner pipe to the surroundings is negligible. We also assume negligible potential or kinetic energy changes and constant physical properties such as specific heats and density. These assumptions also simplify the basic heat-exchanger equations.

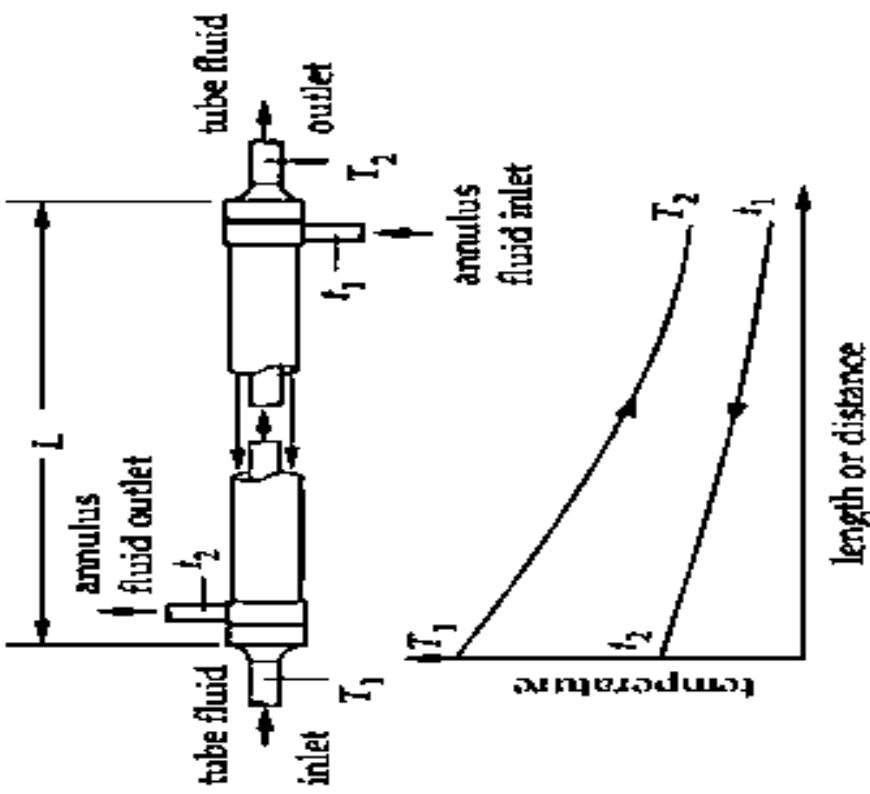
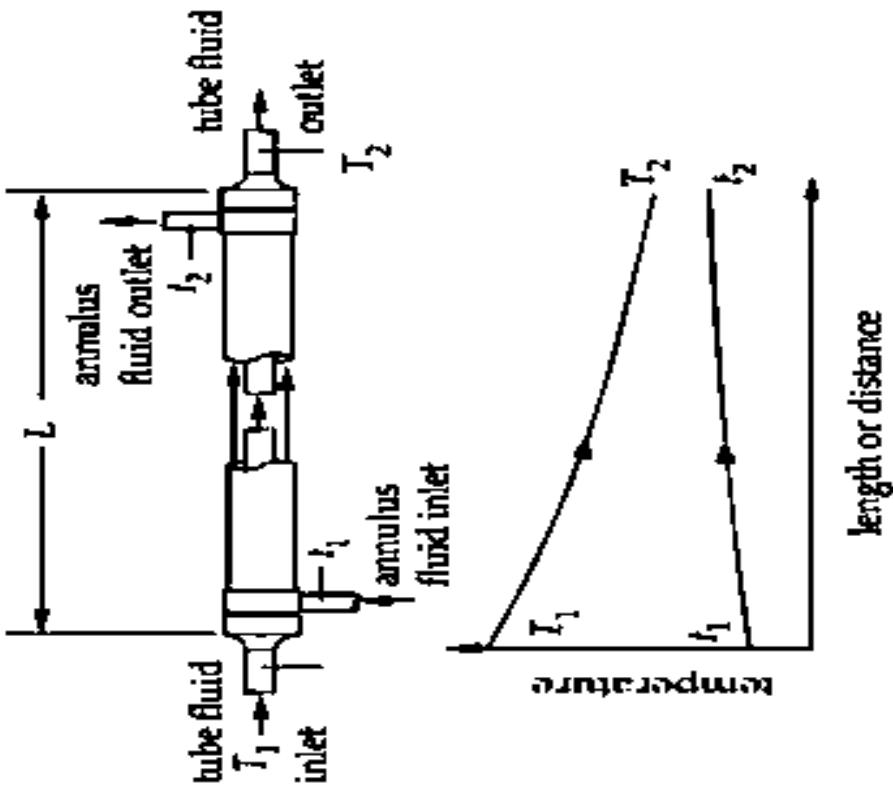
Description:

The apparatus consists of a tube in tube type concentric tube heat exchanger. The hot fluid is hot water which obtained from an insulated water bath using a magnetic drive pump arid it flows through the inner tube while the cold fluid is cold water flowing through the annuls. The hot water flows always in one direction and the flow rate of which is controlled by means of a valve. The cold water can be admitted at one of the end enabling the heat exchanger to run as a parallel flow apparatus or a counter flow apparatus. This is done by valve operations. For flow measurement Rotameters are provided at inlet of cold water and outlet of hot water line. A magnetic drive pump is used to circulate the hot water from a recycled type water tank, which is fitted with heaters and Digital Temperature Controller.

Utilities required:

1. Electric Supply: Single Phase, 220 VAC, 50Hz, 15Amp socket with earth connection.
2. Water Supply: Continuous @ 5 LPM at 1 Bar.

3. Floor Drain Required.
4. Floor Area Required: 1.75 m x 0.5m



1. A double pipe heat exchanger set up in counterflow and the corresponding temperature profile.

2. A double pipe heat exchanger set up in parallel flow and the corresponding temperature profile.

Experimental Procedure

Starting procedure

1. Close all the valves provided on the setup
2. Open the lid of hot water tank, fill the tank with water and put lid back to its position
3. Ensure that switches given on the panel are at OFF position
4. Connect electric supply to the setup
5. Set the desired water temperature in the DTC by operating the increment or decrement and set button of DTC
6. Open bypass valve and switch on the pump
7. Switch ON the heater and wait till desired temperature is achieved
8. Connect cooling water supply to the set up
9. Connect both the outlet (parallel/counter) of cooling water to drain
10. Open the inlet and outlet valve for cold water as per desired mode (parallel/counterflow)
11. Allow cold water to flow through heat exchanger and adjust the flowrate by rotometer and control valve
12. Allow hot water to flow through heat exchanger and adjust the flowrate by rotometer control valve and bypass valve
13. At steady state (constant temperature) record the temperature & flowrate of hot and cold water
14. Repeat the experiment for different flowrate of hot and cold water
15. Repeat the experiment for different bath temperature
16. Repeat the experiment for other mode (counter/parallel flow)

Closing procedure

1. When experiment is over switch OFF heaters
2. Switch OFF pump
3. Switch OFF power supply to panel
4. Stop cooling water supply
5. Drain hot water tank by the drain valve provided

Observation and calculation

Data

D_i = 0.0095 m
 D_0 = 0.0127 m
 L = 1.5 m

Counter current:

S/N	Flow rate mh (Kg/m)	Flow rate mc (Kg/m)	Hot water in (°C)	Hot water out (°C)	Cold water in (°C)	Cold water out (°C)

Co-current:

Tubing Sizes

IDa =

IDp = ODp =

S/N	Flow rate mh (Kg/m)	Flow rate mc (Kg/m)	Hot water in (°C)	Hot water out (°C)	Cold water in (°C)	Cold water out (°C)

Area of pipe $A_i = \pi * D_i * L =$

Area of annulus $A_0 = \pi * D_o * L =$

Fluid Velocity

Results

The Over All heat transfer coefficient =

The local heat transfer coefficient =

\dot{m}_w	=	T_1	=
ρ	=	C_p	=
k_f	=	α	=
v	=	Pr	=
\dot{m}_c	=	t_1	=
ρ	=	C_p	=
k_f	=	α	=
v	=	Pr	=

Assumption

- Steady state conditions exist.
- Fluid properties remain constant and are evaluated at a temperature of fluid.

Nomenclature

T refers to the temperature of the warmer fluid.

t refers to the temperature of the cooler fluid.

w subscript refers to the warmer fluid.

h subscript refers to hydraulic diameter

c subscript refers to the cooler fluid.

a subscript refers to the annular flow area or dimension.

p subscript refers to the tubular flow area or dimension.

1 subscript refers to an inlet condition.

2 subscript refers to an outlet condition.

e subscript refers to equivalent diameter.

Fluid Properties

Any heat exchanger design requires rigorous analysis. One of the most essential parts of the heat exchanger analysis is determination of the overall heat transfer coefficient. The overall heat transfer coefficient is defined in terms of the total thermal resistance to heat transfer between two fluids.

The heat lost by the hot fluid can be calculated

1. Rate of heat transfer from Hot water

$$Q_h = M_h C_{ph} (T_{hi} - T_{h0}), \text{ watt}$$

2. Rate of heat transfer to cold water

$$Q_c = M_c C_{pc} (T_{co} - T_{ci}), \text{ watt}$$

3. Average heat transfer

$$Q = \frac{Q_h + Q_c}{2}, \text{ watt}$$

4. LMTD

$$\Delta T_m = \frac{\Delta T_2 - \Delta T_1}{\ln \frac{\Delta T_2}{\Delta T_1}}, {}^0C$$

5. Overall heat transfer coefficient,

$$U_i = \frac{Q}{A_i F \Delta T_m}, \text{ W/m}^2 {}^0C$$

$$U_o = \frac{Q}{A_o F \Delta T_m}, \text{ W/m}^2 {}^0C$$

Heat transfer rate, is calculated as;

$$Q_h = \dots \text{W}$$

$$Q_c = \dots \text{W}$$

$$Q = \frac{Q_h + Q_c}{2} \text{ W}$$

(Assume $C_{ph} = C_{pc} = 4.176 \text{ J/kg} {}^0C$)

LMTD; Logarithmic mean temperature difference that can be calculated as per the following formula:

$$LMTD = \Delta T_m = \frac{\Delta T_i - \Delta T_o}{\ln \left(\frac{\Delta T_i}{\Delta T_o} \right)}, {}^0C$$

Where

$$\Delta T_1 = T_{hi} - T_{ci} \text{ (for parallel flow)}$$

$$= T_{hi} - T_{co} \text{ (for counter flow)}$$

$$\Delta T_2 = T_{ho} - T_{co} \text{ (for parallel flow)}$$

$$= T_{ho} - T_{ci} \text{ (for counter flow)}$$

- Note that in a special case of Counter Flow Exchanger exists when the heat capacity rates $C_c & C_h$ are equal, then $T_{hi} - T_{co} = T_{ho} - T_{ci}$ thereby making $\Delta T_i = \Delta T_o$. In this case LMTD is of the form 0/0 and so undefined. But it is obvious that since ΔT is constant throughout the exchanger, hence

$$\Delta T_m = \Delta T_i = \Delta T_o$$

(acc. to ref. Fundamental of Engineering Heat & Mass Transfer by R.C. Sachdeva, Pg. 499)

Overall heat transfer coefficient can be calculated by using.

$$Q = UA\Delta T_m$$

$$\therefore U_i = \frac{Q}{(A_i \Delta T_m)} \text{ W/m}^2 \text{ } ^\circ\text{C}$$

$$\therefore U_0 = \frac{Q}{(A_0 \Delta T_m)} \text{ W/m}^2 \text{ } ^\circ\text{C}$$

$$M_h = \frac{F_h x \rho_h}{3600 \times 1000}, \text{ kg/s}$$

$$M_c = \frac{F_c x \rho_h}{3600 \times 1000}, \text{ kg/s}$$

Nomenclature:

M_c	=	mass Cold water flow rate, Kg/s
M_h	=	mass Hot water flow rate, Kg/s
T_{ci}	=	Cold water inlet temp.
T_{hi}	=	Hot water inlet temp.
T_{co}	=	Cold water outlet temp.
T_{ho}	=	Hot water outlet temp.
T_c	=	Mean temp. of cold water
T_h	=	Mean temp. of hot water,
ρ_c	=	Density of Cold fluid, kg/m ³
C_{pc}	=	Specific heat of cold fluid, J/kg- $^\circ\text{C}$
ρ_c	=	Thermal Conductivity of cold fluid, W/m $^\circ\text{C}$
ρ_h	=	Density of Hot fluid, kg/m ³
C_{ph}	=	Specific heat of Hot fluid, J/kg $^\circ\text{C}$
ρ_h	=	Thermal Conductivity of Hot fluid, W/m $^\circ\text{C}$
Q_h	=	Heat lost by hot water, W
Q_c	=	Heat gained by cold water, W
Q	=	Average heat transfer, W
LMTD	=	Logarithm mean temp. difference
A	=	Area of Heat Transfer, m ²
D_i	=	Inner diameter of tube, m
D_o	=	Outer dia of S.S tube, m
L	=	length of the tube, m
U_1	=	Inside overall heat transfer coefficient, W/m ² $^\circ\text{C}$
U_0	=	Outside overall heat transfer coefficient, W/m ² $^\circ\text{C}$
U	=	Overall heat transfer coefficient, W/m ² $^\circ\text{C}$
F_h	=	Flow rate of hot water, LPH
F	=	Flow rate of cold water, LPH

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.

Trouble Shooting:

1. If electric panel is not showing the input on the mains light, check the main supply.

Properties of Water

1. Arora. Domukundwar, "A **course in Heat & Mass Transfer**", 6th ed., Dhanpat Rai & Co. (P) LTD., NY, 2003, Page A.6

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3. McCabe, W.L., Smith, J.C., Harriott, P., "**Unit Operations of Chemical Engineering**", 4th ed. McGraw Hill, NY, 1985.
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FIXED AND FLUIDIZED BED SYSTEM

EXPERIMENT NO: 13

DRYING CHARACTERISTICS OF A GIVEN MATERIAL

Object:

To study the 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 | = | 68.4 – 29 | = | 39.4 g |
| 3. Drying temperature | = | 60.4 °C | | |
| 4. Surface area of the material (A) | = | $52281 \times 10^{-3} \text{ m}^2$ | | |
| 5. Inlet air | | | | |
| a) Dry bulb temp | = | 29°C | | |
| b) Wet bulb temp | = | 28.7°C | | |

6. Air flow rate

$$(G) = 1.78 \times 10^{-4} \text{ Kgs}$$

7. Weight of final sample = 48.4 gm

Calculations:

$$\text{Rate of drying, } = G (H_2 - H_1) \quad \text{eq. (1)}$$

Where:

$$H_2 \text{ is the outlet humidity of air} = \text{kg water/kg dry air}$$

$$H_1 \text{ is the inlet humidity of air} = \text{kg water/kg dry air}$$

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

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°C
2) Initial wet bulb temperature	=	53.9°C
3) LPM	=	6
4) Wt of petri dish	=	29g
5) Wt of dry material	=	49.6g
6) Wt of wet material	=	68.4g
7) Diameter	=	4.5cm
8) Bed height	=	3.7cm
9) V	=	230v
10) I	=	054mA

Temperature after every 1 minute

Dry bulb °C	Wet Bulb °C
59	48.4
46.7	45.8
45.3	44.2
44.8	44.5
45	43.9
45.1	43.4
44.4	42.6
44.8	42.6

46.3	42.7
48.2	43.7
50.2	44.9
52	46.9
54.2	48.3
56.4	50.7
58.7	53.2
60.7	55.2

Calculations

$$1) \quad A = 2Brh = 2 \times 3.14 \times 2.25 \times 10^{-2} \times (3.7 \times 10^{-2}) \\ \therefore A = 5.2281 \times 10^{-3} \text{ m}^2$$

$$2) \quad \frac{dw}{dt} = 6(H_2 - H_1) \\ Q = 6LPM = \frac{6 \times 10^{-3} \text{ m}^3}{60} = 10^{-4} \text{ m}^3/\text{sec}$$

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

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

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

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

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

Moisture content after 2 minutes =

$$\frac{(wt \text{ of wet material} - wt \text{ of dry material})}{(wt \text{ of dry material})} \times 100$$

$$= \frac{(68.4 - 1.032 \times 10^2 \times 60) - 49.6}{(49.6)} \times 10$$

$$= 36.65\%$$

$$\text{Moisture content after 1 minute} = \frac{(68.4 - 0.0137) - 49.6}{(49.6)} \times 100$$

$$= \frac{(68.4 - 1.032 \times 10^2 \times 60)}{(49.6)} \times 10$$

$$= 37.8\%$$

$$\text{Average moisture content} = \frac{36.65 + 37.8}{2} = 37.22 \text{ g/g}$$

Result:

$$\text{Equilibrium moisture} = 20\%$$

$$\text{Critical Moisture} = 34.2\%$$

$$\text{Eqn for falling rate period} = 8.88 \times 10^{-4} w - 0.0011 = \frac{dw}{dt}$$

$$\text{Eqn for Constant rate period} = 0.0082 = \frac{dw}{dt}$$

Experimental Observation

S/N	Time (min)	DBT	WBT (°C)	H ₂	dw/dt (gm)	dw/Δt (gm/m ² s)	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
16	15	58.7	53.2	0.094	0.013	2.45	21.77
17	16	60.7	55.2	0.1	0.014	2.65	20.12
18							
19							
20							

Results:

A plot of drying rate vs moisture content indicates the drying characteristics of the material.

Its critical moisture content is = °h and its equilibrium moisture content is °k The equation for constant drying rate; period is $dw/dt = 8.88 \times 10^{-4} w - 0.0011$ and that for falling rate period is $dw/dt = 0.0082$

CENTRIFUGAL PUMP TEST RIG

EXPERIMENT NO 14

DETERMINATION OF PUMP EFFICIENCY

Objective: Study of Centrifugal pumps characteristics.

Aim:

1. To Determine

- A. Pump Efficiency
- B. Overall Efficiency

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

Main component parts of centrifugal pump are:

- Impeller
- Casing
- Suction pipe with a foot valve and a strainer
- Delivery pipe

Impeller: It is a wheel or rotor which is provided with a series of blades or vanes. It is mounted on the shaft which is coupled to an external source of energy (usually an electric motor) which imparts the required to the impeller thereby making it to rotate.

Casing: It is the airtight chamber which surrounds the impeller. It consists of two opening, one for suction and other for delivery of liquid. The following three types of casings are adopted:

1. Volute casing
2. Vortex casing
3. Casing with guide blades

Suction: A pipe whose one end is connected to inlet of the pump and other end dips into water in a sump is known as suction pipe. Sometimes a foot valve which is a non-return valve or one-way type of valve is fitted at the lower end of the suction pipe used with high power pump to avoid priming process again and again.

Delivery Pipe: A pipe whose one end is connected to the outlet of the pump and other end delivers the water at a required height is known as delivery pipe.

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 $H_s = h_s + h_d$
- **Manometric Head (H_m):** The manometric head is defined as the head against which a centrifugal pump has to work.

$$\begin{aligned} H_m &= \text{Head imparted by the impeller — loss of head in the pump} \\ H_m &= \text{Total head at outlet of the pump — Total head at inlet of pump} \\ H_m &= h_s + h_d + h_{f5} + h_{fd} + V_d^2/2g \\ H_f &= \text{frictional head loss in suction pipe, } h_{fd} = \text{frictional head loss in delivery pipe} \end{aligned}$$

- **Efficiencies of a Centrifugal Pump:** In case of centrifugal pump, the power is transmitted from the shaft of the electric motor to the shaft of the pump and then to 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_o

Manometric Efficiency (η_{man}): The ratio of the manometric head to the head imparted by the impeller to the water is known as manometric efficiency. Mathematically, it is written as

$$\begin{aligned} \eta_{man} &= \text{Manometric head/ Head imparted by impeller to water} \\ &= g H_m / V_w^2 U_2 \end{aligned}$$

Mechanical Efficiency (η_m): The power at the shaft of the centrifugal pump is more than the power available at the impeller of the pump. The ratio of the power available at the impeller to the power at the shaft of the centrifugal pump is known as mechanical efficiency. It is written as

$$\eta_m = \text{power at the impeller/power at the shaft}$$

$$\eta_m = W/g (V_w^2 U_2 / 1000) / S.P.$$

S.P. = Shaft power.

Overall Efficiency (η_o): It is defined as ratio of power output of the pump to the power input to the pump. The power output of the pump in kW = Weight of water lifted $\times H_m / 1000 = W H_m / 1000$

Power input to the pump = Power supplied by the electric motor

= S.P. of the pump

$$\eta_o = \eta_{man} \times \eta_m$$

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.

Utilities Required

Electric Supply : 220 V AC, 50Hz Single Phase Supply with Proper Earthing.

Water Supply : Tap Water Connection V ½ BSP

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 m/sec ²
Density of Water ρ	1000 kg/m ³
Motor Efficiency η _{Motor}	80%
Transmission Efficiency η _{Transmission}	65%
Conversion Factor	1 kg/cm ² = 0.104 m of Water
Tank	400mm x 250mm

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

$$H = 10.3 \times (P_d + \frac{P_d}{760}) \text{ m of Water.}$$

Actual Discharge (Qa)

$$P_d = \frac{A \times R}{t} \text{ m}^3/\text{s}$$

Electrical Input(HP)

$$\text{Electrical Input} = \frac{P \times 3600 \times 1000}{t \times EMC \times 746} \text{ HP}$$

Pump Output

$$\text{PumpOutput} = \frac{g \times \rho \times Q \times H}{746} \text{ HP}$$

Shaft HP

$$\text{Shaft Power} = \text{Electrical Input} \times \eta_{\text{motor}} \times \eta_{\text{Transmission}}$$

Pump Efficiency η_p

$$\eta_p \% = \frac{\text{PumpOutput}}{\text{ShaftPower}} \times 100$$

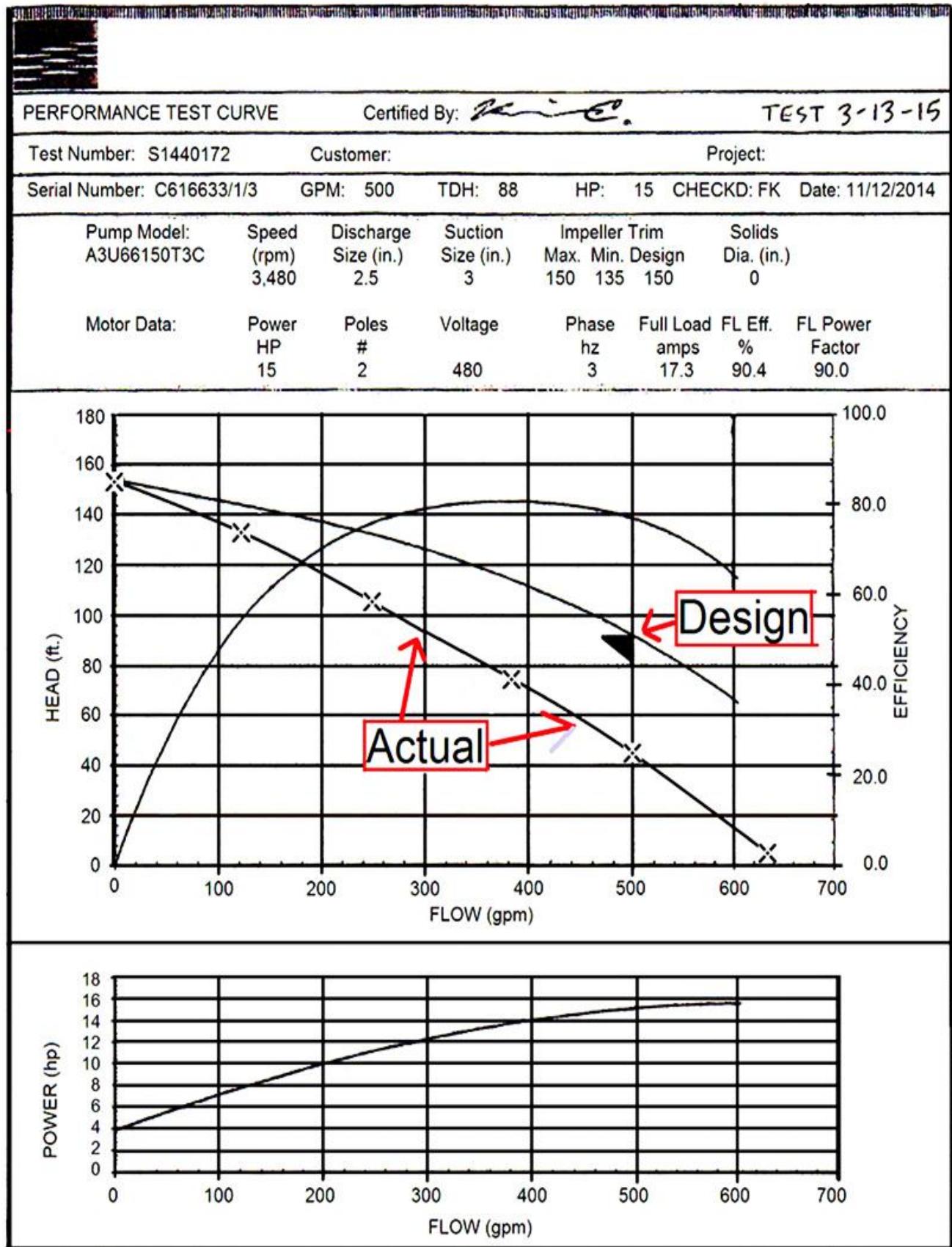
Overall Efficiency η_0

$$\eta_0 \% = \frac{\text{PumpOutput}}{\text{ElectricalInput}} \times 100$$

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.
p = Pulses of energy meter.
Q = Discharge, m³/sec.
t' = Time for P pulses, sec.
g = Acceleration due to gravity = 9.81 m/sec²
ρ = Density of Water = 1000 kg/m³
P_d = Delivery side Pressure Head
P_s = Suction side Pressure Head
R = Rise in the level of Tank
t = Time Taken for R

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.

SCREENING ANALYSIS

EXPERIMENT NO: 15

SEPARATION OF SOLID PARTICLES INTO SIZES AND DETERMINATION OF ITS SURFACE MEAN DIAMETER

experiment A

1. To determine the screen analysis of the product obtained from the crusher and pulverizer.
2. To construct fractional distribution plot, cumulative distribution plot, and histogram presentation of the screen analysis of the given samples.
3. To determine the true arithmetic average diameter, mean surface diameter, mean volume diameter/mean mass diameter and the specific surface (surface area per unit mass) of the products from the crusher and pulverizer.

Experiment B:

4. To estimate the energy requirements and the Rittinger's Number for the crusher and pulverizer.
5. To estimate the crushing efficiency of the crusher and pulverizer.

Apparatus: Mesh of different sizes, mechanical vibrator, weighing balance -and conical flask

Sample: Grinded lime stone or dry sand

Theory

Differential analysis shows that mass fraction in each size increment is a function of the Average particle size or (size range) in the increment.

Standard screens are used to measure the size (and size distribution) of particles in the size range between 3 and 0.0015 inch. Tyler standard screen is based on the opening of the 200 mesh screen, which is established at 0.074mm. The ratio of the actual mesh dimension of any screen to that of the next smaller screen is $\sqrt{2}$.

The size range of an increment implies one for the screen through which the fraction passes and the other on which it is retained.

Thus, the notation $\frac{14}{20}$ means "through 14 mesh and on 20 mesh" or a -35+48 fraction means the fraction of particles that passes through a 35 mesh screen, but is

retained on a 48- mesh screen . Therefore, the particle that stays on a particular screen is oversize while a particle that passes through it is the undersize.

The shape of an individual particle is conveniently expressed in terms of the sphericity ϕ , which is independent of particle size. For a spherical particle of diameter D_p , $\phi_s = 1$; For a non- spherical particle the spheretical is defined by the relation

$$\phi_s = \frac{6V_p}{D_p S_p}$$

Spherical is the ratio of the surface area of this sphere to the actual surface area of the particle.

For sphere, $S_p = \pi D_p^2$ and $V_p = \frac{1}{6}\pi D_p^3$

Specific surface area of the given sample is defined by the relation

$$A_w = \frac{1}{\phi_s} \cdot \frac{1}{\rho_p} \sum_{i=0}^n \frac{x_i}{D_{pi}}$$

The surface mean diameter of the solid particles D_s may be calculated from the number of particles N_i in each size range or from the mass fraction in each sizes range x_i

$$D_s = \frac{1}{\sum_{i=0}^n \frac{x_i}{D_{pi}}}$$

Where number of particles in a sample (N) = $\frac{M}{\rho_p V_p}$

M is the mass of sample, ρ_p is the density of sample, V_p , is the volume of particle, S_p , is the surface area,

x_i is the mass fraction, ϕ is the spheretical and D_{pi} the average particle diameter.

Procedure

- o Arrange the given standard screens serially in a stack, with the pan and smallest mesh at the bottom and largest mesh at the top. Weigh the empty screen with weighing balance before and after the content is introduced, in order to determine the mass of given solid particles.
- o Place the solid particles on the top screen and shake the stack mechanically for 20 minutes.

- Remove and weigh the particles retained on each screen and convert the masses of individual screen increments to mass fractions or mass percentages of the total solid particles.
- Weigh the particles in a pan at the bottom of the stack and convert to mass fraction of the total solid particle as well.

Tabulate the results obtained as presented in the table.

Mesh	Aperture D_{pi} (mm)	Mass fraction retained (x_i)	Average particle diameter in increment (mm)	Cumulative fraction smaller than D_{pi}	Cumulative fraction greater than D_{pi}	$\frac{x_i}{D_{pi}}$
75						
150						
250			.	.		
300						
350						
Pan						

Graph

1. Plot mass fraction against average particle diameter.
2. Plot cumulative mass fraction smaller than particle size against the average particle diameter and cumulative mass fraction greater than particle size against the average particle diameter.

Calculation

1. Calculate the surface mean diameter of the solid particles.

2. Determine the specific surface area of given sample, if its density is 1200kg/m^3 and sphericity is 0.65.

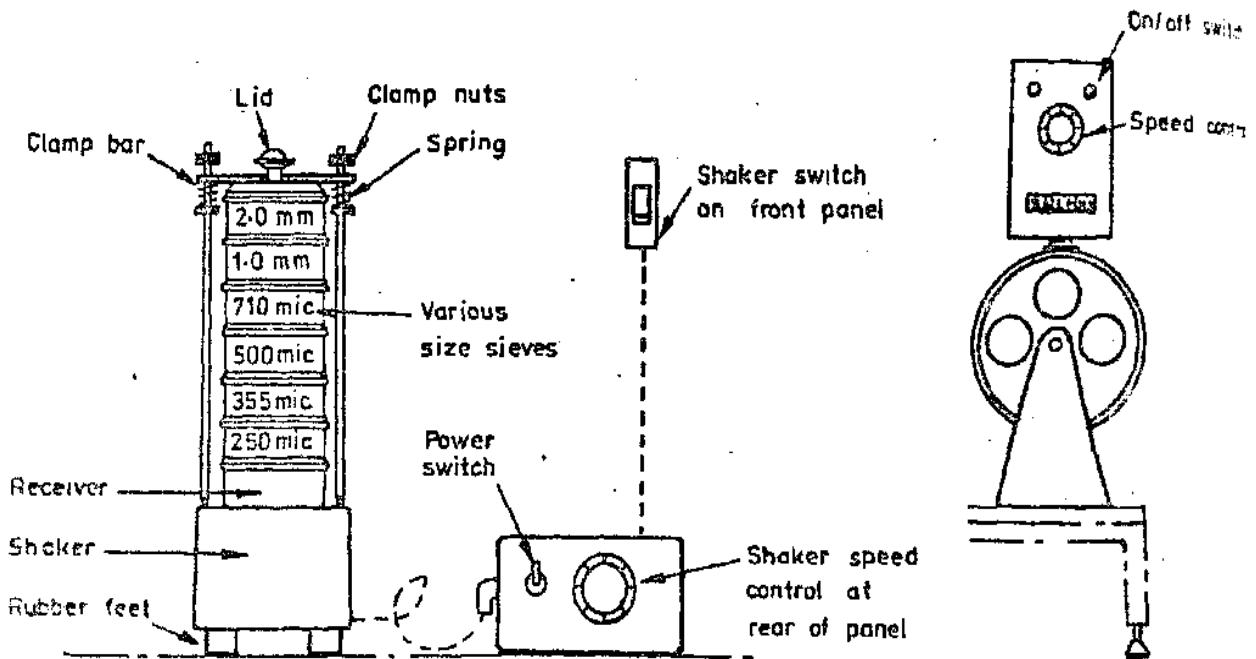


Fig 1. : mechanical vibrator

Experiment B

Materials/Equipment Needed:

- About 1 kg of small rocks practically uniform size from 1-1.5 inches in diameter
- Ro-tap Sieve Shaker
- Standard Tyler screen series composed of the following screens: 200, 150, 100, 80, 60, 40, 30, ..., mesh including cover and pan
- Crusher
- Pulverizer
- Weighing Instrument, Soft/Nylon Bristle Brush, Extra Pan

Procedure

- A. Develop/Outline procedure followed n size reduction of small rocks using the crusher and pulverizer.
- B. Preparation of screen analysis of the products obtained from the crusher and pulverizer.

Basic Operations of Ro-Tap Sieve Shaker

1. Assembles a stack of sieves, beginning with a top cover and then the coarsest (largest) sieve opening on top and a pan on the bottom. Place them into the shaker. When placing the sieves into the Ro-Taps, the hammer should be tilted up and out of the way.
2. Place the sieve cover, with the cork installed, on the top of the stack.
3. Adjust the sieve support clamp bar with the two wing nuts, bringing the top of the sieve cover flush with the upper carrying plate.

Hammer Drop Adjustment

Note: Prior to hammer adjustment; make sure cork in sieve cover is seated firmly. Make sure sieve cover has top edge flush with upper carrying plate.

1. Remove pedestal cover
2. Jog machine until hammer rises to a maximum height, check height with scales.
3. Set height $10\frac{1}{2}$ $\pm \frac{1}{16}$ by loosening screw on coupling and adjusting lift rod.
4. Tighten screw on coupling.
5. Replace pedestal cover.

Starting the Shaker

1. Make sure a sieve stack is in place at this time. Set the test run in time, by simply turning the thumb wheel + (plus) or - (minus) to the desired time in the digital window.
2. Push the start bar to start test and note countdown time. An audible tone will be heard at the end of the test. You can stop or interrupt the test at any time, by simply pushing the stop bar. Note that the remaining test time is frozen on the readout. To continue, simply push the start bar. Note: the timing device also has a clock function. To use this option, hold the "clock" button and adjust to the proper time with the thumb dial.

Performing a Sieve Analysis

1. Select a set of test sieves with mesh openings that will reveal particle distribution at critical sizes. Critical sizes are usually stated in a product specification or are determined by material processing requirements.
2. Assemble a stacked of test sieves (one on top of the other) with coarsest (largest) opening on the top of the stack. A proper sample amount should cover the wire mesh of the top sieve, but not overload the surface. Overloading will cause blinding or blocking of the openings, not allowing the sample to be properly processed.
3. Place the test sieve stack into the sieve shaker, and place the cover on the top of the stack. The sieves must be secured into place. The shaker should be activated and set to operate for their proper length of time.
4. After completion of the agitation, weigh the material retained on each sieve in order to record the data. Weighing should be by grams, with a balance scale having at least a capacity of 500 grams and a sensitivity of 1/10 gram.
5. Using the extra bottom pan, empty the materials retained on the coarsest sieve into the pan. A soft or nylon-bristle brush should be used to gently brush the underside of the sieve, thoroughly removing all of the remaining particles into the pan. The sieve frame can be tapped with the handle of the brush to clean any remaining material on the sieve. Weigh the contents in the pan to the nearest 1/10th gram immediately record the data.
6. If several extra pans are available, it is best not to discard this portion of the sample until the entire process is completed. This same procedure should be repeated on all sieves in the stack. The material passing through the finest sieve into the bottom pan must also be weighed to obtain the total weight for percentage calculations. The total weight of the material retained on the various sieves and in the bottom pan should be extremely close to the weight of the original sample.

APPENDICES:

Raw Data

Table 1.3 Crusher Partial Anaylysis

Total mass of Feed (orig sample)		1112	grams	
Total mass of product (b4 screening)		992	grams	
Total mass of product (after screening)		991	grams	
Mesh Number	Weight of Empty Screen (g)	Weight of Screen Including the Solids (g)	Weight of the Solids (g)	Ave. Particle Diameter, \bar{D}_{pi}
10 (2mm)	490	1434	944	-
12 (1.7 mm)	454	458	4	1.85
18 (1.00mm)	440	454	14	1.35
20 (850um)	428	432	4	0.925
60 (250um)	462	378	84	0.535
80 (180um)	362	360	2	0.214
100 (150um)	348	350	2	0.163
200 (75um)	340	344	4	0.112

Table 1.4 Pulverizer Partial Analysis

 \bar{D}_{pi}

Total mass of Feed (orig sample)	991	grams
Total mass of product (b4 screening)	966	grams
Total mass of product (after screening)	962	grams

Mesh Number	Weight of Empty Screen (g)	Weight of Screen Including the Solids (g)	Weight of the Solids (g)	Ave. Particle Diameter, \bar{D}_{pi}
10 (2mm)	490	710	220	-
12 (1.7 mm)	454	540	86	1.85
18 (1.00mm)	440	680	240	1.35
20 (850um)	428	468	40	0.925
60 (250um)	462	574	112	0.535
80 (180um)	362	450	88	0.214
100 (150um)	348	362	14	0.163
200 (75um)	340	396	56	0.112

SAMPLE OF CALCULATIONS

- Weight Percent

$$\%wt = 100 * \frac{wt\ of\ solid\ on\ sieve}{wt\ of\ sample}$$

For Mesh 10

$$\%wt = 100 * \frac{944}{1112} = 84.89$$

- Cumulative Weight Percent Retained

$$\%cumulative\ wt\ retained = 100 * \frac{wt\ of\ solid\ on\ sieve + wt\ of\ solid\ on\ sieves\ above}{wt\ of\ sample}$$

For Mesh 40

$$\%cumulative\ wt\ retained = 100 * \frac{4 + 944}{1112} = 85.25$$

- Average Particle Diameter

$$\overline{D_{pi}} = (D_1 + D_2)/2$$

For Mesh 12

$$\overline{D_{pi}} = 2.00 + 1.7 = 1.85$$

INFORMATION FLOW DIAGRAM AND EQUATIONS

AVERAGE PARTICLE SIZE

- i. Volume Surface Diameter

$$-D_s = \frac{6}{\phi_s A_w \rho_p}$$

- ii. Arithmetic Mean Diameter

$$-D_n = \frac{\sum_{i=1}^n (x_i D_{\gamma i})}{N_T}$$

- iii. Mass Mean Diameter

$$-D_w = \sum_{i=1}^n X_i - D_{\gamma i}$$

- iv. Mean Surface

- v. Volume Mean Diameter

$$-D_v = \left[\frac{1}{\sum_{i=1}^n \left(\frac{X_i}{D_{\gamma i}^3} \right)} \right]^{1/3}$$

A. Specific Surface Mixture

$$A = Ns_p = \frac{6m}{\phi s \rho p D_p}$$

$$\frac{A_w}{m} = \frac{6m}{\rho p \phi s} \sum_{i=1}^n \frac{x_i}{D_{pi}}$$

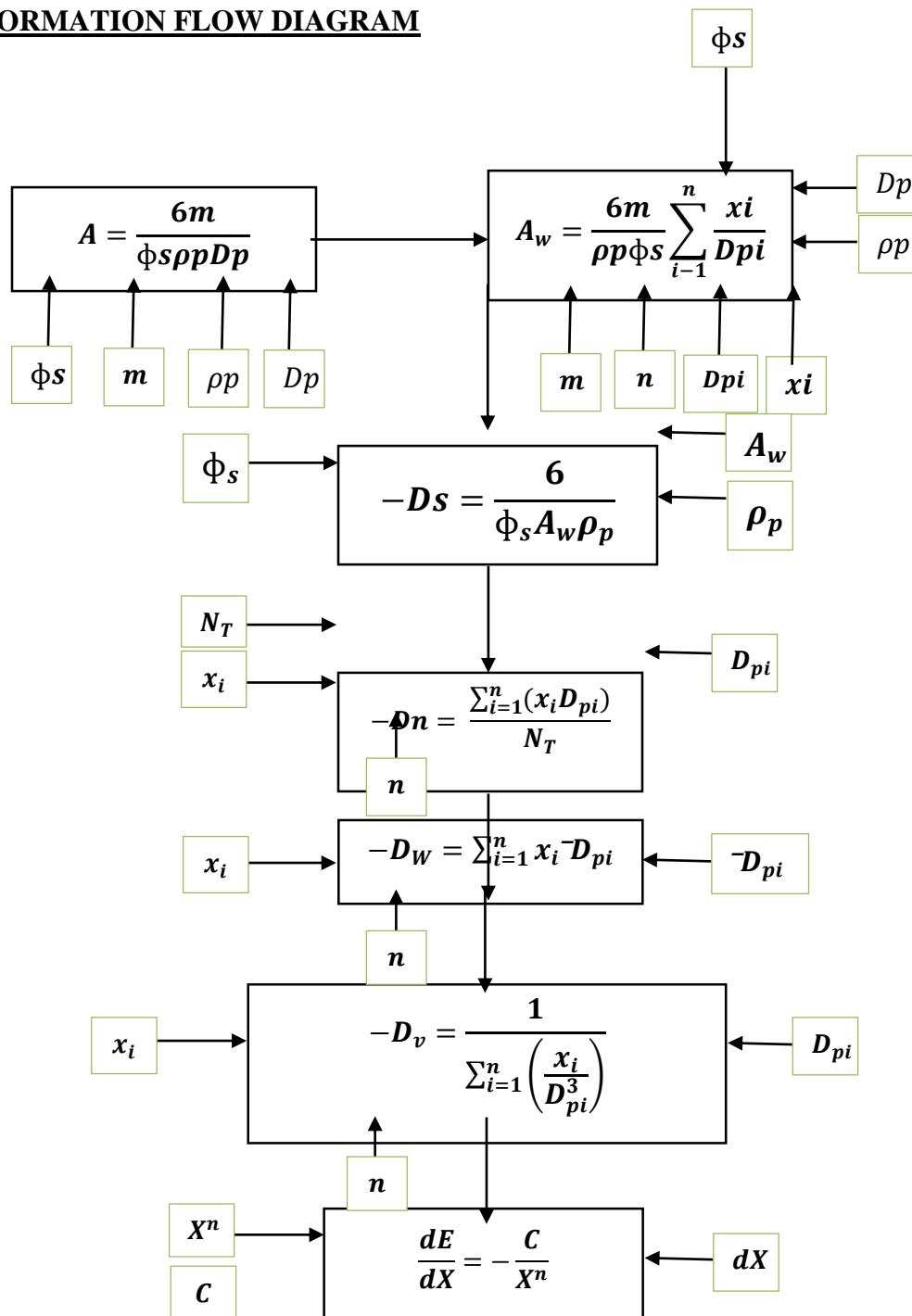
B. Rittinger's Number

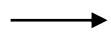
$$\frac{dE}{dX} = -\frac{C}{X^n}$$

C. Crushing Efficiency

$$Efficiency = \frac{M \text{ req'd size}}{M_T} \times 100\%$$

INFORMATION FLOW DIAGRAM





MASS TRANSFER

(Transport Phenomena III)

EXPERIMENT NO. 16

DETERMINATION OF DIFFUSIVITY OF VOLATILE LIQUID (ACETONE) INTO AIR.

Aims/ Objective

The objective of this experiment is;

1. To determine the diffusivity of the vapour of acetone.
2. To study the effect of temperature on the diffusivity.

Apparatus: Air blower, stop watch, beaker, 500ml and 100ml measuring cylinder.

Reagent: Acetone.

Outline:

The knowledge of physical and chemical properties of certain materials is important because very often process engineering deal with the transformation and distribution of these materials in bulk. One such property is *diffusivity*. Mass transfer by diffusion takes place when there is a concentration gradient of the diffusing component. Naturally, the diffusion in gas phase is much faster than the diffusion in liquid phase due to the small spaces between the molecules that hinder another molecule movement. Other factors that will affect the diffusion are temperature, density, concentration and other external factors.

Introduction

This experiment has been designed for student's experiment on the technique of determining diffusivity of the vapor of a volatile liquid based on the established Winkelmann's method. In this method the volatile liquid is allowed to evaporate in a vertical glass tube over the top of which a stream of vapor-free gas is passed. A water bath is provided for maintaining a steady temperature so that there is no eddy current in the vertical tube and mass transfer takes place from the surface by molecular diffusion alone. The rate of evaporation can be followed by the rate of fall of the liquid surface. A traveling microscope is provided for determining, the liquid fall. With the knowledge of the concentration gradient, the diffusivity of the vapor of the volatile liquid can then be calculated.

Theory

When a concentration gradient exists within a fluid consisting of two or more components, there is a tendency for each constituent to flow in such a direction as to reduce the concentration gradient. This is called mass transfer. Mass transfer takes place in either a gas phase or a liquid phase or in both simultaneously. When a liquid is allowed to evaporate in a narrow vertical tube and a steady temperature is maintained, mass transfer takes place from the surface by molecular diffusion alone. This is the technique developed by Winkelmann to determine the diffusivity of the vapor of a volatile liquid. By monitoring the evaporation rate, which is the rate of fall of liquid surface, and with the knowledge of concentration gradient, one may then calculate the diffusivity.

The rate of mass transfer is given by:

$$N'_A = D \left\{ \frac{C_A}{L} \right\} \left\{ \frac{C_T}{C_{Bm}} \right\}$$

1

Where D = Diffusivity (m^2/s)

C_A = Saturation concentration at interface ($kmol/m^3$)

L = Effective distance of mass transfer (mm)

C_{Bm} = Logarithmic mean molecular concentration of vapour ($kmol/m^3$)

C_T = Total molar concentration = $C_A + C_{Bm}$ ($kmol/m^3$)

Considering the evaporation of the liquid:

$$N'_A = \left\{ \frac{\rho_L}{M} \right\} \left\{ \frac{dL}{dt} \right\}$$

2

where

ρ_L = is the density of the liquid (kg/m^3).

M = molecular weight ($kg/kmol$)

Combining equation 1 and 2 we get,

$$\left\{ \frac{\rho_L}{M} \right\} \left\{ \frac{dL}{dt} \right\} = D \left\{ \frac{C_A}{L} \right\} \left\{ \frac{C_T}{C_{BM}} \right\}$$

3

Integrating and putting $L - L_0$ at $t = 0$

$$L^2 - L_0^2 = \left\{ \frac{2MD}{\rho_L} \right\} \left\{ \frac{C_A}{C_{BM}} \frac{C_T}{C_{BM}} \right\} t$$

4

L_0 and L cannot be measured accurately but $L - L_0$ can be measured accurately using the vernier on the microscope.

Thus, rearranging equation 4.

$$(L - L_0)(L - L_0 + 2L_0) = \left\{ \frac{2MD}{\rho_L} \right\} \left\{ \frac{C_A}{C_{BM}} \frac{C_T}{C_{BM}} \right\} t$$

or

$$\frac{t}{(L - L_0)} = \left\{ \frac{\rho_L}{2MD} \right\} \left\{ \frac{C_{BM}}{C_A C_T} \right\} (L - L_0) + \left\{ \frac{\rho_L C_{BM}}{MD C_A C_T} \right\} L_0$$

5

where:

M = molecular weight (kg/mol)

t = time (s)

A plot of $t/(L - L_0)$ against $(L - L_0)$ will give a slope s which also diffusivity (D) can calculated from equation.

$$s = \left\{ \frac{\rho_L}{2MD} \frac{C_{BM}}{C_A C_T} \right\}$$

6

$$D = \frac{\rho_L}{2sM} \frac{C_{BM}}{C_A C_T}$$

or

where:

$$C_T = \left(\frac{1}{Knol Vol} \right) \left(\frac{T_{abs}}{T_a} \right) \quad C_{B1} = C_T$$

$$C_{B2} = \left(\frac{P_a - P_v}{P_a} \right) C_T \quad C_{BM} = \frac{C_{B1} - C_{B2}}{\ln \left(\frac{C_{B1}}{C_{B2}} \right)} \quad C_A = \left(\frac{P_v}{P_a} \right) C_T$$

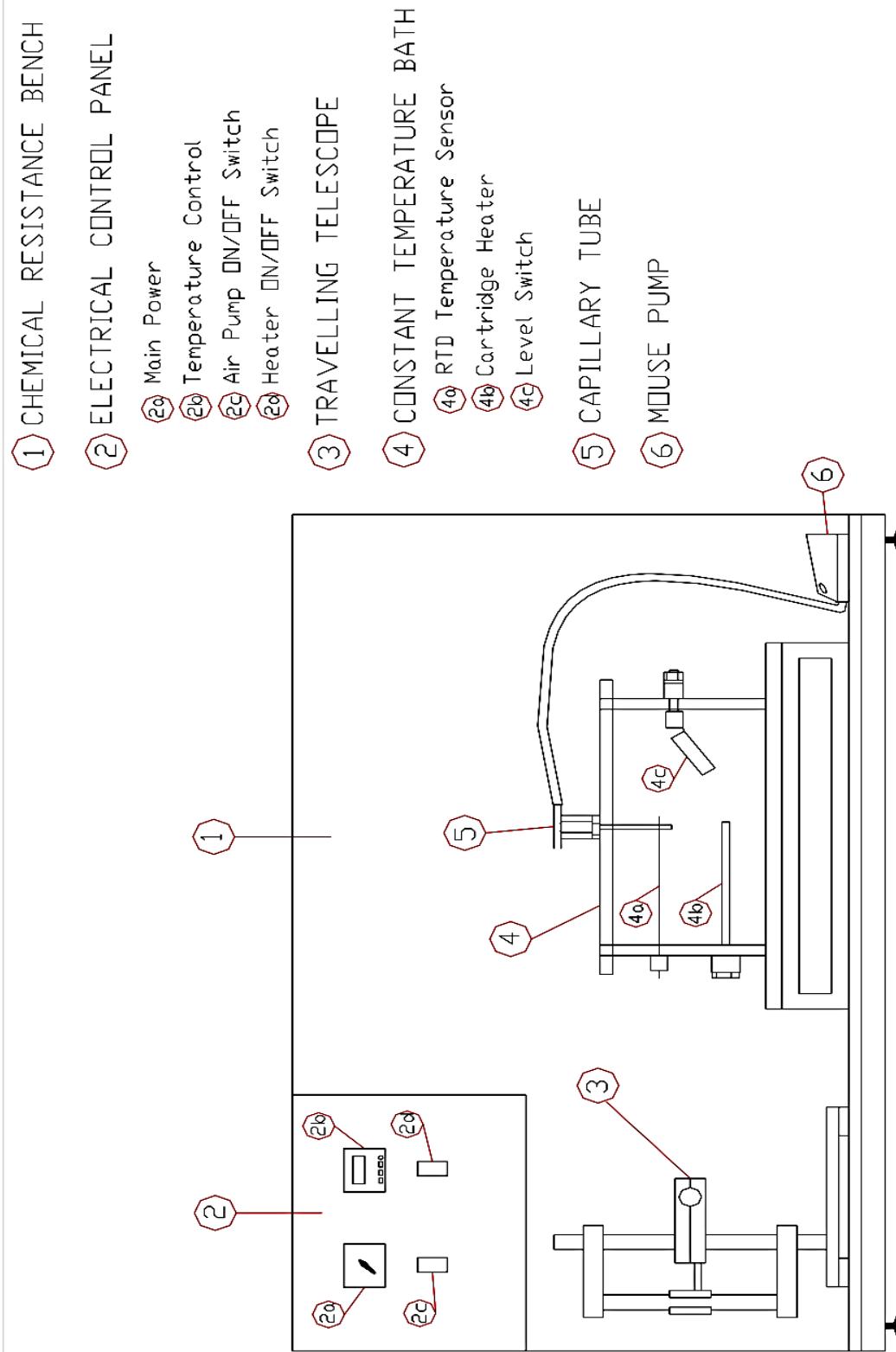


Figure 1: Gas Diffusion Coefficient Apparatus

Start Up and Shut- Down Procedures

Start-up Procedure

Prior to running an experiment, students are advised to perform the following start-up procedure:

1. Fill the water bath with clean (preferably filtered) water to approximately 30 mm from the top.
2. Plug the main cable to the electrical supply. Be sure that the voltage of the supply is correct to suit the equipment.
3. Switch on the main power on the control panel.
4. Adjust the set-point value on the temperature controller to 50 °C. Warning!! Do not set the temperature controller beyond 70 °C.
5. Switch on the heater. Observe the water temperature heats up to 50°C and remains constant.
6. Switch on the air pump. Adjust the needle valve so that a steady low velocity of air stream is detected at the end of the flexible tubing.
7. The equipment is now ready for student experiment.

b) Priming Procedure for the Capillary Tube

Before using the capillary tube in an experiment using acetone, students are advised to clean the inside of the tube.

1. Prepare a weak solution of detergent.
2. Use a Hirschmann pipette to fill the tube with the solution. Tapping the outside of the tube may be necessary if the solution is trapped and does not flow down.
3. Turn the tube upside-down and shake. Empty the tube.
4. Repeat steps 2 to 3 with acetone.
5. The tube is now ready for student experiment.

c) Shut-down Procedure

After the completion of an experiment, students are advised to shut down the equipment as follows:

1. Switch off the heater and air pump.

2. Adjust the set-point value of the temperature controller to approximately 5 degrees below the room temperature.
3. Allow the water to cool down until it is safe to touch. Open the drain valve and empty the water tank.
4. Detach the flexible tubing and clean the capillary tube for next use.

(Refer to priming procedure)

5. Switch off the main power. Unplug the main cable if the equipment will not be used for a long period.

Experimental Procedures

Procedure (A)

1. Perform the start-up procedure as outlined above.
2. Initially switch off the air pump.
3. Partially fill the capillary tube with acetone to a depth of about 35 mm.
4. Carefully insert the capillary tube through the fitting on top of the water bath cover. Do not over-tighten the fitting.
5. Observe the initial level of acetone through the microscope. Record the level in the table.
6. Connects the flexible tubing from the air pump line to one end of the capillary tube. Switch on the air pump.
7. After 10 minutes, switch off the air pump. Disconnect the flexible tubing and detach the capillary tube from the fitting. Observe and record the level of the acetone.
8. Repeat steps 5 to 6 at 10 minutes' intervals.
9. Record the time, acetone level and liquid fall in the table below.

Procedure B

1. Consider a beaker as Winkelmann's vessel and pour known volume of acetone into it. Maintain the content at a constant temperature, while air stream should be passed over the top of the beaker rapidly and adequately, in order to ensure that the partial pressure of the vapour is approximately zero.
2. Measure the initial level of content in a beaker as Z_0 and the internal radius of the beaker(R).
3. The air stream from the blower should be passed for 10 minutes, while the level of volatile liquid in the vessel is noted and recorded.

4. Repeat the experiment for 20 mins 30 mins 40 mins and 50 minutes.

Tabulate the obtained results as below:

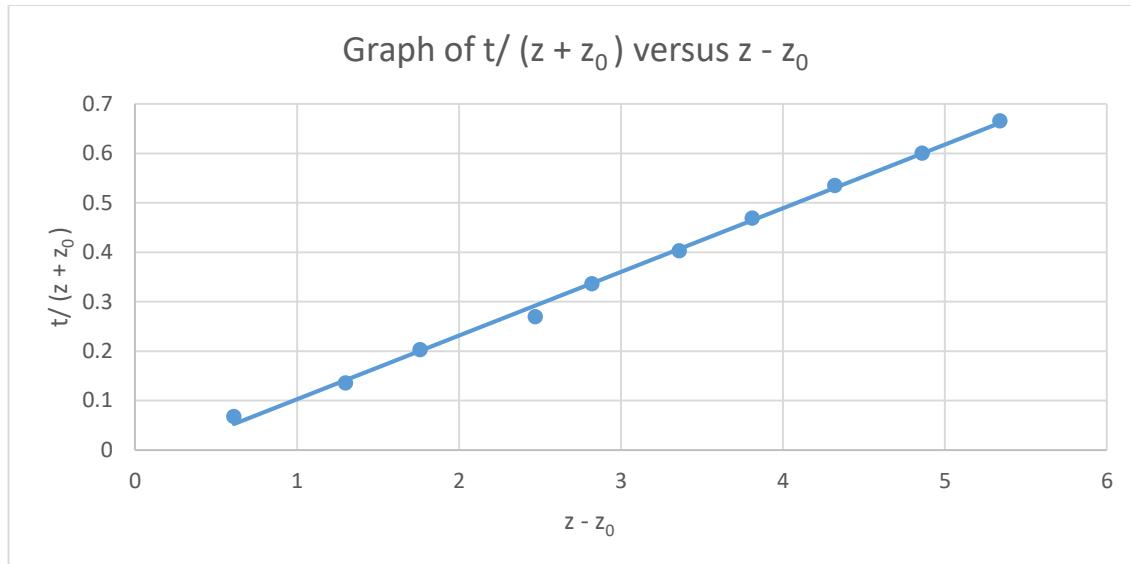
Time (s)	Level of Content, Z(M)
10	
20	
30	
40	
50	

Or

Time, t (s)	Level of Acetone, L (mm)	Liquid Fall (L - L ₀) (mm)	t/(L - L ₀) (ks/mm)

Calculations/Plots

- A plot of $t / (L - L_0)$ against $(L - L_0)$. Determine gas diffusivity, D from the obtained slope, s . Attached all of your calculation at the appendix in the experiment report.
- Compare the experimental value with the theoretical value that can be predicted from empirical equations (e.g. modified Maxwell's equation by Gilliland).
- Discuss the factors that affect the diffusion of acetone from the graph that have been plotted.
- Base on objective of the experiment and the theory in gas diffusion make a conclusion from your finding.



When time, $t = 0$ min, the level of acetone, $z_0 = -10.22$ mm

Time, t (min)	Level of acetone, z (mm)	$z - z_0$ (mm)	$z + z_0$ (mm)	$t/(z + z_0)$ (min/mm)
15	-10.83	0.61	220.61	0.06799
30	-11.52	1.3	221.3	0.13556
45	-11.98	1.76	221.76	0.20292
60	-12.69	2.47	222.47	0.26970
75	-13.04	2.82	222.82	0.33660
90	-13.58	3.36	223.36	0.40294
105	-14.03	3.81	223.81	0.46915
120	-14.54	4.32	224.32	0.53495
135	-15.08	4.86	224.86	0.60037
150	-15.56	5.34	225.34	0.66566

Values for Calculation:

$$1) \rho L = 760.0 \frac{kg}{m^3}$$

$$2) M = 58.08 \frac{kg}{kmol}$$

$$3) \text{ Partial pressure } P^* = 0.8062 \text{ atm}$$

$$4) C_{BM} = \frac{C_{B1} - C_{B2}}{\ln \frac{C_{B1}}{C_{B2}}}$$

where for acetone,

$$C_{B1} = 0.0377 \frac{kmol}{m^3}$$

$$C_{B2} = 0.00731 \frac{kmol}{m^3}$$

$$CA = 0.0304 \frac{kmol}{m^3}$$

$$CT = \frac{0.0377 kmol}{m^3}$$

References

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- Landolt-Bornstein, Gases in Gases, Liquids and Their Mixtures, New York: Springer Berlin Heidelberg.
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EXPERIMENT NO. 16(b)

DETERMINATION OF GAS DIFFUSION COEFFICIENT

Objective:

The objective of this experiment is to calculate diffusion coefficient of a volatile organic compound in air by means of Chapman Enskog equation at room condition.

Background:

The basic unit operations in engineering are momentum, heat and mass transfer. Momentum transfer can be observed in fluid flowing, mixing, and precipitation or filtration operations. Heat transfer in the form of conductive or convective can be seen in evaporation distillation and drying processes. Distillation, absorption, drying, liquid-liquid extraction, adsorption and membrane operations are generally utilized from mass transfer equations in order to model and design of a unit under optimum dimensions and operations conditions.

Properties of materials used in physical, chemical or biological processes are very important. Therefore, the properties of the fluids are the key elements in proses design and engineering applications. Diffusion coefficient is among the most important properties of the fluids. When there is a concentration difference in a stagnant fluid, mass transfer can be described by a diffusion. When a droplet of ink drops into a glass of full of water, the blue color of ink is dispersed gradually in water and at the end, obtained a uniform mixture is a known fact. Similar behavior can be observed for gases. Mass transfer is occurred from high concentration to low concentration. Concentration can be defined as mass or molar units. Mass flux ($\text{kg}/\text{m}^2.\text{s}$) is the amount of mass transferred per unit time and per unit area, molar flux ($\text{kmol}/\text{m}^2.\text{s}$) is defined as the transfer of a compound in its molar quantity per unit time and per unit area.

Diffusional flux is proportional to the concentration gradient of a substance and the proportionality constant is defined as a diffusion coefficient. This can be explained by Fick's first law. For a system of binary components, if diffusion of A in B is shown as D_{AB} , Fick's first law can be written for component A;

$$J_A = -CD_{AB} \frac{dx_A}{dz} \quad \text{eq. (1)}$$

where, J_A is the diffusional flux of molecule A in the z direction (mol/cm^2), c is concentration (mol/cm^3) and dx_A/dz is the change in mole fraction of A with respect to z direction ($1/\text{m}$). Using the corresponding units in Equation 1 and taking the unit time as second, the unit of diffusion coefficient is estimated as cm^2/s . The minus sign in Equation 1 reflects that the mass transfer is occurred in the direction of reducing concentration. Equation 1 can only be used if there is no bulk flow. In the case of bulk motion, its contribution to the total flux of i can be represented as follows;

$$N_i = x_i \sum_{j=1}^n N_j + J_i \quad \text{eq (2)}$$

By using Equation 2 for a binary system, total flux of component A relative to a stationary reference point can be defined in terms of molar quantities by the expression given below [1]:

$$N_A = (N_A + N_B)x_A - CD_{AB} \frac{dx_A}{dz} \quad \text{eq (3)}$$

Examples of Mass Transfer Processes

Mass transfer is important in many areas of engineering and science. Mass transfer occurs when a component in a mixture migrates in the same phase or from phase to phase because of a difference in concentration between two points. Liquid in an open pail of water evaporates into still air because of the difference in concentration of water vapor at the water surface and surrounding air. There is a driving force from the surface to the air. In a fermentation process nutrients and oxygen dissolved in the solution diffuse to the microorganisms. In a catalytic reaction the reactants diffuse from the surrounding medium to the catalyst surface, where reaction occurs. Distillation of ethanol in water is another example of mass transfer [2].

Special Case for A Diffusing Through Stagnant, Nondiffusing B

In the case of diffusion of A through stagnant or nondiffusing B at steady-state, it is assumed that one boundary at the end of the diffusion path is impermeable to component B, so it cannot pass through. One example, shown in Figure 1, is in the evaporation of a pure liquid such as acetone (A) at the bottom of narrow tube, where

a large amount of inert or nondiffusing air (B) is passed over the top. The boundary at the liquid surface at point 1 is impermeable to air, since air is insoluble in acetone liquid. At point 2 the partial pressure $p_{A2}=0$, since a large amount of air is passing by.

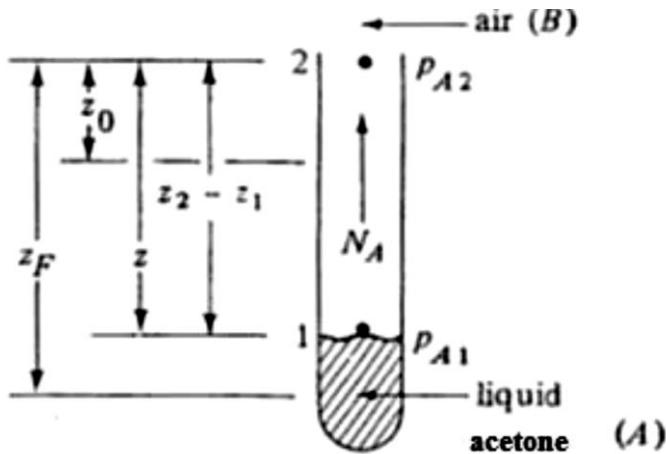


Figure 1: Diffusion of A through stagnant, nondiffusing B

To derive the case for A diffusing in stagnant, nondiffusing B, $N_B=0$ is substituted into the general Equation (3).

$$N_A = -cD_{AB} \frac{dx_A}{dz} + \frac{c_A}{c} (N_A + 0) \quad \text{eq (4)}$$

Keeping the total pressure constant, substituting $c=P/RT$, $p_A=xAP$, and $cA/c=pA/P$ into Equation (4) gives,

$$N_A = -\frac{D_{AB}}{RT} \frac{dp_A}{dz} + \frac{p_A}{P} N_A \quad \text{eq (5)}$$

Rearranging and integrating,

$$N_A = \int_{z_1}^{z_2} dz = -\frac{D_{AB}}{RT} \int_{p_{A1}}^{p_{A2}} \frac{dp_A}{1 - \frac{p_A}{P}} \quad \text{eq (6)}$$

$$N_A = \frac{D_{AB}P}{RT(z_2-z_1)} \ln \frac{P_{A1}-P_{A2}}{P-P_{A1}} \quad \text{eq (7)}$$

Equation (7) is the final equation to be used to calculate the flux of A. However, it is often written in another form. A log mean value of the inert B is defined as follows. Since

$$P = p_{A1} + p_{B1} = p_{A2} + p_{B2},$$

$$P_{BM} = \frac{P_{B1} - P_{B1}}{\ln\left(\frac{P_{B2}}{P_{B1}}\right)} = \frac{P_{A1} - P_{A2}}{\ln\left[\frac{(P - P_{A2})}{(P - P_{A1})}\right]} \quad \text{eq (8)}$$

Substituting Equation (8) into Equation (9),

$$N_A = \frac{D_{AB}P}{RT(z_2 - z_1)P_{BM}} P_{A1} - P_{A2} \quad \text{eq (9)}$$

Diffusion in a Tube with Change in Path Length

At a given time t , the level z from the top drops slowly as diffusion proceeds (Figure 1). The change in liquid level in a narrow tube can be derived by using the initial and final conditions of the liquid level. Pseudo-steady-state condition can be assumed since, level drops slowly. As time progresses, the path length z increases. Assuming a cross sectional area of 1 m^2 , the level drops dz (m) in dt (s) and $p_A (dz \times 1)/M_A$ (kmol of A that have left and diffused). Then,

$$N_A \cdot 1 = \frac{\rho_A (dz \cdot 1)}{M_A dt} \quad \text{eq (10)}$$

At any time t , Equation (9) holds; but the path length is z and Equation (9) becomes as follows, where N_A and z are now variables:

$$\frac{\rho_A}{M_A} \int_{z_0}^{z_F} z \, dz = \frac{D_{AB} P(p_{A1} - p_{A2})}{RT p_{BM}} \int_0^{t_F} dt \quad \text{eq (11)}$$

Solving for t_F

$$t_F = \frac{\rho_A (z_F^2 - z_0^2) RT p_{BM}}{2 M_A D_{AB} P(p_{A1} - p_{A2})} \quad \text{eq (12)}$$

Experimental Set-up

The experimental set-up is comprised of a test tube with an internal diameter of 6

mm, measuring cylinder whose hold up volume is 25 mL, a pump for air flowing and analytical balance for taring the mass change.

Running the Experimental Set-up

1. Put acetone into test tube up to 4 mL
2. Record the initial amount of the acetone.
3. Air is flowing above the test tube by means of a pump at a constant flowrate.
4. Record the mass of acetone at each 15 minutes.

Data that will be recorded

Time (s)	Mass (g)

Calculations

- Liquid levels at the end of each data recording.
- After recording the initial z value (z_0), calculate and then record the z value at each time interval utilizing from the mass relation as given below;

$$z_t = \frac{(m_0 - m_1)}{p_A A} + z_0$$

Time (s)	z_t (m)

According to Equation (12), the slope of time vs square of the change in liquid level is proportional to $1/D_{AB}$. The remaining terms except $1/D_{AB}$ on the right hand side of Equation (12) can be assigned to any x.

Time (s)	x

Result

Plot x with respect to t, and add the graph below.

- Compare the value of diffusivity you calculated with the values in literature.
- If there is a large difference, define the possible errors in experiments and make suggestion to get better result.

- ✓ Vapor pressure of acetone at 20°C = 118 mmHg
- ✓ Density of acetone = 790 kg/m³
- ✓ Molecular weight of acetone = 58.08 kg/kmol.

References

1. Geankoplis, C.J., Transport Processes-Momentum, Heat, Allyn and Bacon, Boston, (1983).
2. McCabe W.L., Smith J., Harriot P., Unit operations of Chemical Engineering, McGraw Hill International Editions, 5th ed., Singapore (1993).

EXPERIMENT NO. 17

(LIQUID DIFFUSION)

DETERMINATION OF DIFFUSION COEFFICIENT OF 2M SODIUM CHLORIDE SOLUTION IN DISTILLED WATER

Aim/Objective

The objective of this experiment is to determine the diffusion coefficient of 2M NaCl solution in deionized water.

Introduction

Diffusion is the transport matter from one point to another point by kinetic energy of random molecular motion. The most common driving force of diffusion is a concentration gradient of diffusing fluids. Concentration gradients tend to move the

fluid in such a direction as to equalize concentrations and destroy the gradients. Diffusion also can force by an activity gradient, pressure gradient, temperature gradient or external force fluid. Diffusion is not restricted to molecular transfer through stagnant layers of solid or fluid.

Diffusion in liquid is sensitive to the composition change but relatively insensitive to changes in pressure. Diffusion of high viscosity, syrup liquids and macromolecules is slower. When solutes molecules diffuse through a solution, solvent molecules must be pushed out of the way. For this reason, liquid-phase inter diffusion coefficients are inversely proportional to both the viscosity of the solvent and the effective radius of the solute molecules.

When a concentration gradient exists within a fluid consisting of two or more components, there is a tendency for each constituent to flow in such a direction as to reduce the concentration gradient. This is known as mass transfer. It takes place in either a gas or a liquid phase or in both phases simultaneously.

Rate of diffusion is given by:

$$J = -D \frac{\partial C}{\partial x} \quad (1)$$

Where J = diffusion flux across unit area to the x-direction (right side), mol/cm²s

D = diffusivity, cm²/s

$\frac{\partial C}{\partial x}$ = concentration gradient in the x-direction, $\frac{mol/cm^3}{cm}$

The negative sign indicates that the flow is from high to low concentration.

By expanding Equation (1) using respective terms constitutive relations, we get

$$\frac{V}{C_M} \frac{dk}{dt} = -D \left(\frac{\pi d^2}{4} \right) N \frac{M}{x} \quad (2)$$

Rearranging gives

$$D = \frac{4Vx}{\pi d^2 N M C_M} \frac{dk}{dt} \quad (3)$$

where V = volume of water in diffusion vessel, L

x = length of capillaries, cm

d = capillaries diameter, cm

N = number of capillaries

M = molar concentration of NaCl solution, mol/L

C_M = conductivity change per unit molar concentration change, $\mu\text{S}/\text{mol/L}^{-1}$

$\frac{dk}{dt}$ = rate of conductivity changes over time

The slope obtained from the plot of conductivity as function of time can be used to calculate the diffusivity

Equipment/ Apparatus/ Material

Armfield Liquid diffusion apparatus

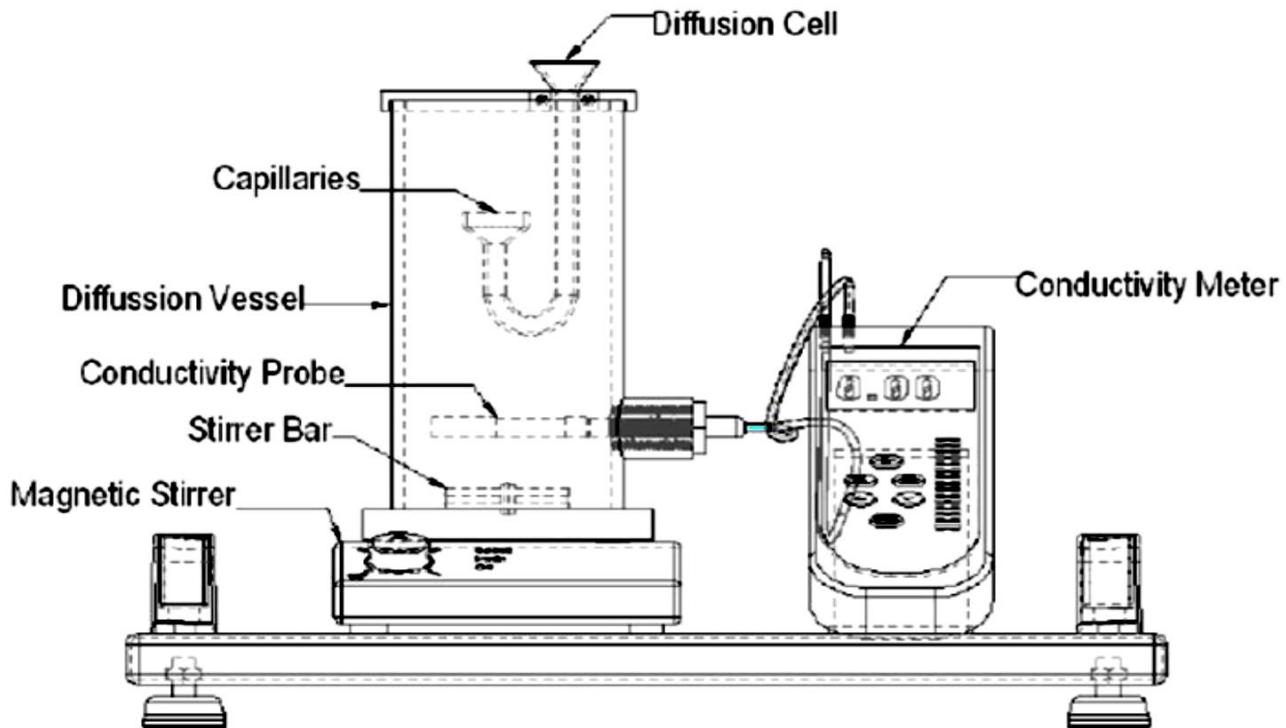


Figure 1a: Liquid Diffusion Coefficient Apparatus

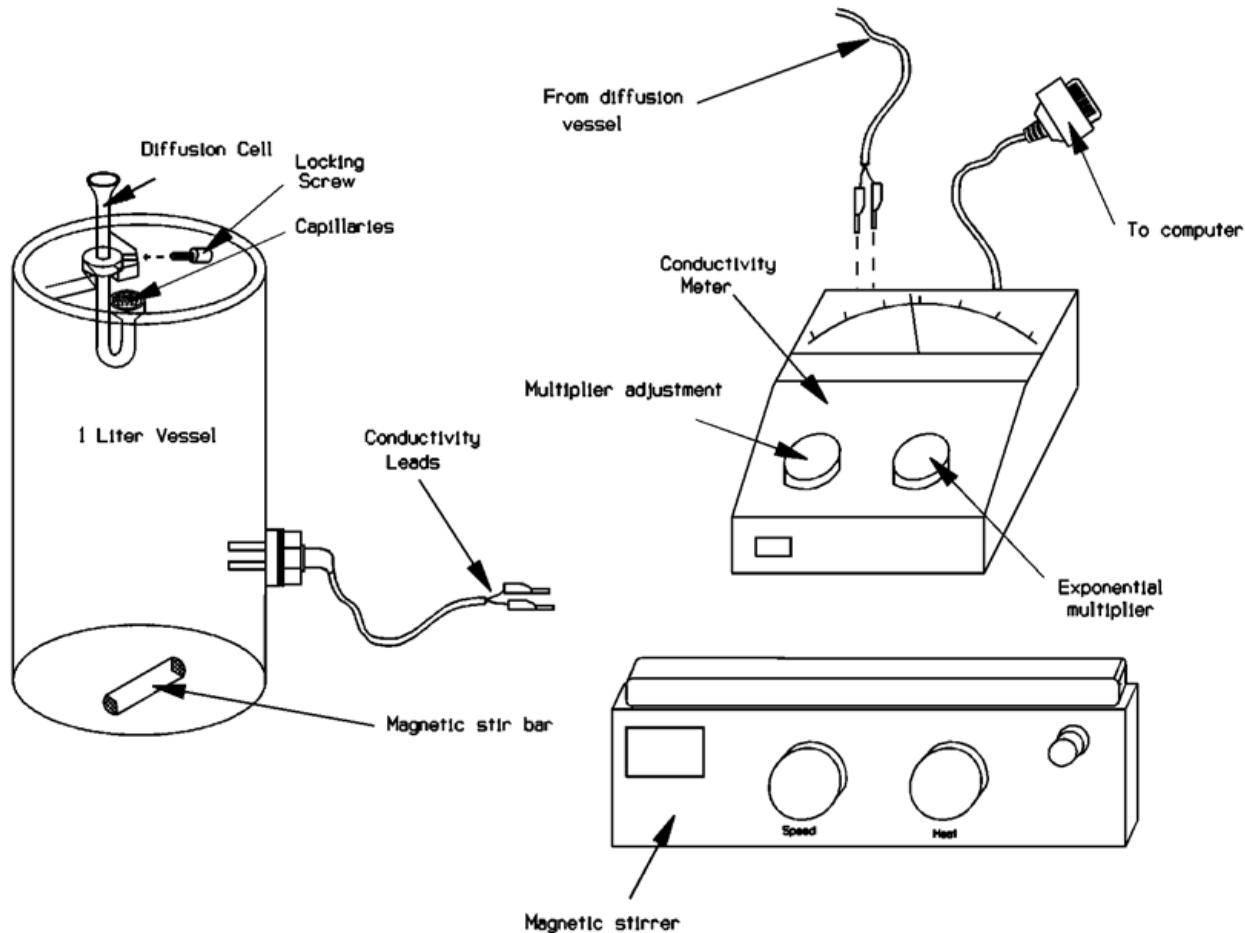


Figure 1b. Equipment used to determine the diffusion coefficient of a liquid

EQUIPMENT

1. Variable speed magnetic stirrer with stirring bar.
2. Specially designed diffusion cell.
3. Test vessel with cell holder (1 liter).
4. Conductivity cell (connects to the test vessel).
5. Conductivity meter.
6. 100 mL volumetric flask.
7. Stopwatch.
8. Ring stand
9. Small clamp
10. Eye dropper
11. 600 mL beaker

CHEMICALS

1. 2 M NaCl solution.
2. Deionized water.

This liquid diffusion coefficient apparatus is used to determine the diffusivity of NaCl solution in distilled water. A known concentration of NaCl solution is placed in a diffusion cell immersed in distilled water. A magnetic stirrer and a conductivity meter are provided to monitor the progress of diffusion over time. A plot of conductivity against time will allow for the determination of the liquid diffusivity. The concentration at the chosen lower ends is taken to be constant while the concentration at top end is effectively zero during experiment.

Experimental Procedures

1. Prepare standard salt solution and get its conductivity by using conductivity meter. (Must ensure the standard curve data covers the experimental sample data).
2. Prepare the solution of 100mL, 3M NaCl.
3. Determine the number of capillaries (holes) of the PVC round plate in the J-tube. (The diameter is 2 mm while the height is 10.0 mm).
4. Clamp the higher end of the J-tube to the J-tube clamer. Be careful when clamping the J-tube.
5. Pour NaCl solution to the J-tube until the liquid just reaches the tops of the capillaries. Kindly wipe away the excess solution with a soft tissue.
6. Insert the connectivity probe to the liquid vessel. Ensure the cable is connected to the digital conductivity meter.
7. Pour 1000 ml of deionised water into the test vessel.
8. Switch ON the magnetic stirrer and set the speed at 300 rpm.
9. Switch ON the conductivity meter. Ensure there is reading shown in the meter.
10. Place the J-tube into the test vessel. Care must be taken in this procedure. No solution should be dropped to deionised water.
11. Fill the test vessel with small amount of water until the capillary tops are submerged approximately 5 mm below the surface of the water. Record the amount of water added to the test vessel.
12. At the same time, when the capillary tops are submerged, start the stop watch.
13. For every 2 minutes, take the conductivity value for a time period of 40 minutes.

14. Once the experiment done, kindly remove all the glassware and rinse with deionised water.

Result

Table 1: Standard curve data for sodium chloride

NaCl concentration (M)	Conductivity
0.0000	
0.0010	
0.0015	
0.0020	
0.0030	
0.0040	
0.0050	
0.0100	
0.0150	

Table 2: Experimental Data

Time (min)	Conductivity

Discussions

Discuss all your results. The questions below only serve as a guideline. Your discussion should not only limit to these questions.

1. Plot a graph of conductivity versus time. Determine the liquid diffusivity of NaCl solution from the obtained slope.

2. Compare the experimental value with theoretical value (can be from the literature review or calculation using liquid diffusion equation, e.g: Wilke-Chang etc.).

References

Harned, H.S., Owen, B.B., "The Physical Chemistry of Electrolytic Solutions", 3rd Edition, Reinhold Publishing Corporation, New York, 1958, pp. 254-255. (QD561.H3274 1958)
 Armfield Engineering Teaching and Research Equipment, Diffusion of a Liquid Apparatus;
 Instruction Manual, April 1993.

INSTRUMENTATION AND PROCESS CONTROL (RESPONSE OF THE FIRST ORDER SYSTEM)

EXPERIMENT NO. 18

DETERMINATION OF THE ACTUAL TEMPERATURE RESPONSE OF A TEMPERATURE MEASURING INSTRUMENT

Apparatus: Stop watch, thermocouple with probe, beaker, tripod stand, Bunsen burner with its fitting s and wire gauze.

Reagent: Water

Theory:

When a temperature measuring instrument is suddenly dipped into a beaker of boiling water, a step change in input temperature is applied to the transducer. The response of the temperature measuring instrument to this step input is exponential in form. The actual thermometer response (Q_0) approaches the step value (Q) exponentially according to the relationship.

$$Q_0 = Q_1 \left(1 - e^{-\frac{t}{T}}\right)$$

Where t = time elapsed after immersion of the thermometer.

T = time constant of the instrument, which is a measure of the speed of response.

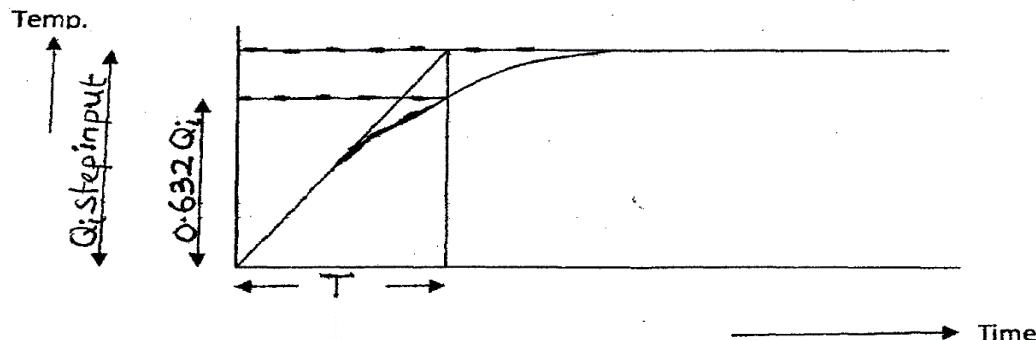


Fig 1. Response of mercury in glass thermometer to a step change in temperature.

Mathematically, the time constant can be shown to be time taken for the thermometer response to reach 63.2% of the step change. The time constant is a measure of the speed of response of the instrument.

Procedure

1. Set the Bunsen burner to produce light blue flame and wire gauze should be placed over the tripod stand.
2. Place a beaker with known volume of water on the tripod stand and allow it to boil.
3. Insert the probe of thermocouple in the beaker containing boiling water and note the temperature after 5 seconds.
4. Repeat the experiment for 10 secs, 15 secs, 20 secs, and 25 secs.
5. Tabulate the results obtained as below

Temperature (°C)	Time (s)
	5
	10
	15
	20
	25

Graph:

plot the graph of temperature of the system against the time interval, determine the slope and the intercept. Use the slope and intercept to calculate G.

$$G = \frac{10S + 4D^2}{2.5}$$

where S is the slope and D is the intercept.

References

- ✓ Collect C.V. and A.D. Hope; Engineering Measurements.
- ✓ John E.W; Modern physics

EXPERIMENT NO. 19

(PID CONTROLLER)

DETERMINATION OF TEMPERATURE AND PRESSURE OF A SYSTEM WITH ON-OFF CONTROLLER

Apparatus: Autoclave incorporated with pressure gauge and temperature measuring meter

Reagent: water

Theory

A thermodynamic system is the totality of microscopic bodies exchanging energy both with one another and with the external medium or surrounding. Control system is a mechanism of regulating process variables such as pressure, temperature, and composition, flow rate within set boundary, mainly to guarantee environmental safety, to meet product specification and to maximize profit.

On-off controller does regulate process variables at initial point of operation while set over a designated time and switch off after time has elapsed.

Controller can be classified into on-off controller, integral controller, proportional controller and proportional plus derivative controller. It can as well be classified according to the kind of power employed in the operation such as pneumatic, hydraulic or electronic controller.

Procedure

- 1) Ensure that the autoclave is fully vented by checking the pressure gauge reads zero, unscrew air cock knob B and opening lid. Connect the given autoclave with the wall socket and introduced water into it, to the level above the heating element.
- 2) Put on the mid-knob at the back of autoclave, before switching on from the main switch. Turn the valve at the side of the autoclave clockwise, in order to enable the pressure gauge to measure the vapor pressure of the fluid.
- 3) After the above operation, observe the system for 10 mins and record both the temperature and pressure from the respective meter on the autoclave.

- 4) Continue the experiment for 20 mins, 30 mins, 40 mins 50 mins, and 60 mins and tabulate the result as below.

Time (min)	Temperature (°C)	Pressure (N/m ²)
10		
20		
30		
40		
50		
60		

Graph

Plot a graph of pressure against temperature and justify Gay-Lussac's law, if the system obeys it.

Reference

Katsuhiko O., Modern Control Engineering

CORROSION AND MATERIAL SCIENCE (CORROSION STUDIES):

EXPERIMENT NO. 20

DETERMINATION OF THE EFFECT OF pH LEVEL ON CORROSION RATE

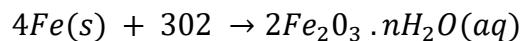
Apparatus: Three- rectangular metal piece (with the same length and breadth), stop watch, beaker, weighing balance, Bunsen burner, wire gauze.

Reagent: Dilute trioxonitrate V acid, sodium hydroxide and water.

Theory

Corrosion is defined as the partial or total wearing away, softening or dissolving of some metallic substance by chemical or electrochemical reaction with its environment.

The rusting of iron, in which iron combine with both oxygen and water to form hydrated iron III oxide, is a very good and prevalent example of corrosion.



There are four main groups of chemical agents that catalyze corrosion-namely, oxygen and oxidized chemicals, acids, alkaline and salt.

Thus, when metal corrode in an aqueous media transport or loss of material in soluble form will occur. Corrosion rate can be measured directly from metal weight loss as a result of chemical or electrochemical reaction with solution that has affinity to corrosion.

The equation for determining the corrosion rate of a material is $R = \frac{12W}{tAp}$

Where

R = corrosion rate in m/s, t time in s

W = weight loss in kg, A area of the material in m^2

ρ = density of the material in kg/m^3

W = $W_1 - W_2$ = weight loss

W_1 = weight of material before corrosion

W_2 = weight of material after corrosion

Procedure

1. Measure the length and breadth of rectangular metal piece given.
2. Weigh the given metal piece before test for corrosion and record(W_1)
3. Kindle Bunsen burner and set it to produce a light blue flame, while wire gauze should be placed over the tripod stand in order to enable evenly distribution of heat on the sample contain in the beaker.
4. Take a known volume dilute trioxonitrate V acid and one of the metal pieces into a beaker and heat for 10 minutes.
5. After heating for 10 minutes, remove the metal piece and re-weigh(W_2)
6. Repeat the experiment with the other metal piece(s) and two other reagents for 10 minutes respectively, as instructed in number 4 and 5 above.

Tabulate the results obtained as below

SAMPLE	Weight of metal piece before heating with reagent (kg)	Weight of metal piece after heating with reagent (kg)	Weight loss (kg)	Corrosion rate (m/s)
SAMPLE A: dil. HNO ₃ + metal piece				
SAMPLE B: NaOH + metal piece				
SAMPLE C: H ₂ O + metal piece				

References

- ✓ Michael B. B (1986). Encyclopedia of Material Science and Engineering
- ✓ Perry et. al; Chemical Engineer's Hand Book

CHEMICAL ENGINEERING THERMODYNAMICS

EXPERIMENT 21: DETERMINATION OF HEAT OF REACTION

OBJECTIVES

- a) To determine the enthalpy change (ΔH) of three exothermic reactions.
- b) To relates the three exothermic reactions with Hess' Law.

INTRODUCTION

This experiment is about determination of reaction heat. This chemical reaction requires energy. Energy is defined as capacity to do work. This energy can be changed by heat and work. During in the experiment, the energy that involves in the chemical reaction is calculated in terms of the amounts of heat released or absorbed. Heat (q) is a form of energy that transfer in and out of the system, stored in a random motion of the molecules and involved a difference in temperature between the system and its surroundings. There are two sign convention for heat, $q_{sys} > 0$ and $q_{sys} < 0$, $q_{sys} > 0$ means heat is transferred from surroundings to the system (endothermic reaction) while $q_{sys} < 0$ means heat is transferred from system to the surroundings (exothermic reaction). Heat is absorbed is called endothermic reaction while heat is released is called exothermic reaction.

Basically, this experiment needs to determine the enthalpy change (ΔH). Enthalpy change (ΔH) is not measured directly but measured through the energy released as heat at constant pressure, ($\Delta H = H_{(products)} - H_{(reactants)}$). This enthalpy change (ΔH) is measured in kilojoules per mole (kJmol^{-1}). ΔH with negative sign is an exothermic reaction (heat is

released) but ΔH with positive sign is an endothermic reaction (heat is absorbed).

There are three exothermic reactions occur in this experiment involving sodium hydroxide (NaOH) that need to carry out. This experiment also had been divided into three parts which were Part A, Part B and Part C. Part A-the first reaction (ΔH_1) is called heat of NaOH solution.

Hess Law state that the standard enthalpy of an overall reaction is equal to the sum of the standard enthalpies of the individual reactions. Based on the experiment, all of the three reactions refer to the Hess Law which the third reaction (ΔH_3) is equal to the sum of the standard enthalpies of the individual reactions ($\Delta H_1 + \Delta H_2$).

MATERIALS AND PROCEDURE

MATERIALS

- 1) Sodium Hydroxide (NaOH) solid
- 2) 1 M NaOH solution
- 3) 0.5 M and 1M Hydrochloric Acid (HCl)
- 4) Distilled water (H₂O)

APPARATUS

- 1) Analytical Balance
- 2) Pipette 25 ml
- 3) Spatula
- 4) Thermometer
- 5) Erlenmeyer Flask 50 ml
- 6) Small Beaker
- 7) Glass Rod

PROCEDURE

Part A: Heat of NaOH Solution (Solid NaOH + Distilled water)

- 1) put 25 ml of distilled water into a 50 ml Erlenmeyer flask and allowed to reached the room temperature.
- 2) Measure and record the temperature of the distilled water in the

Erlenmeyer flask as T_i

- 3) Weigh 0.5g of sodium hydroxide (NaOH) using a spatula.
- 4) Add NaOH into the Erlenmeyer flask and stir using a glass rod until the NaOH is completely dissolve.
- 5) Note the change of temperature while stirring and record a temperature as T_f .
- 6) Discard the solution and rinse thermometer.
- 7) Tabulated your values

Part B: Heat of NaOH Neutralization (NaOH Solution + HCl Solution)

- 1) Measure and put 25 ml of 1M hydrochloric acid (HCl) into a 50 ml Erlenmeyer flask. Allow the acid to stand until room temperature is attain. Record the temperature as T_i .
- 2) Add 25 ml of 1 M NaOH into the flask and stir using a glass rod. Note the rise in temperature and record it as T_f .
- 3) Discard the solution and rinse thermometer.
- 4) Tabulated your values

Part C: Heat of NaOH Solution (Solid NaOH + HCl Solution)

- 1) Measure and put 25 ml of 0.5 M HCl into a 50 ml Erlenmeyer flask. Once room temperature is attained record the temperature as T_i .
- 2) Weight 0.5 g NaOH and transfer it into the Erlenmeyer Flask.
- 3) Stir the mixture until the NaOH is completely dissolve. Record the new temperatures as T_f

RESULT AND DISCUSSION

Part	T_i (°C)	T_f (°C)
Solid NaOH + DH ₂ O		
1M NaOH solution + 1M HCL solution		
Solid NaOH + 0.5M HCL		

1. Find the heat (q) absorbed by the water (released by the NaOH)
2. Find the heat (q) released per gram of NaOH
3. Find the enthalpy change, ΔH_1 in kJ/mol

PRE – LAB QUESTIONS

- Define the term “calorimeter”.
- State the units of energy normally used to measure heat.
- Explain the concept of Hess Law.

POST-LAB QUESTIONS

- Write all ionic equations for the three reactions in the experiment.
- List down all possible sources of error in the experiment.

SAMPLE CALCULATIONS**TABLE OF RAW DATA**

Part	T_i (°C)	T_f (°C)
Solid NaOH + DH ₂ O	23	28
1M NaOH solution + 1M HCL solution	25	31
Solid NaOH + 0.5M HCL	24	33

Part A: Heat of NaOH solution (solid NaOH + Distilled water)

- Find the heat (q) absorbed by the water (released by the NaOH)

$$\text{heat released, } q = m \times c \times \Delta T$$

$$\text{mass} = \text{density} \times \text{volume} \quad g \text{ ml}^{-1} \times 25 \text{ ml} = 25 \text{ g}$$

$$m = m(\text{H}_2\text{O}) = 25 \text{ g} \quad c(\text{H}_2\text{O}) = 4.184 \text{ J/g.}^{\circ}\text{C}$$

$$\Delta T = 5^{\circ}\text{C}$$

$$q = 25 \text{ g} \times 4.184 \text{ J/g.}^{\circ}\text{C} \times 5^{\circ}\text{C} = -523 \text{ J (heat released)}$$

$$q = -523 \text{ J} \div 1000 \text{ J/kJ} = -0.523 \text{ kJ}$$

- Find the heat (q) released per gram of NaOH

$$25 \text{ g} = -0.523 \text{ kJ}$$

$$1 \text{ g} = -0.523 \text{ kJ} \div 25, \quad = -0.02092 \text{ kJ}$$

- Find the enthalpy change, ΔH_1 in kJ/mol

$$(\text{moles of solute} = n(\text{NaOH}) = \text{mass}(\text{NaOH}) \div M(\text{NaOH}))$$

$$m(\text{NaOH}) = 0.5 \text{ g}$$

$$M(\text{NaOH}) = 22.99 + 16.00 + 1.008 = 39.998 \text{ g mol}^{-1}$$

$$n(\text{NaOH}) = 0.5 \text{ g} \div 39.998 \text{ g mol}^{-1} = 0.013 \text{ mol}$$

$$\Delta H_1 = q \div n(\text{NaOH})$$

ΔH_1 is negative (process is exothermic)

$$q = -0.523 \text{ kJ}$$

$$n(\text{NaOH}) = 0.013 \text{ mol}$$

$$\Delta H_1 = -0.523 \text{ kJ} \div 0.013 \text{ mol} = -40.231 \text{ kJ mol}^{-1}$$

Part B : heat of neutralization (NaOH solution + HCl solution)

- Find the heat (q) produced by the reaction of NaOH solution and HCl solution

$$V(\text{HCl}) = 25 \text{ ml}$$

$$V(\text{NaOH}) = 25 \text{ ml}$$

$$C(\text{HCl}) = 1 \text{ M}$$

$$C(\text{NaOH}) = 1 \text{ M}$$

$$\Delta T = 6^\circ\text{C}$$

$$d = 1 \text{ g ml}^{-1}$$

$$m(\text{HCl}), m(\text{NaOH})$$

$$\text{mass} = d \times V$$

$$= 1 \text{ g ml}^{-1} \times 25 \text{ ml}$$

$$m(\text{HCl}), m(\text{NaOH}) = 25 \text{ g}$$

$$q = m_{\text{total}} \times C \times \Delta T$$

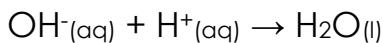
$$= 50 \text{ g} \times 4.184 \text{ J/g.}^\circ\text{C} \times 6^\circ\text{C}$$

$$= 1255.2 \text{ J}$$

$$= 1.255 \text{ kJ}$$

- Find the enthalpy change, ΔH_2 in kJ/mol

- Calculate the moles of water produced:





$$\text{moles}_{(\text{H}_2\text{O})} = \text{moles}_{(\text{OH}^{-\text{(aq)}})}$$

$$\text{moles}_{(\text{OH}^{-\text{(aq)}})} = \text{concentration (mol L}^{-1}\text{)} \times \text{volume (L)} = 1.0 \times (25.0/1000) = 0.025 \text{ mol}$$

$$\text{moles of water produced} = 0.025 \text{ mol}$$

b. Calculate the heat liberated per mole of water produced, ΔH_{neut} :

ΔH_{neut} will be negative because the reaction is exothermic

$$\Delta H_{\text{neut}} = \text{heat liberated per mole of water} = -1 \times q \div \text{moles of water}$$

$$\Delta H_{\text{neut}} = -1 \times 1.255 \text{ kJ} \div 0.025 \text{ mol} = -50.2 \text{ kJ/mol}$$

$$\text{Thus, } \Delta H_2 = -50.2 \text{ kJ/mol}$$

Part C: Heat of NaOH solution (Solid NaOH + HCl solution)

1. Find the heat (q) absorbed by the HCl (released by the NaOH)

$$m(\text{NaOH}) = 0.5 \text{ g}$$

$$V(\text{HCl}) = 25 \text{ ml}$$

$$C(\text{HCl}) = 0.5 \text{ M}$$

$$\Delta T = 9^\circ\text{C}$$

$$d = 1 \text{ g ml}^{-1}$$

$$\begin{aligned} m(\text{HCl}) &= d \times V \\ &= 1 \text{ g ml}^{-1} \times 25 \text{ ml} \\ &= 25 \text{ g} \end{aligned}$$

$$\begin{aligned} q &= m_{\text{total}} \times C \times \Delta T \\ &= 25.5 \text{ g} \times 4.184 \text{ J/g.}^\circ\text{C} \times 9^\circ\text{C} &= 960.228 \text{ J} \\ &= -0.9602 \text{ kJ} \end{aligned}$$

2. Find the heat (q) released per gram of NaOH

$$0.5 \text{ g} = -0.9602 \text{ kJ} \text{ (heat released)}$$

$$\begin{aligned} 1 \text{ g} &= -0.9602 \text{ kJ} \div 0.5 \\ &= -1.9204 \text{ kJ} \end{aligned}$$

3. Find the enthalpy change, ΔH_3 in kJ/mol

$$\Delta H_3 = \Delta H_1 + \Delta H_2$$

$$\begin{aligned}\Delta H_3 &= -40.231 \text{ kJ mol}^{-1} + (-50.2 \text{ kJ/mol}) \\ &= -90.431 \text{ kJ mol}^{-1}\end{aligned}$$

REFERENCES

AUS-e-TUTE. (2014) Chemistry Tutorial : Enthalpy (Heat) of Neutralisation . [online] 5 August 2014. Available from: <http://www.ausetute.com.au/heatneutral.html> [Accessed: 14th October 2015]

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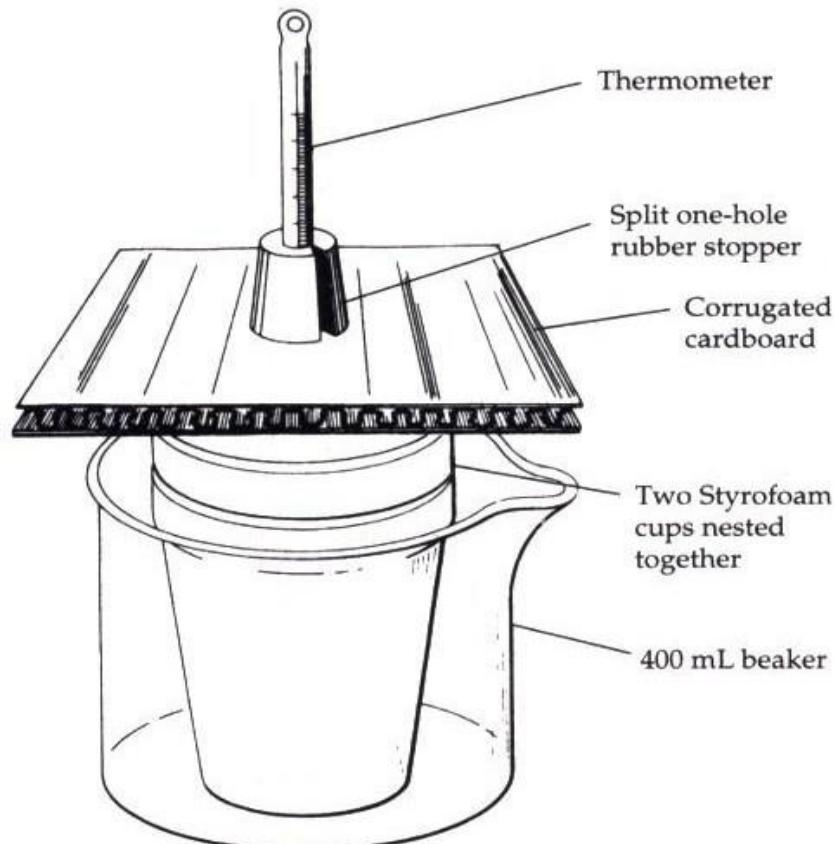


Figure 1: Simple calorimeter

HEAT OF COMBUSTION

EXPERIMENT 22: DETERMINATION OF HEAT OF COMBUSTION

In this activity, the heat of combustion of three liquid alcohols will be determined. Also, the relationship between the number of carbon atoms in an alcohol and its heat of combustion will be identified.

OBJECTIVE:

- (i) At the end of this experiment, the students are expected to:
- (ii) Determine the heats of combustion of three liquid alcohols per gram and per mole.
- (iii) compare the heat of combustion of the three liquid alcohols
- (iv) Relate the number of carbon atoms in an alcohol and its heat of combustion.

MATERIALS:

- Electronic balance, aluminum can, thermometer, iron stand, clamp, boss head, 3 alcohol lamps (ethanol, propanol and butanol), graduated cylinder.

Risk Assessment: Since alcohols are being burned there is exposure of a naked flame and a flammable hazard. Care must be taken to ensure that any spill is cleaned up immediately and safety goggles are to be worn. A fire extinguisher should also be kept close by for emergencies.

PROCEDURE:

1. Weigh the aluminum can and record its mass.
2. Measure 300mL of water and pour it carefully into the can.
3. Insert a thermometer into the can and record its initial temperature (T_1).
4. Place the can in the clamp on the retort stand.
5. Weigh the capped ethanol spirit burner and record the mass.
6. Light the burner and heat the water until the temperature rises by 20°C .
7. Extinguish the flame and cap the burner. Stir the water gently and record the maximum temperature reached (T_2).
8. Reweigh the spirit burner and determine the mass difference.
9. Calculate the standard enthalpy of combustion, (ΔH^0), using the

formula below:

$$\Delta H = \frac{\text{enthalpy change during combustion,} (\Delta H)}{\text{Mole of alcohol}} \quad \text{eq 1}$$

where $\Delta H = mc\Delta t$

m = mass of water

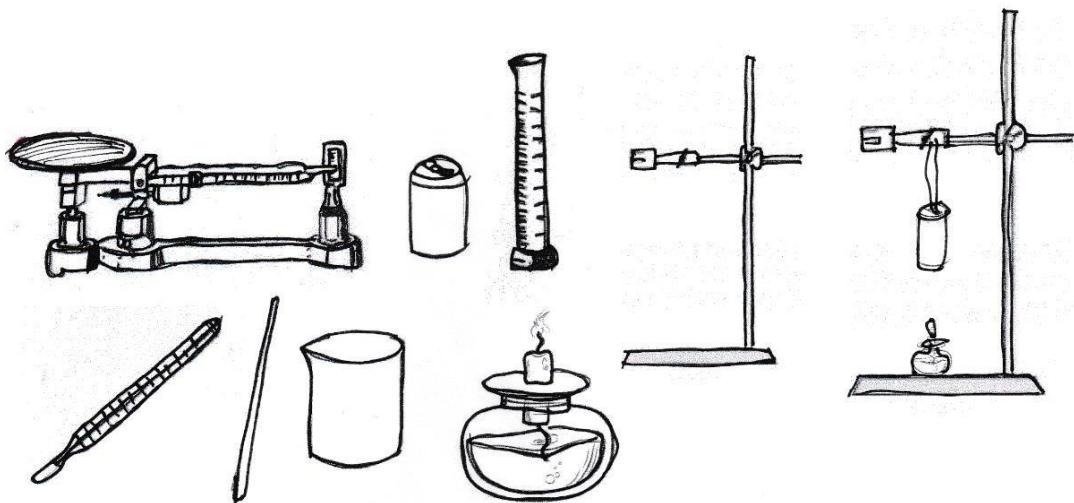
c = specific heat of water

Δt = temperature rise of water

$$\text{Mole of alcohol} = \frac{\text{mass of alcohol burnt}}{\text{Molar mass of alcohol}} \quad \text{eq 2}$$

10. Repeat the process using propanol and butanol.

SET – UP:



DATA AND RESULTS:

	ETHANOL	PROPANOL	BUTANOL
Mass of aluminum can			
Mass of water			
Mass of capped alcohol lamp filled with alcohol before burning			
Mass of capped alcohol lamp filled with alcohol after burning			
Mass of alcohol burnt			

Molar Mass of alcohol			
Initial Temperature of water (T_1)			
Final temperature of water (T_2)			
(ΔH^0) Experimental			
(ΔH^0) Theoretical			
Percent Error			

QUESTIONS & APPLICATIONS:

1. Draw a graph showing the number of carbon atoms (x-axis) and heats of combustion (y-axis).
2. Make a generalization on the relationship of the number of carbon atoms and heat of combustion based on the graph.
3. Based on the obtained heat of combustion, which among the three alcohols is the best fuel? Why?
4. Enumerate possible cause/s of error encountered in the above experiment.
5. A quantity of 1.435 g of naphthalene ($C_{10}H_8$), a pungent-smelling substance used in moth repellents, was burned in a constant-volume calorimeter.
6. A 0.5786 g of unknown substance is burned in a constant – volume bomb calorimeter that has a heat capacity of 1.674 kJ/ $^{\circ}\text{C}$. After the reaction, the temperature increased by $1.432\ ^{\circ}\text{C}$. Find the heat given-off by the burning of the unknown, in kJ/g.

APPENDIX

RAW DATA

	ETHANOL	PROPANOL	BUTANOL
Mass of aluminum can	13.99 g	13.01 g	14.12 g
Mass of water	298.52 g	302.01 g	303.59 g
Mass of capped alcohol lamp filled with alcohol before burning	140.35 g	135.22 g	110.66 g
Mass of capped alcohol lamp filled with alcohol after burning	136.7 g	132.09 g	109.55 g
Mass of alcohol burnt	3.65 g	3.13 g	1.11 g

Molar Mass of alcohol	46.06 g/mol	120.19 g/mol	74.12 g/mol
Initial Temperature of water (T1)	31	31	31
Final temperature of water (T2)	54	50	50
(ΔH^0) Experimental	-363.29 kj/mol	-928.23 kj/mol	-1608 kj/mol
(ΔH^0) Theoretical	-1367.42 kj/mol	-2021kj/mol	-2675.6 kj/mol
Percent Error	1.26 %	1.45 %	1.6 %

Computations:

A. ETHANOL

Mass of alcohol burnt = 140.35g - 136.70g Mass of alcohol burnt = 3.65 g

Molar mass of Alcohol = 46.06 g/mol

(ΔH^0) Experimental

Given: m= 298.52 g

$$C = 4.184 \text{ J/g } ^\circ\text{C}$$

$$\Delta T = 23 \text{ } ^\circ\text{C}$$

$$\Delta H = mc\Delta T$$

$$= (298.52 \text{ g})(4.184 \text{ J/g } ^\circ\text{C}) (23 \text{ } ^\circ\text{C})$$

$$= 28.7 \text{ kJ}$$

$$\Delta H^0 = \Delta H / \text{moles of alcohol}$$

$$= 28.7 \text{ kJ} / 0.079 \text{ mol}$$

$$= -363.29 \text{ kj/mol}$$

Percent Error

$$\% = \frac{|\text{Experimental} - \text{theoretical}|}{\text{Theoretical}} \times 100$$

$$= \frac{| -363.29 - (-1367.42) | \times 100}{-1367.42}$$

$$= 1.26 \%$$

Propanol

$$\text{Mass of alcohol burnt} = (133.02 \text{ g} - 132.09 \text{ g}) \\ = 3.13 \text{ g}$$

ΔH^0) Experimental

Given: $m = 302.01 \text{ g}$

$$C = 4.184 \text{ J/g } ^\circ\text{C}$$

$$\Delta T = 19.1 \text{ } ^\circ\text{C}$$

$$\Delta H = mc\Delta T$$

$$= (302.01 \text{ g})(4.184 \text{ J/g } ^\circ\text{C}) (19.1 \text{ } ^\circ\text{C}) \\ = 24.13 \text{ kJ}$$

$$\Delta H^0 = \Delta H / \text{moles of alcohol} \\ = 24.13 \text{ kJ} / 0.026 \text{ mol} \\ = -928.23 \text{ kJ/mol}$$

$$\% = \frac{|\text{experimental} - \text{theoretical}|}{\text{Theoretical}} \times 100 \\ = \frac{| -928.23 - (-2021) |}{-2021} \times 100 \\ = 1.45 \%$$

Butanol

$$\text{Mass of alcohol burnt} = (110.66 \text{ g} - 109.55 \text{ g}) \\ = 1.11 \text{ g}$$

(ΔH^0) Experimental

Given: $m = 303.59 \text{ g}$

$$C = 4.184 \text{ J/g } ^\circ\text{C}$$

$$\Delta T = 19 \text{ } ^\circ\text{C}$$

$$\Delta H = mc\Delta T$$

$$= (303.59 \text{ g})(4.184 \text{ J/g } ^\circ\text{C}) (19 \text{ } ^\circ\text{C})$$

$$= 24.13 \text{ kJ}$$

$$\Delta H^0 = \Delta H / \text{moles of alcohol}$$

$$= 24.13 \text{ kJ} / 0.015 \text{ mol}$$

$$= -1608 \text{ kJ/mol}$$

$$\% = \frac{|\text{experimental} - \text{theoretical}|}{\text{Theoretical}}$$

$$= | 1608 - (-2675.6) | / -2675.6 \times 100$$

$$= 1.6 \%$$