DEPARTMENT OF CHEMICAL ENGINEERING

UNIVERSITY OF LAGOS

CHEMICAL ENGINEERING LABORATORY III

(CHG 435)

GUIDELINES FOR REPORT WRITING AND EXPERIMENTATION

CONTENTS

INTRODUCTION

Progress in the field of science or technology depends not only on a clear grasp of relevant theoretical principles but also on the quality of experimental investigation carried out in that field. A carefully designed and properly executed experimental programme can best approach solutions to many complex problems of interest to Chemical Engineers. The underlying purpose of laboratory courses in Chemical Engineering is to develop reasonable competence in experimental research work. The early exercises are closely prescribed and serve to illustrate many of the concepts introduced in lecture courses Later, laboratory work begins to take in the nature of a research investigation carried on to gain new knowledge.

The major goals of the undergraduate Chemical Engineering laboratory are as follows:

1. To demonstrate or reinforce principles or phenomena discussed in class.
2. To give the students practice in planning and interacting with the experiment.
3. To develop students' interest in experimentation.
4. To expose the student to open-ended experiments of research and design nature.

The technical report is almost the only means of communicating scientific ideas, and explaining a scientific work and its results. The assessment of the idea or work is inevitably affected by the quality of the written reports. Therefore, composing good technical reports is a vital skill that must be acquired by every Engineer. There are several variants of technical reports depending onthe purpose for which they are written. They are classified as follows:

1. Correspondence and Letter report.
2. Progress Report.
3. Physical Research Report.
4. Process Description.
5. Feasibility Report.
6. Journal Articles.

The physical research report is written to explain physical experiments and their results. It includes the years III and IV laboratory reports and year V Research, Design and, Industrial

Project reports of the University of Lagos, Lagos, Nigeria. Hence, only this type of reporting is exhaustively discussed in this manual. Any deviation from the format spelt herein will attract stiff penalty.

THE PHYSICAL RESEARCH REPORT

There is the basic format for research reports, although there may be differences in the arrangement of the sections of the format. The format is presented below. However, the logic ofa topic may suggest modification of this pattern.

i. TITLE PAGE
ii. DECLARATION
iii. DEDICATION
iv. LETTER OF TRANSMITTAL
v. ACKNOWLEDGEMENT
vi. ABSTRACT
vii. TABLE OF CONTENTS
viii. LIST OF TABLES
ix. LIST OF FIGURES
x. LIST OF SYMBOLS (OR NOTATION)
1. INTRODUCTION
2. LITERATURE REVIEW
3. INSTRUMENTATION AND EQUIPMENT
4. EXPERMENTAL PROCEDURE
5. RESULTS
6. DISCUSSION OF RESULTS
7. CONCLUSIONS AND RECOMMENDATIONS
8. REFERENCES (OR LITERATURE CITED)
9. APPENDICES

Sections 5 and 6 may be combined as RESULTS AND DISCUSSION. Not all reports contain all the sections above, and the contents of each section vary from one report to the other.

A. THE REPORT

Many of the sections of the report in the format above are self-explanatory. However, some sections can be especial1y confusing to beginners. A clear understanding of the contents of these sections can make report writing easy and enjoyable.

FORMAT FOR SHORT REPORT

I.	TITLE PAGE
2,	ABSTRACT
3.	INTRODUCTION
4.	RESULTS: Presentation and relevant plots
5.	DISCUSSION
6.	CONCLUSION
7.	APPENDICES (if any)

Each short report must contain

1. Experimental readings signed by the by the supervisor, who must be physically present during the taken of the readings.
2. Calculated results only. There is no need to show any method used
3. All relevant plots using a minimum number of graph sheets.

FORMAT FOR LONG REPORT

I.	TITLE PAGE
2.	ABSTRACT
3.	TABLE OF CONTENTS
4.	INTRODUCTION
5.	EXPERIMENTAL APPARATUS/DIAGRAM
6.	PROCEDURE
7.	RESULTS: Calculations and relevant plots
8.	DISCUSSION
9.	CONCLUSIONS/RECOMMENDATIONS
10.	REFERENCES
11.	APPENDICES (if any).

These have grown out of experience as the best means of organizing most results of engineering studies. Occasionally, the logic or a topic may suggest modification of pattern. The breakdown of the structure is explained below.

i. TITLE PAGE

A separate cover page is used and must include title of experiment, name, and matriculation number of student and group members as well as date submitted. For example, see page 8 sample title page.

ii. DECLARATION

It needs not be included in the laboratory report. However, it is optional in Design and Research Projects.

iii. DEDICATION

It needs not be included in the laboratory report. However; it is optional in Design and Research Projects.

iv. LETTER OF TRANSMITTAL

This needs to be included in Design and Research Projects (not in the laboratory report). A sample is shown on page 9.

v. ACKNOWLEDGEMENT

This needs to be included in Design and Research projects (not in laboratory report), at least to acknowledge the contributions of some people to the successful completion of the report, especially your supervisor, lecturers, parents, friends, well-wishers and so on.

vi. ABSTRACT

The abstract is a summary of the report, and should preferably be written after the report has been completed. It should contain a statement of the problem; method, final important results and conclusions, if agreed with previously published work. It may be concluded with recommendation: The abstract must be self-contained and understandable when detached from

the main body of the report. However, it should be short, usually **NOT** more than 200 words and **NOT** less than 100 words. It should stand alone, without requiring the reader to refer to the main body of the report. If author must mention previous work, it should be done without citing a reference. The chief purpose of the abstract is to permit the reader to determine whether or not the report contains anything of interest to him.

vii. TABLE OF CONTENTS

This gives the contents of [he reports and their corresponding page numbers. An example is shown on page 10.

viii. LIST OF TABLES/F1GURES

This gives the contents of tables/figures outlined in the report. Examples are shown on page 12. Each list must be on a separate page.

ix. LIST OF SYMBOLS

A notation section is not necessary if all symbols were defined in the text. This section must include only the symbols that were not defined in the text or in equations, their meanings and corresponding units (on a separate page). In the Notation section, Roman symbols should be listed alphabetically first and then Greek letters. The symbols should be those commonly used in chemical engineering and in articles previously published in the area investigated. An example is shown on page 12.

NOTE: All the items mentioned above must be on a separate page and must be numbered using roman numerals.

The shell and tube heat exchanger

A

Long laboratory report

Presented to

The Department of Chemical Engineering

BY

EDWARDS, O.A. (Group A)
Mat. No. 900401037

In Partial Fulfillment
Of the requirements for the course

Chemical Engineering Laboratory III
University of Lagos, Lagos

January 01, 2019

Department of Chemical Engineering,
University of Lagos,
Akoka-Yaba,
Lagos.
December 07, 2019.

The Head,
Chemical Engineering Department,
University of Lagos,
Lagos.

Dear Sir,

LETTER OF TRANSMITTAL

In accordance with the regulations of the Faculty of Engineering and University of Lagos, I do hereby submit a thesis entitled "**THE TRANSIENT CHARACTERISTICS OF A PACKED BED REACTOR FOR LACTOSE-LACTASE HYDROLYSIS"** in partial fulfillment of the requirements for the award of the Bachelor of Science (Honors) Degree in Chemical Engineering at the University of Lagos.

Yours faithfully,

OLAFADEHAN, O.A.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A	Cross-sectional areas of the column, m^2
a	surface area of the spherical pellet per unit volume of pellet, m^2/m^3
C_i	concentration of component i in the fluid phase of the column, kg/m^3
C_{oi}	inlet concentration of component i in the column, kg/m^3
D_{Li}	axial diffusivity for component i in the fluid phase, m^2/s
D_{pi}	diffusivity for component i in the fluid phase within the pore of an adsorbent, m^2/s
D_s	effective diffusivity of solute in the solid phase, m^2/s
dp	particle diameter, m
F	volumetric flow rate of carrier gas, m^3/s
K_i	adsorption equilibrium constant, m^3/kg
k_i	surface reaction rate constant, kg/m^3s
R	external radius of the adsorbent, m
r	radial distance in particle, m
t	time front start of sorption process, s

z axial distance in column, m

z_T length of column, m

Greek Symbols

$\in_b$ void fraction in the bed, dimensionless

$\in_p$ void fraction in the particles, dimensionless

μ viscosity of fluid, Ns/m^2

ρ density of fluid, kg/m^3

ρ_p apparent density of particles, kg/m^3

σ dimensionless radius, r^2/R^2

ι dimensionless time, tD_{pi}/A

However, the body of the report starts with Chapter 1 - Introduction, which should bear Arabic numerals when paging.

1. INTRODUCTION

This section has the first numbered page (in Arabic numerals) of the report. It introduces the readers to the nature of problem, developing a strong justification for the work that is done. After such development, a clear statement of the aims and objectives, significance and limitations of the investigation of the project follows naturally. Note that a statement of aims and objectives (not accomplishments) is what is desired.

2. LITERATURE REVIEW/THEORETICAL PRINCIPLES

This chapter discusses background information that helps to give an insight into the problem or bring the reader up-to-elate with research. The chapter also provides a general survey of literature pertaining to the investigation. The theoretical principles of the report are developed here. Application of the theory is essential to the planning of experiments and the interpretationof results. That is, it is needed to develop a course of action to accomplish the stated objectives and as a reference point in determining how well they were actually accomplished. Whether a new theory is being developer or an old one tested, it is wise to derive all equations used in the

report However, do not derive equations that exist in textbooks, rather such equations must be referenced. Lengthy and detailed equation derivations should be placed in the appendix. An explanation of how al1-working equations will be used in later parts of the report must be given. Finally, define clearly symbols used in the equations, including units under the Notation or List of Symbols section.

3. INSTRUMENTATION AND EQUIPMENT / EXPERIMENTAL PROCEDURE

Section 3.1 deals with instrumentation and Equipment This section should be described with sufficient precision so that a skilled person could perform the experimental set-up for a duplication of the research work if necessary or desirable. The equipment is described in detail with the aid of individual drawings of important items of equipment and an overall flow of equipment and an overflow diagram of the entire arrangement of the equipment. The overall nowdiagram should be neatly drawn and should show all va1ues, lines, controls, items of equipment measuring devices, instruments and so on. That portion not actually used should be indicated by dotted lines. All important dimensions of the apparatus must be dearly indicated. For short laboratory reports, a list of equipment and their manufacturers is sometimes acceptable. The purpose of this section is to demonstrate that the equipment used was adequate to accomplish theaims and objectives of the investigation.

Section 3.2 deals with Experimental Procedure. A step-by-step account of the experiment that was carried out during the investigation is given here. The purpose is to show the general procedure followed in the laboratory was adequate to obtain the desired data. Nothing of importance should be omitted. For example, give a detailed description of any reagents used, together with the methods of analysis. A general format for writing the start-up, operating and. shutdown procedures is as follows:

1. Discuss special and general safety considerations for personnel and equipment.
2. Write a step-by-step cookbook procedure to get the equipment running under normal conditions and, not a procedure for the experiment itself.
3. Give the procedure for operating the equipment under normal conditions including the manner in which the data was gathered and the instructions to be followed in changing operating conditions.

4. Clearly show the normal step-by-step and emergency shutdown procedures.

This section must not be written in a list form, rather in paragraph(s). The final document should allow another investigator to duplicate the investigation and obtain similar results.

4. RESULTS AND DISCUSSION

Section 4.1 deals with the Experimental Results These results are actually presented in tables, graphs, photographs and so on, together with, the necessary connecting and explanatory prose. This is done by transcribing the raw data' taken in the laboratory into a neater and more orderly format. The original, untouched data sheets are placed in the appendix. No interpretation or discussion of these results is desired at this point. The following explanation is necessary.

1. Graphical representations of results greatly facilitate their discussion and the appreciation of observed trends and comparisons wit h theoretical models.
2. Tabular data may be presented with greater accuracy than graphical representation. When a trend is sufficient to establish the use of a model, graphs are preferable. For an engineering design, the objective of the study may be precise data, in which case graphical representation will have little value.
3. It is preferable not to report the same results in both graphical and tabular form. Tabular data, both never and derived, should be placed in an appendix if results are presented graphically.
4. When both new and derived data are relatively few, it is not necessary to place them in an appendix.
5. The result section should indicate at some point the independent variables and their settings (or ranges) used in the experiment.

Section 4.2 deals with Discussion of Results. This is the most important part of the report. The results obtained using the procedure described in Section 3.1 are rationalized and analyzed using the theoretical principles outlined in Section 2.2 of the report. Usefulness and significance of the analyzed results must be discussed and their relationships to the overall problem properly established. Interpretation and speculation are encouraged. Averages and trends should be listed and commented upon. Sources of errors and the validity of assumptions are discussed

Comparisons are made with previously published data and conclusions drawn. Clarity of writing and a sure understanding of the underlying physical principles are essential to the satisfactory execution of this section. In particular, the material must be presented in a logical order to facilitate understanding on the part of the reader. Evidence of originality and insight is expected.

5. CONCLUSIONS AND RECOMMENDATIONS

Section 5.1 deals with Conclusions. This section is composed of statements of facts that are proved during the investigation. These statements must be paragraphed. Do not generalize. For example, if a process is investigated between $1m^3/s$ and 10 m^3/s, do not conclude that "The pressure drop increases with flow rate rather one says Pressure drop increases from 1.83 kN/m^2 10 3.14 kN/m^2 as the air flow rate increases from 1 m^3/s to 10 m^3/s.

Section 5.2 deals with Recommendations. This section should contain suggestions on the improvement of either the equipment or the nature of the experiment. Explain what you think ought to be done to enhance accuracy of the results obtained and what other experiments can be performed using the same equipment/materials, and probably comment on the state of the equipments used.

BIBLIOGRAPHY OR REFERENCES

The List of References (or Bibliography or Literature Cited) must include all references contained in the report. References can cite a person or person's surnames only without initials ortitles in the text but with full identification in the bibliography. The reference number is placed as a superscript or in parenthesis next to the name or the last of several names. For example,

Yoshida[1] and Westerterp[2,3] measured K_LS

Or

Yoshida (1) and Westerterp (2,3) measured K_LS

Use only one style, superscript or parenthesis, throughout the text. Where names were not given, the reference number (superscript or in parenthesis) should be placed after a word (if possible), which identifies the subject of the references For example, Numerous investigators have reported on the dehydrogenation of cyclohexane on nickel, l chromia and molybdena, 2 palladium, 3 rhenium, 4 and platinum5-12 If not next to a word then put the number (superscript or in parenthesis) at the end of a phrase or sentence, which identified the subject. References can also

be cited in the text by the last name of the author (both authors when only two, first author and et al. when more than two) and year.

Do not number references in this case. For example,

Olafadehan (2001) showed the detailed development of the orthogonal col1ocation points for binary and ternary systems. OR Bridges and Houghton (1959), Sinfelt et a1. (1960) reported on the dehydrogenation of cyclohexane on platinum OR The dehydrogenation of cyclohexane on platinum has been reported (Bridges and Houghton, 1959; Sinfelt et al., 1960).

Give complete information, including the names of all authors, year, and the title of the article, journal name, volume, issue, and page number. Issue number is omitted if paging is done on yearly basis. The date is sometimes included with the year in place of the issue number. Examples are illustrated below:

1. Locket, M. 1. (1995) "Flooding of Rotating Structured Packing and its Application to Conventional Packed Columns," *Trans. IChemE,* 73, part A, 379-384.
2. Olafadehan, O. A., and A. A. Susu (200]) "Development of Orthogonal Collocation Method for Simultaneous Quaternary Adsorption in Porous Medh.) in Using Linear, Freundlich and Langmuir Adsorption Isotherms," *J Sci. Tech. Biotechnol.,* 26,1-10.
3. Susu, A. A, F E. Enoh, and A. F. Ogunye (1980) "Cyclohexane Dehydrogenation. Kinetics on a Platinum-Rhenium/Aluminium Oxide Catalyst with Hydrogen and Inert. Diluents," *J. Chem.Tech.Biotechnol.,* 30, 735-:747.

For single publications, books, theses or pamphlets, referencing should take this format.

4. Engare, T. Y, and D. N. Himmelblau (1989), *Optimization of Chemical Processes,* McGraw-Hill, Singapore, pp3 13-358.
5. Olafadehan, O. A. (1994) "The Design of a Solid-Waste Management System with Resource and Energy Recovery, "M.Sc. Thesis, University of Lagos: Lagos, Nigeria.

The style for edited books is slightly modified as follows:

6. Carlelon, H. R. (1972) *in Amorphous Materials.* Edited by Douglas, R. W. and Ellie, B. Wiley Interscien1e, New York, pp 103-111.

For an unknown or unnamed authors, alphabetized by the journal or organisation publishing the Information. All examples are given thus:

7. Anon (1954) "Neutron-soaking Sponges," Chem. Eng. Sci., **61,** 12, 132.

For patents, referencing is done thus:

8. Fenske, E. R. (1966), to Universal Oil Products Co., U. S. Patent 3, 249, 650, May 3.

For unpublished work, "in press" means formally accepted for publication by the indicated journal or publisher. The use of 'private communication' and 'unpublished data' is not recommended unless absolutely necessary because the reader may find it impossible to locate the original material. An example is given for this case:

9. Olafadehan O. A, and A A Susu (2001) "Modelling of Ternary Adsorption and Reaction in Porous Medium," *Compo* & *Chem. Eng.*, in press.

APPENDIX

Appendices should be used to relieve the main body of the report from becoming over burdened by original data, lengthy derivations of theoretical relationships and sample calculations. By removing such materials to the appendices, one is telling the reader that these materials are ancillary to the main body of the report. The reader may then consult them as his interest dictates. Therefore, they should be complete and well organized. Sampleca1culations should be given in logical order and with adequate detail Units should be clearly indicated.

WRITING STYLE

The report should be written in an acceptable technical style. Generally, the use of past tense is recommended. Every section, except conclusion and bibliography (or references) must contain an introductory paragraph. Formula should be given special attention. They must be numbered according to chapter/section, the number appearing on the right margin of the line to facilitate further references to the formula. Abbreviations should be used sparingly in the text and with due regard to the context and to the training of the reader. Short words must be spelt out. Abbreviations should not be used where the meaning will not be clear. In case of doubt, do not abbreviate any word. Abbreviations are permitted in table headings. In decimal numbers having no units, place a zero before the decimal point, 0.641 not .641.

LABORATORY SAFETY INSTRUCTIONS

Safety in the laboratory must be of vital concern to all those engaged in experimental science work. It is therefore the responsibility of everyone to adhere strictly to the basic safety precautions provided and to avoid any acts of carelessness that can endanger his life and that of others around him. It is equally important to always abide by all the instructions for conducting the experimental work during the laboratory sessions. Below are some guidelines for general laboratory safety and procedures:

1. All students must be familiar with the locations and operational procedures of the Emergency Shower, Fire Extinguishers, Gas Masks and Fire Blankets. Make sure you understand how the experimental apparatus works and what all of the adjustments do before you attempt to operate it.
2. Laboratory coats, safety glasses and safety shoes MUST be worn at all times during the laboratory session. NO THOABS and open sandals are allowed during the laboratory sessions. Be sure you have asked, and received an answer, from the Professor or the TA, about any possible hazards related to your experiment before attempting to operate it.
3. Care must be used in the handling of chemicals to avoid spills and to avoid contact with the skin. Eating, drinking and smoking are strictly PROHIBITED in the laboratory at all times. Laboratory glassware should NEVER be used for drinking purpose.
4. Report any injury immediately for First Aid treatment, no matter how small.
5. Report any damage to equipment or instrument and broken glassware to the laboratory instructor as soon as such damage occurs.

INSTRUCTIONS

1. You must attend your practical on the day you are scheduled to. Any reason for absence must be communicated in good time.
2. Lateness will not be entertained.
3. Late submission attracts a penalty.
4. Ensure you put on your laboratory coat (white).
5. Short reports should be submitted before the expiration of one week from the day the experiments are performed,

6. Long reports should be submitted before the expiration or two weeks from the day the experiments are performed.
7. Every student must submit one long report while the rest will be short reports.

PENALTIES FOR LATE SUBMISSION

1 day	**5 marks**
2days	**10 marks**
3days	**15 marks**

Report(s) that shall be more than 3 days late may neither be accepted nor graded

LAB. EXPERIMENTS SUPERVISION

The supervision for each of the experiments is shown below:

EXPERIMENT	TITLE	SUPERVISOR
1.	Microbial Culturing and Handling	Mrs. M. Amokun
2.	Marcet Boiler	Mr. A. Akinola
3	Free and Forced Convection	Mr. A. S. Akinyanju
4	Saponification of Ethyl Acetate Using Stirred Tank Reactors in Series	Mr. F. A Adeyemo
5	Bernoulli's Principle Demonstration	Mr. O. Ogunwunmi

EXPERIMENT ONE

MICROBIAL CULTURING AND HANDLING.

1.1 INTRODUCTION

Microbial culturing and handling involve the growth and manipulation of microorganisms in a controlled laboratory environment. It is a fundamental technique used in various fields, including microbiology, biotechnology, and medicine, to study microbial properties, identify pathogens, and produce antibiotics or other microbial products.

1.1.1 MICROBIAL CULTURING.

Microbial culturing involves providing microorganisms with suitable growth conditions, such as nutrients, temperature, and pH, to allow them to multiply and form visible colonies. Various culture media, such as agar plates or broth cultures, are used to provide these conditions and facilitate microbial growth.

Steps in Microbial Culturing:

1. **Sample Collection**: Collect the sample from the desired source, ensuring proper sterility and preservation to prevent contamination.
2. **Media Preparation:** Prepare the appropriate culture medium based on the expected microorganisms and their growth requirements.
3. **Inoculation:** Inoculate the culture medium with the sample using sterile techniques to prevent contamination. This can be done using loop inoculation, streak plating, or other methods.
4. **Incubation:** Incubate the inoculated culture medium at an appropriate temperature and atmosphere for the microorganisms to grow. Incubation times vary depending on the specific microorganisms.
5. **Observation and Monitoring:** Observe the culture regularly for signs of growth, such as colony formation, turbidity, or color changes.
6. **Subculturing:** If necessary, subculture the microorganisms onto fresh media to maintain growth or isolate specific colonies.

NOTE: Before culturing, all medium and glassware must be sterilized using an autoclave. This is to ensure that only the microbes in the sample are grown on the solid media.

1.2 MICROBIAL HANDLING.

Proper microbial handling is crucial to prevent contamination, ensure safety, and maintain the integrity of the culture. Key aspects of microbial handling include:

1. **Aseptic Techniques**: Employ strict aseptic techniques to prevent the introduction of contaminants. This includes sterilization of equipment, work surfaces, and consumables.
2. **Personal Protective Equipment (PPE):** Wear appropriate PPE, such as gloves, lab coats, and safety glasses, to protect yourself from potential hazards.
3. **Proper Disposal:** Dispose of contaminated materials and waste properly to prevent the spread of microorganisms.
4. **Labeling and Documentation:** Clearly label all cultures and maintain accurate records of procedures and observations.
5. **Waste Segregation:** Segregate liquid and solid waste containing microorganisms for proper disposal or treatment.

1.2 METHODS OF DETECTING AND IDENTIFYING MICROORGANISMS.

- **Culture plating:** This is the most common method for detecting and identifying microorganisms. A sample is spread onto a nutrient agar plate, and the plate is incubated at a suitable temperature for the microorganisms to grow. Colonies that form on the plate are then examined to identify the type of microorganism present.
- **Microscopic examination:** This method can be used to detect and identify microorganisms that are too small to see with the naked eye. A sample is placed on a slide and stained so that the microorganisms can be seen under a microscope.
- **Biochemical tests:** These tests are used to identify microorganisms based on their ability to carry out certain biochemical reactions. For example, some microorganisms can ferment sugars, while others can produce enzymes that break down certain compounds.

1.3 MICROSCOPICAL AND MACROSCOPICAL OBSERVATION OF MICROBIAL CULTURES

1.3.1 INTRODUCTION

This area of chemical engineering is called biochemical engineering. Biochemical engineering is a field that applies the principles of chemical engineering to the study of biological systems. This includes the study of microorganisms, which are tiny living organisms that can only be seen with a microscope. The shape, size, and grouping of microbial cells are important characteristics that can be used to classify and identify different species of microorganisms. In addition, how microorganisms react to different stains can also be used for these purposes.

Staining is a technique that is commonly used in microbiology to make microorganisms more visible under the microscope. This is done by applying a dye to the microorganisms, which causes them to change color. Different types of stains can be used to reveal different structures of the microorganisms. For example, Gram stain is a common staining technique that differentiates between gram-positive and gram-negative bacteria. Gram-positive bacteria will stain blue, while gram-negative bacteria will stain red.

1.4 TECHNIQUE USED TO ENUMERATE AND ISOLATE BACTERIAL COLONIES IN A SAMPLE.

Yes, there are two main techniques used to enumerate and isolate bacterial colonies in a sample:

1. **POUR PLATE METHOD**: In this method, a known volume of the liquid sample is mixed with molten agar medium and poured into a sterile petri dish. The agar medium then solidifies, and the microorganisms in the sample grow and form colonies on the surface of the agar. The number of colonies can be counted and the number of microorganisms in the original sample can be estimated.
2. **SPREAD PLATE METHOD**: In this method, a known volume of the liquid sample is spread onto the surface of a sterile agar plate using a sterile loop or spreader. The microorganisms in the sample then grow and form colonies on the surface of the agar. The number of colonies can be counted and the number of microorganisms in the original sample can be estimated.

Here is a table summarizing the key differences between the two methods:

Feature	Pour plate method	Spread plate method
Mixing sample with agar	Sample is mixed with molten agar and poured into a petri dish	Sample is spread onto the surface of a solidified agar plate
Distribution of colonies	Colonies are distributed throughout the agar	Colonies are distributed on the surface of the agar
Sensitivity	More sensitive than the spread plate method	Less sensitive than the pour plate method
Advantages	Can be used to enumerate and isolate a wider range of microorganisms	Can be used to isolate single colonies from a mixed culture
Disadvantages	Requires more agar	Requires more time to perform

The choice of which method to use depends on the specific application. The pour plate method is more sensitive than the spread plate method and can be used to enumerate and isolate a wider range of microorganisms. However, the spread plate method can be used to isolate single colonies from a mixed culture.

1.5 TYPES OF DILUTION

There are two main types of dilution methods: serial dilution and extinction dilution.

- Serial dilution: In serial dilution, a sample is diluted in a series of steps. For example, a 1:10 dilution is made by adding 1 ml of the sample to 9 ml of diluent. A 1:100 dilution is made by adding 1 ml of the 1:10 dilution to 9 ml of diluent. This process can be repeated until the desired dilution factor is reached.
- Extinction dilution: In extinction dilution, a sample is diluted in a series of tubes containing broth. The tubes are then incubated, and the most dilute tube in which growth occurs is considered to contain a single microorganism.

1.5.1 EXTINCTION DILUTION METHOD.

The extinction dilution method is a technique used to isolate pure colonies of microorganisms from a mixed culture. The method is based on the principle that if a mixed culture is diluted sufficiently, one of the tubes will contain only a single type of organism. Upon incubation, this tube will contain a pure culture of the organism.

Procedure for carrying out Extinction dilution on a sample:

1. Prepare a series of tubes containing 9 ml of broth media.
2. Using sterile pipetting techniques, transfer 1 ml of the mixed culture into the first tube of broth medium.
3. Mix the culture thoroughly and, using a second sterile pipette, transfer 1 ml from the first tube to the second.
4. Repeat procedures 2 and 3 until all the tubes have received 1 ml of broth from the tube just preceding it in sequence.
5. Incubate the tubes at 37°C until growth appears.

Additional notes:

- The sterility of the pipettes and tubes is critical to the success of this method.
- The volume of the mixed culture that is transferred should be consistent from tube to tube.
- The incubation time should be sufficient for the organism to grow, but not so long that the culture becomes overgrown.

1.5.2 SERIAL DILUTION METHOD

In microbiology, serial dilution is used to enumerate microorganisms in a sample. This is done by diluting the sample in a series of steps, each time by a factor of 10. The diluted samples are then plated on agar plates and the number of colonies that form is counted. The number of colonies is then used to estimate the number of microorganisms in the original sample.

Procedure for carrying out serial dilution on a sample:

1. **Prepare a sterile diluent**.
   The diluent should be sterile to prevent the introduction of microorganisms that could interfere with the results. Sterile water or broth are commonly used as diluents.

2. **Label a series of test tubes or vials.**
   Label each tube or vial with the corresponding dilution factor. For example, if you are making a serial dilution with a factor of 10, you will need tubes or vials labeled 1:10, 1:100, 1:1000, and so on.

3. **Add 9 ml of diluent to each tube or vial.**
   Use a sterile pipette to add 9 ml of diluent to each tube or vial.

4. **Add 1 ml of the sample to the first tube or vial.**
   Use a sterile pipette to add 1 ml of the sample to the first tube or vial. Make sure to mix the sample thoroughly with the diluent.

5. **Transfer 1 ml of the diluted sample from the first tube or vial to the second tube or vial.**
   Use a sterile pipette to transfer 1 ml of the diluted sample from the first tube or vial to the second tube or vial. Mix the diluted sample thoroughly with the diluent in the second tube or vial.

6. **Repeat step 5 until you have reached the desired dilution factor.**
   Continue transferring 1 ml of the diluted sample from one tube or vial to the next until you have reached the desired dilution factor.

7. **Plate 1 ml of each diluted sample onto an agar plate.**
   Use a sterile loop to spread 1 ml of each diluted sample onto a separate agar plate.

8. **Incubate the plates at an appropriate temperature for the microorganisms to grow.**
   The incubation time will depend on the type of microorganisms being tested. For example, E. coli typically requires 24 hours of incubation at 37°C to grow.

9. **Count the number of colonies on each plate**.
   Use a colony counter or a magnifying glass to count the number of colonies on each plate.

10. **Use the formula to estimate the number of microorganisms in the original sample.**
    The formula to estimate the number of microorganisms in the original sample is:

    Number of microorganisms/ml = (Number of colonies) / (Volume plated) x (Dilution factor)

CALCULATIONS EXAMPLE

To calculate the Mean count per plate.

Given 3 plates with each having 165, 172, and 168 bacteria colonies

The average Mean count per plate = $\frac{165+172+168}{3}$ = 168.33

If 0.5 ml contains 168.33

Then 1 ml will contain 168.33/0.5 =336.7colonies Dilution

Factor (DF) = 10^7

Population density = 336.7 X 10^7

Thus, the population density of bacteria present in the soil in the soil sample was 3367 X 10^6 cfu/g (cfu/g means colony forming units)
For the example above 1 g of soil sample was used.
Population density per kg = 3367 X 10^6 X 1000 of soil sample.

EXPERIMENT TWO

MARCET BOILER

Thermodynamics is a study related to energy and entropy, which also deals with heat and work. It is a set of theories that are related to macroscopic properties, visible with the naked eye which we can measure the volume, pressure, and temperature.

Thermodynamics study about the interchange of heat and work between a system and the surroundings, which occurs when the system undergoes a process. Thermodynamics is also concerned with the changes in the properties of fluid. Ideal gas law is a law, which relates pressure, temperature and volume of gases. The relationship between them may be deduced fromthe kinetic theory and is therefore called the Ideal Gas law. The ideal gas law was originally determined empirically and is simply:

$$PV = nRT$$

Where,

P= Absolute pressure

V= Volume

n= Amount of substance (moles)

R= Ideal gas constant

The Marcet boiler is a device used to investigate the relationship between pressure and temperature of saturated steam in equilibrium with water. The slope $(dT/dP)_{SAT}$ obtained from the experimental data is compared with calculated data from the steam table.

Clausius-Clapeyron Equation states that:

$$(dT/dP)_{SAT} = \frac{Tv_{fg}}{h_g}$$

$$(dT/dP)_{SAT} = \frac{T(v_f - v_g)}{h_f - h_g}$$

Where,

$$h_f + h_{fg} = h_g$$

$$h_{fg} = h_g - h_f$$

If $\nu_g >> \nu_f$,

Therefore,

$$dT/dP)_{SAT} = \frac{T(v_f - v_g)}{h_f - h_g} = \frac{Tv_g}{h_{fg}}$$

In which,

v_f= specific volume of saturated liquid

v_g = specific volume of saturated vapor

h_f = enthalpy of saturated liquid

h_g= enthalpy of saturated vapor

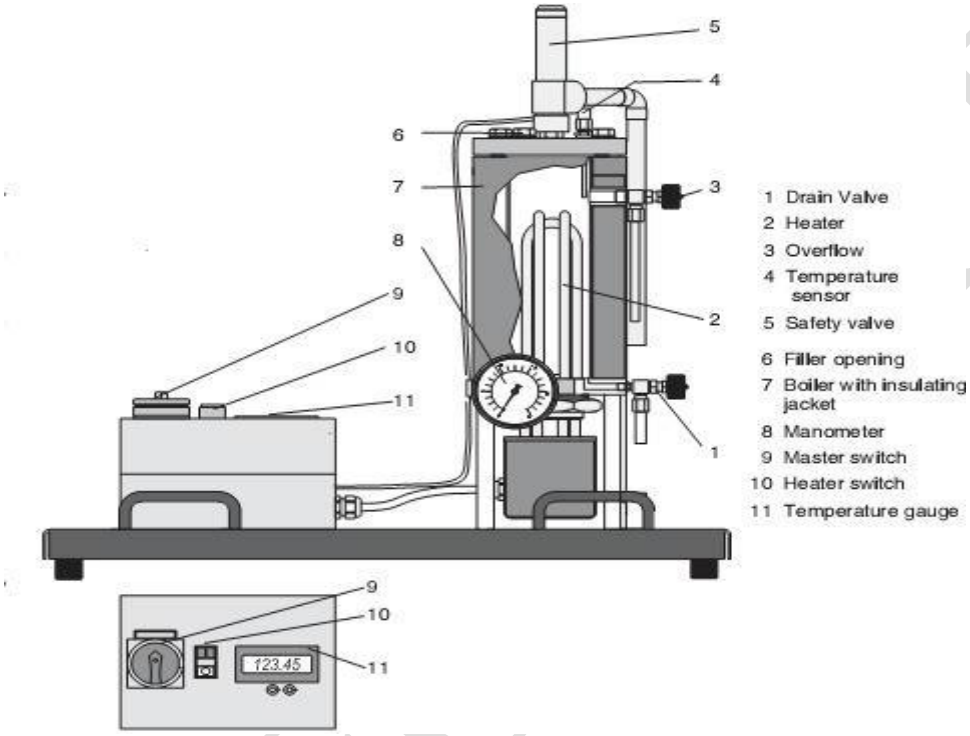
h_{fg} = latent heat of vaporization

OBJECTIVES

1. To study the relationship between the pressure and the temperature of saturated steam in equilibrium with water.

2. To understand the concept of the relationship of pressure and temperature of steam in equilibriumwith water.

Marcet Boiler



PROCEDURES

1. Turn on the power supply switch.
2. If the boiler is initially filled with water, open the valves at the level side tube to check the water level. Pour in additional distilled water if necessary. Then, close the valves.
3. Set the temperature controller to 185°C, which is slightly above the expected boiling point of the water at 10 bar (abs).
4. Open the valve at feed port and turn on the heater.

Important: Always make sure that the valves at the level sight tube are closed before

turning on the heater, as the sight tube is not designed to withstand high pressure and temperature.

5. Observe the steam temperature rising as the water boils.
6. Allow steam to come out from the valve for about 30 seconds, and then close the valve. This step is important to remove air from the boiler as the accuracy of the experimental results will be significantly affected when air is present.
7. Record the steam temperature and pressure when the boiler is heated until the steam pressure reaches 10 bar (abs).

   Warning: Never open the valves when the boiler is heated as pressurized steam can cause severe injury.

8. Then, turn off the heater and the steam temperature and pressure will begin to drop. Allow the boiler to cool down to room temperature.
9. Record the steam temperatures at different pressure readings when the boiler is heated and cooled.
10. Switch off the heater and allow the boiler temperature to drop.

    Note: Do not open the valve at the water inlet port as it is highly pressurized at high temperature.

Table of Results.

Pressure p (Bar)		**Temperature , T**				**Measured slope, dP/dT**	**Calculated slope,** Tv_g/h_{fg}
Gauge	**Absolute**	**Increase (ºC)**	**Decrease (ºC)**	**Average T_{ave} (ºC)**	**Average T_{ave} (ºK)**		
0.00							
0.10							
0.20							
0.30							

0.40							
0.50							
0.60							
0.70							
0.80							
0.90							
1.00							
1.10							
1.20							
1.30							
1.40							
1.50							
1.60							
1.70							
1.80							
1.90							
2.00							
2.50							
3.00							
3.50							
4.00							
4.50							
5.00							

5.50							
6.00							
6.50							
7.00							
7.50							
8.00							
8.50							
9.00							
9.50							
10.00							

EXERCISES

Atmospheric pressure :_____ bar

Atmospheric temperature :_____(^{0}C)

i. Prepare a graph with temperature, T against absolute pressure, P.

ii. Measure/calculate the slope of the graph using certain points.

iii. Plot $dT/dP)_{SAT}$ versus P, and $\frac{Tv_g}{h_{fg}}$ versus P on the same graph

iv. Give the reason why it is necessary to remove air from the boiler at the beginning of the experiment.

v. Compare the graph plotted from the experimental data to that of the calculated data with explanation.

vi. Comment on any discrepancy and sources of error of the experiment.

vii. Discuss the liquid and vapour behavior observed through the experiment and list some examples of its industrial applications.

EXPERIMENT THREE

FREE AND FORCED CONVECTION

Objective:

Determination of heat transfer coefficient for free and forced convection for different geometries.

INTRODUCTION

There are three modes for heat transfer: convection, conduction, and radiation. The Convection heat transfer plays an important role in many industrial applications. Based on different criteria, convection can be divided into different categories from different aspects. In the most general division, it is subdivided into free and forced convection. In the forced convection, the fluid to be heated is blown or pumped past the heated surface by employing a pump or a fan, while in natural (or free) convection, fluid flow is naturally achieved based on the density variation in the heated fluid.

The heat transfer rate to the fluid, Q can be calculated using the first law of thermodynamics for the heated fluid:

$$\dot{Q} = \dot{m}\ \Delta h \qquad 1$$

where Δh is the enthalpy variation of the fluid in the duct and is the mass flow rate which is calculated as:

$$\dot{m} = \rho\, w\, A \qquad 2$$

Where ρ is the air density, ***w*** is the averaged velocity and A is the cross-sectional area of the duct which is equal to 0.0144 m2 in this experiment. The air density can be found in thermodynamics tables. Using perfect gas assumption for the air, Eq. (1) becomes:

$$\dot{Q} = \dot{m}\ C_p\, \Delta T \qquad 3$$

The temperature difference ΔT is calculated from the difference between the average inlet and outlet temperatures. The specific heat capacity of the air C_p is also dependent on the air temperature and should be found in thermodynamics tables. Since the temperature varies in the duct length, the value should be evaluated in the average temperature of air in the duct, T_M

$$T_M = \frac{T1+T2}{2} \qquad 4$$

The heat sources on the test stand consist of electrical resistors; thus, the amount of power that is

consumed by the heaters, P_e, can be considered as a measure of the amount of heat released. The factor for efficiency ŋ provides information on the losses that occur during heat transfer. This factor indicates the portion of the input energy that is transferred to the fluid. This can be written as follows:

$$ŋ = \frac{\dot{Q}}{P_e} \qquad 5$$

The efficiency shows all losses which result from convection and radiation to the surroundings and not to the fluid. The transfer of heat from a surface to a fluid can be described mathematically as follows:

$$\dot{Q} = A\,\alpha\,T_m \qquad 6$$

where α is the heat transfer coefficient and T_m is the average temperature. The heat transfer rate is the same as the amount calculated from Eq. (3). Determination of T_m is challenging. If one assumes that temperature is varying linearly along the duct, T_m will be identical to T_M calculated from Eq. (4). Another important value introduced in the literature is Log Mean Temperature (LMT). It is calculated using the following formula:

$$T_m = \frac{(T_{0\,in} - T_{L\,in}) - (T_{o\,out} - T_{L\,out})}{\ln\frac{(T_{o\,in} - T_{L\,in})}{(T_{o\,out} - T_{L\,out})}} \qquad 7$$

Since the surface temperature T_0 of the heater remains almost constant across the entire area and only the temperature of the air T_L changes significantly between the inlet and the outlet, one can simplify this equation:

$$T_m = \frac{(T_{L\,out} - T_{L\,in})}{\ln\frac{(T_{o\,in} - T_{L\,in})}{(T_{o\,out} - T_{L\,out})}} \qquad 8$$

Therefore, the heat transfer coefficient, α, can be evaluated from Eqns. (3), (6), and (8). The heat transfer depends not only on the temperature difference and the surface material of the heater but is also influenced by the flow regime, i.e., laminar or turbulent flow. Reynolds number is a criterion for defining whether a flow is turbulent or laminar.

For pipes, there is laminar flow at Re < 2300. In the flat plate, this is the case at Re < 10^5

However, there are other values for fins. The Reynolds number is defined as:

$$R_e = \frac{w\,l}{v} \qquad 9$$

where l is characteristic length scale which is the plate length for flat surfaces and v is the kinematic viscosity of the fluid. The kinematic viscosity of the air v is temperature dependent and can be taken

from thermodynamics tables at T_M. The Nusselt number is dimensionless and is used in measuring heat transfer rates:

$$N_u = \frac{\propto l}{k} \qquad 10$$

where k is thermal conductivity. The Nusselt number can be calculated once the heat transfer coefficient, α, is known. The following equation offers a further way of determining the Nusselt number for a parallel flow over a smooth surface (plate) approximating a laminar flow:

$$\mathrm{Nu} = 0.664\ \mathrm{Re}^{0.5}\mathrm{Pr}^{0.33} \qquad 11$$

Using the values obtained from Eq. (11) it is possible to check the accuracy of experiments for flat plate heater. The heat transfer coefficient α can be determined experimentally using 12 below.

$$\alpha = \frac{\dot{m} \cdot c_p \cdot (T_2 - T_1)}{A_\alpha \cdot (T_4 - T_1)} = \mathrm{f}(Nu) \qquad 12$$

Procedure

At the beginning of the experiment the heater element with the flat plate is connected to the control and display unit prior to being fixed in the air duct. Once the power supply has been connected, the potentiometer on the control unit is set to 100% and the surface temperature T_0 is measured using the thermocouple. Once a steady state condition has been reached, there is no noticeable temperature change at the surface of the heater element, the temperature is saved. The heater is then placed in the duct. Once again it is necessary to wait until a steady state condition is reached. The following values are measured for evaluation:

- Temperature T_{in} at the inlet to the air duct;
- Volumetric flow rate at the inlet to the air duct;
- Temperature T_{out} at the outlet of the air duct.

This experimental sequence is applicable to all the subsequent experiments, see Table 1. In the case of the pipe bundle and the heater with fins, the surface temperature can be measured prior to fittingin the air duct using the measuring glands.

Turn on the fan and repeat the abovementioned sequence. Increase the fan power to 100% of its rated capacity with the heater at full power.

The temperature drop within the heated pipe bundle is measured on the heater insert for the free and forced convection cases. The heater insert is operated at 100% power output and the thermocouple is pushed into the air duct through the measuring gland such that the tip is in the center of the cylinder bore. The thermocouple is then removed from the first measuring gland and inserted in the other three holes in the cylinder.

Table 1: Measured data sheet.

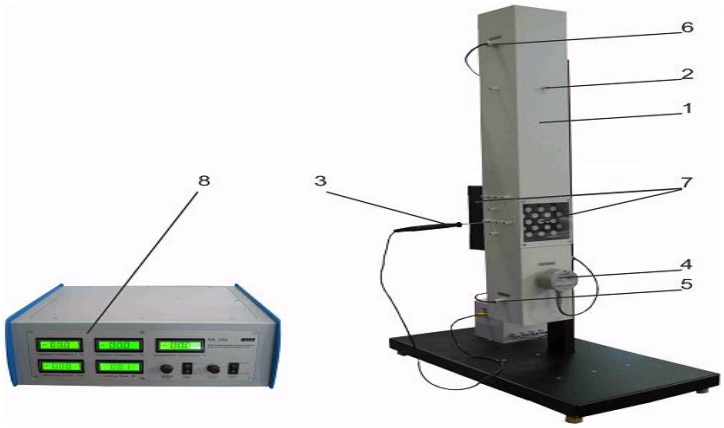
	Flat Plate		Pipe bundle		Fins	
	natural	forced	natural	forced	natural	forced
T_{in}						
T_{out}						
w (m/s)						
P_{el}						
η						

After completing the measurements, find the efficiency of the system for each heater and the convection mode. Determine the effects of the flow regime on the heat transfer rate. For the flat plate heater calculate the accuracy of the experimental data with comparison of the measured values to the oneobtained from Eq. (11).

Discussion

1) What are the differences between laminar and turbulent flows? Which one has the higher heat transfer coefficient?

2) What is the difference in the measured values of heat transfer coefficient if one uses linear average temperature instead of LMT?



1	Air duct	6	Pt100 element for outlet temperature T_2
2	Measuring glands	7	Pipe bundle heater insert (fins & flat plate not shown)
3	Thermocouple, temperature T_3		
4	Flow sensor	8	Control and display unit
5	Pt100 element for inlet temperature T_1		

8.3 Physical properties of air

T in °C	ρ in $\frac{kg}{m^3}$	c_p in $\frac{kJ}{Kg \cdot K}$	λ in $\frac{W}{K \cdot m}$	η in $10^{-6} \cdot \frac{kg}{m \cdot s}$	ν in $10^{-6} \cdot \frac{m^2}{s}$	a in $10^{-6} \cdot \frac{m^2}{s}$	Pr
-20	1,3765	1,004	0,02301	16,15	11,73	16,6	0,71
0	1,2754	1,004	0,02454	17,10	13,41	19,1	0,70
20	1,1881	1,007	0,02603	17,98	15,13	21,8	0,70
40	1,1120	1,008	0,02749	18,81	16,92	24,5	0,69
60	1,0452	1,009	0,02894	19,73	18,88	27,4	0,69
80	0,9859	1,010	0,03038	20,73	21,02	30,5	0,69
100	0,9329	1,012	0,03181	21,60	23,15	33,7	0,69
120	0,8854	1,014	0,03323	22,43	25,33	37,0	0,68
140	0,8425	1,017	0,03466	23,19	27,53	40,5	0,68
160	0,8036	1,020	0,03607	24,01	29,88	44,0	0,68
180	0,7681	1,023	0,03749	24,91	32,43	47,7	0,68
200	0,7356	1,026	0,03891	25,70	34,94	51,6	0,68
250	0,6653	1,035	0,04243	27,40	41,18	61,6	0,67
300	0,6072	1,046	0,04591	29,20	48,09	72,3	0,67
400	0,5170	1,069	0,05257	32,55	62,95	95,1	0,66
500	0,4502	1,093	0,05848	35,50	78,86	119	0,66
600	0,3986	1,116	0,0635	38,30	96,08	143	0,67
700	0,3577	1,137	0,0678	40,87	114,3	166	0,69
800	0,3243	1,155	0,0713	43,32	133,6	190	0,70
900	0,2967	1,171	0,0743	45,65	153,9	214	0,72
1000	0,2743	1,185	0,0768	47,88	175,1	237	0,74

Tab. 8.1 Physical properties of dry air at 1 bar

EXPERIMENT FOUR

SAPONIFICATION OF ETHYLACETATE USING STIRRED TANK REACTORS IN SERIES

As a rule, chemical processes are not spontaneous and are incomplete. Indeed, in the majority of cases, the reaction products only formed gradually.
The speed of the reaction can be very varied, as reactants only react with one another if they meet with a sufficiently large amount of energy. An increase in the temperature therefore increases the conversion of the reactants. The time for which the reactants are in contact is a further criterion.

The conversion of the reactants is thus dependent on:
- The nature of the reactants
- The concentration and mixing of the reactant
- The time that the reactants are in contact
- The reaction temperature

For each chemical reaction, there exists a process that splits the product of the reaction back into the original reactants. This counter-reaction is, in turn, temperature dependent. It thus sets the equilibrium between the concentrations of the initial reactants and the product. This situation is termed dynamic as both reactions occur side by side without interruption; however, the reactant concentration does not change.

The response time and position of this equilibrium can be influenced, for example, by:

- Change in the time for which the reactants are in contact or the duration of the period in the reactor.
- Change of the reaction temperature.

These relationships are to be checked based on the saponification of ether with sodium hydroxide.
The following reaction occurs:

$$CH_3\,COO\,CH_2\,CH_3 + OH^- + Na^+ \rightleftarrows HOCH_2\,CH_3 + CH_3\,COO^- + Na^+$$

$$\text{acetic ether} + \text{sodiumhydroxide} \rightleftarrows \text{ethanol} + \text{sodiumacetate}$$

The ether molecules are split and each disintegrates into an acetate ion and an ethanol molecule. During this process the hydroxide ions in the sodium hydroxide are consumed. The progress of the reaction and conversion of the reactants can thus be tracked extremely well by the change in the hydroxide concentration. Alternatively, a conductivity measurement or volumetric analysis with acid can be used.

From the conductivity values, the percentage conversion of the reactants S can be calculated with the aid of the following equation:

$$S = \left(1 - \frac{(\kappa - \kappa_e)}{(\kappa_o - \kappa_e)}\right) 100\,\%$$

κ: Actual measured value for conductivity

κ_0: Initial conductivity of the 2.3 % sodium hydroxide
κ_e: Conductivity of the end product produced
(sodium acetate solution 1/20 molar,~1 mS/cm)

Such a cascade consists of several stirred tanks and a process with dead time connected in series.
The arrangement of stirred tanks in series offers the advantage that in one setup, solutions with varying degrees of progress of the reaction are available.

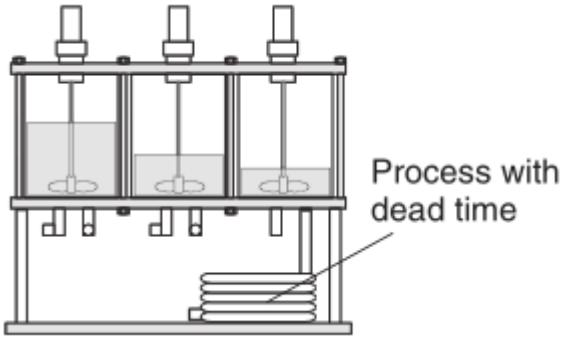


Figure 2.1 Stirred tanks and a process with dead time process in series

2.1 Task of the Experiment
- Study the influence of the stirring time to the conversion-process in the Stirred Tanks in Series.
- Study the performance of a cascade of three equal-volume CSTRs in series.

2.2 Experimental Procedure
– Check and ensure all connections to the reaction vessels and the measuring sensors are in place.
– Prepare a glass beaker with 400 ml of 2.3 % sodium hydroxide, using the measuring sensor, measure the conductivity and temperature and
– Prepare a glass beaker with 400 ml of 5 % ethyl acetate solution, using the measuring sensor, measure the conductivity and temperature and note.
– Connect the correct (see 2.2) chemical hoses from the pumps to the cascade using the rapid action connectors
– Ensure that the end of the overflow hose from the delay section is in the collecting tray
– Place all three-way valves in the correct open position

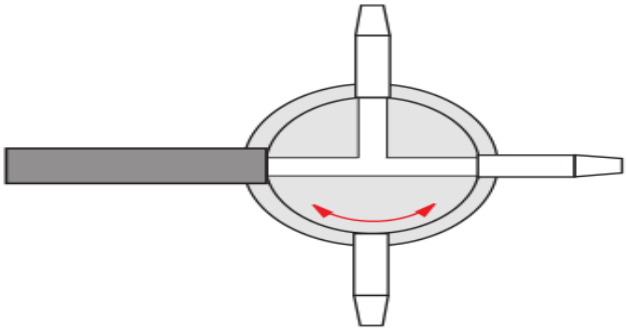


Figure 2.2: Three-Way Valves

– Switch on both chemical pumps and adjust to the same flow rate of approx. 80%
– Switch on the stirrers one after the other, once the blades are covered with sufficient liquid, and set to a

medium speed
– Once the reaction mixture has reached all tanks and sections, with the aid of the measuring point selector measure all four values for conductivity and reaction temperature and note
– Reduce the flowrate of both chemical pumps to the same value of around approx. 40%
– At intervals of one minute, log the values at all four measuring points until a stable state is reached.

After the end of the experiment:
– Undo all connections to the reaction vessels and remove the measuring sensors
– Rinse measuring sensors with water
– Drain reaction vessels and section and rinse out with water
– Drain both chemical tanks and rinse out
– Operate both chemical pumps with water to clean them
– Correctly dispose of the product of the reaction collected in the collecting tray
– Switch off unit at master switch

2.3 Evaluation of Experiments
– Convert measured results for conductivity into percentage conversion of the reactants and compare.

EXPERIMENTAL DATA SHEET

CE 310 Chemical Reactors Trainer **Experiment No.**						
Experiment reactor type:				**Date:**		
				Sodium hydroxide 2.3 % κ_oL:		
				Ether solution 5% κ_oE:		
				Room temperature T_o in ^oC:		
S/N	**Pump 1, %**	**Pump 2, %**	**Time, min**	**Reaction Temperature, ^oC**	**Conductivity, mS/cm**	**Conversion of Reactant, %**
1.						
2.						
3.						
4.						
5.						
6.						

EXPERIMENT FIVE

EXP. TITLE: BERNOULLI'S PRINCIPLE DEMONSTRATION
AIM: TO INVESTIGATE BERNOULLI'S LAW

1. INTRODUCTION:

Bernoulli's principle is a fundamental concept in fluid dynamics that describes the behavior of a moving fluid. It states that an increase in the fluid's speed in a stream results in a decrease in pressure or potential energy. Bernoulli's principle essentially illustrates the relationship between the fluid's speed and pressure. The principle is often applied to various fields, including aviation, engineering, and hydraulics. For example, it helps explain how airplane wings generate lift and how fluid flows through pipes and nozzles.

2. THEORY

For a constant head h, Bernoulli's equation can be written as:

$\frac{P_1}{\rho} + \frac{W_1^2}{2} = \frac{P_2}{\rho} + \frac{W_2^2}{2}$ = Const. 1

Where P_1 and P_2 are the pressures at points 1 and 2 along the liquid path, and W_1 and W_2 are the flow velocities at the two points. Also, ρ is the constant density of the liquid flowing.

Allowing for friction losses in the liquid stream and since P = ρgh, pressure P_1 and P_2 can be converted to static pressure heads h_1 and h_2 as follows:

$h_1 + \frac{W_1^2}{2g} = h_2 + \frac{W_2^2}{2g} + h_v$ 2

Where h_1 and h_2 are pressure heads at points 1 and 2, and h_v is the pressure head loss in the system.

For liquid flow in a closed system such as the venturi tube (Fig. 1), the mass rate of flow is a constant, such that:

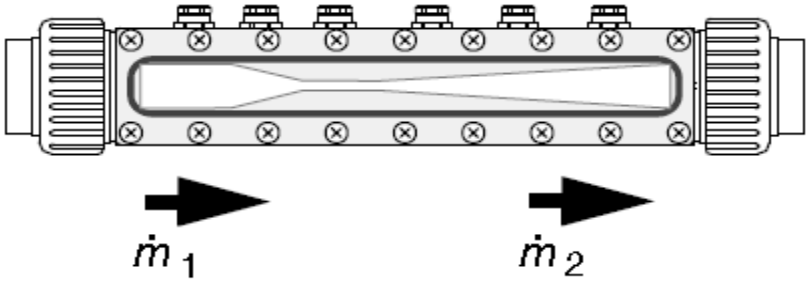


Figure 1: A ve

$\dot{m_1} = \dot{m_2}$ 3

Recall that:

Mass flow rate, $\dot{m}$ = volumetric flow rate, $\dot{v}$ X density, ρ i.e.

$\dot{m} = \dot{v} X \rho$ 4

Thus,

$v_1^{\cdot} X \rho = v_2^{\cdot} X \rho$ 5

Therefore,

$v_1^{\cdot} = v_2^{\cdot}$ = const. 6

This means that the volumetric flow rate through the venturi tube is also a constant.

Also, recall that:

Volumetric flow rate, $v^{\cdot}$ = Cross-sectional area, A X Velocity, V i.e.

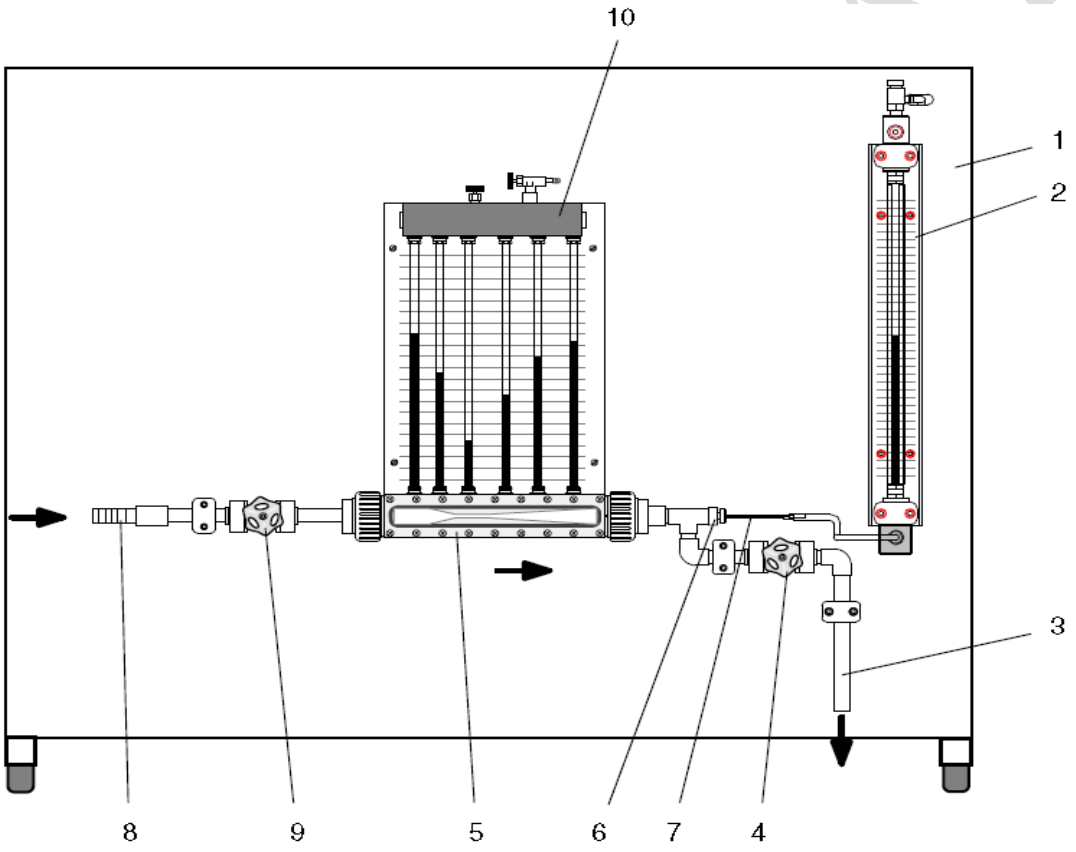
$V^{\cdot} = A X w$ 7

Thus,

$A_1 x w_1 = A_2 x w_2$ = Const. 8

3. Experimentation

3.1 Experimental Setup (Fig. 2)



1	Assembly board
2	Single water pressure gauge
3	Discharge pipe
4	Outlet valve
5	Venturi nozzle with six measurement points
6	Compression gland
7	Probe for measuring overall pressure (can be moved axially)
8	Hose connection, water supply
9	Inlet valve
10	6-fold water pressure gauge (pressure distribution in the Venturi nozzle)

Figure 2: Setup of experiment.

3.2 Procedure

1. Make a hose connection between the hydraulic bench and the experiment setup.
2. Open discharge of hydraulic bench.
3. Set the cap nut -1 (Fig. 3) of probe compression gland such that slight resistance is felt on moving probe.
4. Open the inlet and outlet valves.
5. Switch on the pump on the hydraulic bench and slowly open its main cock.
6. Open vent valves - 2 (Fig. 4) on water pressure gauges.
7. Carefully close the outlet valve until pressure gauges are flushed.
8. By simultaneously setting the inlet and outlet valves, regulate the water level in pressure gauges such that neither upper (UL) nor lower range limit (LL) is overshot or undershot (Fig. 5).
9. Record pressures at all measurement points (static pressure, h1 – h6). Then move the overall pressure probe to the corresponding measurement level and note down the overall pressure.
10. Determine the volumetric flow rate. To do so, use a stopwatch to establish the time t required to raise the level in the tank of the hydraulic bench from 20L to 30L i.e. 10L difference.

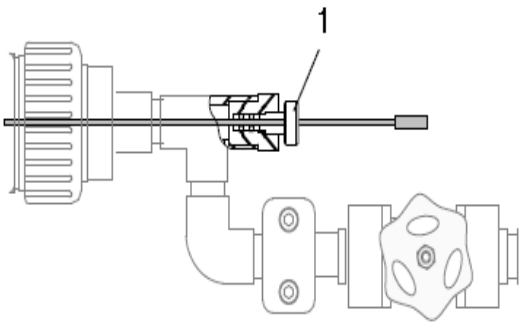


Figure 3: Cap nut for measuring overall pressure

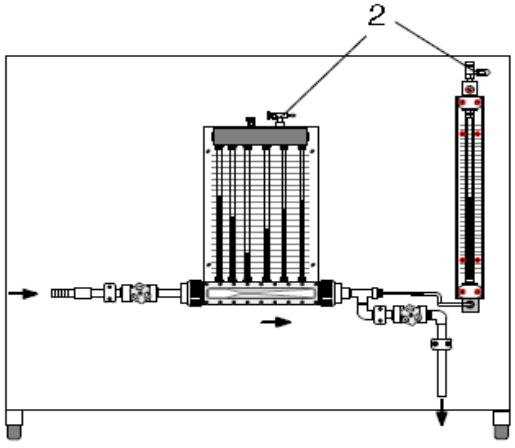


Figure 4: Pressure gauges vent valves.

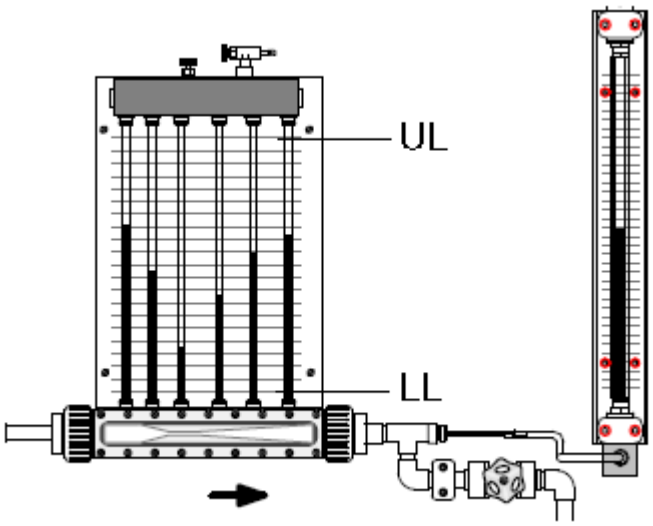


Figure 5: Upper (UL) and lower (LL) limits for the 6-fold pressure gauge.

Record your experiment readings as in the following table.

Measuring points, *i*	h_{stat} mm H_2O	h_{total} mm H_2O	h_{dyn} mm H_2O	Measured velocity, $W_{meas.}$, mmH_2O	Area at each measuring point A, mm^2	Reference velocity, W^-	Calculated velocity, $W_{calc.}$ mmH_2O	Time for 10L liquid flow t, S	Volumetric flowrate, $V \cdot, \frac{L}{s}$
i1									
i2									
i3									
i4									
i5									
i6									

Exercise:

1. Plot the measured and calculated velocity profiles of the liquid through the venturi tube against the measuring points at a constant volumetric flow rate and label each profile.
2. Describe the velocity profiles of the liquid through the venturi meter.

Appendix:

Obtain:

- Dynamic pressure head, h_{dyn} as $h_{dyn} = h_{total} - h_{stat}$ …… 1

- Measured velocity, $W_{meas} = \sqrt{2.g.}$ hdyn ……..……..2

- Reference velocity, $W_i^- = \frac{A_1}{A_i}$ …… 3

- Calculated velocity, $W_{calc.} = (\frac{V\cdot}{A_1})\ x\ W_i^-$ ……..4

Where $(\frac{V\cdot}{A_1})$ is a constant scalar multiplier.