

**COLLEGE OF ENGINEERING
CHEMICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**

BINDER REPORT COVER PAGE

**CHEG 4101 – P01
Chemical Engineering Laboratory II**

FALL 2021 SEMESTER

NAME OF INSTRUCTOR: Dr. Jorge Gabitto

**PRAIRIE VIEW A&M UNIVERSITY
ROY G. PERRY COLLEGE OF ENGINEERING
DEPARTMENT OF CHEMICAL ENGINEERING
CHEG 4101- Chemical Engineering Lab. II
FALL 2021**

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Course Description in ABET Format

CHEMICAL ENGINEERING DEPARTMENT CHEG 4101 CHEMICAL ENGINEERING LAB. II

1.	Course number and name:	CHEG 4011 CHEMICAL ENGINEERING LAB. II
2.	Credits and contact hours:	1 credit hour; 3 contact hours
3.	Instructor's or course coordinator's name:	Dr. Jorge F. Gabitto
4.	Text book: Title:	NA
	Author:	NA
	Publisher, Year & Edition:	NA
	a. Other Supplemental material	Holman, J. P., <i>Experimental Methods for Engineers</i> , 4 th Ed., or newer, McGraw-Hill, New York, 1986.
5.	Specific course information	
	a. Brief description of the content of the course (catalog description)	CHEG 4011. (0-3) Credit 1 semester hours. Continuation of CHEG 3011, but directed to separation processes such as gas absorption, fractional distillation, extraction, and drying. Study of reaction rates and equilibria in simple chemical systems. Emphasis is placed upon experimental data required for the scale-up to commercial scale equipment.
	b. Prerequisites or Co-requisites	CHEG 3023 and CHEG 3043; COMM 1003; and ENGL 1133 or 1143.
	c. *Indicate whether a required, elective, or selected elective (as per definition provided) course in the program	Required
6.	Specific goals for the course	Students will be able to :
	a. Specific learning outcomes	1. Demonstrate ability to perform quantitative physical measurements and operate laboratory scale equipment. 2. Design, plan, and operate experiments. 3. Communicate proficiently in oral and written formats.
	b. Explicitly indicate which of the student outcomes listed in Criterion 3 or any other outcomes are addressed by the course.	This course addresses: Outcome 3 An ability to communicate effectively with a range of audiences. Outcome 5 An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.

		Outcome 6 An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.	
7	Brief list of topics to be covered	Topic 1 Laboratory Safety and Loss Prevention (Video Presentation) Topic 2 Laboratory Safety and Loss Prevention Quiz Topic 3 Design of Experiments Quiz Topic 4 Fractionation (Expt. No. 1) Topic 5 Friction losses in pipelines (Expt. No. 2) Topic 6 Gas-Liquid Absorption (Expt. No. 3) Topic 7 Centrifugal Pumps (Expt. No. 4) Topic 8 Final Presentation	

***Required** courses are required of all students in the program, **elective** courses (often referred to as open or free electives) are optional for students, and **selected elective** courses are those for which students must take one or more courses from a specified group.

II ASSESSMENT RESULTS FOR CURRENT AND PAST THREE PERIODS

Program Outcomes Assessed in this course

Outcome 3

An ability to communicate effectively with a range of audiences.

Outcome 5

An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.

Outcome 6:

An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.

Assessment Summary of Class Semester Outcomes Averages

Outcomes	3	5	6
Semester	Semester Class Average (%)	Semester Class Average (%)	Semester Class Average (%)
Fall 2021	67.7	66.7	86.7
Fall 2020	77.7	68.9	84.6
Fall 2019	79.4	86.4	86.7
Comments on Trend of Data (Improving or deteriorating)	The class average has decreased slightly over last semester. Most students fulfilled minimum requirements.	The class average has significantly decreased; No students fulfilled the minimum required. There could be influence from change in offering the course. More work is needed.	The class average has decreased slightly over last semester. Most students fulfilled minimum requirements.

Ideal Semester Class Average = 75% (or as defined by the program)

End of Semester Course Assessment Reports Fall 2021 and Last Two Assessment Periods.

Each summary contains the following Information

1. Performance Statistics

- Total number of students in class
- The class average performance (**stated as %**) in each course outcome assessed in this class and the **two previous times course was assessed**.
- The acceptable class average for the class in each outcome area as set by your Department.
- Percentage of students who scored below the expected average in each outcome.

2. Implementation Summary

- Brief summary of plans implemented during the semester based on last assessment report

3. Perceived Problems

- Instructor's **critical evaluation** of perceived problems that affected students' performance. **Realistic problems should be identified throughout the semester and summarized in this section of the report.**

4. New Plans for Addressing Problems

- Instructor's plans for addressing the perceived problems the next time the class is taught. **These should be specific enough for another instructor to implement. Most of these should be things that, you, the instructor can implement to help students to improve. Be creative.**

5. Overall Trend over last three assessment periods

- Instructors summary of overall performance trend for each outcome measured over the last three periods.

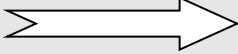
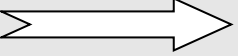
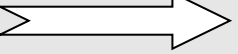
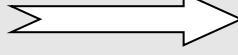
5. Were Expectations Met?

- Compare both class average and percent of students achieving the expected outcome.

Table 2.1. END OF SEMESTER COURSE OUTCOME ASSESSMENT REPORT
CHEG4101-P01 Chemical Engineering Laboratory II
Fall 2021 SEMESTER

Report Prepared by: Dr. Jorge Gabitto

Report Date: December 18, 2021

Semester	Analysis Type	Number of Students	Outcome 3 Oral and Written Communication			Outcome 5 Ability to design and conduct experiments.			Outcome 6 Ability to function on multi-disciplinary teams.		
			Expected Average	Class Average	% Students Meeting Expected Average	Expected Average	Class Average	% Students Meeting Expected Average	Expected Average	Class Average	% Students Meeting Expected Average
Fall 2021	Direct	15	75	76.3	66.7	75	75.5	67.7	75	80.2	86.7
Fall 2020	Direct	13	75	77.7	84.6	75	68.9	75.0	75	84.6	66.6
Fall2019	Direct	18	75	79.4	78.7	75	86.4	100.0	75	86.7	100.0
Implementation Summary			Lab report format distributed to students and discussed. A class on how to prepare reports/presentations added.			Practice sessions in laboratory describing procedures for data acquisition and analysis. Design of experiments lecture.			Evaluation of student participation in and out of the laboratory.		
Perceived Problems			Students could not write logical conclusions and could not adequately comment on the results.			Students perform well the data acquisition part of the experiment, but fail in data analysis. This issue leads to wrong conclusions.			Uneven participation in conducting the laboratory experiments and preparing the corresponding Lab. Report.		
Plans for Addressing Problems			The instructor did: 1. Samples of conclusions on research report can be given to students. 2. Instructor discussed the reports with the students in class, and privately. 3. The students are encouraged to discuss their reports/presentations with the instructor BEFORE turning them in.			The following is recommended for implementation next course offering: 1. Draft data analysis will be required during lab. class. 2. Quizzes will be administered to stress the need for proper data analysis. Students will be encouraged to check their lab. Reports before turning them in.			The instructor proposes: 1. Assign every group a group leader. The leader is responsible for even student participation. The leader evaluates student participation in every report/presentation. 2. The instructor evaluates student participation by direct observation plus given individual quizzes when appropriate.		
Overall Trend over Periods			Students' performance has slightly decreased compared to previous semesters. More work is needed on report writing.			The class average has increased significantly over last semester. Still more work is needed.			The class average has slightly decreased over last semester. A influence on switching to online teaching is found. More work on group dynamics needed.		

Student and Class Performance in Outcomes

**CHEG 4101-Y01
FALL 2021 SEMESTER**

Outcome 3 Oral & Written Communication Report 4 & Final Pres		Outcome 5 Ability to function on multi-disciplinary teams. Report 2 + 3		Outcome 6 Ability to design and conduct experiments DOE Quiz + report 3	
	Total		Total		Total
8	1	7.75	1	8.75	1
7.1		7.1		7.5	1
7.8	1	7.8	1	8.9	1
8	1	7.75	1	8.75	1
8	1	7.75	1	7.75	1
7.1		7.1		8	1
7.1		7.1	0	5	
8	1	7.75	1	8.25	1
7.8	1	7.8	1	8.9	1
7.8	1	7.8	1	8.9	1
7.1		7.1		8	1
7.8	1	7.8	1	8.9	1
7.1		7.1		6.5	
7.8	1	7.8	1	8.4	1
8	1	7.75	1	7.75	1
114.5	10	113.25	10	120.25	13
7.633333333	66.67	7.55	66.67	8.016667	0.866667

	Design of Exp.	Report I	Report II	Report III	Report IV	Final Pres.
Student 1	10	5.5	6.8	7.5	7	8.5

Student 2	8	4.8	6	7	7	7.2
Student 3	10	4.8	5.5	7.8	7.8	7.8
Student 4	10	5.5	6.8	7.5	7	8.5
Student 5	8	5.5	6.8	7.5	7	8.5
Student 6	9	4.8	6	7	7	7.2
Student 7	3	4.8	6	7	7	7.2
Student 8	9	5.5	6.8	7.5	7	8.5
Student 9	10	4.8	5.5	7.8	7.8	7.8
Student 10	10	4.8	5.5	7.8	7.8	7.8
Student 11	9	4.8	6	7	7	7.2
Student 12	10	4.8	5.5	7.8	7.8	7.8
Student 13	6	4.8	6	7	7	7.2
Student 14	9	4.8	5.5	7.8	7.8	7.8
Student 15	8	5.5	6.8	7.5	7	8.5

CHEMICAL ENGINEERING LAB. III
Fall 2021

Title of Assignment: Quiz 1
Laboratory Safety

TOPICS COVERED IN QUIZ 1

- 1. Laboratory and Industrial Safety**

1. Write out what these acronyms stand for:
 - a. PPE –
 - b. SDS –
2. What does an SDS contain?
 - a. Contains manufacturer's label information only
 - b. Describes only product usage
 - c. Contains safety and toxicological information
 - d. Contains no information if a mixture
3. How long do you rinse off in a shower or eyewash station if you get a chemical spilled on you?
 - a. 7 minutes
 - b. 15 minutes
 - c. 30 minutes
4. A graduate student was working with concentrated sulfuric acid. She splashed some of the acid onto her latex gloves and it quickly burned a hole through the gloves and caused a second-degree burn. Why did the student suffer a second degree burn to her hand?
 - a. The area where the chemical splashed was not covered by the gloves
 - b. She was not paying attention when she was using the chemical
 - c. The glove that she was wearing was the wrong type for that chemical
5. Proper chemical storage includes all **except**:
 - a. Dating the chemicals when they are received and opened
 - b. Storing alphabetically within their hazard classes
 - c. Keeping away from heat and sunlight
 - d. Storing flammables in a household refrigerator and/or freezer
6. Proper chemical storage of organic solvents includes all **except**:
 - a. Inside the hood
 - b. In specifically designated cabinets
 - c. In special containers away from heat and sunlight
 - d. Storing in big amounts in tabletops
7. It is fine to eat and drink in a lab.
 - a. True
 - b. False
8. It is fine to store glass and metallic objects together.
 - a. True
 - b. False
9. The purpose of the Hazardous Communication Program is:
 - a. To make sure that the animals used are protected
 - b. Assure anyone working with hazardous chemicals know the hazards and how to protect themselves
 - c. None of the above are correct
10. You are passing by a biological laboratory and see a lab employee working while wearing open toe shoes, and without a lab coat. Is this acceptable working attire for a biological laboratory?
 - a. Yes
 - b. No

ABOVE AVERAGE

(100)

CHEG 4031 Safety QUIZ

Name: Vatallio Abrams II

1. Write out what these acronyms stand for:
 - a. PPE - Personal Protective Equipment
 - b. MSDS - Material Safety Data Sheet
2. What does an MSDS contain?
 - a. Contains manufacturer's label information only
 - b. Describes only product usage
 - ☒ c. Contains safety and toxicological information
 - d. Contains no information if a mixture
3. How long do you rinse off in a shower or eyewash station if you get a chemical spilled on you?
 - a. 7 minutes
 - ☒ b. 15 minutes
 - c. 30 minutes
4. A graduate student was working with concentrated sulfuric acid. She splashed some of the acid onto her latex gloves and it quickly burned a hole through the gloves and caused a second-degree burn. Why did the student suffer a second degree burn to her hand?
 - a. The area where the chemical splashed was not covered by the gloves
 - b. She was not paying attention when she was using the chemical
 - ☒ c. The glove that she was wearing was the wrong type for that chemical
5. Proper chemical storage includes all except:
 - a. Dating the chemicals when they are received and opened
 - b. Storing alphabetically within their hazard classes
 - c. Keeping away from heat and sunlight
 - ☒ d. Storing flammables in a household refrigerator and/or freezer
6. Proper chemical storage of organic solvents includes all except:
 - a. Inside the hood
 - b. In specifically designated cabinets
 - c. In special containers away from heat and sunlight
 - ☒ d. Storing in big amounts in tabletops
7. It is fine to eat and drink in a lab.
 - a. True
 - ☒ b. False
8. It is fine to store glass and metallic objects together.
 - a. True
 - ☒ b. False
9. The purpose of the Hazardous Communication Program is:
 - a. To make sure that the animals used are protected
 - ☒ b. Assure anyone working with hazardous chemicals know the hazards and how to protect themselves
 - c. None of the above are correct
10. You are passing by a biological laboratory and see a lab employee working while wearing open toe shoes, and without a lab coat. Is this acceptable working attire for a biological laboratory?
 - a. Yes
 - ☒ b. No

AVERAGE

100

CHEG 4031 Safety QUIZ

Name: Tanya Watson

CHEG 4031 - P03

1. Write out what these acronyms stand for:
 - a. PPE - Personal protective equipment
 - b. MSDS - Material Safety Data Sheet
2. What does an MSDS contain?
 - a. Contains manufacturer's label information only
 - b. Describes only product usage
 - ☒ c. Contains safety and toxicological information
 - d. Contains no information if a mixture
3. How long do you rinse off in a shower or eyewash station if you get a chemical spilled on you?
 - a. 7 minutes
 - ☒ b. 15 minutes
 - c. 30 minutes
4. A graduate student was working with concentrated sulfuric acid. She splashed some of the acid onto her latex gloves and it quickly burned a hole through the gloves and caused a second-degree burn. Why did the student suffer a second degree burn to her hand?
 - a. The area where the chemical splashed was not covered by the gloves
 - ☒ b. She was not paying attention when she was using the chemical
 - c. The glove that she was wearing was the wrong type for that chemical
5. Proper chemical storage includes all **except**:
 - a. Dating the chemicals when they are received and opened
 - b. Storing alphabetically within their hazard classes
 - ☒ c. Keeping away from heat and sunlight
 - d. Storing flammables in a household refrigerator and/or freezer
6. Proper chemical storage of organic solvents includes all **except**:
 - a. Inside the hood
 - b. In specifically designated cabinets
 - ☒ c. In special containers away from heat and sunlight
 - d. Storing in big amounts in tabletops
7. It is fine to eat and drink in a lab.
 - a. True
 - ☒ b. False
8. It is fine to store glass and metallic objects together.
 - a. True
 - ☒ b. False
9. The purpose of the Hazardous Communication Program is:
 - a. To make sure that the animals used are protected
 - ☒ b. Assure anyone working with hazardous chemicals know the hazards and how to protect themselves
 - c. None of the above are correct
10. You are passing by a biological laboratory and see a lab employee working while wearing open toe shoes, and without a lab coat. Is this acceptable working attire for a biological laboratory?
 - a. Yes
 - ☒ b. No

BELOW AVERAGE

00%

CHEG 4031 Safety QUIZ

Name: Sabrina Nee

- ✓ 1. Write out what these acronyms stand for:
 - a. PPE – Personal Protective Equipment +5
 - b. MSDS – Material safety data sheet +5
- ✓ 2. What does an MSDS contain?
 - a. Contains manufacturer's label information only
 - b. Describes only product usage
 - Ⓒ. Contains safety and toxicological information
 - d. Contains no information if a mixture
- ✓ 3. How long do you rinse off in a shower or eyewash station if you get a chemical spilled on you?
 - a. 7 minutes
 - Ⓒ. 15 minutes
 - c. 30 minutes
- ✓ 4. A graduate student was working with concentrated sulfuric acid. She splashed some of the acid onto her latex gloves and it quickly burned a hole through the gloves and caused a second-degree burn. Why did the student suffer a second degree burn to her hand?
 - a. The area where the chemical splashed was not covered by the gloves
 - b. She was not paying attention when she was using the chemical
 - Ⓒ. The glove that she was wearing was the wrong type for that chemical
5. Proper chemical storage includes all except:
 - a. Dating the chemicals when they are received and opened
 - Ⓒ. Storing alphabetically within their hazard classes
 - c. Keeping away from heat and sunlight
 - d. Storing flammables in a household refrigerator and/or freezer
- ✓ 6. Proper chemical storage of organic solvents includes all except:
 - a. Inside the hood
 - b. In specifically designated cabinets
 - c. In special containers away from heat and sunlight
 - Ⓒ. Storing in big amounts in tabletops
- ✓ 7. It is fine to eat and drink in a lab.
 - a. True
 - Ⓒ. False
- ✓ 8. It is fine to store glass and metallic objects together.
 - a. True
 - Ⓒ. False
- ✓ 9. The purpose of the Hazardous Communication Program is:
 - a. To make sure that the animals used are protected
 - Ⓒ. Assure anyone working with hazardous chemicals know the hazards and how to protect themselves
 - c. None of the above are correct
- ✓ 10. You are passing by a biological laboratory and see a lab employee working while wearing open toe shoes, and without a lab coat. Is this acceptable working attire for a biological laboratory?
 - a. Yes
 - Ⓒ. No

**CHEMICAL ENGINEERING LAB. II
FALL 2021**

Title of Assignment: Quiz 2

TOPICS COVERED IN QUIZ 2

1. Design of Experiments

Design of Experiments Quiz

Question 1

1 / 1 pts

1. List two requirements to select an acceptable experiment.



Suitable subject and acceptable cost



Suitable subject and no matter the cost



Any subject matter and acceptable cost



Suitable subject and no matter safety conditions

Question 2

1 / 1 pts

2. How far you should go on your theoretical search?



Far enough.



It does not matter.



As far as possible.



Copy and paste everything you can.

Question 3

1 / 1 pts

3. If you have a problem with one dependent variable and two independent ones, how many experimental variables you should try to measure?



2



As many as you can.



1



It is not clear.

Question 4

1 / 1 pts

4. If you have a problem with one dependent variable and two independent ones , the range of the independent variables will determine what kind of domain?



Rectangle



Cube



Straight line



Triangle

Question 5

1 / 1 pts

5. If you have a problem with one dependent variable and two independent ones, show how the errors in the independent variables will impact the dependent one.



$$dy = dy/dx1 \, dx1 + dy/dx2 \, dx2$$



$$dy = A1 \, dx1 + A2 \, dx2$$



$$dy = A1 \, dx1 + A2 \, (dx1)^2$$



$$dy = dy/dx1 \, dx1$$

Question 6

1 / 1 pts

6. If you propose to measure a physical property list the two steps to generate credible experimental data.



Pick real value. Add and subtract experimental error



Pick any value. Add and subtract experimental error



Pick real value. Add experimental error



Pick real value. Subtract experimental error

Question 7

1 / 1 pts

7. If you are verifying a physical principle list the two steps to generate credible experimental data.



Pick the equation representing the principle. Add and subtract experimental errors.

☐

Pick the equation representing the principle. Report several values.

☐

Pick the equation representing the principle. Add experimental errors.

☐

Make-up some values. Add and subtract experimental errors.

Question 8

1 / 1 pts

8. Which are the two kinds of experimental errors.

☒

Random and deterministic.

☐

Random and made-up.

☐

There are not two kinds.

☐

Calculated and measured.

Question 9

1 / 1 pts

9. Should you consider more than one alternative to achieve your proposed goal?

☒

Yes

☐

No

☐

Maybe

☐

As many as you can

Question 10

1 / 1 pts

10. Should you consider cost?

☒

Yes

☐

No

☐

Maybe



I do not know.

Quiz Score: 10 out of 10

CHEMICAL ENGINEERING LAB. II FALL 2021

Design of Experiments Quiz Grade Distribution

The course was administered online; therefore, there are not copies of the individual assignments. The statistics for the course are:

Above average ($> 9/10$) = 13 students.

Average ($> 8/10$) = 1 students.

Below average ($< 8/10$) = 1 students.

Title of Assignment: Quiz 3

TOPICS COVERED IN QUIZ 3

1. Writing Reports

CHEMICAL ENGINEERING LAB. II
FALL 2021

SAMPLE QUIZ QUESTIONS and SOLUTION FOR QUIZ 3

Writing Reports Quiz

Question 1

1 / 1 pts

Figure captions and Table captions are placed:

Correct!



Below the Figure and above the Table



Above the Figure and Table



Below the Figure and Table



Above the Figure and Below the Table

Question 2

1 / 1 pts

Figure captions and Table captions are labeled:

Correct!



Sequentially and in ascending order



If required, in any order



If desired, in any order

Question 3

1 / 1 pts

Choose all the appropriate responses.

Theory section:

Correct!



Contains equations that are used to treat raw data



Contains inferences about the experiment

Correct!



Contains citations

Correct!



Must refer to pertinent background information for the experiment being reported

Question 4

0 / 1 pts

Abstract and Conclusions sections are similar except that:

☐

Abstract contains a high-level summary of the experiment objective

Correct Answer

☐

Conclusions contain forward-looking statements

You Answered

☒

Conclusions contain a high-level summary of the results

☐

Abstract contains forward-looking statements

Question 5

1 / 1 pts

Data acquired using data acquisition software are typically:

Correct!

☒

Timed data

☐

Current vs. voltage

☐

Response vs. rate

☐

Dependent on length

Question 6

1 / 1 pts

It is better to represent raw data (dependent variable vs. independent variable) as a:

☐

Table

Correct!

☒

Graph

Question 7

1 / 1 pts

Apart from the data points, a graph must contain the following elements:

☐

Figure caption, axes labels with units and appropriate scale only

☐

Axes labels, legend or key and appropriate scale only

Correct!

☒

Figure caption, axes labels with units, legend or key, appropriate scale

☐

Axes labels with units and legend or key only

Question 8

1 / 1 pts

Which chart type should you use in Excel for plotting series data (dependent variable vs. independent variable)

☐

Bubble

☐

Bar

☐

Line

Correct!

☒

Scatter

Question 9

1 / 1 pts

The purpose of the Discussion in the Results & Discussion section is to:

☐

Discuss what's wrong with the results

Correct!

☒

Explain, analyze and interpret the results

☐

Show the results

☐

Explain and analyze the results

Question 10

1 / 1 pts

The Discussion in the Results & Discussion section must be linked to:



Procedure

Correct!



Theory



Conclusions



Abstract

Quiz Score: 9 out of 10

CHEMICAL ENGINEERING LAB. II FALL 2021

Writing Laboratory Reports Quiz Grade Distribution

The course was administered online; therefore, there are not copies of the individual assignments. The statistics for the course are:

Above average ($> 8/10$) = 7 students.

Average ($< 8/10$ and $> 7/10$) = 4 students.

Below average ($< 7/10$) = 4 students.

**CHEMICAL ENGINEERING LAB. II
FALL 2021**

Title of Assignment: REPORT I

TOPICS COVERED IN REPORT I

Report I covers the following topic:

1. Fractional Distillation.

Objective

To compare the performance of a distillation column with the McCabe-Thiele design procedure and with ASPEN simulations.

CHEMICAL ENGINEERING LAB. II

FALL 2021

RUBRIC AND GRADING SCHEME FOR LAB. REPORTS

Laboratory Grading Sheet Reports

Technical Content

Maximum Grade

- | | |
|-----------------------|----------|
| 1. Abstract/Objective | 5points |
| 2. Theory | 5 points |
| 3. Results | 5 points |
| 4. Conclusions | 5 points |

Writing Content

- | | |
|-----------------|----------|
| 5. Organization | 5points |
| 6. Language | 5points |
| 7. Write-up | 5 points |
| 8. Appearance | 5points |

Every report will be graded according to the items described in this grade sheet.

Technical Content	Maximum	Grade
Abstract/Objective	5	
Theory	5	
Results	5	
Conclusions	5	
Total =	20	
Writing Content		
Organization	5	
Language	5	
Professional content	5	
Appearance	5	
Total =	20	

ABOVE AVERAGE

Prairie View A&M University
Roy G. Perry College of Engineering



Chemical Engineering Laboratory II
CHEG 4101- P01

Lab #1: Distillation Column

Group Members: Alessia Williams, Amiya Rogers, Chinenye Ihe, Franck Nangomoko,
Taylon Owens

Lab Completed: September 27, 2021

Technical Content	Maximum	Grade
Abstract/Objective	5	4
Theory	5	5
Results	5	5
Conclusions	5	4
Total =18/20	20	18
Writing Content		
Organization	5	5
Language	5	4
Professional content	5	4
Appearance	5	5
Total = 36/40 or 0.9	20	18

Abstract

Distillation columns are commonly used in the chemical and petrochemical industry to separate homogeneous liquid mixtures into their pure components, or some predetermined concentration. Distillation columns are the most commonly used separation apparatus, and are relatively inexpensive. This process is performed by heating the mixture, causing the components to evaporate at different rates based on their component boiling point. Distillation allows for the favorable manipulation of concentrations in a mixture to achieve a desired product. It is a matter of facilitating the movement of the more volatile fluid over the less volatile fluid, known as the low key and high key, respectively. The more volatile component, lower boiling point, escapes the liquid phase and travels up the column as a vapor continuously coming in contact with the liquid less volatile component, higher boiling point, attempting to extract more of itself during each encounter. The purpose of this design is to evaluate and compare the actual, theoretical, and simulated column performance for an equimolar mixture of ethanol and water.

Theory

Distillation is a widely used process in which a liquid or vapor mixture is separated into its component fractions. More specifically, stage distillation is arranged in continuous flash-vaporization stages where the vapor and liquid products are allowed to make a countercurrent interaction. As the vapor leaves the top of the column, it will condense partially or fully depending on the type of condenser used. Some of the distillate will then be returned as liquid to the column to help with the purification of the most volatile component. As the reflux liquid flows down the column, it will exchange mass with the vapor going up the column. This process is being repeated until the liquid reaches the bottom of the column where it is partially vaporized. The vapor from the reboiler is sent back to the column at the same time the liquid product is being withdrawn as the products.

The schematic of a traditional distillation column is shown in Figure 1, below.

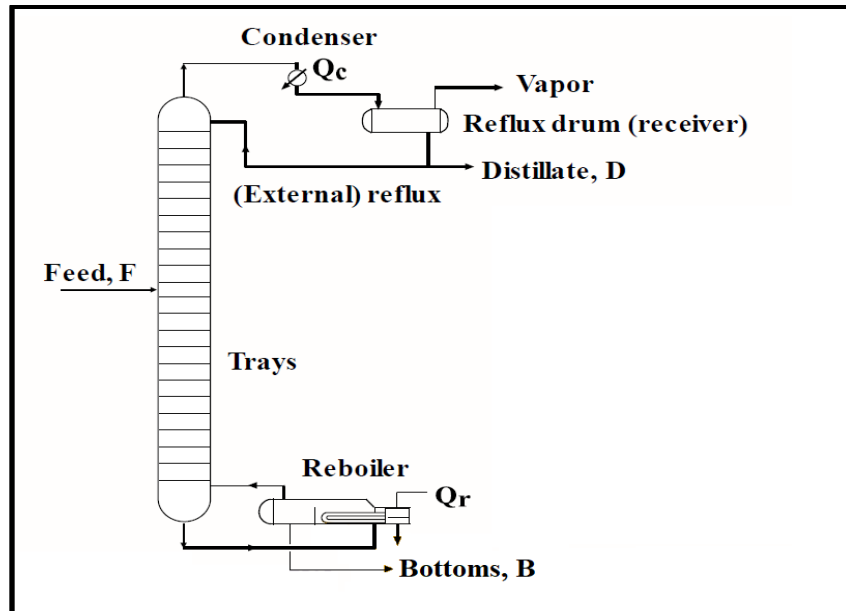


Figure 1: Tray Distillation Column

Figure 2 and 3 take a closer look into the stages, and how the liquid and vapor interact within a stage. The distillation column can be divided into two sections. The first section, above the feed tray, is called the rectifying section, and the second section, below the feed tray, is the stripping section.

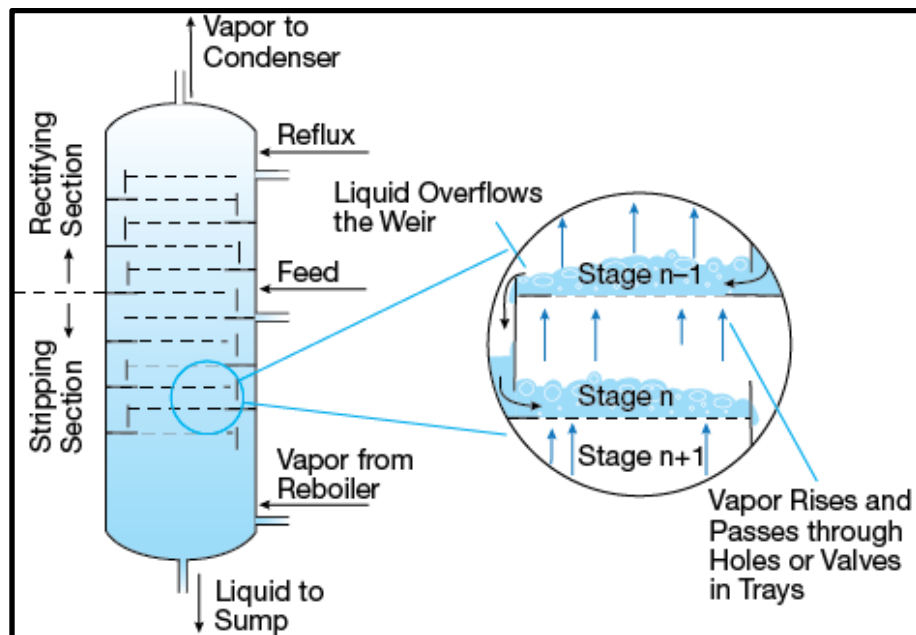


Figure 2:Distillation Column Tray Stages

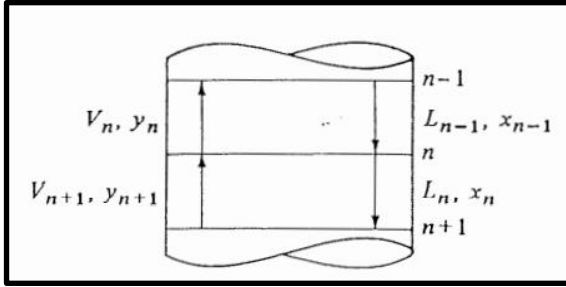


Figure 3: Tray Stages for Material Balance

In a particular stage, the vapor coming from stage “n+1” comes from a higher temperature and mixes with the lower temperature liquid from stage “n-1”. Due to the temperature difference, heat transfer takes place until the temperature of the stage becomes constant. Additionally, as soon as they mix, mass transfer takes place until the chemical potential of each phases are equal. At this point, the vapor leaving this stage is now in equilibrium with the liquid leaving the same stage. The material balance for a given component is as follows:

$$V_{n+1}y_{n+1} + L_{n-1}x_{n-1} = L_nx_n + V_ny_n \quad (1)$$

Where:

1. V_{n+1} is the vapor entering on the “nth” stage from the bottom of the column
2. y_{n+1} is the vapor phase composition entering on the “nth” stage from the bottom of the column
3. L_{n-1} is the liquid entering on the “nth” stage from the top of the column
4. x_{n-1} is the liquid phase composition entering on the “nth” stage from the top of the column
5. V_n is the vapor leaving the “nth” stage to the top of the column
6. y_n is the vapor phase composition leaving the “nth” stage to the top of the column
7. L_n is the liquid leaving the “nth” stage to the bottom of the column
8. x_n is the liquid phase composition leaving the “nth” stage to the bottom of the column

If the flow rate for the liquid coming down is greater than the flow rate of the vapor coming up an undesired phenomena known as downcomers occurs where liquid begins to travel down through the holes in the tray. If the reverse happens the column could dry out. Both cause the column to operate inefficiently.

The McCabe-Thiele approach is a graphical one, and uses the VLE plot to determine the theoretical number of stages required to effect the separation of a binary mixture. It assumes constant molar overflow which would imply molar heats of vaporization of the components are roughly the same, heat effects are negligible, and every mole of vapour condensed, 1 mole of liquid is vaporized. In order to graph the number of theoretical stages using the McCabe-Thiele method, it is imperative to develop at least two of three operating lines. The operating lines define the mass balance relationship between the liquid and vapor phases in the column. The constant molar overflow assumption also ensures the operating lines are straight lines. The operating lines needed are:

1. Rectifying Operating Line

2. Feed condition Line (q-line)
3. Stripping Operating Line

Rectifying Operating Line:

This line is developed from the total mass balance and the composition mass balance equation and uses an important parameter known as the reflux ratio. The reflux ratio is the ratio between the liquid and the distillate flow rates.

$$y_{n+1} = \frac{R}{R+1} x_n + \frac{1}{R+1} x_D \quad (2)$$

Where:

1. R is the reflux ratio given by: $R=L/D$
2. x_D is the distillate liquid composition

Feed Condition Line:

The condition of the feed stream will heavily impact the stripping and the rectifying sections of the column. For example, if the feed is mostly liquid it will add more onto the liquid that is already inside the column. On the contrary, if the feed is mostly vapor, it will add more onto the vapor that is already inside the column and will travel up the column faster. The equations that represent the feed conditions are:

$$q = \frac{\text{heat needed to vaporize 1 mol of feed at entering conditions}}{\text{molar latent heat of vaporization of feed}} \quad (3)$$

$$q = \frac{H_v - H_f}{H_v - H_L} \quad (4)$$

Where:

1. H_v is the dew point enthalpy at the feed
2. H_f is the feed enthalpy
3. H_L is the bubble point enthalpy at the feed
4. $q > 1$ when feed is subcooled
5. $q = 1$ when feed is at its bubble point
6. $0 < q < 1$ when feed is between its bubble point and dew point
7. $q = 0$ when the feed is at its dew point

Stripping Operating Line:

$$y_{m+1} = \frac{L_m}{V_{m+1}} X_m + \frac{BX_B}{V_{m+1}} \quad (5)$$

Once 2 of the 3 lines have been calculated the third can be found from the intersection of the other two, and a prominent point on that line (x_B , x_D , y_F). In order to determine the efficiency of a column the actual trays used in an experiment must be compared to the theoretical stages found when performing the McCabe-Thiele method. That equation can be seen below.

$$\text{Column Efficiency} = \frac{\text{number of ideal trays}}{\text{number of actual trays}} \times 100\% \quad (6)$$

The McCabe-Thiele method assumes:

- Ideal stages
- Steady state column operation
- Constant molar overflow

- Constant complete pressure and temperature
- All vapors and liquids are saturated.

Ethanol and water have boiling points that are relatively close together, 173.1°F and 212°F, respectively. Their close boiling point temperature makes it hard to separate them using traditional separation methods, leading to an azeotrope. This azeotrope can be seen in the figure below.

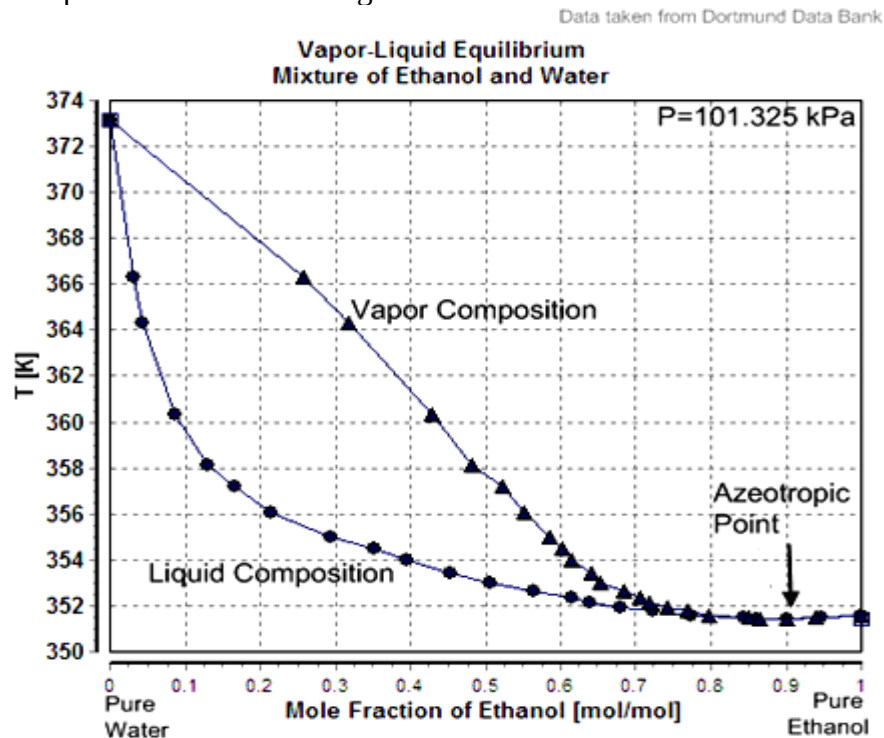


Figure 4: Txy Diagram for Ethanol and Water with Azeotrope

Because ethanol has a lower boiling the major of it, x_D , will be taken off in the Distillate, D; and a small amount, x_B , will be taken off in the Bottoms, B.

Procedure

Equipment:

Armfield UOP3CC Distillation column
 Armfield interface device
 Windows™ PC with Armfield UOP3CC software installed
 About 5 liters of 50 mol% ethanol and water feed mixture
 Timer
 Volumetric cylinder
 Stock solutions of different known percentage of ethanol
 Abbey Refractometer

Armfield UOP3CC Distillation column

1. Connect the Armfield UOP3CC Distillation column to the Windows™ PC with Armfield UOP3CC software using the Armfield interface device.

2. In the WindowsTM PC with Armfield UOP3CC software, there are 8 plates, numbered from top to bottom, in the distillation column and a feed stream going between plate 4 and 5. Input temperature for the top plate and the boiler.
3. In the WindowsTM PC with Armfield UOP3CC software, set the reflux ratio to 5:1
4. To measure the flow rate going to the bottoms, use a timer and a volumetric cylinder to get the total volume over a period of time. Repeat 2 more times.
5. To measure the flow rate coming out from the top of the distillation column, set the reflux ratio equal to zero.
6. Open the valve labelled v3, the stream going back to the distillation column.
7. Use a timer and a volumetric cylinder to get the total volume over a period of time. Repeat 2 more times.

Abbey Refractometer

1. Prepare stock solutions of different known percentage of ethanol in water
2. Generate a calibration curve of refractive index of mol % ethanol
3. From the distillation column, take some samples from the bottoms and the distilled product
4. Use the refractometer to produce a refractive index of the samples from the bottoms and the product.
5. Correlate the refractive index of the samples to the calibration curve.

McCabe-Thiele Diagram

1. An xy- diagram is conducted using the liquid mole fraction, x and the vapor mole fraction, y of ethanol
2. The feed line, q is drawn in at .5 liquid mole fraction
3. The rectifying line which begins at the feed line, q is drawn to connect with the the mole fraction is the distillate which is .9
4. The stripping line is drawn from the mole fraction in the bottoms which is .287 to the feed line, q
5. The process is then stepped off from the rectifying and stripping to the curve until the steps reach the bottoms mole fraction

Aspen Hysys

1. The component are entered into the system, pure component of ethanol and water
2. The Thermodynamic property is selected, Lee-Kessler
3. A distillation column is selected and added to the flow diagram
4. The column is selected once in the flow diagram to input temperature, pressure, mole fraction of components in the feed, distillate and bottoms, as well as the amount of trays, and reflux ratio
5. The system is then run to see if it converges
6. The information obtained after the system converges is the heat duty, Q

Results and Discussions

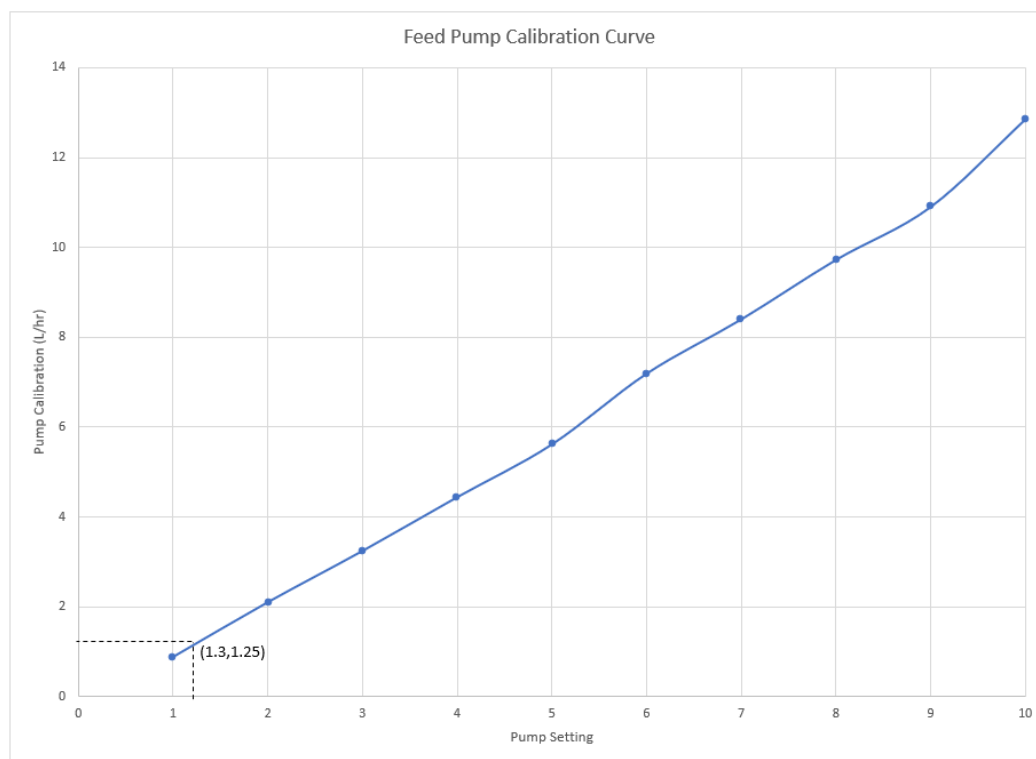


Figure 5: Feed Pump Calibration Curve

As part of the data given the reflux ratio, R , is equal to 5 and the feed composition, x_F , is 0.5. The feed flow rate for the Armfield was calculated by graphing the pump calibration data. From the calibration curve above, interpolation techniques were employed to determine the feed flow rate when the pump setting was set to 1.3. As seen on the graph above, when the pump setting is 1.3, the interpolated flow rate value is 1.25 L/hr (interpolated between pump setting 1 and 2).

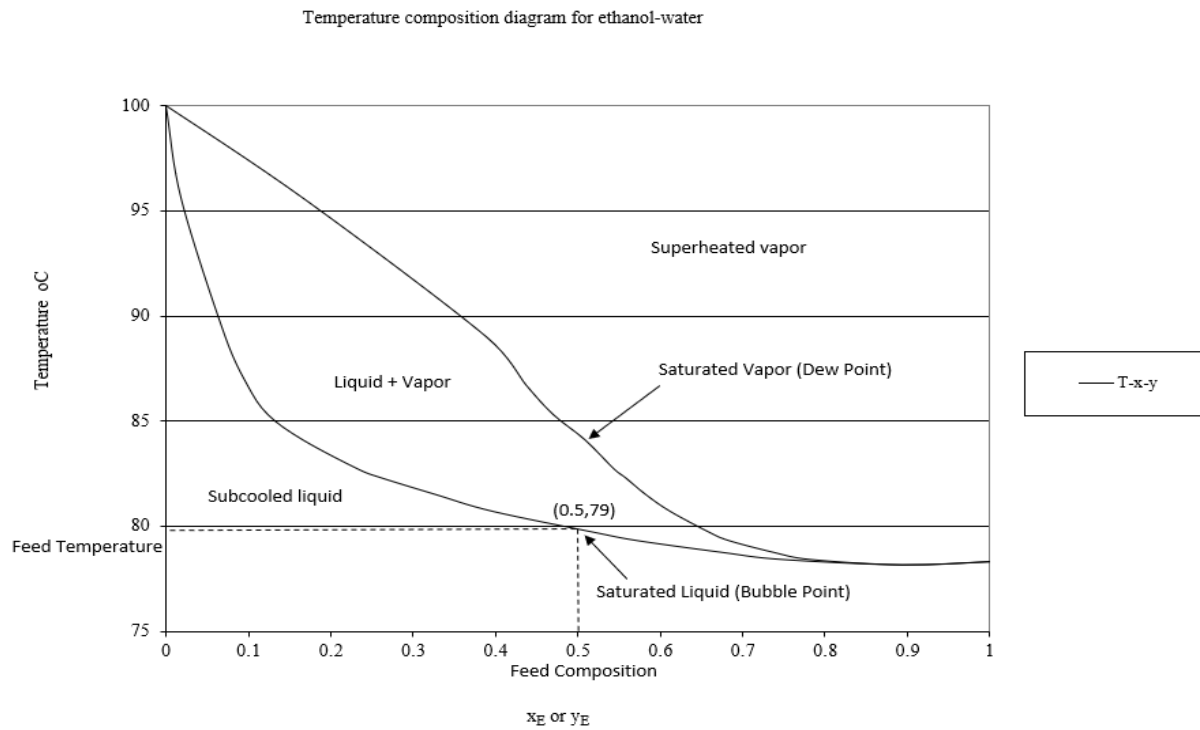


Figure 6: Txy Diagram for Ethanol and Water

Based on the temperature of the feed stream the q-line was determined to be 1 since the feed was entering the column as saturated liquid. The result of this determination is shown in the graph above.

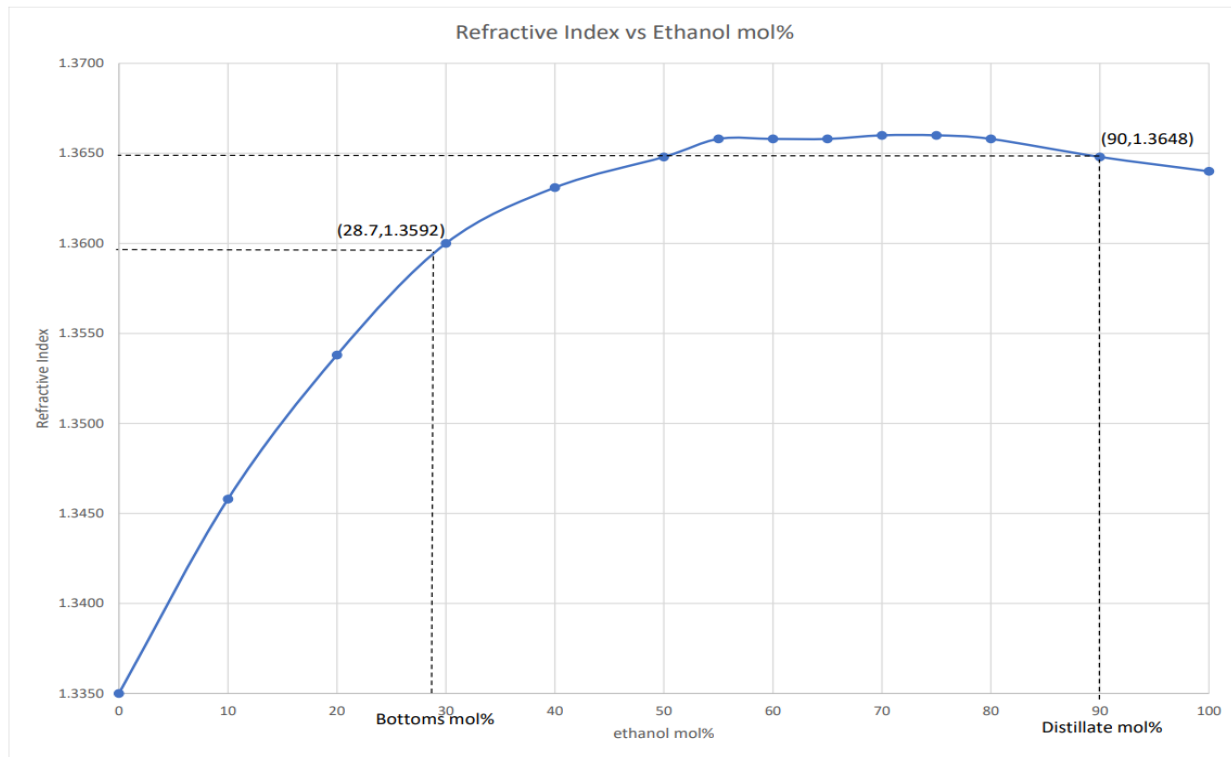


Figure 7: Refractive Index vs. Ethanol Mole Percentage

The mole fraction of ethanol in the distillate stream, x_D , and in the bottoms stream, x_B , were calculated by measuring the refractive index of ethanol at different concentrations. According to the graph above, ethanol has a refractive index of 1.3648 when its molar composition is 90% and an index of 1.3592 when its molar composition is 28.7% (interpolated value between 20 and 30 mol%)

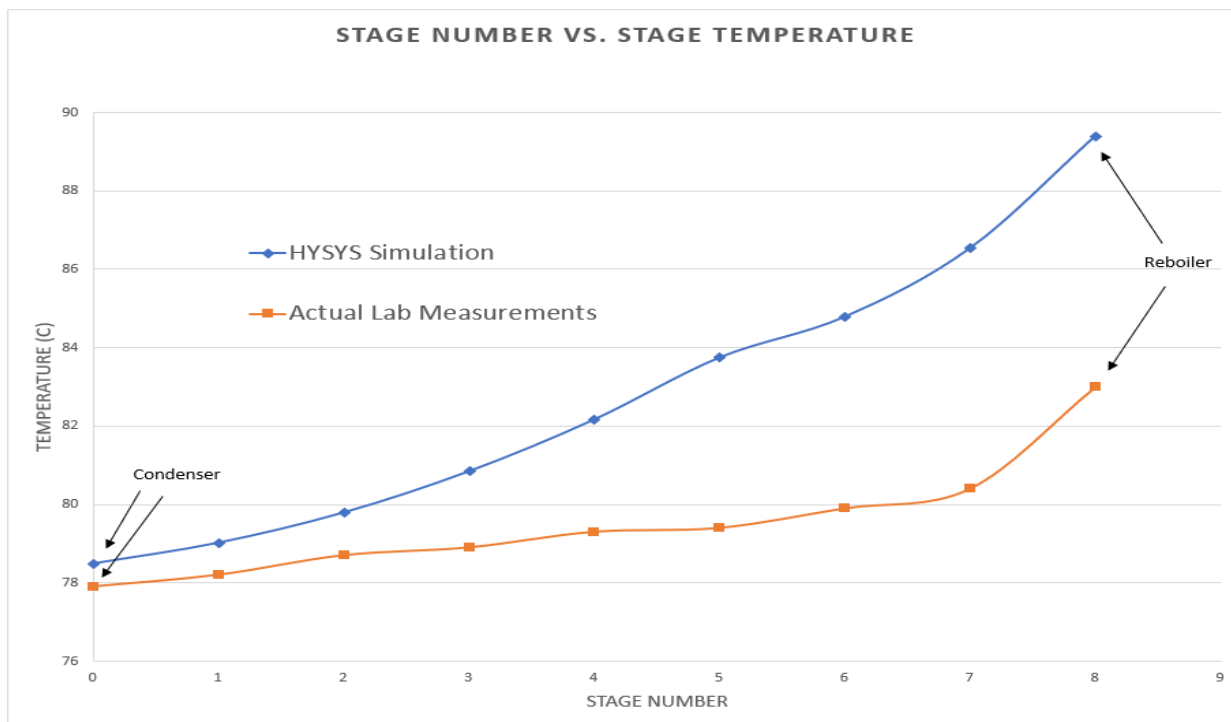
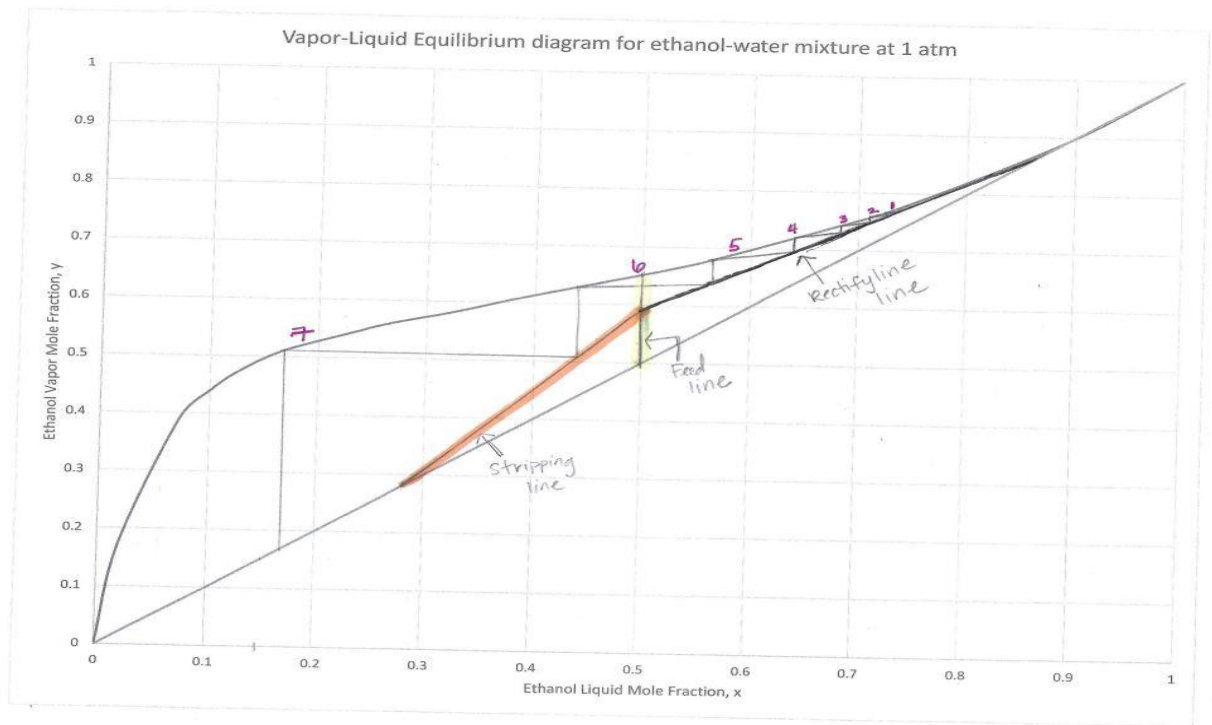


Figure 8: Stage Number vs Stage Temperature



Hand drawn McCabe Thiele

Figure 9: Hand Drawn McCabe Thiele

After performing the distillation column distillation in Aspen HYSYS, it was compared with the performance of the Armfield lab distillation column. Aspen HYSYS simulation showed higher tray temperatures as well as higher reboiler and condenser temperatures.

The hand drawn McCabe Thiele Diagram shows 6.5 ideal trays to converge. In the experiment, the actual number of trays is 9, resulting in a column efficiency of 72%. The McCabe Thiele is less accurate due to the azeotrope at mole fraction .9. The graph would need to be magnified to accurately show the steps from the rectifying line to the feed line, q .

Aspen HYSYS Simulation Results

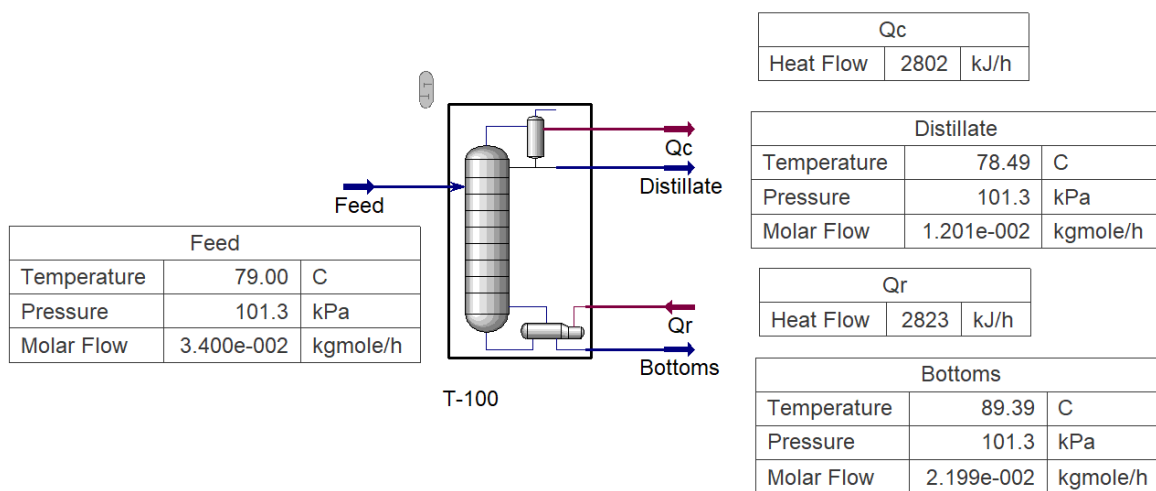


Figure 10: Aspen HYSYS Distillation Column Simulation

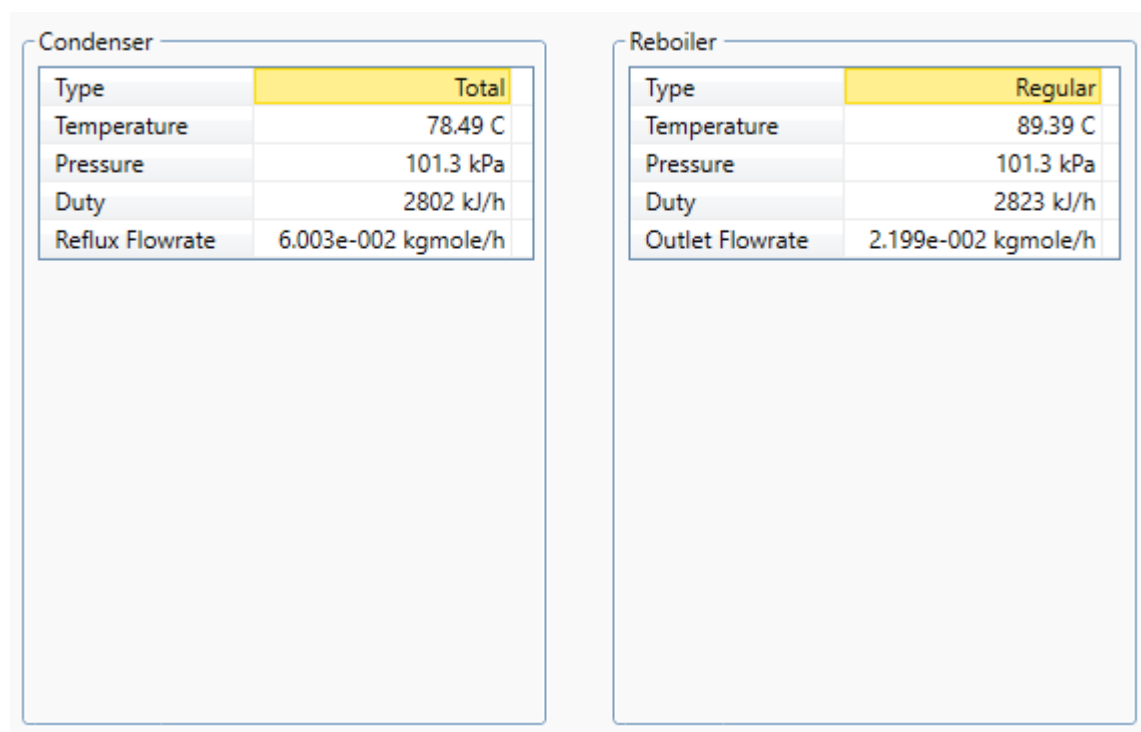


Figure 11: Aspen HYSYS Condenser and Reboiler Duties

Name	Feed @COL1	Distillate @COL1	Bottoms @COL1
Vapour	0.0000	0.0000	0.0000
Temperature [C]	79.00	78.49	89.39
Pressure [kPa]	101.3	101.3	101.3
Molar Flow [kgmole/h]	3.400e-002	1.201e-002	2.199e-002
Mass Flow [kg/h]	1.089	0.5364	0.5530
Std Ideal Liq Vol Flow [m3/h]	1.291e-003	6.712e-004	6.196e-004
Molar Enthalpy [kJ/kgmole]	-2.766e+005	-2.709e+005	-2.789e+005
Molar Entropy [kJ/kgmole-C]	85.27	62.06	97.58
Heat Flow [kJ/h]	-9406	-3252	-6133

Figure 12: Aspen HYSYS Streams Detail

Conclusion

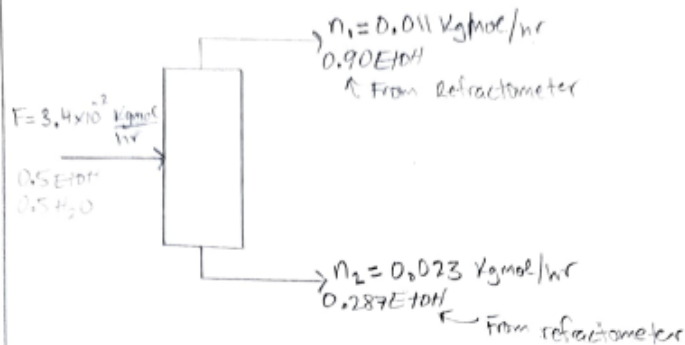
Distillation columns are commonly used to separate mixtures of fluids. The purpose of the experiment was to evaluate and compare the actual and theoretical column performance of an equimolar mixture of ethanol and water. The design used the Armfield UOP3CC distillation column and software to get the actual data. Aspen Hysys was used to simulate the distillation column. McCabe Thiele diagram was used to determine the ideal number of stages, which proved to be less accurate than the actual design because of the azeotrope of water and ethanol. McCabe Thiele diagram gave the ideal number of stages to be 6.5 whereas the actual distillation was set at 9 stages with an efficiency of 72%. Aspen Hysys simulation showed higher temperatures in the trays, as well as in the reboiler and condenser. The refractometer was used to determine the mole percent of ethanol distillate which had a refractive index of 1.3648 thus its molar composition was at 90% and the mole percent of the bottoms which had a refractive index of 1.3592 thus the molar composition was at 28.7%. In order to create a more pure ethanol product, there could have been more trays in the distillation column or we could have had another distillation column connected to the first distillation.

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Appendix

Hand Calculations



Pump Setting: 1.3 → Interpolate from "Feed Pump Calibration"

Setting	L/hr
1	0.887
1.3	F
2	2.105

← Feed flow rate

$$\therefore \frac{1-2}{1.3-2} = \frac{0.887-2.105}{F-2.105} \Rightarrow \frac{-1}{-0.7} = \frac{-1.218}{F-2.105} \Rightarrow (F-2.105)(1.43) = -1.218$$

$$\therefore (F-2.105) = -0.852 \Rightarrow F = 1.25 \frac{\text{L}}{\text{hr}}$$

For equimolar mix: $\rho_{\text{mix}} = 0.5\rho_{\text{H}_2\text{O}} + 0.5\rho_{\text{EtOH}}$; $\rho_{\text{H}_2\text{O}} = 1000 \frac{\text{kg}}{\text{m}^3}$
 $\rho_{\text{EtOH}} = 789 \frac{\text{kg}}{\text{m}^3}$

$$\therefore \rho_{\text{mix}} = 0.5(1000 \text{ kg/m}^3) + 0.5(789 \text{ kg/m}^3)$$

$$\rho_{\text{mix}} = 894.5 \text{ kg/m}^3 \leftarrow \text{Density of the feed solution}$$

$$\therefore F = 1.25 \frac{\text{L}}{\text{hr}} \cdot \frac{1 \text{ m}^3}{1000 \text{ L}} \cdot \frac{894.5 \text{ kg}}{1 \text{ m}^3} \Rightarrow F = 1.10 \text{ kg/hr}$$

Volumetric
flow rate
Conversion
factor
Solution
Density

Convert to moles: $MW_s = 0.50 MW_{\text{H}_2\text{O}} + 0.50 MW_{\text{EtOH}}$

$$MW_s = 0.50(18 \text{ kg/kgmol}) + 0.50(46 \text{ kg/kgmol})$$

$$MW_s = 32 \text{ kg/kgmol} \quad \therefore F = 1.10 \frac{\text{kg}}{\text{hr}} \cdot \frac{\text{kgmol}}{32 \text{ kg}} \Rightarrow F = 3.4 \times 10^{-2} \frac{\text{kgmol}}{\text{hr}}$$

$$\text{EtOH balance: } 0.50(3.4 \times 10^2 \frac{\text{kgmol}}{\text{hr}}) = 0.90 n_1 + 0.287 n_2$$

$$\text{Total balance: } 3.4 \times 10^2 \frac{\text{kgmol}}{\text{hr}} = n_1 + n_2$$

$$\therefore 0.017 \frac{\text{kgmol}}{\text{hr}} = 0.90 n_1 + 0.287(3.4 \times 10^2 \frac{\text{kgmol}}{\text{hr}} - n_1)$$

$$0.017 \frac{\text{kgmol}}{\text{hr}} = 0.90 n_1 + 9.8 \times 10^3 \frac{\text{kgmol}}{\text{hr}} - 0.287 n_1$$

$$\therefore 7.2 \times 10^{-3} \frac{\text{kgmol}}{\text{hr}} = 0.113 n_1 \Rightarrow n_1 = 0.011 \frac{\text{kgmol}}{\text{hr}}$$

$$\therefore n_2 = (3.4 \times 10^2 - 0.011) \text{kgmol/hr} \Rightarrow n_2 = 0.023 \text{kgmol/hr}$$

AVERAGE

CHEMICAL ENGINEERING LAB II CHEG 4101 P01

Lab 1: Determination of Overall Column Efficiency for a Distillation Column



Shanelle Bryant

Willie Conner

Jevaun Christie

Ryan Livingston

Timothy Waugh

Chemical Engineering

CHEG 4101-P02, 5:00 p.m.

September 25, 2021

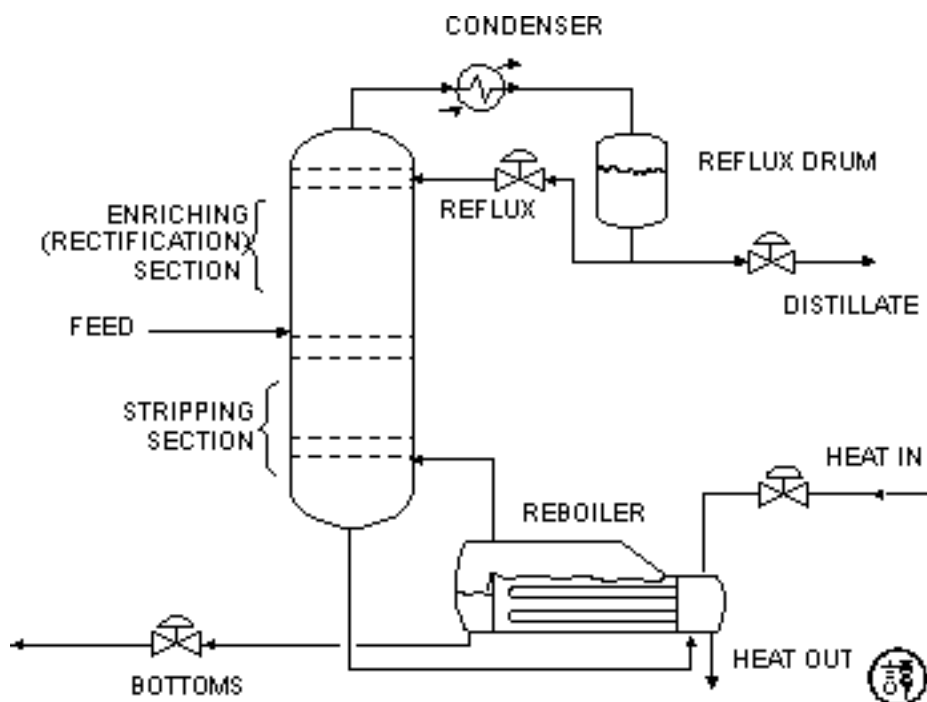
Abstract:

The purpose of this experiment was to determine the column efficiency for the distillation process of an equimolar ethanol-water mixture using McCabe-Thiele. For this experiment, a reboiler was utilized to power the column. Ethanol being the lightest component and having a lower boiling point was turned to vapor and exited the column from the top and water fell to the bottom as it's the heaviest component. These findings highlight the importance of knowing the boiling points of every necessary component as well as understanding the effects of density in the distillation process. The overall goal was to efficiently separate water from the ethanol-water mixture which is showcased when majority of the most volatile component (ethanol) moves upward in a gaseous phase and your desired product sinks to the bottom, in a liquid phase (water).

Theory:

Distillation is a separation process widely used in industry to cater for separating liquid mixtures based on their differences in boiling points and volatilities. Distillation can be used to separate both binary system of mixtures and multivariable component mixtures. For the Binary mixtures, a light key component is selected based on which component is the most volatile component between the two whereas the heavy key is the least volatile component. A multivariable component system also operates with the light key-heavy key selection principle. The light key in this case is the more volatile component in the mixture not the most volatile. This principle holds because, any component that is more volatile than the light key automatically exits the top of the column as distillate in the process. All the remaining component less volatile than the light key automatically goes to the bottom. The column is operated at the boiling temperature of the lighter component. This component is heated up to its boiling point, vaporizes and rises to the top of the column. The vaporized lighter component exits the column at the top as the distillate and is condensed either partially to saturated vapor and liquid or totally to saturated liquid.

Although the distillate is mostly composed of the lighter component, there is still a very small fraction of the heavy key component always left in the distillate. This depends on the efficiency

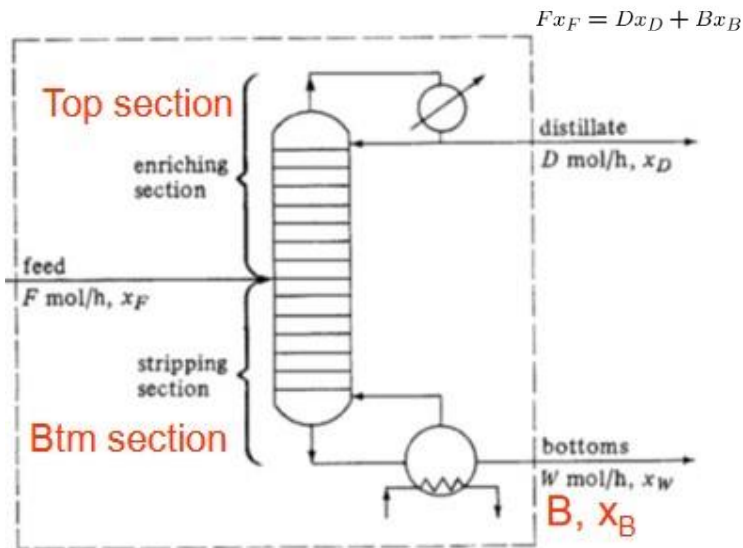


at which the distillation column is being operated. The heavy key component on the other hand, falls to the bottom of the column which give it its term bottoms product. The process is illustrated in figure one below.

Figure 1: Distillation Column mode of Operation

The balance across a distillation column is based on the input which is the feed (mixture needed to be separated), the distillate (the lighter components), and the bottoms (the heavy components). Based on figure 2 below, the balance is as follows:

$$F = D + B$$



The purpose of this lab experiment is to determine the overall column efficiency of a distillation column. This is dependent on the trays or stages required to achieve the separation. Specifying the distillate purity and bottoms purity greatly impacts the number of trays needed to achieve the separation. The number of trays also determine how high the column must be designed. The theoretical number of trays is determined based on either the McCabe-Thiele graphical method, Fenske Equation (assuming total reflux and constant relative volatility) or O'Connell efficiency. Now for the column's efficiency, several methods are used but the most common is the Murphree's efficiency model. This method analyzes the efficiency based on the ratio of theoretical number of stages and to the actual number of stages. Murphree's efficiency is illustrated in the equation below.

$$E_{MV} = \frac{y_n - y_{n-1}}{y_n^* - y_{n-1}}$$

Here y_n is the mole fraction of a particular component in the vapor leaving tray n , y_{n-1} is the mole fraction of the same component in the vapor entering tray n , and y_n^* is the composition of vapor

that would exist if the vapor leaving the tray were in equilibrium with the actual liquid leaving the tray, x_n . In a similar manner the Murphree liquid efficiency is defined as:

$$E_{ML} = \frac{x_n - x_{n+1}}{x_n^* - x_{n+1}}$$

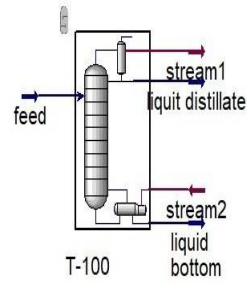
The terms x_{n+1} and x_n are the compositions of the liquid entering and leaving tray n respectively, and x_n^* is the composition of liquid in equilibrium with the vapor leaving the tray, y_n .

Procedure:

1. Using the equipment, Armfield UOP3CC Distillation column, Armfield interface device, and WindowsTM PC with Armfield UOP3CC software installed, record and measure the following:
 - a. Reflux ratio, R , x_D , x_F , x_B
 - b. the temperatures of each stage
 - c. volumetric flow rates of the distillate
 - d. D using valve V7 and the bottoms
 - e. L using valve V6
2. Using the recorded/measured flowrates mentioned above, determine the molar flow rates.
3. Determine the volumetric flow rate of the feed using the calibration curve for the pump vs. feed flow.

Results :

Energy Streams			
		stream1	stream2
Heat Flow	kJ/h	2918	2916



Compositions			
	feed	liquid distillate	liquid bottom
Comp Mole Frac (Ethanol)	0.5000	0.8105	0.3094
Comp Mole Frac (H2O)	0.5000	0.1895	0.6906

Material Streams				
		feed	liquid distillate	liquid bottom
Vapour Fraction		0.0000	0.0000	0.0000
Temperature	C	79.62	77.81	81.32
Pressure	kPa	101.3	100.6	100.6
Molar Flow	kgmole/h	3.266e-002	1.242e-002	2.024e-002
Mass Flow	kg/h	1.047	0.5063	0.5403
Liquid Volume Flow	m3/h	1.240e-003	6.252e-004	6.148e-004
Heat Flow	kJ/h	-8987	-3378	-5608



Discussion:

The equation of state, that we went on to select was the Wilson equation. This was the best one out of the options due to the conditions of our system. The first setting of 1.3 gave a volumetric flow rate of 1.24l/hr. which was a volumetric flowrate basis for our HYSYS. One of the assumptions we made, was taking an atmospheric pressure of 1atm, which led to some minor adjustments in the experiment. There will be slight differences between the ASPEN HYSYS results, and theoretical predictions that were made in the refractive average index. We

were also able to determine our number of trays, which is about 8. In the hysys simulation, we are also able to see our heat flow.

Conclusions:

The overarching goal of this experiment was to determine the column efficiency for the distillation of an equimolar ethanol-water mixture. To successfully do this, the McCabe-Thiele method was used yielding a column efficiency of XX. Another goal of this experiment was to obtain the volumetric flow rate of the feed. By generating a calibration curve for the pump vs. feed flow, using the distillates' volumetric flowrate, recorded reflux ratios and the temperatures of each stage, we were able to obtain a feed volumetric flow rate of XX.

References:

BELOW AVERAGE

**Prairie View A&M University
Chemical Engineering Department**



**Lab #3: Fluid Flow Across a Packed Column to Measure Pressure Drop ~~Impact~~ for
Two-Phase Flow**

CHEG 4104—P01 Chemical Engineering Lab II

Tiarra Rodrigues, Shimere Gregory, Doron Montgomery, Reema Matti, Cinthia Sahin

Due Date: 10/04/2021

Date Conducted: 09/27/2021



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- Key Findings
- Major Conclusions Drawn

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- Treatment of Data
- Discussion

Conclusion

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Appendix

Abstract

Purpose

The purpose of this experiment is to extract the solute from the gas stream using a liquid and measure the drops in pressure. The two variables that are used for measuring pressure drops are air and liquid flowrates. The patterns displayed in the drop in pressure against the air and liquid flow rates are compared to the estimated values as provided in the available literature. The flooding point is also observed where the main equipment used is the Edibon CAGC. The vertical cylindrical tube measures 1400 mm in height and 75 mm in diameter. To complete an effective mass transfer, the Raschig rings (measured at 10*10 mm and the specific area of packing is $\alpha = 440 \text{ m}^2/\text{m}^3$) are included within the distillation equipment to carry out an effective procedure. The theoretical values against which the experimental data is compared are derived from the Ergun Equation for packed columns. The results indicate that there was a consistency between the experimental data and the theoretical data.

Key Findings

Gas-liquid pressure must be higher at the bottom of the column. Due to the density of liquid, it flows through the gas pressure utilizing gravity. Keeping the gas and liquid constant, the experiment will come to a limiting condition called flooding. Mass transfer technology is used in various processes within industries such as food manufacturing, water treatment, oil and gas, and many other sectors.

Major Conclusions Drawn

The main idea of the Raschig rings is to create an efficient mass transfer system. When using countercurrent flow, the system receives the highest driving force of concentration between the two phases. The Raschig rings used are too large for industry, however for a laboratory scale, they draw a significant result for the conclusion.

Theory

Introduction

In gas liquid absorption, air and water are involved for demonstration. Usually, in absorption, solute or a few solutes from a gas stream are separated by absorption in liquid so that desired component is easily separated. It is worth mentioning that there are no solute phases and two bulk phases such as water and air are involved in the process. In counter current absorption column, gas is entered from bottom which contacts with liquid coming from the top while passing through the installed packing. If the packing is wetted by a liquid, the column volume available for gas flow becomes reduced by the volume of the liquid fraction.

Objective

The objectives of this experiment are listed below.

- Measure the pressure drop as a function of air rate for 3 different liquid flows.
- Compare measurements taken in lab with what is available in the literature and make correlations.
- Determine the void fractions of the packed bed.
- Determine the effects of liquid holdups on the pressure drops within the packed bed columns.
- Determine the packing factor experimentally with the use of flooding velocity calculations.
- Figure out what the flooding point is within the different conditions.

Background

The flooding point is defined when the gas flow expels as much air as possible (air blows as hard as it can) and no more air can enter the column because the maximum velocity of air passing through column has been achieved. The loading point is defined when the falling liquid becomes impeded by air flow causing

additional liquid to hold up. The volume of the liquid begins to expand while entraining entry gas bubbles in the liquid. This further causes the liquid to be thrown up and results in poor mass transfer. The relative displacement of the two water levels is measured to calculate the pressure drop (ΔP). Refer to Figure 1 in the Appendix.

Procedure

1. CAGC in action using the program. Click start for the computer control and give the file a name. The initial high pitch sound is the pump. The first step of this study was to determine the subject of the lab conducted. The team determined the subject of this experiment is utilizing the Edibon equipment to measure pressure drops.
2. Second, the team defined the goals and objectives of this experiment which are listed below.
 - a. Measure the pressure drop as a function of air rate for 3 different liquid flows.
 - b. Determine the effects of liquid holdups on the pressure drops within the packed bed columns.
 - c. Figure out what the flooding point is within the different conditions.
 - d. Determine the packing factor experimentally with the use of flooding velocity calculations.
 - e. Determine the void fractions of the packed bed.
 - f. Compare measurements taken in lab with what is available in the literature and make correlations.
3. Third, the team began to research any relevant theories and published data from similar experiments. This step helped with collecting reference materials and developing a greater understanding of the lab. Overall, what the team discovered is that the CAGC equipment takes liquid (water) from the tank and pumps it to the top of the column. The liquid falls due to gravitational force over the Raschig elastic rings. The rings act as an active area for the liquid and gas to make contact and perform their mass transfer (or the exchange of solids). This experiment is not for extraction purposes, it is looking at pressure drops across columns. Apart from introducing water, air is introduced as the gas space from the bottom of the setup. They will contact each other in a counter-current manner. The pressure across the column can be measured either across half of the column or across the entire column.
4. Fourth, the team selected the dependent and independent variable(s) to be measured or controlled. The variables the team chose are listed below.
 - a. Independent
 - i. Flow rate of the liquid
 - ii. Flow rate of the gas
 - b. Dependent
 - i. Pressure drops of the whole column
 - ii. Pressure drops of half the column
5. Fifth, the team began the procedure for the experiment which is listed below.
 - a. Turn on CAGC (The on switch is under the computer desk)
 - b. Open the CAGC software on the computer
 - c. Once the software is open click "Start" and save the file with a name
 - d. Review the following steps to check if the lab is properly set up.
 - i. Make sure the tank under the column is filled to the water line.
 - ii. Use a flask or a beaker to fill with deionized water.
 - iii. At VT-2, ensure plastic clamp is open to allow water into plastic tubing connected to the manometer.
 - iv. Place a beaker at the end of the tubing V-1 to catch water. Ensure that the valve is in the closed position (horizontal) for V-1.

- v. Place a funnel into plastic tubing of VT-2. Slowly pour deionized water into the funnel. Fill the manometer until both bulbs are full and water level on the left side of the ruler is filled to at least 120 mmH₂O
 - vi. Locate VT-5 to find the value of the full column and the half column.
 - vii. Carefully remove the plastic tubing on the left side of the valve
 - viii. Obtain the funnel and place in the plastic tubing
 - ix. Obtain a catchment container and place it under V-2.
 - x. Make sure the valve at the bottom of the U (of V-2) is in the closed position.
 - xi. Carefully pour in the deionized water until both the left and right side read between 120-130mm of deionized water.
 - xii. Carefully reattach the tubing to the valve.
 - xiii. Take note of the water level readings for both VT-5 and VT-2 before running the experiment; this means while both the pump and the compressor are off. Side note: once the experiment begins, the water levels will begin to change.
 - xiv. Make sure that your valves are in the appropriate opened or closed positions. Refer to the picture below (red indicators). the orientation of VT-1 will be important.
 - xv. The valves that are used for the lab are V2 (exit valve).
- e. To start the water pump click start and ok.
- f. Click PID (this will stop varying water flow) which is a controller. From there this controller will manipulate the SetPoint SC-1 i.e. the liquid flow.
- g. Input a value from .1-2.8 L/min in the SetPoint SC-1.
- h. To change the air flow, locate the VR-1 valve and turn it clockwise or counterclockwise to achieve aa desired flow rate
- i. To read the air flow find the top of the metal indicator. Take this and the corresponding percentage of the air flow.
- j. The next piece of equipment to be turned on is the compressor (AS-1). This step starts changing the water levels within the left and right tubes on V2.
 - i. VR3 controls the water flowrate.
 - ii. VR1 controls the airflow rate.
 - iii. Sidenote: The airflow and water flow are read in percentages and need to be converted to be used in calculations. The conversions will be listed below:
 - 1. Airflow
 - a. MAX 85%/68 [l/min]
 - b. MIN 0%/0 [l/min]
 - 2. Water flow
 - a. MAX 75%/2.9 [l/min]
 - b. MIN 0%/0 [l/min]
- k. To manually operate the controller, turn off PID and turn the AB-1 actuator “virtual” knob to change the values of SetPoint SC-1.
- 6. Sixth, the team selected the appropriate chemicals for the experiment to be conducted safely. The chemicals used will be listed below.
 - a. Deionized Water and distilled water
- 7. Seventh, the team selected the appropriate methods for measuring/independent variables. The variables selected by the team are listed below.
 - a. Independent
 - i. Flow rate of the liquid = using the program
 - ii. Flow rate of the gas = using the program and the widest part of the metal indicator
 - b. Dependent
 - i. Pressure drops of the whole column = the program

- ii. Pressure drops of half the column = the program
- 8. Eighth, the team designed a methodology used to process the results accordingly. The team created an excel spreadsheet with each case on it and their corresponding graphs.
- 9. The conclusions expected from the team were completely different from what we were supposed to execute. Dr. Antoine and Dr. Gabitto had different expectations from the lab, and it confused the team. The team expected the lab to be more organized than what was provided and what the team was told.

Schematic Diagram

Refer to Figure 2 in the Appendix.

Results & Discussion

Treatment of Data

Refer to Figures 3-5 in the appendix for visual depictions of the scatterplot.

For the first objective, the team was tasked with measuring the pressure drop as a function of air rate for 3 different liquid flows. The pressure drops are listed for 3 different airflows in the Appendix labeled Table 1.

To determine the effects of liquid holdups (h_L) on the pressure drops within the packed bed columns, the team proceeded to research references and look through the provided material. Unsurprisingly, the Beggs-Brill model outperformed the model in our lab utilizing oil-air flow, the liquid holdup increased to become proportional to the column's pipe diameter and reach a similar gas-liquid ratio. The experiment's gas to liquid ratio came to be less than 100, and their variable concerning inclined angles (within the range of 0-30°) had very little effect on liquid holdup.

Another objective the team was tasked with solving was figuring out what the flooding points were at different conditions. In the Appendix labeled Table 2, the team has taken the average of different max flow rates in which the liquid completely filled the tank and mass transfer was inefficient.

The team did not have the opportunity to determine the packing factor experimentally with the use of flooding velocity calculations. The packing factor ended up being an unnecessary calculation due to the information being provided by the professor.

Determine the void fraction of the packed bed. The void fraction calculations are listed in Appendix as figures 6 and 7.

The team Compare measurements taken in lab with what is available in the literature and make correlations. The team was unsuccessful in retrieving useful data from the experiment due to human error. The team was able to retrieve similar results from the literature, but not the same and the comparison was not valid. The directions were confusing, and the group took the incorrect values which cannot yield any comparisons between actual and theoretical values. The team will prepare better for the next lab, because of the experience that everyone had. With this being said, the team decided to use the given data and base our report off of the theoretical data taken by the professors. It was the best decision also because of the group members who were virtual and became confused with the lab as well.

Discussion

There were various combinations used in the experimentation processes. The results of the liquid flow

rate were between 0.5 L/min and 2.8 L/min. The gas flow rates ranged from 14 L/min to 68 L/min. In the case of the pressure drop, the results ranged between 0.85 mmH₂O to 21.5 mmH₂O. From these results, it is evident that the pressure drops increase when the air flow rate increases. The liquid flow rate also corresponded with the rise in the liquid hold up. The accuracy in this experiment was ensured through repetition where the results were consistent, which implies high accuracy.

Conclusion

From conducting this experiment, we were able to measure the pressure drops for all three water rates in valves V-1, V-2, and V-3. We were also able to conclude that our experimental pressure drop correlated with our predicated values from our collected data based off our simulation. As the pressure drop increased, the air flow rate increases and as the total pressure drop decreased the liquid flow rate decreased as well. The pressure drops were in direct correlation with our experimental values. As stated previously, we found that our minimum liquid flow rate was 2.8 L/min. We were able to evaluate three cases for our liquid flow rate correlation to the pressure drop. We noticed that as our gas flow rates were increasing in each case but with a constant value which indicates there was some flooding happening in our column.

Technical Content	Maximum	Grade
Abstract/Objective	5	2
Theory	5	2
Results	5	1
Conclusions	5	2
Total =7/20	20	7
Writing Content		
Organization	5	5
Language	5	2
Professional content	5	3
Appearance	5	2
Total = 19/40 or 0.48	20	12

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1. Billet, R. and Schultes, M. "Modelling of Pressure Drop in Packed Columns," *Chem. Eng. Tech.*, **14**, 89-95, 1991.
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**CHEMICAL ENGINEERING LAB. II
FALL 2021**

Title of Assignment: LAB. II REPORT

TOPICS COVERED IN REPORT

Virtual Report II covered the following topic:

1. Friction in pipes and fittings

Objective:

To show the effect of flow rate, pipe diameter, and pipe roughness on the pressure in pipes.
To show the effect of flow rate on the pressure drop in a gate valve.

CHEMICAL ENGINEERING LAB. II

FALL 2021

RUBRIC AND GRADING SCHEME FOR LAB. REPORTS

Laboratory Grading Sheet Reports

Technical Content

Maximum Grade

9. Abstract/Objective	5points
10. Theory	5 points
11. Results	5 points
12. Conclusions	5 points

Writing Content

13. Organization	5points
14. Language	5points
15. Write-up	5 points
16. Appearance	5points

Every report will be graded according to the items described in this grade sheet.

Technical Content	Maximum	Grade
Abstract/Objective	5	
Theory	5	
Results	5	
Conclusions	5	
Total =	20	
Writing Content		
Organization	5	
Language	5	
Professional content	5	
Appearance	5	
Total =	20	

ABOVE AVERAGE

CHEG 4101- P01 (ChemE Lab II)

Lab 2: Friction in Pipes



Fall 2021

CHEG 4101—P01 Chemical Engineering Lab II

Tiarra Rodrigues, Shimere Gregory, Doron Montgomery, Reema Matti, Cinthia Sahin

Date Due: 10/21/2021

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Abstract

The friction in pipes lab is a traditional experiment that has been used for years to explain and learn about fluid dynamics. This section of the course is structured to allow those conducting the experiment to study the performance of different flow rates and with varying conditions. The goal of this lab, Friction in Pipes, was to establish the relationship between the pressure drop due to friction and the velocity of fluid in smooth and rough pipes with different inner diameters (ID). Furthermore, the lab required us to determine the friction factor for each straight pipe and verify the pressure drop of water as it flows through a gate valve for a pipe with a 26.5 mm ID. The experimental results were entered into tables and graphs and assessed with theoretical projected behavior from fluid mechanics models. This lab and its results are applicable to the real world because friction in pipes affects the flow of fluid in the piping systems in residential & commercial buildings and is vital to the work of aeronautical, industrial, and chemical engineers.

Theory

In fluid mechanics, there are two types of classified flows. Through demonstration, Osborne Reynolds identified them as turbulent flow and laminar flow.

- **Turbulent flow** represents the path in which particles do not move in an orderly manner as they occupy different relative positions in successive cross-sections. In turbulent flows, the pressure drop is proportional to the square of the velocity.
- **Laminar flow** showcases the state in which “individual fluid particles move along their trajectories independent of the particles in the adjacent layers” (Brown, 1991). Here the pressure drop and current velocity are proportional.

For areas that do not have a clear relation between the flow velocity and pressure loss, Reynolds number is used.

$$Re = \frac{\rho U d}{\mu} \quad (I)$$

where:

ρ : The fluid density (kg/m^3)

μ : The dynamic viscosity ($kg/m \cdot s$)

d : The pipe diameter (m)

U : its velocity (m/s)

When studying fluid flow for any application, viscosity is a crucial material property.

Dynamic viscosity, μ , used in equation I “represents the force needed to make the fluid flow at a certain rate. Kinematic viscosity tells us how fast the fluid is moving when a certain amount of force is applied” (Nieto, 2015). The two common types of viscosities can be related by the following equation:

$$\nu = \frac{\mu}{\rho} \quad (II)$$

The following table displays the water kinematic viscosity values depending on the temperature.

Temperature (°C)	Kinematic viscosity (m ² /seg).10 ⁻⁶
5	1.52
10	1.308
15	1.142
20	1.007
25	0.897
30	0.804
35	0.727
40	0.661
50	0.556

Table 1: Kinematic viscosity values for H₂O based on temperature

In relation to Reynolds number, Re , kinematic viscosity is inversely proportional.

$$Re = \frac{U d}{\nu} \quad (III)$$

Pressure drop can occur in pipes through different ways. One of those ways is through friction loss. To account for the friction loss in the pipe, the Darcy-Weisbach law is used. “The Darcy–Weisbach equation is a phenomenological equation, which relates the major head loss, or

pressure loss, due to fluid friction along a given length of pipe to the average velocity” (Connor, 2019). After rearranging the equation, the value of the friction coefficient is obtained:

$$h_f = h_2 - h_1 \quad (\text{IV})$$

$$f = h_f \left(\frac{L}{D} \right) \left(\frac{2g}{v^2} \right) \quad (\text{V})$$

where:

h_1 : Height of the water column at the beginning of the pipe (m)

h_2 : Height of the water column at the end of the pipe (m)

h_f : Pressure drop (m)

f : Friction coefficient (*dimensionless*)

L : Length of the pipe (m)

D : Inner diameter of the pipe (m)

V : Average velocity of the fluid (m/s)

g : Gravity acceleration (m/s^2)

The friction factor, f , is a function of different terms.

- For Laminar flow ($N_R < 2000$): $f = \frac{64}{N_R}$
- For turbulent flow ($4000 < N_R < 10^5$) with $e/D = 0$: $f = \frac{0.316}{N_R^{0.25}}$
- For turbulent flow ($N_R > 4000$) with $e/D > 0.0$: $f = 0.25 \times \left(\log \left(\frac{e}{3.7D} + \frac{5.74}{N_R^{0.9}} \right) \right)^{-2}$ (Miller's Eqn.)

Flow and fluid's velocity are related by means of this formula:

$$Q = Av = \frac{\pi D^2}{4} v \quad (\text{VI})$$

where:

A : Area of the section (m^2)

v : Average velocity of the fluid (m/s)

D : Diameter of the section (m)

Other losses in pressure drops in exceptional cases can only be determined in experimental ways. Due to the fact that they are generated by an energy dissipation because of turbulences, they can be expressed in function of the kinetic height corrected by means of an empirical coefficient (k):

$$h_f = K \left(\frac{v^2}{2g} \right) \quad (\text{VII})$$

where:

h_f : Pressure drop (m)

K: Empirical coefficient (dimensionless)

g: Gravity acceleration (m/s^2)

v: Velocity of the flow (m/s)

Note: Approximate values of K can be summarized through singular losses tables.

The Darcy-Waisbach equation can be used to calculate the pressure drop in meters due to frictional losses and is calculated as so:

$$h_f = \frac{8fLQ^2}{gD^5\pi^2} \quad (\text{VIII})$$

Experimental Procedure

1. Connect the hydraulic bench to the AFT/AFTB/AFTC/AFTP.
2. Activate the “mushroom button” of the hydraulic bench with the V1, V2, V3, V4, V5, V6, V7 and the regulation valve number 23 closed.
3. Connect the unit and switch on the pump.
4. Open the V1 valve and wait until all the air from the pipe is expelled.
5. Connect the pressure taps of the corresponding manometer to the inlet and outlet of pipe number 2. The manometric tubes will be chosen when there are water column differences lower than 800 mm.

Results & Discussion

Experiment 1:

Experiment 1 used a rough PVC pipe with an internal diameter of 17 mm. Using the formulas provided, we were able to achieve our data provided in the appendix. We noticed that for each flow rate, Reynold's number was above 4,000 but less than 100,000 ($4103 < NRE < 105$); therefore, the Miller's equation was used to calculate our friction factor. The friction factor was detrimental in the friction losses calculations by using the Darcy-Waisbach equation (Equation VIII).

Experiment 2:

Used a rough PVC pipe with an internal diameter of 23 mm. Using the formulas provided, we were able to achieve our data provided in the appendix. We noticed that, just as in experiment 1, for each flow rate, the Reynolds number was above 4,000 but less than 100,000 ($4103 < NRE < 105$). Therefore, to calculate our friction factor, we used Miller's equation, which would allow us to calculate our friction losses by using the Darcy-Waisbach equation (Equation VIII).

Experiment 3:

Experiment 3 used a smooth PMMA pipe with an internal diameter of 6.5 mm. Using the formulas provided, we were able to achieve our data provided in the appendix. Due to the pipe's smoothness, Miller's equation was not used for this experiment for the friction factor. Since we have turbulent flow and Reynolds number is between 4,000 and 100,000 ($4000 < Nr < 105$), we used the equation matching these specifications in the theory section with no roughness. From here, we proceeded to use the Darcy-Waisbach equation precisely as done in experiment 1.

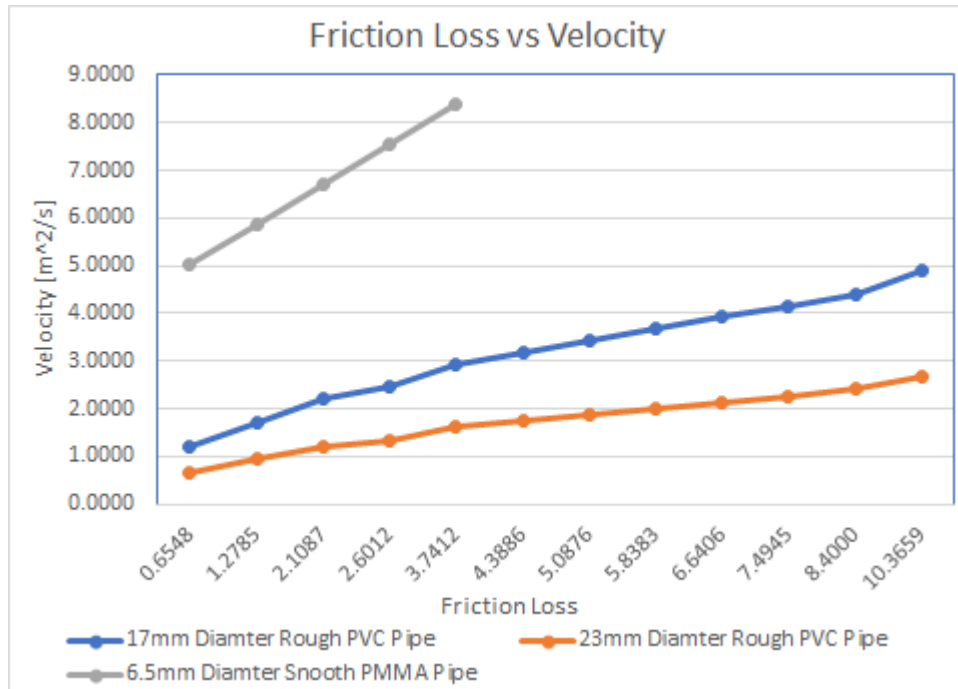


Figure 1: Friction Loss vs. Velocity through varying pipe diameters

Experiments 1 through 3 were all done throughout pipes and plotting them all on a graph. We see that even though experiment 3 used a smooth pipe, which should have reduced the frictional losses, it has the smallest diameter, which caused it to have the highest velocity, thus leading to the highest pressure drop. This observation is also found between experiments one and two. They both have the same material. However, experiment one used a 17mm diameter while experiment two used a 23mm diameter, which caused the tube in experiment one to have a higher pressure drop.

Experiment 4:

Experiment 4 involved passing fluid through a gate valve with a given internal diameter of 26.5 mm. The friction factor through a gate valve was calculated by applying a different minor loss equation. Eqn. (9) from the lab manual gives us a route to calculate the friction coefficient in

a gate valve. This equation presents K, a coefficient that depends on the singularity and the average velocity, and is calculated by:

$$K = \frac{2g\Delta h}{v^2}$$

Where Δh is the pressure drop.

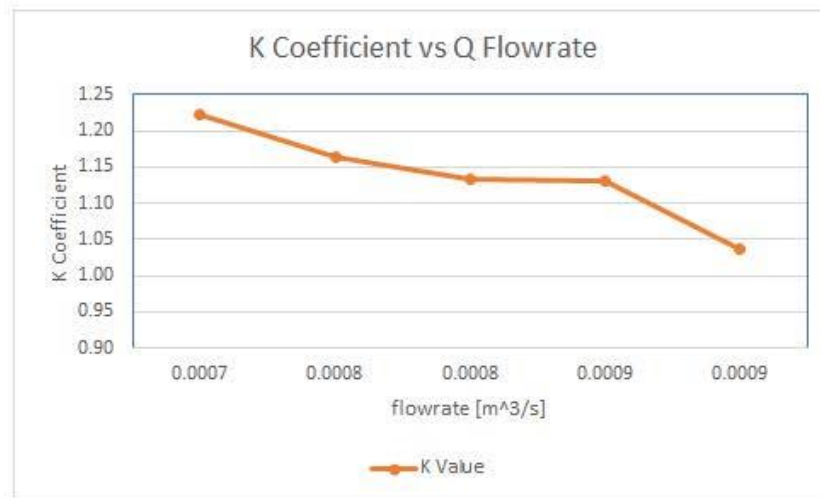


Figure 2: K coefficient Vs Flow Rate (Q)

Graph 2 shows the comparison between the K value and the flowrate and we can see that as the flow rate increases, the K coefficient begins to decrease.

Conclusion

In conclusion, the friction loss in pipe flow was successfully demonstrated by this experiment and measured the flow rate in circular pipes. Our lab group then successfully compared the different pipe fittings in terms of flow, pressure, and velocity. We observed that as the flow rate increases, the K coefficient begins to decrease. A smooth pipe was used in experiment 3, reducing the frictional losses, and its smallest diameter caused it to have the highest velocity and lead to the highest pressure drop. This observation is also found between experiments one and two which both had pipe with the same material. However, the difference in diameters in one and two, 17 and 23 millimeters, caused the tube to have a higher pressure drop. The report's final recommendations convey that PVC pressure pipes with large internal diameters are booming in reducing pressure compared to galvanized pipes due to the greater friction in galvanized pipes.

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Appendix

ID:17 mm Rough PVC Pipe

Flow (Q) [L/hr]	Flow (Q) [L/min]	Flow (Q) [m ³ /s]	Area Of Pipe [m ²]	Velocity (u) [m/s]	Height 1 (hf1) [mmH ₂ O]	Height 2 (hf2) [mmH ₂ O]	Reynolds #	Relative Roughness (e)	Friction Factor (f)	Friction Losses (hf)
1000	16.6667	0.0003	0.0002	1.2244	588	398	23205	0.0002	0.0964	0.6548
1400	23.3333	0.0004	0.0002	1.7142	682	348	32487	0.0002	0.0960	1.2785
1800	30.0000	0.0005	0.0002	2.2040	775	233	41769	0.0002	0.0958	2.1087
2000	33.3333	0.0006	0.0002	2.4488	821	107	46411	0.0002	0.0957	2.6012
2400	40.0000	0.0007	0.0002	2.9386	912	97	55693	0.0002	0.0956	3.7412
2600	43.3333	0.0007	0.0002	3.1835	997	14	60334	0.0002	0.0956	4.3886
2800	46.6667	0.0008	0.0002	3.4284	5099	3773	64975	0.0002	0.0955	5.0876
3000	50.0000	0.0008	0.0002	3.6733	5506	4079	69616	0.0002	0.0955	5.8383
3200	53.3333	0.0009	0.0002	3.9181	5812	4283	74257	0.0002	0.0955	6.6406
3400	56.6667	0.0009	0.0002	4.1630	6118	4283	78898	0.0002	0.0954	7.4945
3600	60.0000	0.0010	0.0002	4.4079	6526	4487	83539	0.0002	0.0954	8.4000
4000	66.6667	0.0011	0.0002	4.8977	7036	4793	92821	0.0002	0.0954	10.3659

Table 2: Experiment 1 with 17 mm ID rough PVC

ID:23 mm Rough PVC

Flow (Q) [L/hr]	Flow (Q) [L/min]	Flow (Q) [m ³ /s]	Area Of Pipe [m ²]	Velocity (u) [m/s]	Height (hf1) [mmH ₂ O]	Height 2 (hf2) [mmH ₂ O]	Reynolds #	Relative Roughness (e)	Friction Factor (f)	Friction Losses (hf)
1000	16.6667	0.0003	0.0004	0.6689	285	250	6342	0.0002	0.0862	0.1291
1400	23.3333	0.0004	0.0004	0.9365	338	272	8879	0.0002	0.0849	0.2494
1800	30.0000	0.0005	0.0004	1.2041	396	292	11416	0.0002	0.0842	0.4087
2000	33.3333	0.0006	0.0004	1.3378	436	306	12684	0.0002	0.0839	0.5030
2400	40.0000	0.0007	0.0004	1.6054	510	328	15221	0.0002	0.0835	0.7209
2600	43.3333	0.0007	0.0004	1.7392	544	334	16490	0.0002	0.0834	0.8445
2800	46.6667	0.0008	0.0004	1.8730	580	345	17758	0.0002	0.0832	0.9778
3000	50.0000	0.0008	0.0004	2.0068	625	350	19027	0.0002	0.0831	1.1209
3200	53.3333	0.0009	0.0004	2.1405	665	356	20295	0.0002	0.0830	1.2738
3400	56.6667	0.0009	0.0004	2.2743	704	360	21564	0.0002	0.0829	1.4364
3600	60.0000	0.0010	0.0004	2.4081	736	362	22832	0.0002	0.0828	1.6087
4000	66.6667	0.0011	0.0004	2.6757	810	364	25369	0.0002	0.0827	1.9827

Table 3: Experiment 2 with 23 mm ID rough PVC

6.5 mm Smooth PMMA pipe

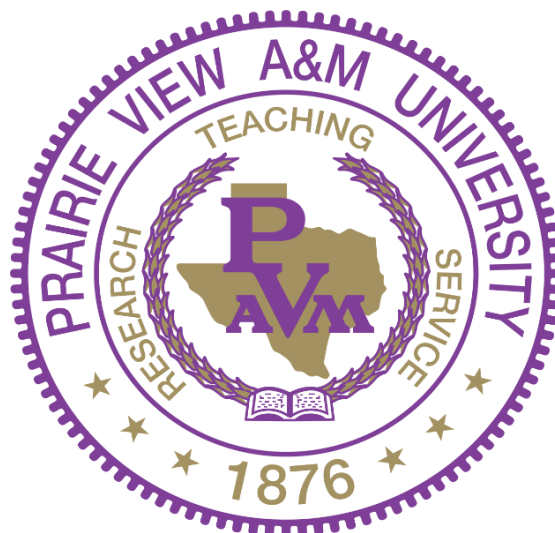
Flow (Q) [L/hr]	Flow (Q) [L/min]	Flow (Q) [m ³ /s]	Area Of Pipe [m ²]	Velocity (u) [m/s]	Height (hf1) [mmH ₂ O]	Height 2 (hf2) [mmH ₂ O]	Reynolds #	Relative Roughness (e)	Friction Factor (f)	Friction Losses (hf)
600	10.0000	0.0002	0.0000	5.0252	4895	1020	47645	0.0000	0.0214	6.4007
700	11.6667	0.0002	0.0000	5.8627	6730	1224	55586	0.0000	0.0206	8.3827
800	13.3333	0.0002	0.0000	6.7003	7954	1326	63527	0.0000	0.0199	10.5893
900	15.0000	0.0003	0.0000	7.5378	9177	1632	71468	0.0000	0.0193	13.0132
1000	16.6667	0.0003	0.0000	8.3753	11625	1835	79409	0.0000	0.0188	15.6480

Table 4: Experiment 3 with 6.5 mm ID smooth pip

ID: 26.5 mm Gate Valve							
Flow (Q) [L/hr]	Flow (Q) [L/min]	Flow (Q) [m ³ /s]	Area Of Pipe [m ²]	Velocity (u) [m/s]	Height (hf1) [mmH ₂ O]	Height 2 (hf2) [mmH ₂ O]	K Value
2600	43.3333	0.0007	0.0006	1.3101	223	116	1.22
2800	46.6667	0.0008	0.0006	1.4109	260	142	1.16
3000	50.0000	0.0008	0.0006	1.5117	302	170	1.13
3200	53.3333	0.0009	0.0006	1.6124	342	192	1.13
3400	56.6667	0.0009	0.0006	1.7132	365	210	1.04

Table 5: Experiment 4 for Gate Valve for a pipe with 26.5 mm ID

AVERAGE



**Chemical Engineering
Lab II Group 1
Design of Experiment
Fluid Friction in Pipes for CHEG
4101**

**Chemical Engineering
CHEG 4101-P01, 5:00
p.m.**

**Reema Matti, Cinthia Sahin
October 14th, 2021**

To

Dr. Jorge F. Gabitto

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ABSTRACT

The Friction in Pipes experiment focuses on the study of behavior of closed flows and allows the study of pressure drops in pipes as well as in different hydraulic accessories. Using straight pipes with different diameters, in different kinds of fittings, (rough or smooth), are often used on an industrial scale. We can study the loss of by friction by using the internal diameter of a pipe, the length of a pipe, and the pipe's flowrate. The goal of this experiment was to first detect the relationship between pressure drop due to the friction and the velocity of the fluid through a smooth and rough pipe with different inner diameters (17mm, 23mm, 6.5mm). The second objective is to determine the friction factor for each straight-run pipe and compare experimental data results with theoretical predicted behavior from fluid mechanic models. The third goal of this experiment is to determine the pressure drop of the fluid when it flows through a gate valve using a 26.5mm pipe diameter. To conduct this experiment, we combined the use of fluid friction apparatus (AFT/AFTB/AFTC/AFTP) with a hydraulic bench. Then, after the whole unit was connected, the pump switch on, the valve of the corresponding pipe was opened until all the air was expelled. The manometric tubes will be chosen when there are water column differences lower than 800mm. This series will be repeated with smooth and rough pipes of variables inner diameters (17mm, 23mm, 16.5mm, and 6.5mm). We were able to measure fluid friction within four different pipes which were observed. We concluded that the pressure drops, and volumetric flowrate have a directly proportional relationship.

THEORY

According to Osborne Reynolds, there are two types of currents that could be established in a pipe. One current is Laminar Flow, which is described as having a proportion relation between the pressure drop and the current velocity. A laminar flow is characterized by fluid particles following smooth paths in layers. The other current is Turbulent flow, which is described as the pressure drop being proportional to the square of the velocity. This type of flow is characterized by fluid motion having chaotic changes in pressure and flow velocity. To classify current, we use a dimensionless parameter called the Reynolds number Re ($Re = \rho U d / \mu$) where: ρ is the fluid density [kg/m³], U : its velocity [m/s], μ : The dynamic viscosity [kg/m·s] and d is the pipe diameter [m].

PROCEDURE

Experiment 1: Pressure drop due to friction in a rough pipe with an inner diameter of 17mm

Step 1: Connect the hydraulic bench to the AFT/AFTB/AFTC/AFTP.

Step 2: Activate the “mushroom button” of the hydraulic bench with the V1, V2, V3, V4, V5, V6, V7 and the regulation valve number 23 closed.

Step 3: Connect the unit and switch on the pump.

Step 4: Open the V1 valve and wait until all the air from the pipe is expelled.

Step 5: Connect the pressure taps of the corresponding manometer to the inlet and outlet of pipe number 2. The manometric tubes will be chosen when there are water column differences lower than 800 mm.

Step 6: Regulate with the regulation valve number 23 the flow which runs through the pipe.

Experiment 2: Pressure drop due to friction in a smooth pipe with an inner diameter of 16.5mm

Step 1: Connect the hydraulic bench to the AFT/AFTB/AFTC/AFTP. Step 2: Activate the “mushroom button” of the hydraulic bench with the V1, V2, V3, V4, V5, V6, V7 and the regulation valve number 23 closed.

Step 3: Connect the unit and switch on the pump.

Step 4: Open the valve V4 and the angle seat valve number 7 and wait until all the air from the pipe is expelled.

Step 5: Connect the pressure taps of the corresponding manometer to the inlet and outlet of the pipe number 5. The manometric tubes will be chosen when there are water column differences lower to 800 mm.

Step 6: Regulate with the regulation valve number 23 the flow which runs through the pipe.

Experiment 3: Pressure drop due to friction in a smooth pipe with an inner diameter of 6.5mm

Step 1: Connect the hydraulic bench to the AFT/AFTB/AFTC/AFTP.

Step 2: Activate the “mushroom button” of the hydraulic bench with the V1, V2, V3, V4, V5, V6, V7 and the regulation valve number 23 closed.

Step 3: Connect the unit and switch on the pump.

Step 4: Open the V3 valve and wait until all the air from the pipe is expelled.

Step 5: Connect the pressure taps of the corresponding manometer to the inlet and outlet of the pipe number 4. The manometric tubes will be chosen when there are water column differences lower to 800 mm.

Step 6: Regulate with the regulation valve number 23 the flow which runs through the pipe.

Experiment 4: Pressure drop in a gate valve

Step 1: Connect the hydraulic bench to the AFT/AFTB/AFTC/AFTP.

Step 2: Activate the “mushroom button” of the hydraulic bench with the V1, V2, V3, V4, V5, V6, V7 and the regulation valve number 23 closed.

Step 3: Connect the unit and switch on the pump.

Step 4: Open the valve V5 and the gate valve number 8 and wait until all the air from the pipe is expelled.

Step 5: Connect the pressure taps of the corresponding manometer to the inlet and outlet of the valve number 8 (gate valve). The manometric tubes will be chosen when there are water column differences lower to 800 mm.

Step 6: Regulate with the regulation valve number 23 the flow which runs through the pipe. It is recommended to start with a flow of 10 l/min and increase 5 l/min for each data taking.

Result & Discussion

The ability to be able to measure a fluid friction within pipes was a design originated by Edibon. This design consists of a system operating by using a water valve to set the flow rate measured by a flow meter. Four different pipes were observed separately to get an accurate reading of the fanning friction factor. Initial data were acquired from the experiment. These included a constant length between pipes as 59.5 inches, flowrates, pressure (readings are obtained from a manometric device) and the individual pipe diameters for all four pipes. Finally, HP1 and HP2 were used to measure the pipe’s pressure and, LP1 and LP2 were used to obtain the pipe’s readings, respectively.

Dimensionless Parameter, $Re = \rho U d / \mu$ (1)

Kinematic Viscosity $\rightarrow \nu = \mu / \rho$ (2)

Reynolds number $\rightarrow Re = U d / \nu$ (3)

Hydraulic $\rightarrow h_f = h_2 - h_1$ (5)

Average velocity $\rightarrow Q = A v = (\pi D^2 / 4) v$ (7)

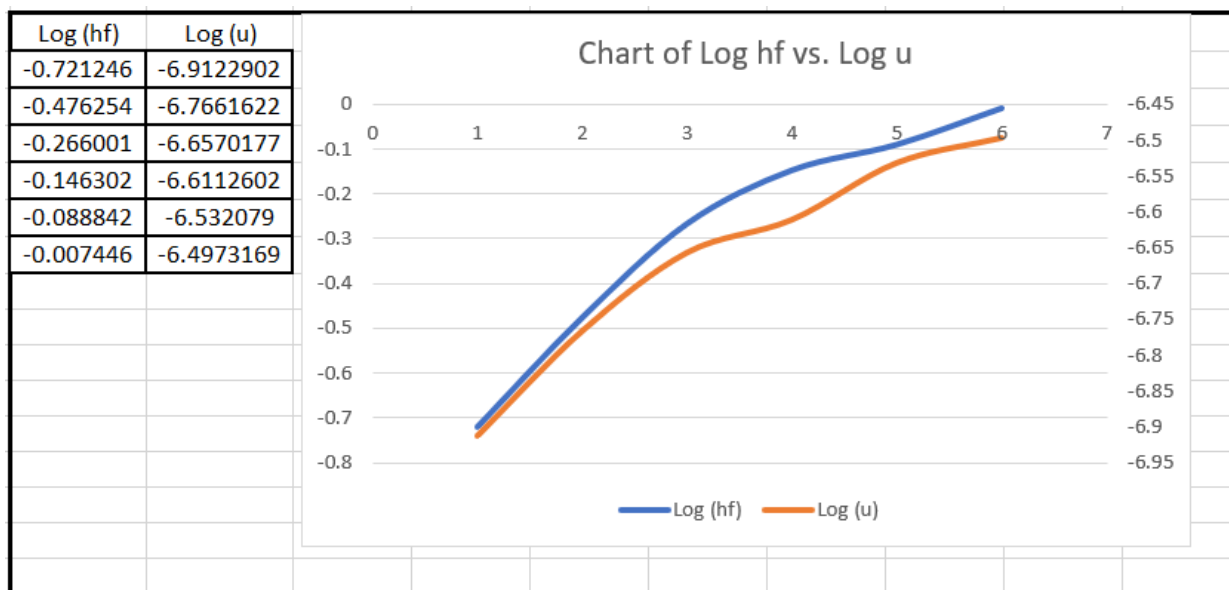
Experiment 1: Pipe #2 with 17mm inside diameter

Recording Data:

FLOW Q (L/hr)	Pressure 1 (mm H ₂ O)	Pressure 2 (mm H ₂ O)	Height h_f (mm H ₂ O)
1000	588	398	190
1400	682	348	334
1800	775	233	542
2000	821	107	714
2400	912	97	815
2600	997	14	983

Results:

Flow Q (L/hr)	Flow Q (m ³ /s) e-05	Velocity u (m/s) e-07	Height h_f (m H ₂ O)	Log (h_f)	Log u	Re
1000	2.78	1.22	0.190	2.279	-0.721	2.319349802
1400	3.89	1.71	0.334	2.524	-0.476	3.247089723
1800	5.00	2.20	0.542	2.734	-0.266	4.174829644
2000	5.56	2.45	0.714	2.854	-0.146	4.638699604
2400	6.67	2.94	0.815	2.911	-0.089	5.566439525
2600	7.22	3.18	0.983	2.993	-0.007	6.030309485



Experiment 2: Pipe #5 with 23mm inside diameter

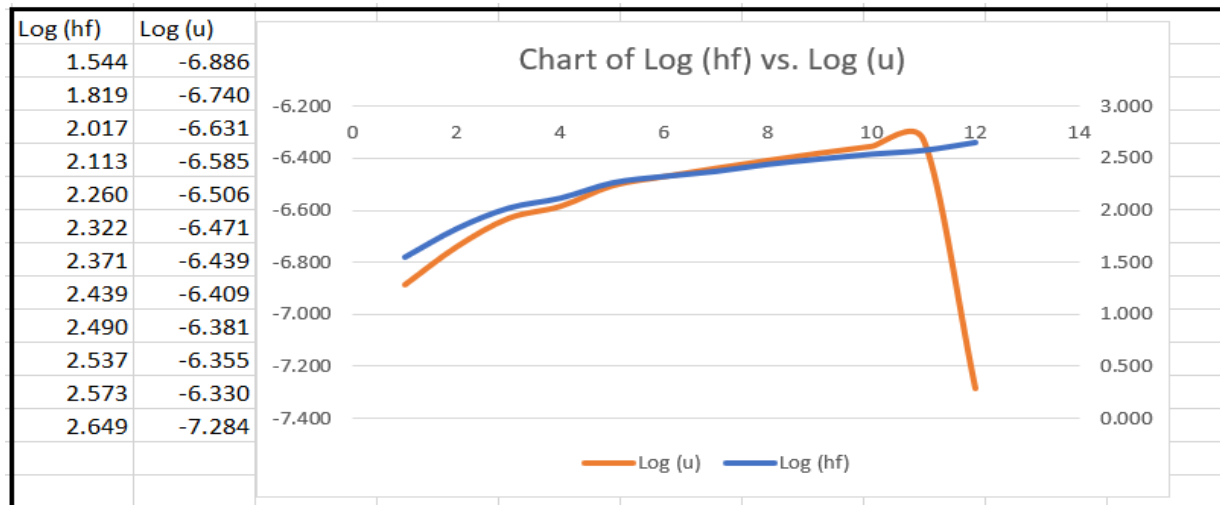
Record Data:

FLOW Q hf (L/hr) H ₂ O)	Pressure 1 (mm H ₂ O)	Pressure 2 (mm H ₂ O)	Height (mm)
1000	285	250	35
1400	338	272	66
1800	396	292	104
2000	436	306	130
2400	510	328	182
2600	544	334	210
2800	580	345	235
3000	625	350	275
3200	665	356	309
3400	704	360	344
3600	736	362	374
4000	810	364	446

Flow Q (L/hr)	Flow Q (m ³ /s)	Velocity u (m/s) e- 04	Height hf (mm H ₂ O)	Log (hf)	Log u	Re
1000	0.017	1.30	35	1.544	-6.886	3333.33
1400	0.023	1.82	66	1.819	-6.740	4666.67
1800	0.030	2.34	104	2.017	-6.631	6000.00
2000	0.033	2.60	130	2.113	-6.585	6666.67
2400	0.040	3.12	182	2.260	-6.506	8000.00
2600	0.043	3.38	210	2.322	-6.471	8666.67

2800	0.047	3.64	235	2.371	-6.439	9333.33
3000	0.050	3.90	275	2.439	-6.409	1000.00
3200	0.053	4.16	309	2.490	-6.381	1066.67
3400	0.057	4.42	344	2.537	-6.355	11333.33
3600	0.060	4.68	374	2.573	-6.330	1200.00
4000	0.067	0.52	446	2.649	-7.284	1333.33

Results:



Experiment 3: Pipe #4 with 6.5mm inside diameter

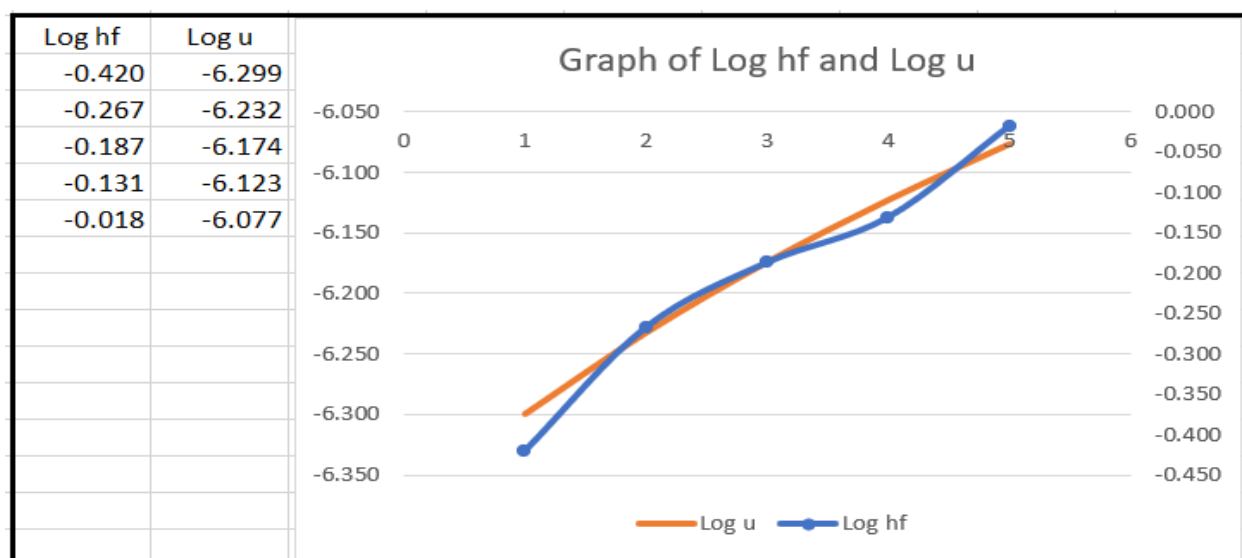
Record Data:

FLOW Q hf (L/hr) H ₂ O)	Pressure 1 (mm H ₂ O)	Pressure 2 (mm H ₂ O)	Height (mm)
600	0.48	0.1	0.38
700	0.66	0.12	0.54
800	0.78	0.13	0.65
900	0.90	0.16	0.74
1000	1.14	0.18	0.96

Flow Q (l/hr)	Flow (m³/s) 04	Q e- 04	Velocity u (m/s) e- 04	Height hf (mm H2O)	Log (hf)	Log u	Re
600	1.67		0.1	0.38	-0.420	-6.299	2184.87
700	1.94		0.1	0.54	-0.267	-6.232	2621.84
800	2.22		0.1	0.65	-0.187	-6.174	2840.32
900	2.50		0.1	0.74	-0.131	-6.123	3277.3

1000	2.78	0.1	0.96	-0.018	-6.077	3714.27
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Result:



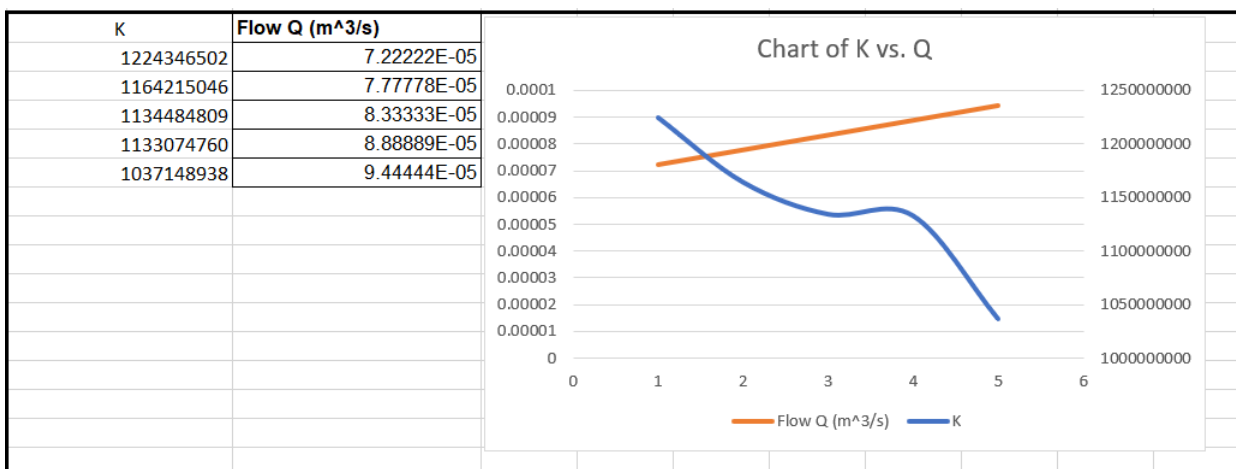
Experiment 4: Pipe #?

Record Data:

FLOW Q hf (L/min) H ₂ O)	Pressure 1 (mm H ₂ O)	Pressure 2 (mm H ₂ O)	Height (mm)
2600	223	116	107
2800	260	142	118
3000	302	170	132
3200	342	192	150
3400	365	210	155

Result:

Flow Q (l/min)	Flow Q (m ³ /s)	Velocity u (m/s) e- 07	Height hf (mm H ₂ O)	Log (hf)	Log u	Re
2600	0.043	1.309	107	2.029	-6.880	
2800	0.047	1.410	118	2.072	-6.851	
3000	0.050	1.511	132	2.121	-6.821	
3200	0.053	1.612	150	2.176	-6.793	
3400	0.057	1.712	155	2.190	-6.766	



CONCLUSION

In each experiment, we calculated variables like pressure drop, Reynold's number, and velocity using varying methods to account for the pipe's roughness and other system constraints. The general trend found was that the smaller the velocity was, the lower Reynold's number became, meaning that the flow was more likely to be laminar. The most interesting trends found were in Experiments 3 & 4, as the pressure drop and viscosity log or the coefficient of singular losses has almost no correlation. The trendlines seemed to correlate up until a certain point in each chart. Experiment 3 happens when the flow changed drastically from turbulent to laminar and back to turbulent. This phenomenon may have meant that the Reynold's number equation used no longer accurately represent the flow. In experiment 4, It is shown that the coefficient of singular losses is not a linear trend but is inherently negative or downward.

REFERENCES

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10. Chem 4011 lab manual
11. Czubai, A., Sopko, N., Patel, A., Ahmari, H., & Kabir, S. (2019, August 14). Experiment #4: Energy Loss in Pipes. Retrieved October 15, 2020, from <https://uta.pressbooks.pub/appliedfluidmechanics/chapter/experiment-4/>

BELOW AVERAGE



Lab #2 Fluid Friction in Pipes

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CHEG 4102 P02 Chemical Engineering Lab II

Group 2

September 29, 2021

Abstract

The goal of this experiment is to determine the relationship between pressure drop due to friction and velocity of the fluid in both smooth and rough pipes with different inner diameters. This experiment was done in a closed system. This enabled us to study the pressure drops in the pipes. We used an AFTC/AFT/AFT-B/AFT-B unit to run our experiment and utilized the first three pipes to conduct this experiment. Energy can be lost due to friction in straight pipes of different sizes and this can be studied on a certain range of Reynold's number. Calculating Reynold's number we can identify if the flow will be laminar or turbulent. After conducting twenty-seven trials, we were able to conclude that because of the roughness in the pipes, the flow of fluid from the beginning of the pipe to the end will be turbulent.

Theory

Osborne Reynolds was the first to demonstrate the distinction between the two types of flow in his classic experiment reported in 1883. A horizontal glass pipe was immersed into a glass-walled tank filled with water. Provisions were made to introduce a filament of dyed water into the stream from the entrance of the tube, and the flow was controlled by a regulating valve located at the outlet of the glass pipe. Reynolds observed and found that the jet of the colored water displayed *laminar flow* at low flow rates. When the flow rate was increased and reached its critical velocity, the water no longer flowed in a laminar motion. At this point, the thread of the colored water became wavy, *transitional*, and eventually spread uniformly throughout the glass tube. Otherwise known as *turbulent flow*.

Thus resulting in the formulation of the Reynolds number equation and the following conclusions on the types of flow:

$$Re = \frac{DV\rho}{\mu} = \frac{DV}{\nu} = \frac{\text{inertial forces}}{\text{viscous forces}}$$

- D : Diameter of pipe/tube
- V : Velocity of fluid
- ρ : Density of fluid
- μ : Dynamic viscosity

- V : Kinematic viscosity

Laminar Flow

- Low velocities
- Small Length scales
- High kinematic viscosities
- $Re < \text{critical } Re (2000)$
- Viscous forces are dominant
- Pressure drop directly proportional to velocity
- $f = \frac{64}{Re}$

Turbulent Flow

- High velocities
- Large length scales
- Low kinematic viscosities
- $Re > \text{critical } Re (2000)$
- Inertial forces are dominant
- Pressure drop directly proportional to square of the velocity
- $f = \frac{.316}{Re^{1/4}}$

Once these values are determined we will be able to calculate our pressure drop due to friction using the *Darcy-Weisbach Law*.

Darcy-Weisbach Law...

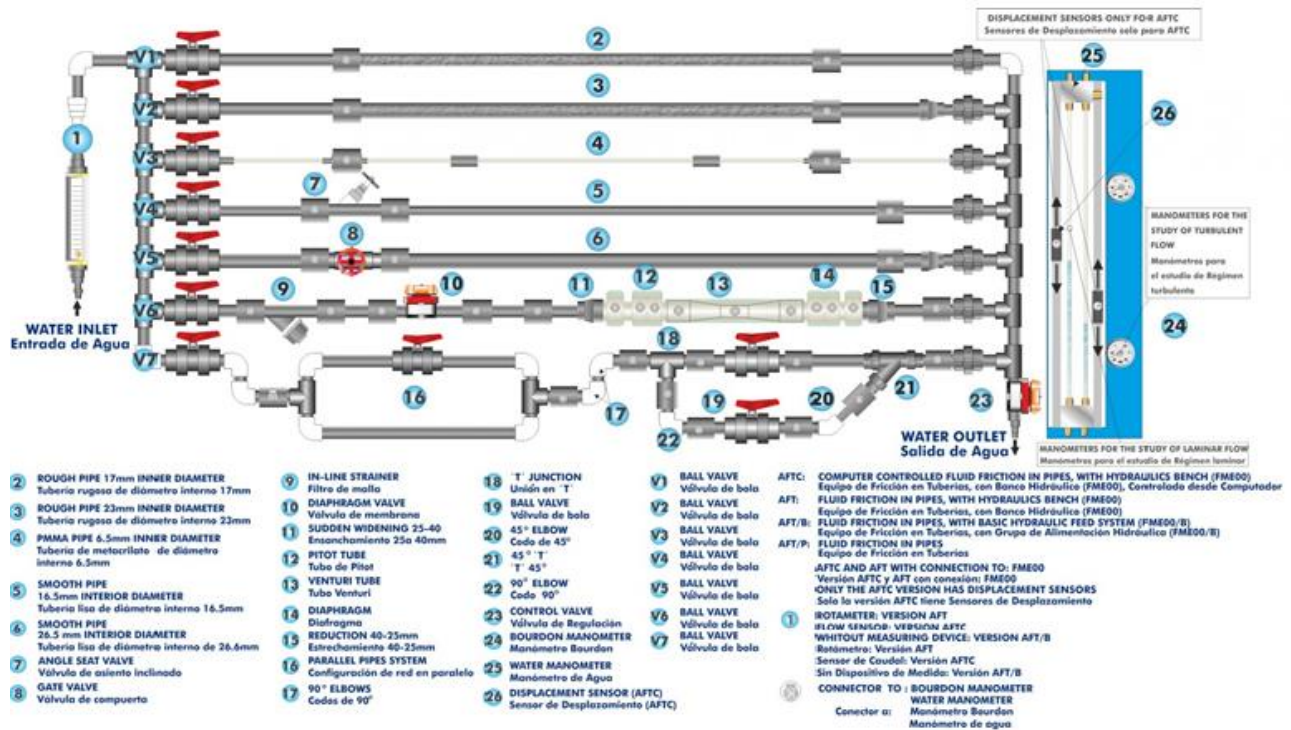
$$h_f / \Delta p = f \frac{L}{D} \times \frac{V^2}{2g} = \frac{8fLQ^2}{gD^5\pi^2}$$

- f : Friction factor
- L : Length
- D : Diameter
- Q : Flow rate
- h_f : The Loss due to friction (head)
- Δp : Loss due to friction

The goal of this experiment is to determine the relationship between pressure drop due to friction and velocity of the fluid in both smooth and rough pipes with different inner diameters. By measuring the pressure drop across the pipes using the manometer and pressure gauge, as detailed in the Procedure, we will use these equations to derive our *Reynolds number*, *friction factor*, and *Darcy-Weisbach Law* (pressure drop). Thus, aiding in providing a quantitative explanation, with practical application, to sharpen our understanding of fluid flow.

Procedures

Step 1: Made sure everything was connected and turned the generator on.



Step 2: Open the valve for the pipe used (V1 for pipe 2, V2 for pipe 3, V3 for pipe 4).

Step 3: Open the valves for the low-pressure gauges.

Step 4: Connect the high-pressure taps to the used pipe.

Step 5: If high pressure couldn't be read, the low-pressure taps were connected.

Step 6: Rotate the flowmeter knob until the desired flow rate is achieved.

Step 7: Record the pressure drop.

Step 8: Record pressure drop for the other 2 flow rates chosen.

Step 9: Repeat for each pipe used.

The variables measured were pressure drop and the length of each pipe. Pressure drop was measured by either the difference of the two high-pressure gauges or low-pressure gauges. The length of each pipe was measured by an app called Measure.

The variable manipulated and measured was volumetric flow rate. The volumetric flow rate was measured by a flowmeter.

Results and Discussion

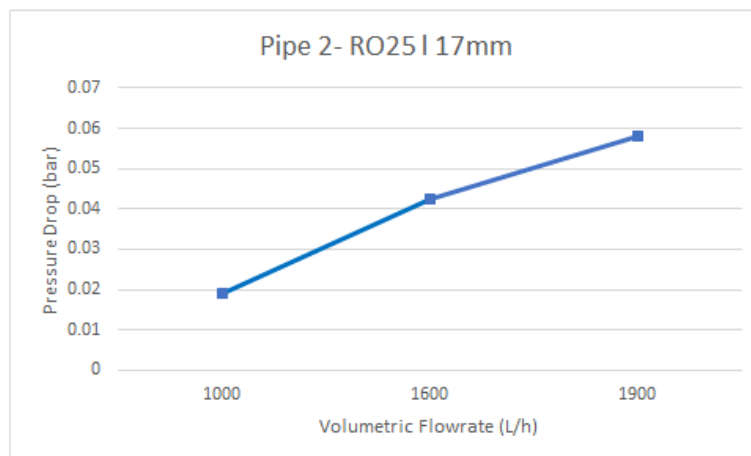


Figure 1: Pressure Drop vs. Volumetric Flow Rate in Pipe 2

Figure 1 depicts the increase in Pressure Drop rate as Volumetric Flow Rate increases in the rough 17mm piping. There is an exponential relationship between the two variables which displays a slight curve in line. The exponential function is on the verge of plateauing if the volumetric flow rate was to be increased.

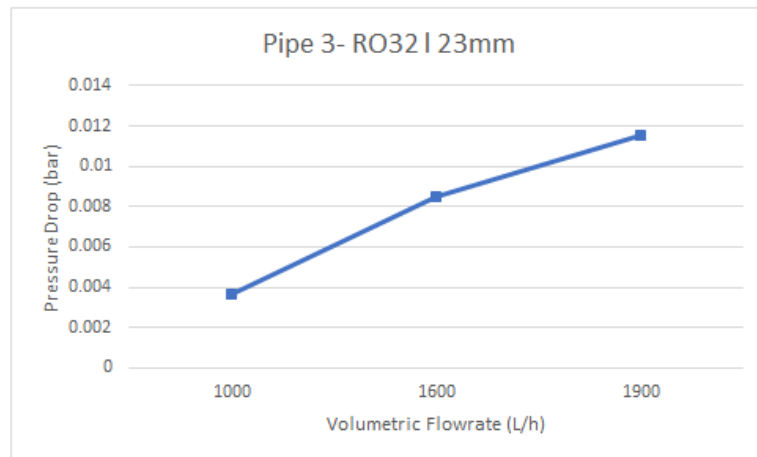


Figure 2: Pressure Drop vs. Volumetric Flow rate in Pipe 3

Figure 2 depicts the increase in Pressure Drop rate as the Volumetric Flow Rate increases in the 23 mm rough piping. There is an exponential relationship between the two variables which displays a slight curve in line. The exponential function is on the verge of plateauing if the volumetric flow rate was to be increased.

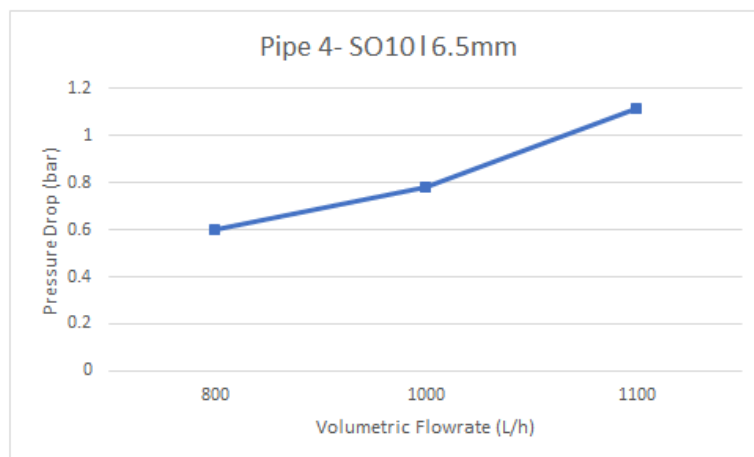


Figure 3: Pressure Drop vs. Volumetric Flow Rate in Pipe 4

Figure 3 depicts the increase in Pressure Drop rate as the Volumetric Flow Rate increases in the smooth narrow 6.5 mm piping. There is an exponential relationship between the two variables which displays a slight curve in the line.

Reynold's number: $Re = \frac{\rho v D}{\mu}$

Volumetric Flow Rate to fluid velocity

$$Q = v \times A$$

Volumetric Flow Rate

$$800 \text{ L/h} = 0.00022 \frac{\text{m}^3}{\text{s}}$$

$$1000 \text{ L/h} = 0.000278 \frac{\text{m}^3}{\text{s}}$$

$$1100 \text{ L/h} = 0.0003056 \frac{\text{m}^3}{\text{s}}$$

$$1600 \text{ L/h} = 0.000444 \frac{\text{m}^3}{\text{s}}$$

$$1900 \text{ L/h} = 0.000528 \frac{\text{m}^3}{\text{s}}$$

Pipe 2- RO25 | 17mm

For 1000 L/h

- $\text{Re} = \frac{1000 \text{ kg/cm}^3 \times 0.306 \text{ m/s} \times 0.017 \text{ m}}{1.002 \times 10^{(-3)} \text{ Ns/m}^2} = 5190$
- $f = \frac{.316}{5190^{1/4}} = 0.037230$

For 1600 L/h

- $\text{Re} = \frac{1000 \text{ kg/cm}^3 \times 0.489 \text{ m/s} \times 0.017 \text{ m}}{1.002 \times 10^{(-3)} \text{ Ns/m}^2} = 8300$
- $f = \frac{.316}{8300^{1/4}} = 0.033107$

For 1900 L/h

- $\text{Re} = \frac{1000 \text{ kg/m}^3 \times 0.5815 \text{ m/s} \times 0.017 \text{ m}}{1.002 \times 10^{(-3)} \text{ Ns/m}^2} = 9870$
- $f = \frac{.316}{9870^{1/4}} = 0.0317035$

Pipe 3- RO32 | 23mm

For 1000 L/h

- $\text{Re} = \frac{1000 \text{ kg/cm}^3 \times 0.167 \text{ m/s} \times 0.023 \text{ m}}{1.002 \times 10^{(-3)} \text{ Ns/m}^2} = 3830$
- $f = \frac{.316}{3830^{1/4}} = 0.040169$

For 1600 L/h

- $\text{Re} = \frac{1000 \text{ kg/cm}^3 \times 0.267 \text{ m/s} \times 0.023 \text{ m}}{1.002 \times 10^{(-3)} \text{ Ns/m}^2} = 6130$

- $f = \frac{.316}{6130^{1/4}} = 0.0357126$

For 1900 L/h

- $Re = \frac{1000 \text{ kg/m}^3 \times 0.3177 \text{ m/s} \times 0.023 \text{ m}}{1.002 \times 10^{(-3)} \text{ Ns/m}^2} = 7290$
- $f = \frac{.316}{7290^{1/4}} = 0.034198$

Pipe 4- SO10 | 17mm

For 1000 L/h

- $Re = \frac{1000 \text{ kg/cm}^3 \times 1.66 \text{ m/s} \times 0.0065 \text{ m}}{1.002 \times 10^{(-3)} \text{ Ns/m}^2} = 10768$
- $f = \frac{.316}{10768^{1/4}} = 0.0310208$

For 1600 L/h

- $Re = \frac{1000 \text{ kg/cm}^3 \times 2.09 \text{ m/s} \times 0.0065 \text{ m}}{1.002 \times 10^{(-3)} \text{ Ns/m}^2} = 13558$
- $f = \frac{.316}{13558^{1/4}} = 0.0292845$

For 1900 L/h

- $Re = \frac{1000 \text{ kg/m}^3 \times 2.30 \text{ m/s} \times 0.0065 \text{ m}}{1.002 \times 10^{(-3)} \text{ Ns/m}^2} = 14920$
- $f = \frac{.316}{14920^{1/4}} = 0.2859$

The results show that the flow through all 3 pipes was turbulent. Pipes 2 and 3 consisted of sand, so turbulent flow was expected. The fourth pipe was smooth and there was the uncertainty of what the flow would be.

During the lab, pipe 2 seemed the roughest and hardest pipe to experiment with, so the fact that it's more turbulent than pipe 3 is unsurprising. The smooth pipe (pipe 4) being much more turbulent than pipes 1 and 2 wasn't expected.

Based on the graphs, all 3 pipes experienced proportional relationships between the volumetric flow rate and pressure drop.

Conclusion

Taking everything into account this experiment was to choose the association between pressure drop in view of grating and speed of the fluid in both smooth and rough pipelines with different estimations. In light of the diagrams, every one of the 3 pipes lines experienced corresponding connections between the volumetric stream rate and pressure drop. By estimating the pressure drop across the pipelines utilizing the manometer and tension check we had the option to decide the connection between pressure drop because of rubbing and speed of the liquid in both smooth and rough pipelines with various inward measurements. After carrying out twenty-seven trials, we were able to conclude that due to the roughness within the inside of the pipes, the flow of fluid from the start of the pipe to the end of the pipe may be turbulent.

**CHEMICAL ENGINEERING LAB. II
FALL 2021**

Title of Assignment: REPORT III

TOPICS COVERED IN REPORT III

Report 3 covers the following topic:

1. Pressure drop in two-phase flows in packed beds.

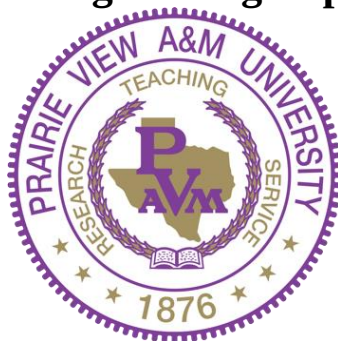
Objective

To determine the pressure drop for several conditions of two phases (gas, liquid) in flow.

To determine the flooding point under the different conditions.

ABOVE AVERAGE

**Prairie View A&M University
Chemical Engineering Department**



**Lab #3: Fluid Flow Across a Packed Column to Measure Pressure Drop
for Two-Phase Flow**

CHEG 4101 —P01 Chemical Engineering Lab II

Tiarra Rodrigues, Shimere Gregory, Doron Montgomery, Reema Matti, Cinthia
Sahin

Due Date: 10/04/2021

Date Conducted: 09/27/2021



Abstract

Gas absorption is a mass transfer operation where component(s) in a gas phase are transferred to the liquid phase when the two phases come in contact with one another. The solubility of the component(s) being transferred is higher in the liquid phase than in the gas phase. This process is commonly used in chemical and petrochemical plants in the design of rectification, absorption, and desorption columns. At the loading point air starts to prevent the liquid from flowing down the column. A dangerous condition known as flooding occurs when the air flow becomes too high, ejecting water from the column, causing the system to operate inefficiently. This experiment was conducted using Edibon CAGC equipment and SAGED, a computer and software system. The goals of this experiment were to: observe pressure drop as a function of varying air flow rates as liquid flow rates are held constant, observe the flooding point, determine the loading point, and compare calculated data with data found in literature. A packed tower with glass Raschig rings is used. They are tubular often having similar lengths and diameters. The void fraction was calculated to be 0.951. Pressure dropped increased as the gas flow rate increases as well as the liquid flow rates, which is consisted with the literature and industry practice. To optimize efficiency, it is necessary to operate as close as possible to flooding.

Theory

Liquid water is pumped to the top of a packed column and is allowed to travel down the column by means of gravity. As the liquid is falling, air is pumped up the column creating a counter-current interaction with the liquid allowing for mass transfer to take place on the packing surface. In order for the air to travel up the column, there needs to be a pressure gradient that moves the air from a high pressure point to a lower pressure point.

For the scope of this experiment, the main goal is to measure the pressure drop for various flow rates of two-phase flows and determine the corresponding loading and flooding points. The pressure drop in a packed-bed column can be evaluated using the equation below:

$$\frac{\Delta P}{H} = \varphi_l \frac{f_w a}{(\varepsilon - h_l)^3} \frac{F_v^2}{2K} \quad (1)$$

Where:

φ_l : Resistance factor

f_w : Wetting factor indicating the percentage of solid area that is covered in liquid

a : Specific particle area defined as the ratio of the surface area of the packing and the volume of the packing

ε : Void fraction in the column defined as the ratio of the packing volume and the volume of the column

h_l : Liquid hold up and is characterized as the ratio of the liquid volume and the volume of the column

F_v : Gas capacity factor defined as the product of the superficial gas velocity and the square-root of the gas density

K : Wall factor and is defined by the following equation:

$$\frac{1}{K} = 1 + \frac{2}{3} \frac{1}{1-\varepsilon} \frac{D_p}{D_c} \quad (2)$$

where D_p is the particle diameter and D_c is the column diameter.

To further simplify the pressure-drop equation, the resistance factor and the wetting factor are combined and obtained from the following set of equations:

$$\varphi_i f_w = C_p f(S) \left(\frac{64}{Re_g} + \frac{1.8}{Re_g^{0.08}} \right) \left(\frac{\varepsilon - h_l}{\varepsilon} \right)^{(3-x)} \quad (8)$$

$$f(S) = \exp \left(\frac{Re_l}{200} \right) \text{ for } x = 1.5 \quad (9)$$

Where:

Re_g : Gas Reynolds Number and is determined by the following equation:

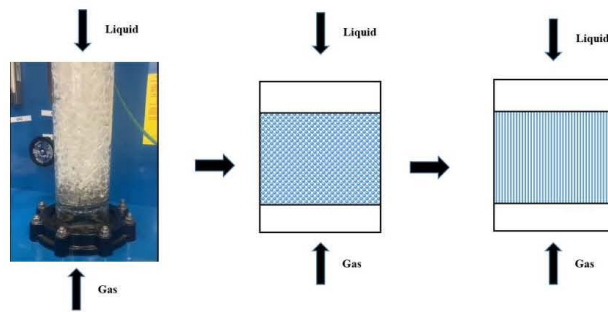
$$Re_g = \frac{u_g}{1-\varepsilon} \frac{D_p}{\mu_g} \quad (10)$$

Re_l : Reynolds Number of the liquid water and is determined by the following equation:

$$Re_l = \frac{u_l}{a} \frac{\rho_l}{\mu_l} \quad (11)$$

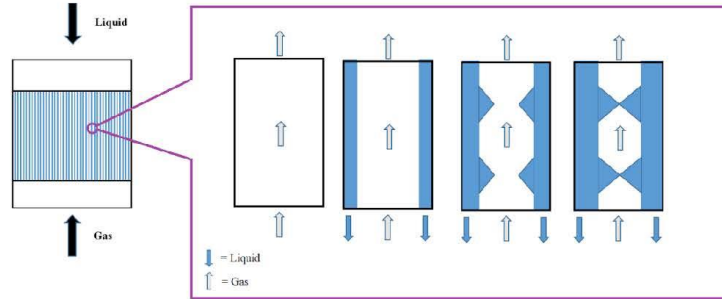
In Figure 1, the image to the left is the real column. The middle image is the real column representation of a packed bed column. The image to the right is the theoretical representation using ideal horizontal capillaries where liquid and gas interface.

Figure 1: Real Column vs Theoretical Column



The image shown below illustrates an increase in interaction between liquid and gas in the theoretical representation.

Figure 2: Gas and Liquid Interaction



The liquid holdup is determined by the following set of equations:

$$h_l = h_{l,s} + (h_{l,fl} - h_{l,s}) \left(\frac{u_g}{u_{g,fl}} \right)^{13} \quad (3)$$

$$h_{l,fl} = 0.3714 * \varepsilon \quad (4)$$

$$h_{l,s} = \left(\frac{12 \mu_l u_l a^2}{g \rho_l} \right)^{\frac{1}{3}} \quad (5)$$

Below the loading point water can travel down the column with minimal interaction with the air, and the system acts under the steady state assumption. Between the loading point and the flooding point air and water interaction begins to have a negative effect on the efficiency of the column. High velocity gas entrains water droplets carrying them back up the packed column and forming pools of liquid within the packing.

The flooding point is an inoperable condition within the column where the liquid velocity becomes zero. At this point the liquid has filled the entire column. The high pressure necessary to move the air will cause damage to the column packing. The flooding point is determined by the following set of equations:

$$u_{g,fl} = \sqrt{\frac{2 g h_{l,fl} \rho_l}{a \varphi_{fl} \rho_g} \frac{(\varepsilon - h_{l,fl})^{3/2}}{\varepsilon^{1/2}}} \quad (6)$$

$$\varphi_{fl} = \frac{g}{c_{fl}^2} \left[\frac{Q_l}{Q_g} \left(\frac{\mu_l}{\mu_g} \right)^{0.2} \sqrt{\frac{\rho_g}{\rho_l}} \right]^{0.4} \quad (7)$$

Where:

$h_{l,s}$: Liquid holdup at the loading point

$h_{l,fl}$: Liquid holdup at the flooding point and occurs when the volume of the liquid is the same as the volume of the column

$u_{g,fl}$: Superficial gas velocity at the flooding point

φ_{fl} : Resistance factor at the flooding point

Q_l and Q_g : Volumetric flow rates of the liquid and the gas, respectively.

When designing a column, it is common to design the gas velocity to be 80% of the flooding velocity, avoiding the inefficiencies associated with flooding while maximizing liquid and gas interaction.

The table below has physical properties associates with the equations presented above. These properties are at standard temperature and pressure.

Table 1: Physical Properties and Constants

Physical Properties	Symbol	Value
Kinematic viscosity of the liquid	μ_l	$8E^{-4} Pa*s$
Kinematic viscosity of the gas	μ_g	$1.87E^{-5} Pa*s$
Dynamic viscosity of the liquid	ν_l	$1E^{-6} \frac{m^2}{s}$
Dynamic viscosity of the gas	ν_g	$1.5E^{-5} \frac{m^2}{s}$
Density of the liquid	ρ_l	$1000 \frac{kg}{m^3}$
Density of the gas	ρ_g	$1.293 \frac{kg}{m^3}$
Specific particle area	a	$112.6 m^{-1}$
Gravitational constant	g	$9.8 \frac{m}{s^2}$
Column diameter	D_c	7.5 mm
Particle diameter	D_p	.0026 mm
Wall factor	K	1.47
Void fraction	ε	0.951
Packing factor	C_p	0.763
Packing factor @ flooding point	C_{fl}	1.547

Procedures

1. The atmospheric pressure (read in a barometer) and the operating temperature of the column (temperature of the water) are measured, in order to correct the gas flow measured in the flowmeters.
2. The air blower is connected (to check that the security valve is open).
3. Open the VR-1 valve and close VR-2.
4. Notice the air flow (read under normal conditions in the corresponding flowmeter, previously calibrated, and set to the operation conditions, atmospheric pressure and temperature) is fixed by means of the VR-1 valve. To write down the fall of pressure read the V-2 manometers on the panel. This is the pressure that the gas suffers when crossing the column.
5. Connect the water pump, after having checked previously that the VR-3 valve is open.
6. Fix the desired value for the water flowrate to a percentage of the max with the VR-3 valve and read from the flowmeter; start low. (**NOTE:** Liquid Flow - Max 75% flow, 2.9 L/min; Min 0% flow, 0 L/min)
7. Allow the system to run for a few minutes to establish a stationary state (pressure variation with the time is not observed).
8. For the fixed liquid flow measure the load losses corresponding to 8 different gas flows and read directly in the flowmeter corresponding to VR-1; start low.
9. Calculate the pressure difference in V-2. First for the top of the column and then for half the column removing their respective tubes and connecting them to VT-1. (**NOTE:** Air Flow - Max 85% flow, 68 L/min; Min 0% flow, 0 L/min)
10. Repeat the points 6 to 9 for five other liquid flow rates.

Materials

- Deionized water
- Funnel
- Beaker or flask
- Catchment containers
- Paper towels

Knowns:

- Column length: 1400 mm
- Column inner diameter (ID): 75 mm
- Packing: Raschig ring supported by a nylon plane

Figure 3: Edison CAGC System Laboratory Setup



Table 2: Important Valves and Sensors

Valve/Sensor	Function
VR-1	Air flow control valve (L/min)
VR-3	Water flow control valve (L/min)
SC-1	Water flow sensor (L/min)
SPD-1	Air flow sensor (L/min)
SPD-3	Pressure measure for entire column (mmH2O)
SPD-4	Pressure measure for lower half of column (mmH2O)

NOTE:

1. Be sure to accurately read the meniscus.
2. Turn control valves slowly to reduce surface tension.
3. Avoid flooding

Results

Figure 5 represents calculated data for the total column pressure drop versus air flow rate. The data is similar to Figure 4, but it attempts to eliminate human error that was experienced in Figure 4 by keeping air flow consistent starting at 10 L/min continuing to 70 L/min, with increments of 10 L/min. Figure 4 is more realistic representation of the pressure drop with air flow rate showing less uniformity than Figure 5. The pressure drop at lower liquid flow rates begins to surpass those at higher flow rates as the air flow rate increases, showing human error.

Figure 4: Total Column Pressure Drop vs. Air Flow Rate

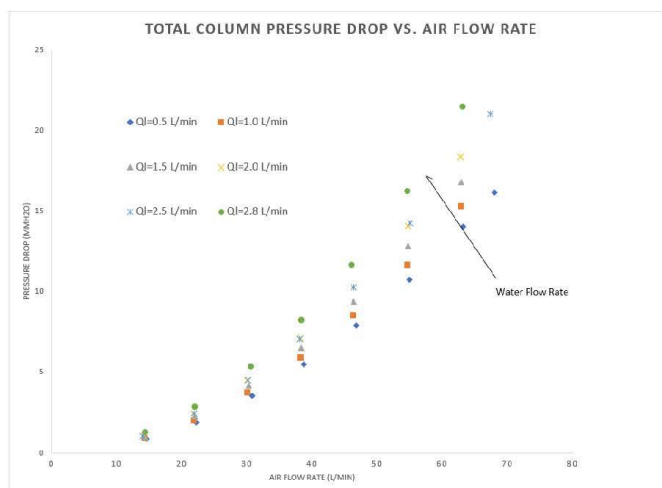
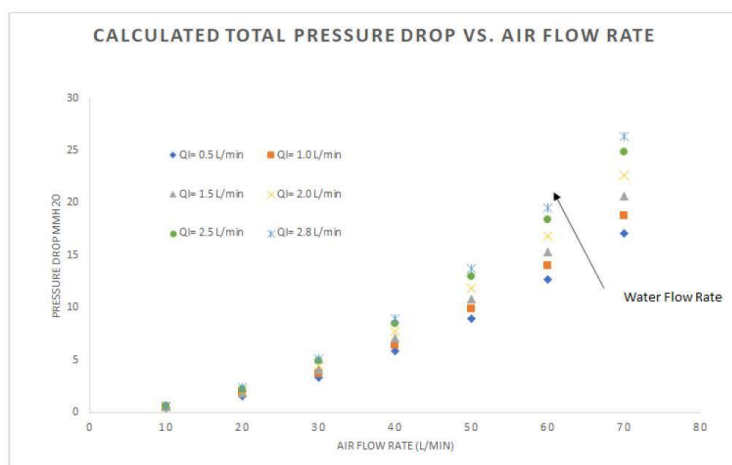


Figure 5: Calculated Total Pressure Drop vs Air Flow



The data in figures 6 and 7 are consistent with figures 5 and 6, but just for half the column. The pressure drop is consistent through the entirety of the column.

Figure 6: Half Column Pressure Drop vs Air Flow Rate

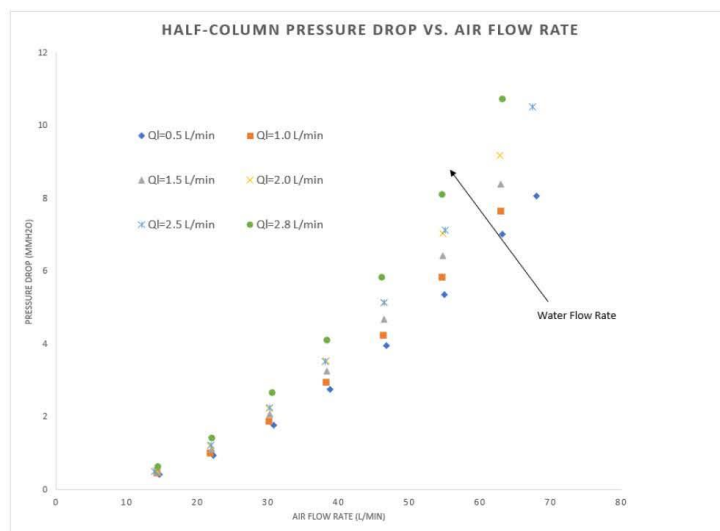
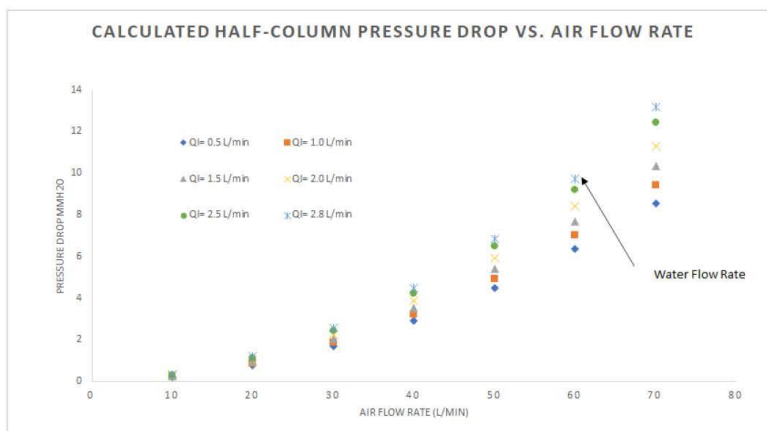


Figure 7: Calculated Half-Column Pressure Drop vs Air Flow



Figures 8 and 9 are similar the figures 5 and 6 but with the data switched. Either was the data is depicted displays similar results.

Figure 8: Total Pressure Drop vs Water Flow Rate

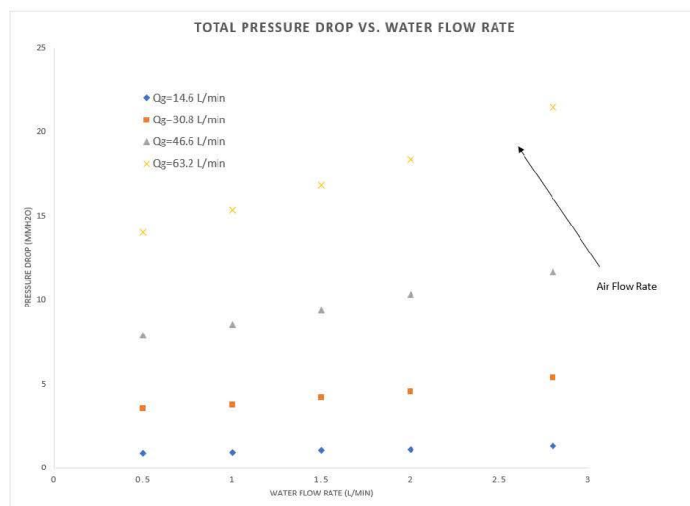


Figure 9: Calculated Total Pressure Drop vs. Water Flow Rate

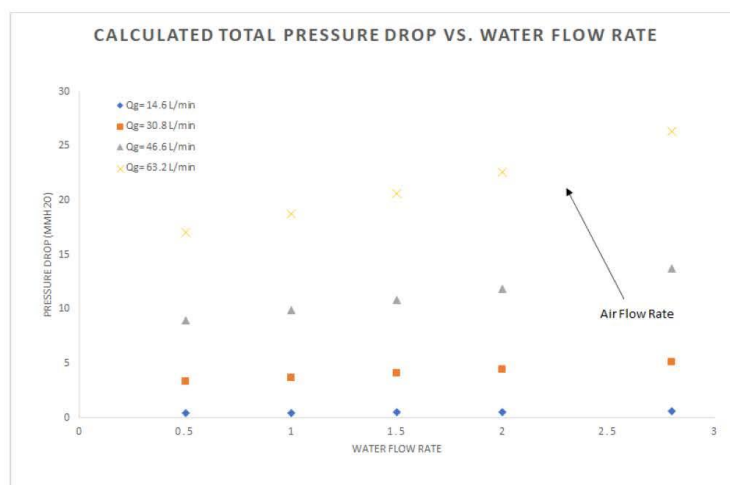
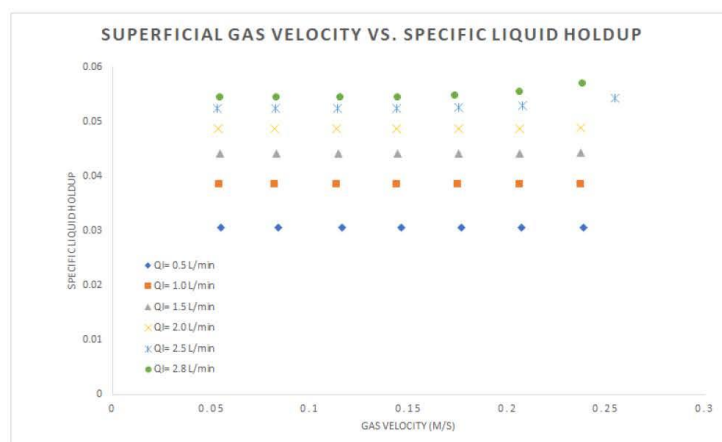


Figure 10 how were the loading point and flooding point begin. At lower liquid flow rates, the loading point and flooding point aren't realized, and the lines remain linear. Deviation from linearity can be seen at the liquid flow rates of 2.5 L/min and 2.8 L/min around the 0.18 m/s superficial gas velocity.

Figure 10: Superficial Gas Velocity vs Specific Liquid Holdup



Discussion

The void fraction in industry for Raschig rings is typically around 0.94; the experiment void fraction is 0.951. This is consistent with industry standards for packed bed columns.

For the experimental data we are able to determine as the air flow and water flow increases, the pressure drop will also increase. The pressure drop will also increase if the air flow rate is kept constant, while increasing the water flow rate. The relationship between a constant water flow rate and an increasing air flow will also yield an increase in the pressure drop.

Figure 10 represents a linear relationship between the liquid and gas, which is preferable when utilizing a packed bed column. Once a deviation occurs, the liquid and gas have more interaction with each other, causing an excess of liquid to accumulate in the packed bed; this is the loading point. An increase in the loading point can potentially cause the liquid to escape from the top of the column, which denotes the flooding point.

The graph showing the Superficial Gas Velocity vs. Specific Liquid Holdup showed a minimal deviation throughout. However, a slight deviation begins to occur at a gas velocity of 0.15 m/s and flow rate of 2.5 L/min. If the experiment continued past the given gas velocity of 0.25 m/s, a loading point and flooding point curve would be visible on the graph.

Conclusion

Gas adsorption is a process commonly used in chemical and petrochemical plants for the design of rectification, absorption, and desorption columns. As we can see from the experiment the calculated and experimental results have minimal differences. The calculations are consistent with literature review and experimental results. Both the calculations and the experimental results show as both the air flow and water flow rates increase; the pressure drop will decrease. They also show with any increase in flow rate, the pressure drop will increase. To operate at optimal efficiency the column should run at a higher percentage of the flooding point, as this is when the gas and liquid have the most contact. With the liquid and gas interaction at a higher rate, the mass transfer has a higher yield. The Edibon CAGC equipment and SAGED in the experiment did not operate at a high efficiency. The optimal relationship between the flow rates and the packed column is at 80% of the flooding point.

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AVERAGE



CHEG 4101- P01

Chemical Engineering Laboratory II

Lab Experiment #3:

Pressure Drop in Packed Bed for Two-Phase Flow

Group #1

Lab Completed: November 1, 2021

Submitted by

Alessia Williams

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Chinenye Ihe

Franck Nangomoko

Taylon Owens

Submitted to

Dr. Jorge Gabitto

Abstract

Absorption assists with the understanding of component behavior under various phases and conditions. Gas-liquid absorption is a practical teaching method of separations which is essential in the daily operations of Chemical Engineers. The goal of this experiment is to measure the pressure drop for several conditions of two phases, gas-liquid flow and to determine the flooding point under different conditions. The CAGC unit by Edibon is used to study hydrodynamic and absorption processes in packed columns. When using this unit, the experimental results show that an increase in flow rate and gas flow results in an increase in pressure drop. This relationship allows an understanding of how two-phase flow phenomena can impact pressure drop which is a critical component in plant productions and determining operating conditions. By conducting this experiment, an understanding of the effects of pressure drop in a packed bed for two-phase flow

is gained.

Theory

The Computer Controlled Gas Absorption Column Unit “CAGC” is a scale unit designed to study the sciences concerning forces acting on or exerted by fluids.¹ It is also used to examine absorption processes in a packed column.¹ Figure 1 displays Edibon CAGC Computer Controlled Gas Absorption Unit used for this experiment.¹



Figure 1. Computer Controlled Gas Absorption Column by Edibon.¹

Gas-liquid absorption processes consist of two phases, gas, and water with a desired goal to extract solutes from the gas phase into the liquid phase.² The experiment consists of two bulk phases of air and water.² The experimental unit is randomly packed with Raschig Rings with a concurrent flow occurring through the column.² Water is flowing downward, while air is flowing upward.² The loading point is determined when gas affects the downflow of the liquid and liquid pools appear in the packing.² The flooding point is determined when the packing is filled with gas and liquid cannot flow down through it.² Flooding pressure drop is determined by the empirical equation developed by Kister and Gill (K2). Equation 1 expresses flooding pressure drop.²

$$\Delta p_{flood} = 0.115 F_p^{0.7} \quad (Eq. 1)$$

Here, the packing factor (F_p) in ft^{-1} is used to calculate the flooding pressure drop (Δp_{flood}). The column in this experiment has an upper limit to the flowrate of gas, the flooding velocity, which restricts the tower from operating.² The relationship between gas flow rate and pressure drops is proportional to the flow rate to power 1.8.²

Procedure

The Edibon CAGC experimental equipment is used to study hydrodynamic, and absorption processed in packed columns.¹ The experiment consists of four experiments with the objective of determining the relation between pressure drop, gas flow and flow rate of two phase, gas-liquid flow. Various sets of values for pressure drop are measured at different flow rates and gas flows during the experiment. After pressure drops are measured, conversion of gas flow percentage to

L/min and flooding pressure drop are done. Next, plots for pressure drop-gas velocity must be completed along with identification of flooding points. A detailed, step by step procedure is listed below.²

1. Correct the gas flow measured in the flowmeters to the atmospheric pressure and operating temperature of the column are measured.
2. Connect air blower.
3. Open the VR-1 valve and close VR-2.
4. Air flow is controlled by VR-1 valve. Write down the fall of pressure that the gas suffers when crossing the column.
5. Record the load losses corresponding to 4 different air flows. This allows the points of the gas flow-fall of pressure graphic to be obtained, corresponding to the dry filling.
6. Check that VR-3 valve is open and connect to the water pump
7. Water flow is controlled/fixed by the VR-3 valve, set to desired value.
8. Stationary state is expected to be reached.
9. Measure the load losses corresponding to 4 different gas flows for each liquid flow fixed.
10. Repeat steps 6 to 9 for three different liquid flows. This obtains the relationships gas flow and pressure drop for these liquid flows.

Results and Discussion

By following the procedure mentioned above, the results below were obtained. The liquid flowrates, in L/min, for experiments 1-4 were .5, 1.1, 1.7, and 2.3. The four different gas flow rates tested in each experiment, in L/min, were 10.4, 26.4, 42.44, and 58.4. These values are represented in Table 1. The calculated flooding pressure drop is 166.7 mmH₂O/m because the packing factor for the Raschig Ring used in the experiment is above 60ft⁻¹. Compared with each experiment, the calculated flooding pressure drop is higher than the one found while conducting the lab.

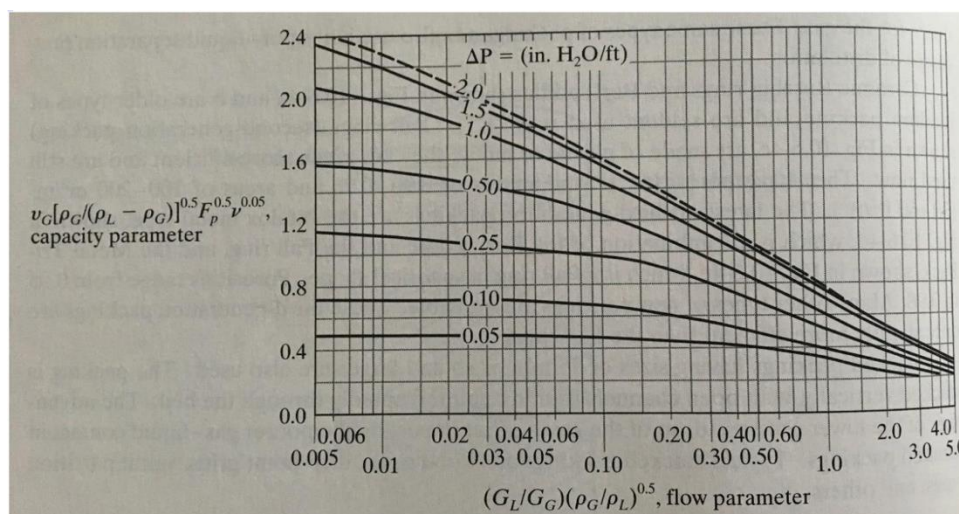


Figure 1. Pressure drop correlation for random packings by Strigle. Data from R.F. Strigle Jr., Random Packings and Packed Towers, © 1987, Houston: Gulf Coast Publishing Company. Using Figure 1, the relationship between the measured pressure drop and the pressure drop using Strigle's equation was observed. When comparing the two, it was found that the measured pressure drops for each experiment were lower than the pressure **drip** using the Strigle equation.

	Liquid Flow Rate L/min	Gas Flow Rate L/min
Experiment 1	.5	10.4
		26.4
		42.4
		58.4
Experiment 2	1.1	10.4
		26.4
		42.4
		58.4
Experiment 3	1.7	10.4
		26.4
		42.4
		58.4
Experiment 4	2.3	10.4
		26.4
		42.4
		58.4

Table 1. Experimental Flow Rates

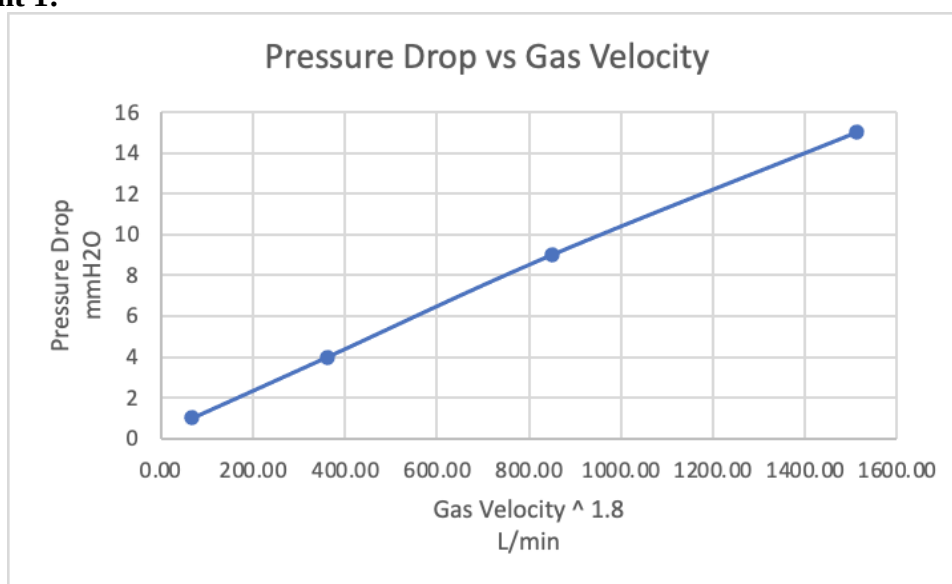
Experiment 1:

Figure 2. Pressure Drop vs Gas Velocity at Water Flow Rate of .5 L/min

By taking the gas flow rate to the exponent of 1.8, the relationship between gas flow rate and pressure drop was observed. As shown in Figure 2, it is verified that as the gas flow rate is increased at low velocities, the pressure drop is proportional to the flow rate to the 1.8 power. Due to the low liquid flow rate of .5L/min, it was determined that the flooding and loading points could not be observed.

Experiment 2:

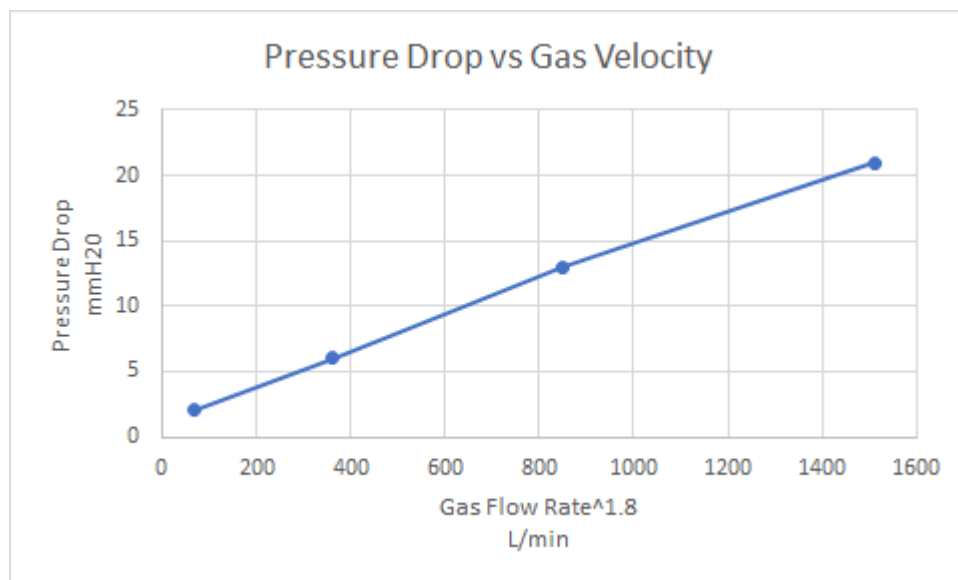


Figure 3. Pressure Drop vs Gas Velocity at a water flow rate of 1.1 L/min

Following the same procedure as experiment 1, the relationship between gas flow rate and pressure drop was determined at a steady liquid flow rate of 1.1 L/min. Figure 3 shows that the gas flow rate raised to the 1.8 power is proportional to the pressure drop. The linear plot shows that an increase in gas flow rate resulted in proportional increases in pressure drop. The liquid flow rate of 1.1 L/min was too low to observe a flooding or loading point.

Experiment 3:

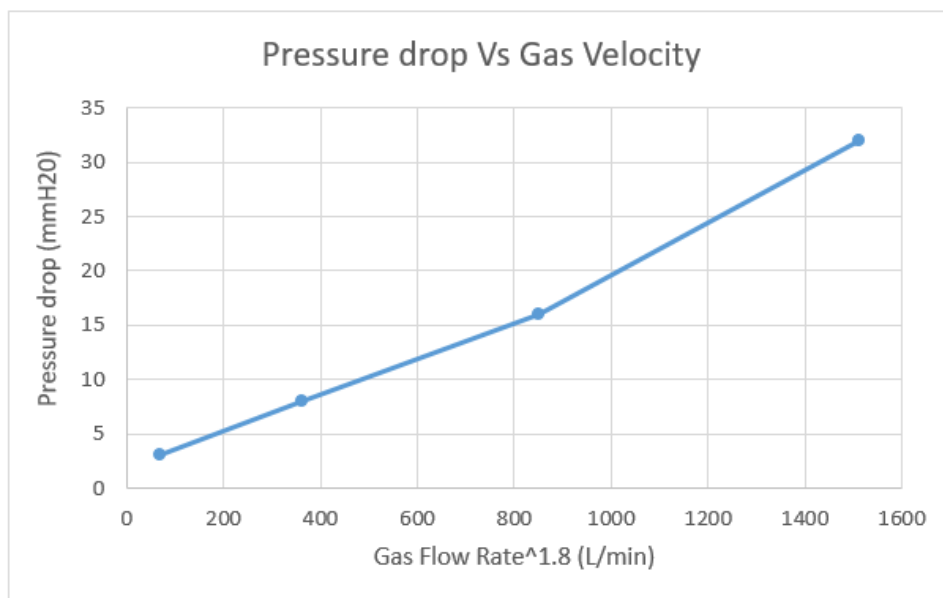


Figure 4. Pressure Drop vs Gas Velocity at a water flow rate of 1.7 L/min

The above graph shows a plot of pressure drop against the Gas velocity raised to 1.8 at a Liquid flow rate of 1.7 L/min. This plot **was achieved** by varying the gas flow rate. From the graph we can see that pressure drop is directly proportional to the gas flow rate raised to 1.8. So, as we increase the gas flow rate at a constant liquid flow rate, the pressure in the column builds up. From the data we obtained from the experiment we found our flooding point to be around a gas flow rate of 58.4 liters per minute. This can be seen as the gas and liquid cannot flow down through the column. In the same way we were able to observe our loading point, the point where the gas starts interfering with the flow of the liquid down the column. The loading point was found to be at a gas flow rate of 30.56 liters per minute.

Experiment 4:

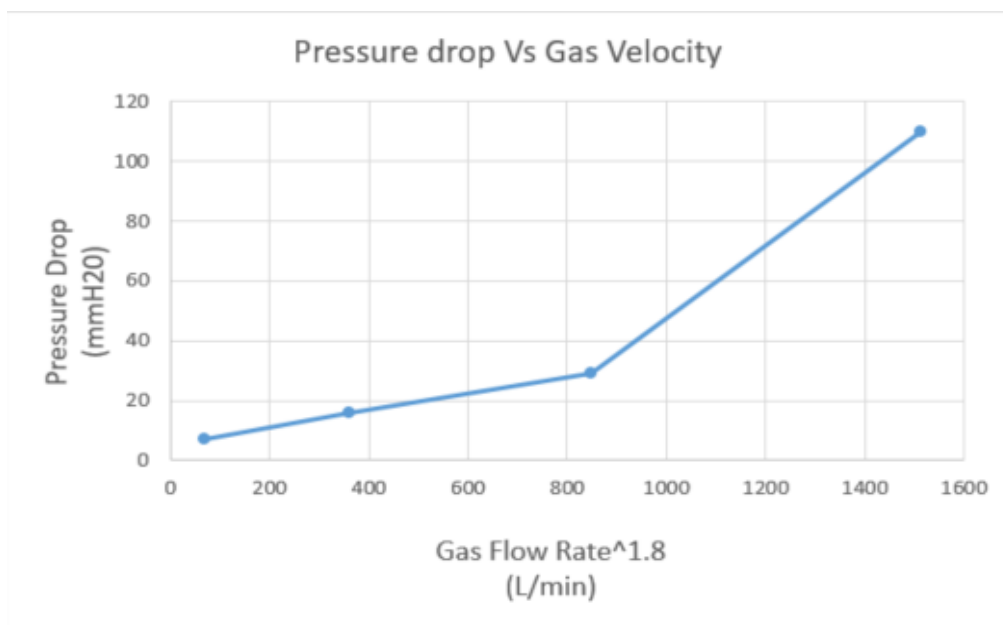


Figure 5. Pressure Drop vs Gas Velocity at a water flow rate of 2.3 L/min

By following the same proceedings from the previous experiments, we can see a similar pattern as the pressure drop increases, the gas flow rate raised to 1.8 increases too. From the graph we have a drastic increase in pressure drop from 35 to 110 mmH₂O. This is due to the high effect of the flooding point at a gas flow rate of 47.37 L/min. We were also able to get calculate our loading point at a gas flow rate of 14.52 L/min. These effects could be seen very noticeable in this experiment due to the large liquid flow rate of 2.3 L/min.

Conclusion

In this lab, pressure drop and flooding in a randomly packed tower were observed. Through the completion of four different experiments, it was concluded that the pressure drop is proportional to the flow rate to the 1.8 power. It was also noted that pressure drop began to rise as the liquid flow rate was increased. The flooding and loading points were also observed for Experiments 3 and 4. As the liquid flow rate increased, the gas velocity at the flooding point decreased. It was concluded that the liquid flow rates in Experiments 1 and 2 were too small to observe any flooding or loading.

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Appendix

Table 2. Flow Rates and Pressure Drop for Experiment 2

Gas Flow Rate	Gas Flow Rate [^] 1.8	Pressure Drop
10.4	67.71	2
26.4	362.15	6
42.4	849.69	13
58.4	1511.97	21

BELOW AVERAGE



CHEG 4101- P01

Chemical Engineering Laboratory II

Lab Experiment #3:

Pressure Drop in Packed Bed for Two-Phase Flow

Group #1

Lab Completed: November 1, 2021

Submitted by

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Here, the packing factor (F_p) in ft^{-1} is used to calculate the flooding pressure drop (Δp_{flood}). The column in this experiment has an upper limit to the flowrate of gas, the flooding velocity, which restricts the tower from operating.² The relationship between gas flow rate and pressure drops is proportional to the flow rate to power 1.8.²

Procedure

The Edibon CAGC experimental equipment is used to study hydrodynamic, and absorption processed in packed columns.¹ The experiment consists of four experiments with the objective of determining the relation between pressure drop, gas flow and flow rate of two phase, gas-liquid flow. Various sets of values for pressure drop are measured at different flow rates and gas flows during the experiment. After pressure drops are measured, conversion of gas flow percentage to L/min and flooding pressure drop are done. Next, plots for pressure drop-gas velocity must be completed along with identification of flooding points. A detailed, step by step procedure is listed below.²

11. Correct the gas flow measured in the flowmeters to the atmospheric pressure and operating temperature of the column are measured.
12. Connect air blower.
13. Open the VR-1 valve and close VR-2.

14. Air flow is controlled by VR-1 valve. Write down the fall of pressure that the gas suffers when crossing the column.
15. Record the load losses corresponding to 4 different air flows. This allows the points of the gas flow-fall of pressure graphic to be obtained, corresponding to the dry filling.
16. Check that VR-3 valve is open and connect to the water pump
17. Water flow is controlled/fixed by the VR-3 valve, set to desired value.
18. Stationary state is expected to be reached.
19. Measure the load losses corresponding to 4 different gas flows for each liquid flow fixed.
20. Repeat steps 6 to 9 for three different liquid flows. This obtains the relationships gas flow and pressure drop for these liquid flows.

Results and Discussion

By following the procedure mentioned above, the results below were obtained. The liquid flowrates, in L/min, for experiments 1-4 were .5, 1.1, 1.7, and 2.3. The four different gas flow rates tested in each experiment, in L/min, were 10.4, 26.4, 42.44, and 58.4. These values are represented in Table 1. The calculated flooding pressure drop is 166.7 mmH₂O/m because the packing factor for the Raschig Ring used in the experiment is above 60ft⁻¹. Compared with each experiment, the calculated flooding pressure drop is higher than the one found while conducting the lab.

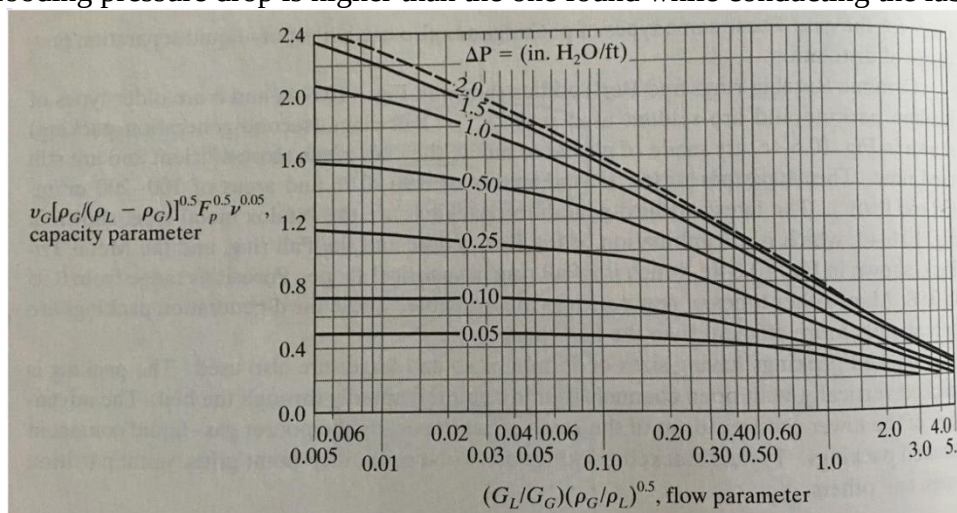


Figure 1. *Pressure drop correlation for random packings by Strigle. Data from R.F. Strigle Jr., Random Packings and Packed Towers, © 1987, Houston: Gulf Coast Publishing Company.* Using Figure 1, the relationship between the measured pressure drop and the pressure drop using Strigle's equation was observed. When comparing the two, it was found that the measured pressure drops for each experiment were lower than the pressure **drip** using the Strigle equation.

	Liquid Flow Rate L/min	Gas Flow Rate L/min
Experiment 1	.5	10.4
		26.4
		42.4
		58.4
Experiment 2	1.1	10.4
		26.4
		42.4
		58.4
Experiment 3	1.7	10.4
		26.4

Experiment 4	2.3	42.4
		58.4
		10.4
		26.4
		42.4
		58.4

Table 1. Experimental Flow Rates

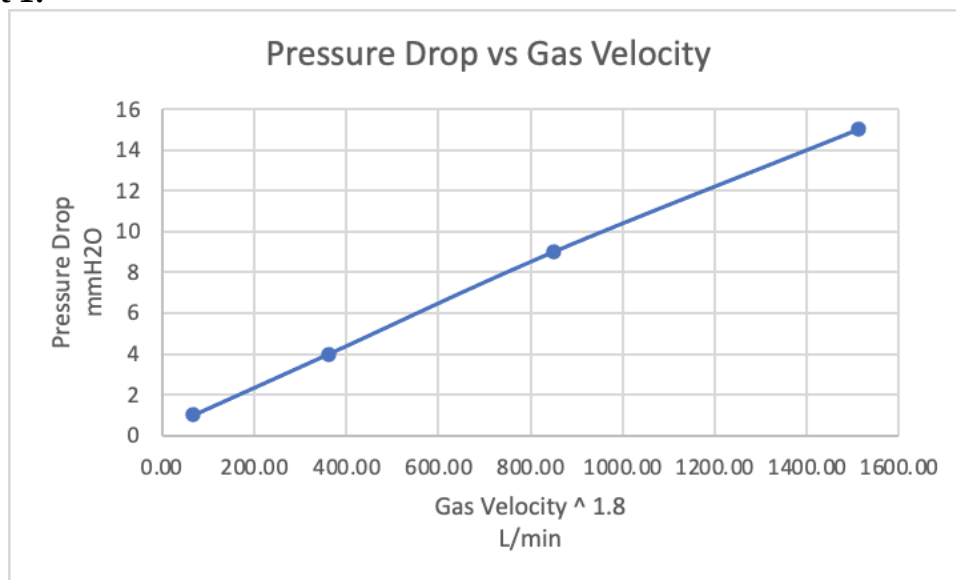
Experiment 1:

Figure 2. Pressure Drop vs Gas Velocity at Water Flow Rate of .5 L/min

By taking the gas flow rate to the exponent of 1.8, the relationship between gas flow rate and pressure drop was observed. As shown in Figure 2, it is verified that as the gas flow rate is increased at low velocities, the pressure drop is proportional to the flow rate to the 1.8 power. Due to the low liquid flow rate of .5L/min, it was determined that the flooding and loading points could not be observed.

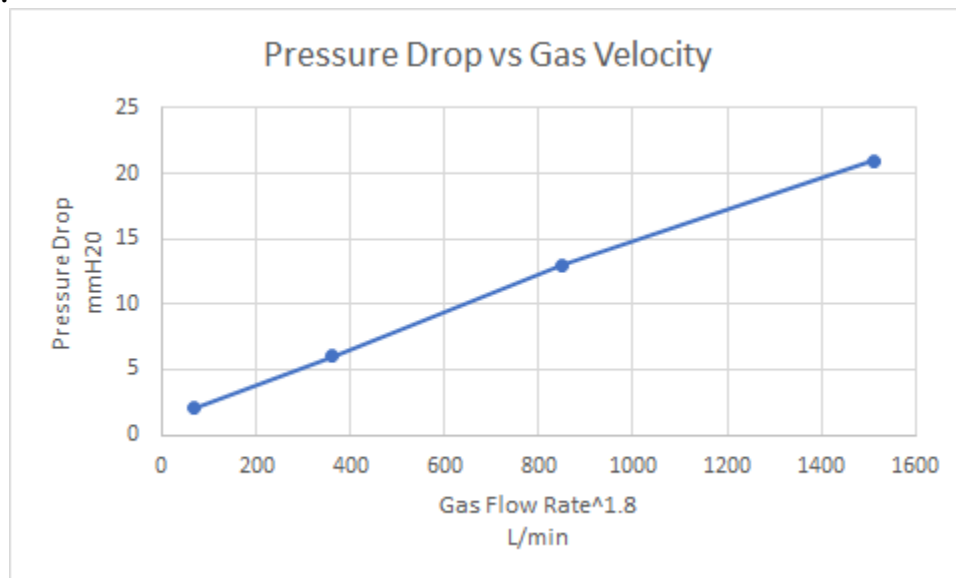
Experiment 2:

Figure 3. Pressure Drop vs Gas Velocity at a water flow rate of 1.1 L/min

Following the same procedure as experiment 1, the relationship between gas flow rate and pressure drop was determined at a steady liquid flow rate of 1.1 L/min. Figure 3 shows that the gas flow rate raised to the 1.8 power is proportional to the pressure drop. The linear plot shows that an increase in gas flow rate resulted in proportional increases in pressure drop. The liquid flow rate of 1.1 L/min was too low to observe a flooding or loading point.

Experiment 3:

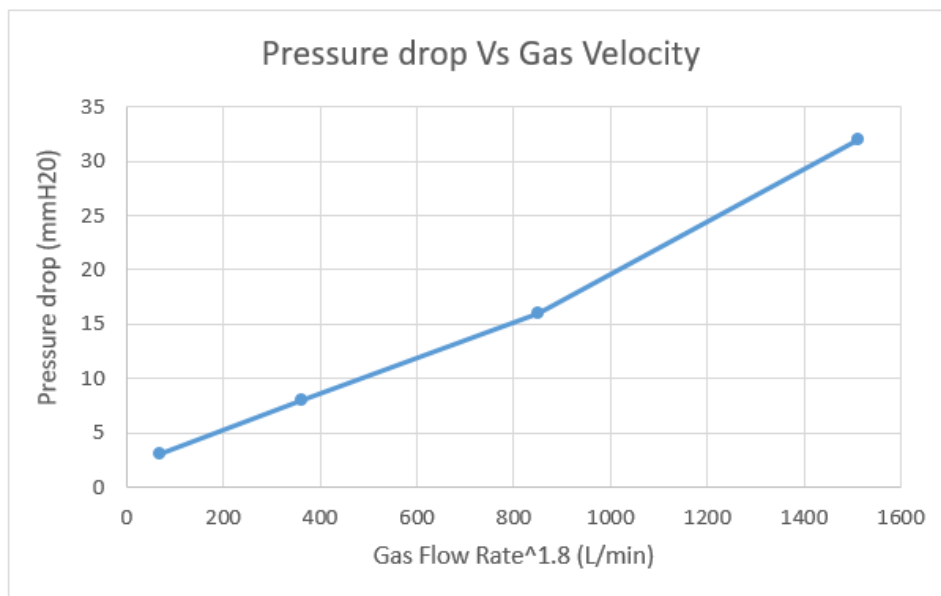


Figure 4. Pressure Drop vs Gas Velocity at a water flow rate of 1.7 L/min

The above graph shows a plot of pressure drop against the Gas velocity raised to 1.8 at a Liquid flow rate of 1.7 L/min. This plot **was achieved** by varying the gas flow rate. From the graph we can see that pressure drop is directly proportional to the gas flow rate raised to 1.8. So, as we increase the gas flow rate at a constant liquid flow rate, the pressure in the column builds up. From the data we obtained from the experiment we found our flooding point to be around a gas flow rate of 58.4 liters per minute. This can be seen as the gas and liquid cannot flow down through the column. In the same way we were able to observe our loading point, the point where the gas starts interfering with the flow of the liquid down the column. The loading point was found to be at a gas flow rate of 30.56 liters per minute.

Experiment 4:

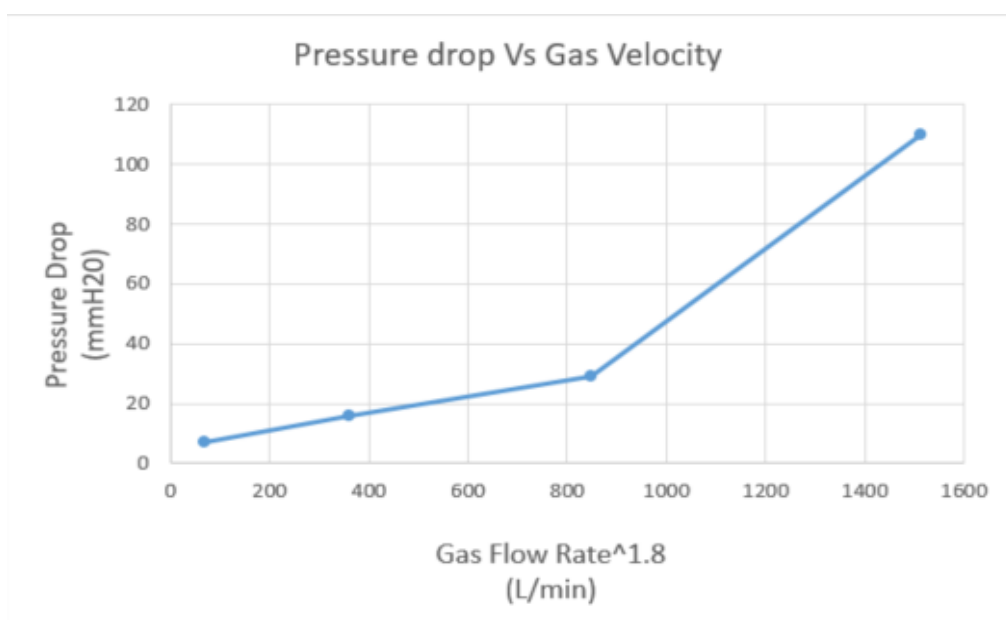


Figure 5. Pressure Drop vs Gas Velocity at a water flow rate of 2.3 L/min

By following the same proceedings from the previous experiments, we can see a similar pattern as the pressure drop

increases, the gas flow rate raised to 1.8 increases too. From the graph we have a drastic increase in pressure drop from 35 to 110 mmH₂O. This is due to the high effect of the flooding point at a gas flow rate of 47.37 L/min. We were also able to get calculate our loading point at a gas flow rate of 14.52 L/min. These effects could be seen very noticeable in this experiment due to the large liquid flow rate of 2.3 L/min.

Conclusion

In this lab, pressure drop and flooding in a randomly packed tower were observed. Through the completion of four different experiments, it was concluded that the pressure drop is proportional to the flow rate to the 1.8 power. It was also noted that pressure drop began to rise as the liquid flow rate was increased. The flooding and loading points were also observed for Experiments 3 and 4. As the liquid flow rate increased, the gas velocity at the flooding point decreased. It was concluded that the liquid flow rates in Experiments 1 and 2 were too small to observe any flooding or loading.

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Appendix

Table 2. Flow Rates and Pressure Drop for Experiment 2

Gas Flow Rate	Gas Flow Rate $\wedge$ 1.8	Pressure Drop
10.4	67.71	2
26.4	362.15	6
42.4	849.69	13
58.4	1511.97	21

**CHEMICAL ENGINEERING LAB. II
FALL 2021**

Title of Assignment: LAB. IV REPORT

TOPICS COVERED IN LAB. IV REPORT

Report IV covered the following topic: Centrifugal pump (Expt. No. 4)

Objectives:

- To obtain head, power and efficiency graphs for a centrifugal pump.
- Determine the maximum efficiency and the flow rate at which this occurs.
- Compare the operation of two centrifugal pumps connected in series and in parallel.
- Compare the curves you obtain with those shown in literature.

ABOVE AVERAGE



**Chemical Engineering
CHEG 4101-P01, 5:00
p.m.**

**Alexus Lovelace, Ebonie Henderson , Cherish Vaughn, Irene Atatah, and Duaa
Abadri**

November 17th, 2021

To

Dr. Jorge F. Gabitto

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ABSTRACT

Centrifugal pumps are very popular and commonly used type of pump for the transfer of fluid and to amplify the delivery pressure. Indeed, the following experiment is based on the transfer of water from a reservoir using a centrifugal pump. The experimental unit provides the determination of the characteristic behavior for single operation and interaction of two pumps. Here, an FM51 Series and Parallel Pump unit is set up appropriately alongside an Armfield interface device to capture different needed valuable readings that will serve to plot the graph. The apparatus consists of a tank and pipework which delivers water to and from two identical centrifugal pumps. Assuming a pump setting of 80% is specified in the software and pump 2 is selected as the desired pump for the experiment. The flow rate is adjusted by changing only the discharge valve. Gate valve and inlet and gate valve and the discharge all completely open. Results are recorded in set of 3 until the valve is completely close.

THEORY

A pump is a mechanical device used to move gases, liquids, or slurries. A pump moves liquids or gases from a lower pressure to a higher pressure and is responsible for this pressure difference. There are two types of pumps: positive displacement and dynamic. Like the one utilized in this experiment, the Dynamic pump uses rotational energy to transport fluids. To be specific, a centrifugal pump is the type of dynamic pump used.

The total pressure head is used in the industry to determine the suction a pump can provide regardless of the suction conditions. The head measures the level or vertical height at which a fluid reaches. Below are the mathematical expressions for the total head, which are evaluated throughout the experiment.

$$H_T = P/(\rho * g) + z + v^2/(2*g)$$

Thus,

$$\Delta H_T = \Delta H_s + \Delta H_v + \Delta z$$

Where,

H_T represents the total pressure head

$v^2/(2*g)$ represents the kinetic term

PURPOSE

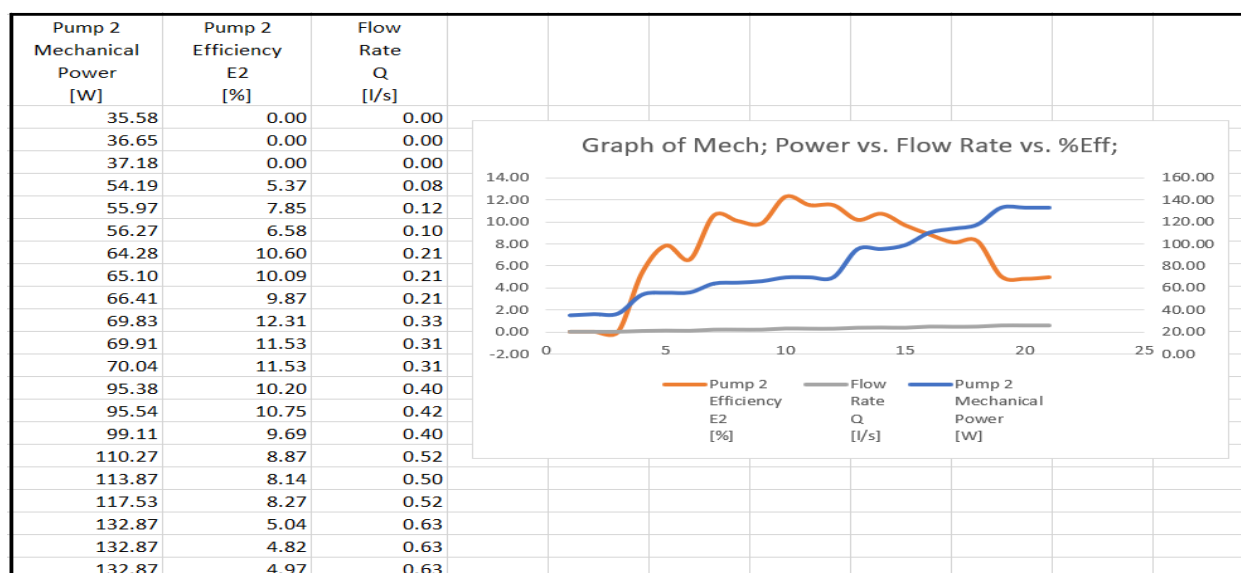
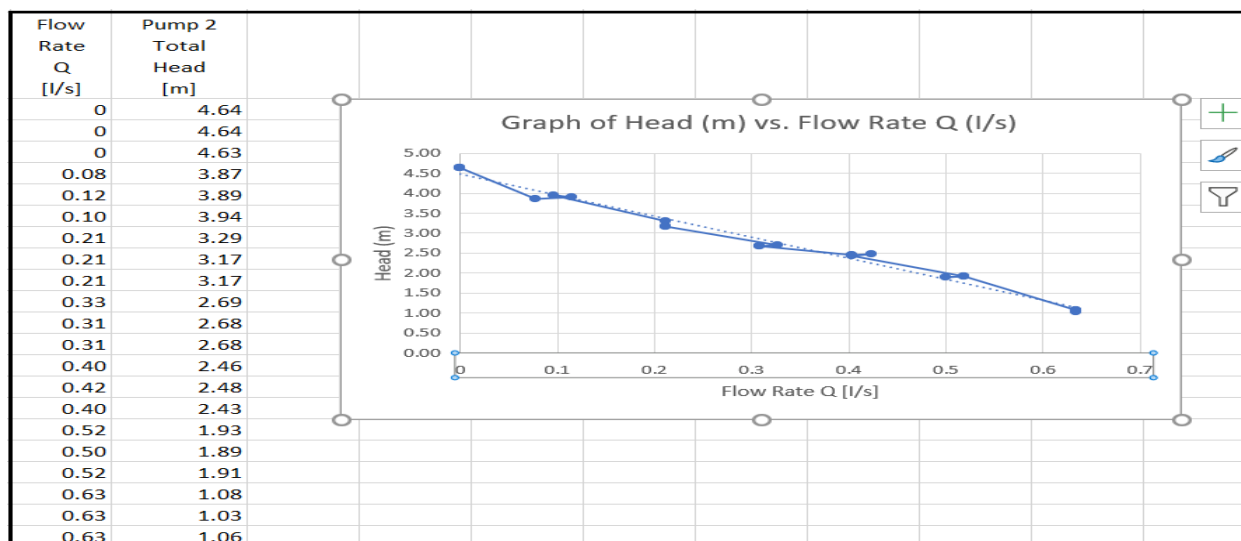
The goal of this experiment is to demonstrate measurements obtained during a in a single pump experiment, while scrutinizing the results on discharge and total head of operating pumps in series.

PROCEDURE

Utilizing the FM51 Series and Parallel Pumps, the inlet valve was completely opened. Pump 2 was turned on from the computer control. The pump 2 out valve was placed into the open position. Placed at a particular position, a three-way valve created suction to eliminate any backflow into the first pump. The pump 1 out valve was placed in the closed position. The inlet valve controlled the flow into pump 2. The discharge from pump 2 flowed through the outlet valve, which controls the discharge. The flow rate was adjusted by controlling the discharge valve. The outlet valve was completely opened for the experiment. Using the computer console, a table was prepared to where the data was automatically recorded, by pressing the go key. It was advised to press the go key three times for each measurement. The outlet valve was closed one full rotation, and the data was recorded using the go key. This procedure was repeated until the outlet valve was fully closed. The flow was measured using a flow sensor, connected to the outlet valve. The pressure was measured by a pressure sensor located behind pump 2. Another sensor, called the flow sensor was placed at the suction valve. The head of the pump can be calculated as the pressure in the discharge minus pressure in the suction, divide by the density the fluid, and divided by the acceleration of gravity.

RESULTS

To overcome a large system that one pump can handle, centrifugal pumps in series are used but when an identical centrifugal pump in series are used, the head will be doubled. That is while at the same flow rate, the head will be twice the head of that of a single pump.



From the graph above, it shows a relatively low pressure increase in a fluid. This “Head vs. Flow Rate” graph show that it starts constantly while it is open at 16.7% and remains slightly constant at 83.3% which shows a rise in both the flow rate and total rate.

The maximum efficiency for the power and efficiency vs. flowrate as seen on the graph is 10.60% which is occurring at 0.21 l/s. So, as the power decreases, the flow rate remains constant and efficiency fluctuates as the flow rate increases.

CONCLUSIONS

In conclusion, the expected results were met. The maximum efficiency and the flow rate at which it occurs were determined. When the outlet valve, which controlled the flow, was opened, the

water temperature decreased slightly. Both the inlet pressure and the pump 2 pressure increased. The flow rate (Q) decreased. The water density increased, as well as the pump 2 total head, and the pump 2 mechanical power, as the flow rate decreased. However, the pump 2 hydraulic power decreased. The pump 2 efficiency increased to a point and then started to decrease.

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AVERAGE

Prairie View A&M University
Roy G. Perry College of Engineering
Department: Chemical Engineering



CHEG 4101- P01
Chemical Engineering Laboratory II
Lab Experiment #4:
Centrifugal Pump Experiment
Group #1
Lab Completed: November 15, 2021

Submitted by
Alessia Williams
Amiya Rogers
Chinenye Ihe
Franck Nangomoko
Taylon Owens

Submitted to
Dr. Jorge Gabitto

Abstract

Characteristic curves assist with the understanding of the performance in a centrifugal pump. Characteristic curves are a graphical method used to determine the relation between flow rate and pressure in a centrifugal pump which is essential in the daily operations of Mechanical, Civil, and Chemical Engineers. The goal of this experiment is to investigate the characteristic curves for a single centrifugal pump and compare the behavior of 2 centrifugal pumps in parallel against two in series. The TecQuipment Two-Stage Series and

Parallel Pumps – H83 is used to find the characteristics of centrifugal pumps working alone or in series or parallel. When using this unit, the experimental results show that as flowrate increased, total head decreased and as flowrate increased, power increased. This relationship allows an understanding of how pump characteristics can give essential information which is critical in determining the operating regions of a pump and increasing pump life. By conducting this experiment, an understanding of the effects of characteristics in centrifugal pump is gained.

Theory

The objective for this lab was to obtain head, power, and efficiency graphs for a centrifugal pump. We also must determine the maximum efficiency and flow rate at which this occurs, then compare the curves we've obtained with those shown in Figure 1. In plants there are many types of pumping machinery, but the most common are centrifugal pumps. These pumps use centrifugal or rotational energy to move fluids. They are used to increase the mechanical energy of liquids. From the given lab manual, we are told that the operating characteristics of a centrifugal pump may be described using graphs of the pump performance. We looked at how centrifugal pumps ran first singularly, and then ran another pump in series and finally in parallel. Figures 2,3, and 4 show the theoretical flow diagrams for each pump test. There are also three most used graphical representations of pump performance: change in total head produced by the pump (H_t), power input to the pump (P_m), and pump efficiency (E). The following portion will show the equations given for change in total head pressure, power input, and pump efficiency, which were utilized within the experiment that are later discussed further in this report.

Total Head

We know that the change in total head produced as a result of the work done by the pump is calculated using equation one:

Equation 1:

$H_t = \text{change in static head } (H_s) + \text{change in velocity head } (H_v) + \text{change in elevation } (H_e)$

1.1 $H_s = \text{change in static head} = (P_{out} - P_{in})/pg$

where,

P_{out} = fluid pressure at outlet in Pa

P_{in} = fluid pressure at inlet in Pa

1.2 $H_v = \text{change in velocity head} = (V_{out} - V_{in})^2/2g$

where,

V_{in} = fluid velocity at inlet in m/s

V_{out} = fluid velocity at outlet in m/s

H_e = change in elevation = vertical distance between inlet and outlet

1.3 $H_{t \text{ series}} = H_1 + H_2$

1.4 $H_{t \text{ parallel}} = H_1 = H_2$

Power Input

The mechanical power input to the pump can be calculated using equation two:

Equation 2:

$P_m = \text{rotational force} \times \text{angular distance} = 2\pi nt$

where,

n = rotational speed of pump in revolutions per second

t = shaft torque in N.m

Pump Efficiency

The efficiency of the pump can be calculated using equation three:

Equation 3:

$$E = 100 \times P_h / P_m$$

where,

3.1 P_h = hydraulic power imparted to fluid = $H_t Q \rho g$

where,

Q = volume flow rate in m^3/s

P_m = mechanical power absorbed by pump = $2\pi n \tau$

Equation 4:

$$Q_{\text{Tseries}} = Q_1 = Q_2$$

$$Q_{\text{Tparallel}} = Q_1 + Q_2$$

4.1 Parallel Pumps:

$Q \approx 2Q_{\text{single}}$ at constant Head

4.2 Series Pumps:

$H_T \approx 2H_{\text{Tsingle}}$ at constant Flow

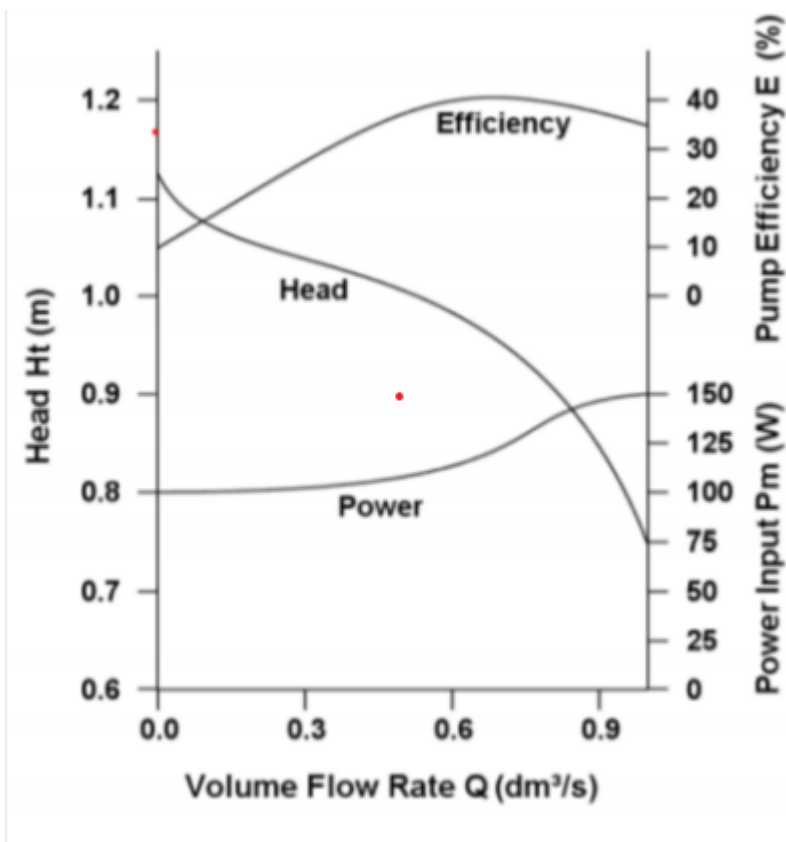


Figure 1. Used to compare our curves from the experiment

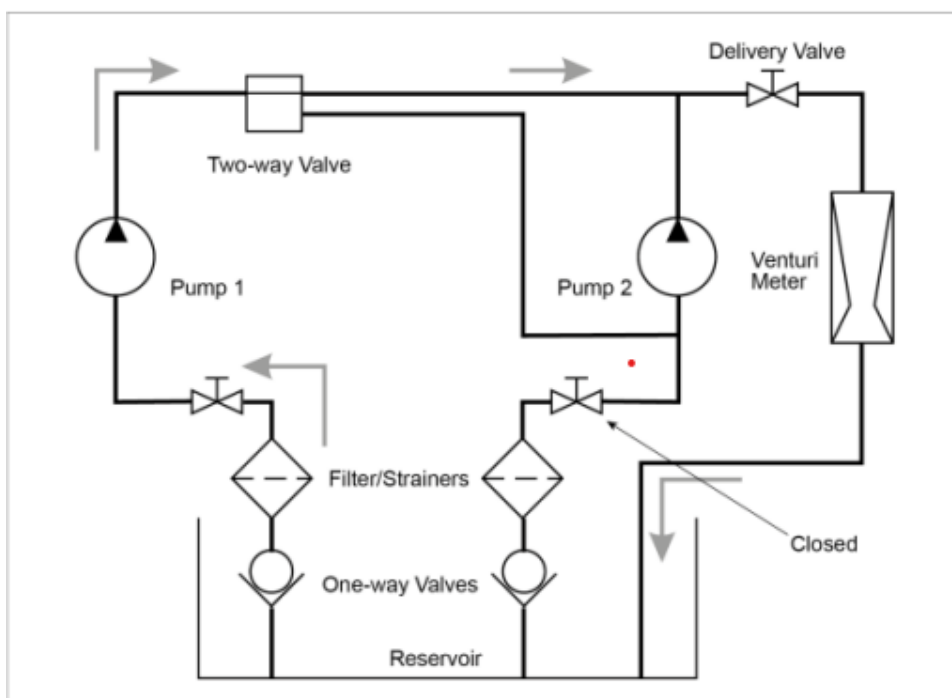


Figure 2. Flow diagram for a single pump test

Ideally, a single stage centrifugal pump has a single impeller. They are excellent for applications with high flow rates and low-pressure purposes. Single-stage pumps are usually used in pumping services like high-flow and total dynamic head (TDH) from low to moderate ranges.

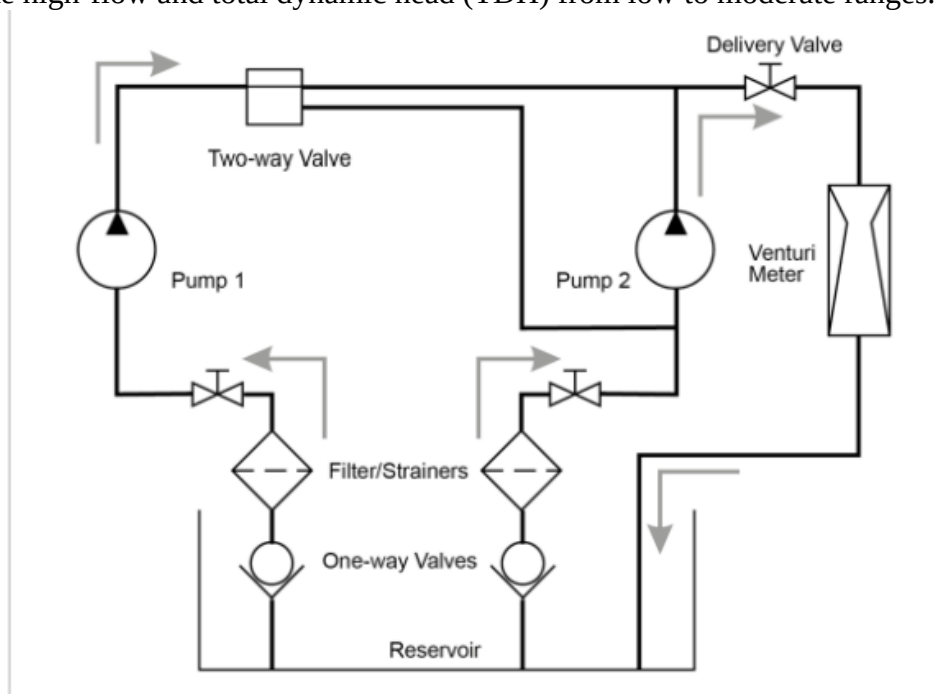


Figure 3. Flow diagram for a parallel pump test

The parallel stage pumps have two impellers working side by side. They are used generally for middle-head applications. When two or more pumps are arranged in parallel their resulting performance curve is obtained by adding the pumps flow rates at the same head. Centrifugal pumps in parallel are used to overcome larger volume flows that one pump can handle alone. For

two identical pumps in parallel and the head kept constant – the flow rate doubles compared to that of a single pump.

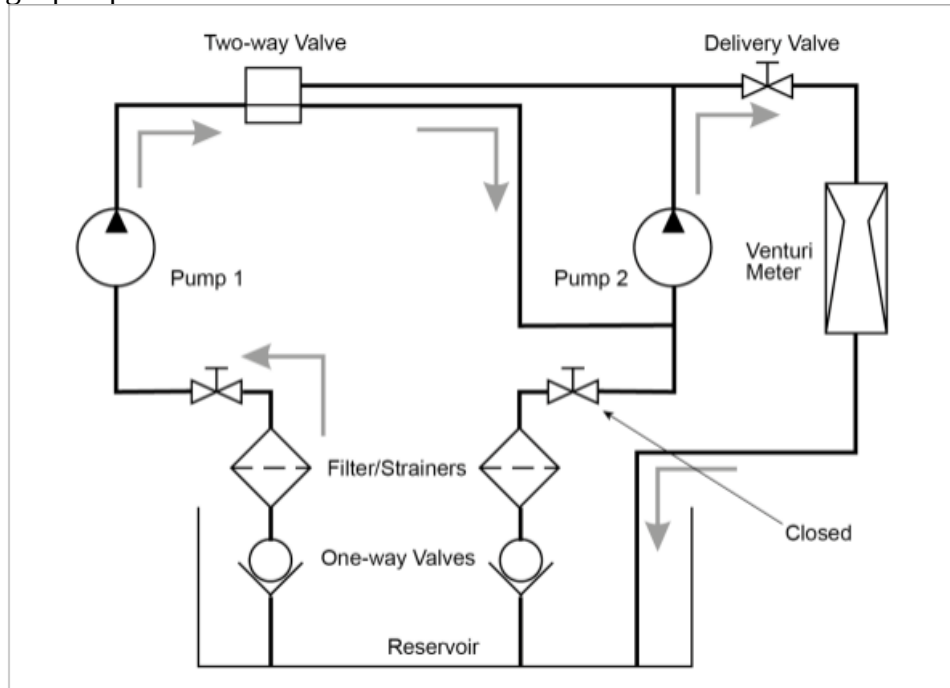


Figure 4. Flow diagram for a series pump test

These pumps are designed with two or three impellers connected in series. They are used in high-head services. When two (or more) pumps are arranged in series their resulting pump performance curve is obtained by adding their heads at the same flow rate. Centrifugal pumps in series are used to overcome larger system head loss than one pump can handle alone. For two identical pumps in series the head will be twice the head of a single pump at the same flow rate.

Procedure

The TecQuipment Two-Stage Series and Parallel Pumps – H83 is used to find the characteristics of centrifugal pumps working alone or in series or parallel. The experiment consists of three experiments with the objective of investigating the characteristic curves for a single centrifugal pump and comparing the behavior of 2 centrifugal pumps in parallel against two in series. Various sets of values for flow, power, and efficiency are measured during the experiment. After flow, power and efficiency are measured, characteristic curves for pressure must be completed. A detailed, step by step procedure is listed below.¹

1. Use the bleed line to bleed all pressure gauges.
2. Turn on the equipment.

Series Pumps

1. Create a blank results table by clicking on the icon with the pencil
2. Use both pumps for series configuration. Switch off both motor drive isolators.
3. Open Pump 1 inlet valve. Close Pump 2 inlet valve. Set the two-way valve to direct flow straight to the inlet of Pump 2. Fully open the delivery valve.

¹ *1 TQ H83 Two-Stage Centrifugal Pump Characteristics Lab Manual. CHEG 4011. Prairie View A&M University, n.d. Accessed November 15, 2021.*

4. Switch on both Motor Drive isolators. Start the pump motors and run them to below maximum speed
5. Adjust the motor speed for pumps 1 and 2 by turning the black dial on each pump console to the speed required for the experiment. Record readings for pressure and flow for various dial settings. Make sure to take 3 replicates for each pump dial setting by clicking on the acquire data button 3 times. Try to record data for the pumps having the same rpms.

Parallel Pumps

1. Create a blank results table by clicking on the icon with the pencil.
2. Use both pumps for parallel configuration. Switch off both motor drive isolators.
3. Open both inlet valves and set the two-way valve to direct flow straight to the delivery pipe. Fully open the delivery valve.
4. Switch on both motor drive isolators. Start the pump motors and run them to below maximum speed.
5. Adjust the motor speed for pumps 1 and 2 by turning the black dial on each pump console to the speed required for the experiment. Record readings for pressure and flow for various dial settings. Make sure to take 3 replicates for each pump dial setting by clicking on the acquire data button 3 times. Try to record data for the pumps having the same rpms.

Single Pump

1. Create a blank results table by clicking on the icon with the pencil.
2. Take readings using the VDAS on Pump 1 only.
3. Switch off both motor pump isolators.
4. Close pump 2 inlet valve and set the 2-way valve to direct flow straight to the delivery pipe. Fully open pump 1 inlet and the delivery valve.
5. Start the pump motor and run it to below maximum speed.
6. Adjust the motor speed for pump 1 by turning the black dial to the speed required for the experiment. Record readings for pressure and flow for various dial settings. Make sure to take 3 replicates for each pump dial setting by clicking on the acquire data button 3 times.

Results & Discussion

In the experiment, data was collected for pumps in series and parallel and a single pump setup. The following figures compare the results of the experiment with Figure 1. The common trends with all the graphs are that as flowrate increased, total head decreased and as flowrate increased, power increased. Moreover, the maximum efficiency of the pumps is identified for each pump configuration with the highest efficiency coming from the series operation.

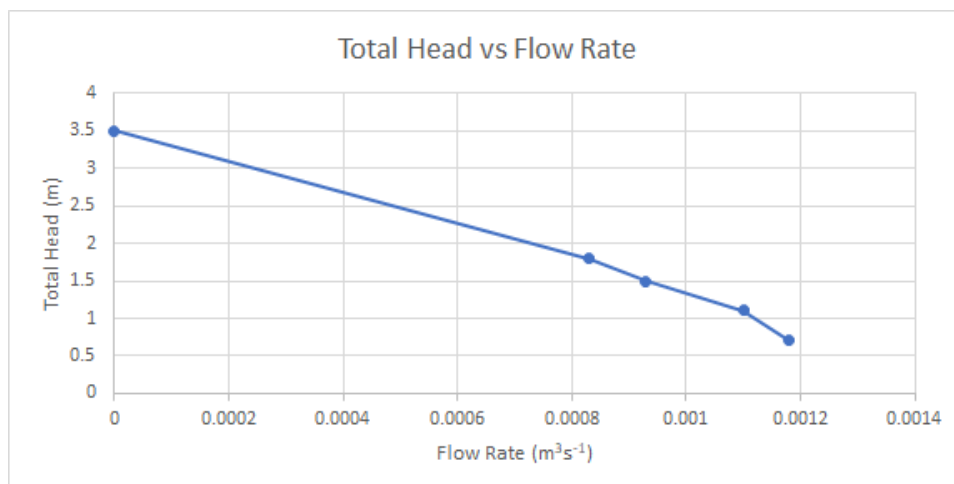


Figure 5. Total Head Trend for Single Pump

The data expressed in Figure 5 illustrates the trendline for total head in Pump 1 over different flow rates. It is observed that as flow rate increases, total head decreases. This trend matches the trendline in Figure 1 of the Chemical Engineering Laboratory II Separations and Fluid Mechanics pdf. Figure 1 expresses data for the typical performance of a pump.

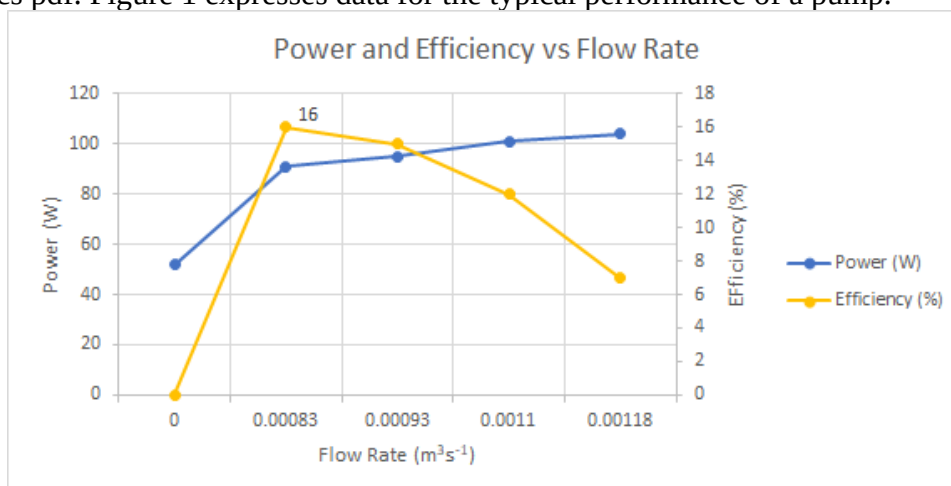


Figure 6. Power and Efficiency Trends for Single Pump

The data expressed in Figure 6 illustrates the trendline for Overall Power and Efficiency of Pump 1 over different flow rates. It is observed that as flow rate increases, the overall power of the pump increases. The power of the pump sharply increases when the flow rate increased from 0 to $0.00083 \text{ m}^3\text{s}^{-1}$, but has a gradual growth trend for the rest of the flow rate increases. This trend matches the typical pump power trendline depicted in Figure 1 of the Chemical Engineering Laboratory II Separations and Fluid Mechanics pdf where at high flow rates there is a noticeable increase in power output. The power trendline for typical pump power in Figure 1 illustrates a slower initial increase in power but that is due to smaller flow rate increases. Due to the similarity between the power trend in Figure 6 and Figure 1 of the reference pdf, it can be concluded that over the same range of flow rates, the plot of the overall power output reading for Pump 1 would exhibit the full power trendline seen in Figure 1.

In Figure 6, the max efficiency of the single pump, 16%, was reached at the first flow rate

of $0.00083 \text{ m}^3\text{s}^{-1}$. The overall pump efficiency decreases with increasing flow rate after this point. This trendline matches the trend of the general pump efficiency in Figure 1 of the Chemical Engineering Laboratory II Separations and Fluid Mechanics pdf where there is a decline in efficiency at flow rates 0.7 and higher. Since Figure 1 shows data trends at lower flow rates than was tested in this experiment, the overall pump efficiency increases with increasing flow rate up to about $0.7 \text{ dm}^3\text{s}^{-1}$ where it then begins to decrease at higher flow rates. Due to the similarity between the efficiency trend in Figure 6 and Figure 1 of the reference pdf, it can be concluded that over the same range of flow rates, the plot of the overall efficiency reading for Pump 1 would exhibit the full efficiency trendline seen in Figure 1.

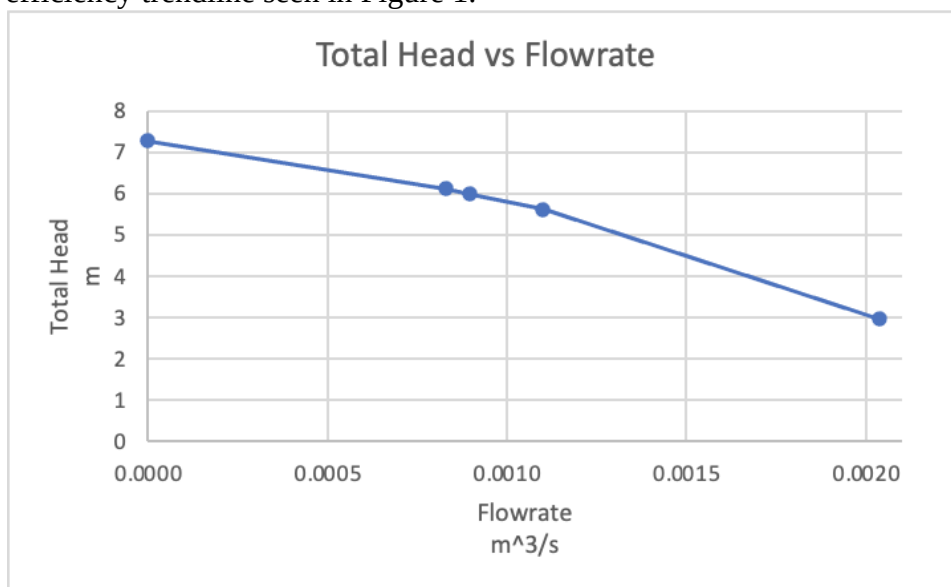


Figure 7. Head vs Flowrate for Parallel Pumps

As shown in Figure 7, as flowrate increased, total head decreased. This trend follows the shape of Figure 1 which also shows a decrease in total head as the volumetric flow rate is increased. The main differences between Figure 7 and Figure 1 are that the parallel pumps are operating at a higher volumetric flowrate and power.

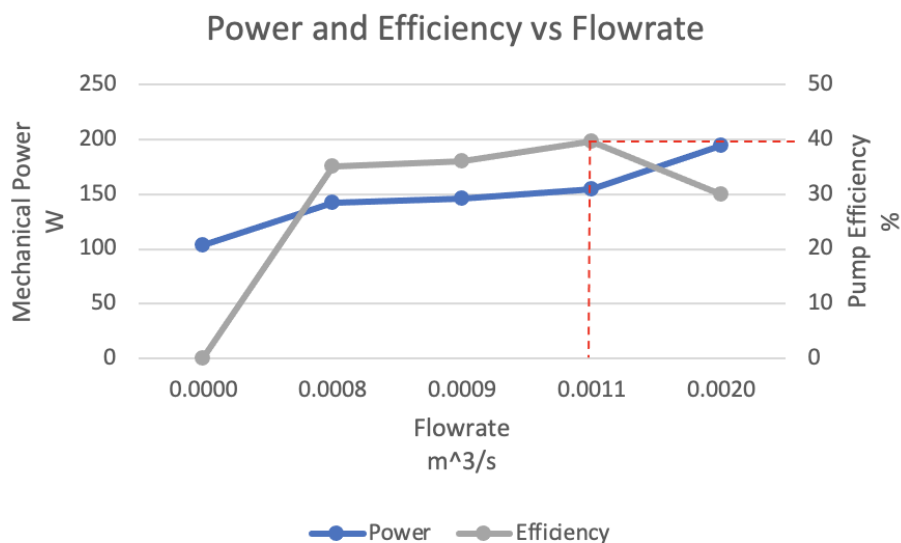


Figure 8. Power & Efficiency vs Flowrate for Parallel Pumps

Figure 8 shows the relationship between power, efficiency, and the flowrate. As expected, an increase in the flowrate required an increased pump power. On the other hand, though the power steadily increased, the pump had a max efficiency of about 40% that occurred at a flowrate of $.0011 \text{ m}^3/\text{s}$. These values are identified by the red dotted line. Just as with Figure 7, the lines in Figure 8 also correspond with the shape of Figure 1 although the exact values are different. The differences in the axes are the same as described in Figure 7, though the efficiency in Figure 1 is also about 40%.

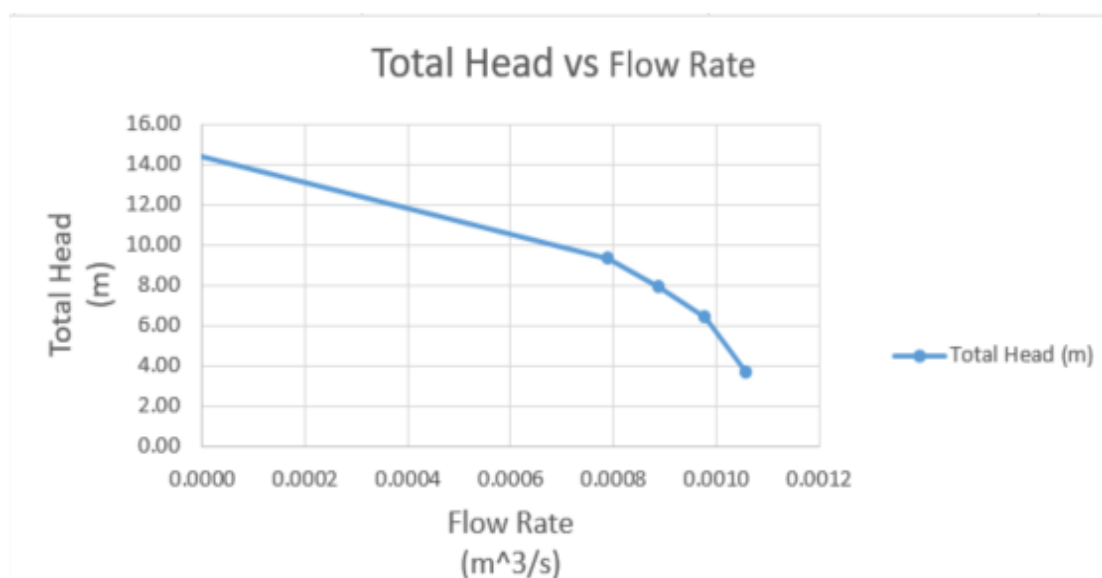


Figure 9. Flowrate vs Head for Series Pumps

From the above plot in figure 9, we can see that as flowrate increases, the total head decreases. This is similar to Figure 1 as head decreases with an increase in volumetric flow.

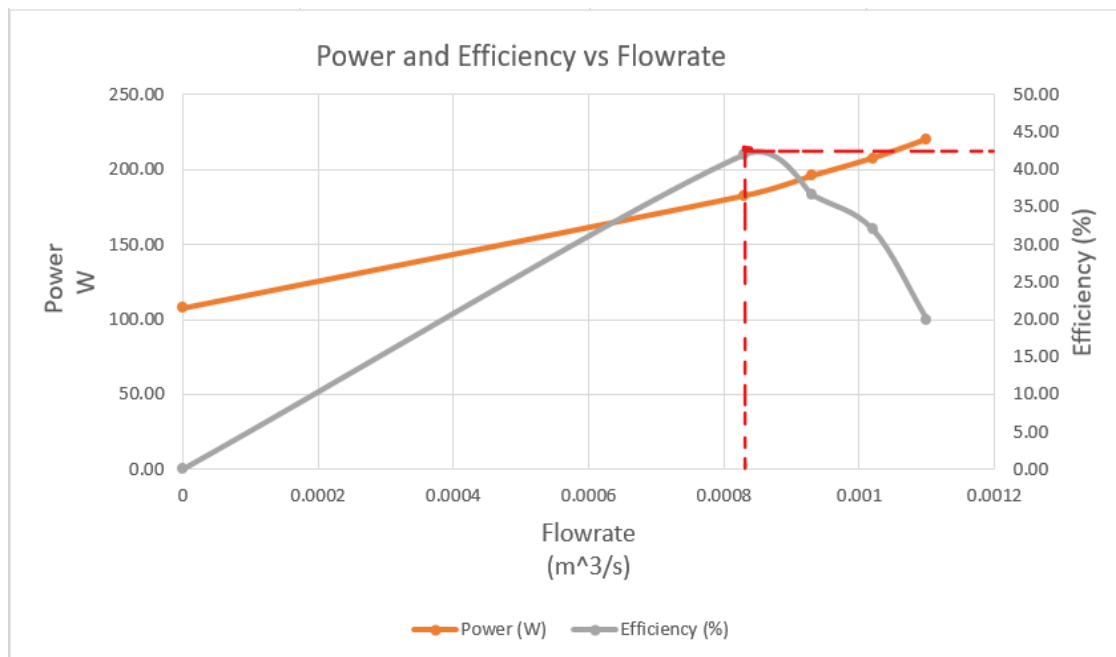


Figure 10. Flowrate vs Power & Efficiency for Series Pumps

From the above plot of Flowrate against Power and efficiency, we can see that, with the pumps in series the power increases as the flowrate increases. In the same way the efficiency increase as the flowrate increases. Two pumps in series increase the head of flow by doubling the head while the heads of the single and two pumps in parallel stay the same. In theory pumps in series' head should double but in real life that is not the case as we end up having about 14.6 meters head. Comparing to the single and parallel pump efficiency, pumps in series have a higher efficiency of 42% (max) at a flowrate of 0.00083m³/s. As we can also see, as the flowrate increases so does the power increases.

Conclusion

In this lab, characteristic curves were found for a single pump configuration. As previously mentioned, this setup had the lowest efficiency. When comparing two pumps in series with two in parallel, the pumps in series had the highest overall efficiency. While no one pump can be 100% efficient, this experiment helps to determine what is the best pump setup for single or dual operation needs. We were also able to observe graphically how the series and parallel flowrates and head compare with that of a single pump.

References

1. Armfield Ltd Instruction Manual FM51 PC-0055747, Issue 8 November 2015, Exercise A https://www.engineeringtoolbox.com/pumps-parallel-serial-d_636.html
2. TQ H83 Two-Stage Centrifugal Pump Characteristics Lab Manual. CHEG 4011. Prairie View A&M University, n.d. Accessed November 15, 2021.

BELOW AVERAGE

**Prairie View A&M University
Chemical Engineering Department**



Lab 4 #: Friction losses in pipelines
Tiarra Rodrigues, Shimere Gregory, Doron Montgomery
Due Date: 12/01/2021
Date Conducted: 10/15/2021

Table of Contents

Abstract

- Purpose
- Key Findings
- Major Conclusions Drawn

Theory

- Introduction
- Objective
- Background
- Schematic Diagram

Results & Discussion

- Treatment of Data
- Discussion

Conclusion

References

Appendix

Abstract

Purpose

The purpose of this experiment is to study the behaviors of closed flow systems focusing on the pressure drops and friction losses within smooth and rough pipes in which fluid is being transported. The main driving force within the pipe is the pressure gradient within the pipe. The two variables that are used for measuring pressure drops are air and liquid flowrates. In pipes, there are two main types of flows that could occur, laminar and turbulent. The patterns displayed in the drop in pressure against the air and liquid flow rates are compared to the estimated values as provided in the available literature. We are to determine the relationship between the pressure drop due to the friction and velocity of the fluid in all 4 pipes with different inner diameters. The theoretical values against which the experimental data is compared are derived from the pressure drop, pressure increase and velocity equations for pipelines. The results indicate that there was a consistency between the experimental data and the theoretical data.

Key Findings

As the flow of the fluid decreased the velocity also decreased. The flow and the velocity have a proportional relationship to one another. We also noticed that the pressure drop decreased as the velocity and flow decreased. The relationships between the velocity, flow, roughness of the pipe, and friction loss within the pipes had an inversely proportional effect on one another.

Major Conclusions Drawn

The main conclusion that we were able to come across within doing this experiment was that the relationships between the friction loss and pressure drop made a significant impact on our results. In conducting the experiment, we were able to notice that there was a direct proportional relationship between the flow rate and pressure drop through each pipe.

Theory

Introduction

Fluid friction in pipes is a common occurrence in pipelines. As mentioned previously, there are two main types of currents established within a pipe which are laminar flows and turbulent flows and occasionally transitional flow in which flow is occurring between both laminar and turbulent. In circular pipes, it has been found within previous experiments that flows in circular pipes have a Reynolds number of about 2000 but is not always a common occurrence when transitioning from one flow to another. Water flow in pipes usually contains energy in three forms: kinetic, potential and pressure energy. Water mass flowing from one section to another can cause energy loss. It is worth mentioning that when a fluid is flowing through a pipe, fluid resistance can happen in which energy is lost due to friction. The resistance of flow in a pipe can be related to pressure, pipe length, waterpower of pipe diameter, and power of the mean velocity.

Objective

The objectives of this experiment are listed below.

- Determine the friction factor for each of the 4 pipes
- Compare data taken in the lab with what is available in the literature and make correlations
- Determine the pressure drop of the fluid when it flows through a gate valve
- Determine the relationship between the pressure drops due to friction and velocity of the fluid within a smooth or rough pipe with different inner diameters

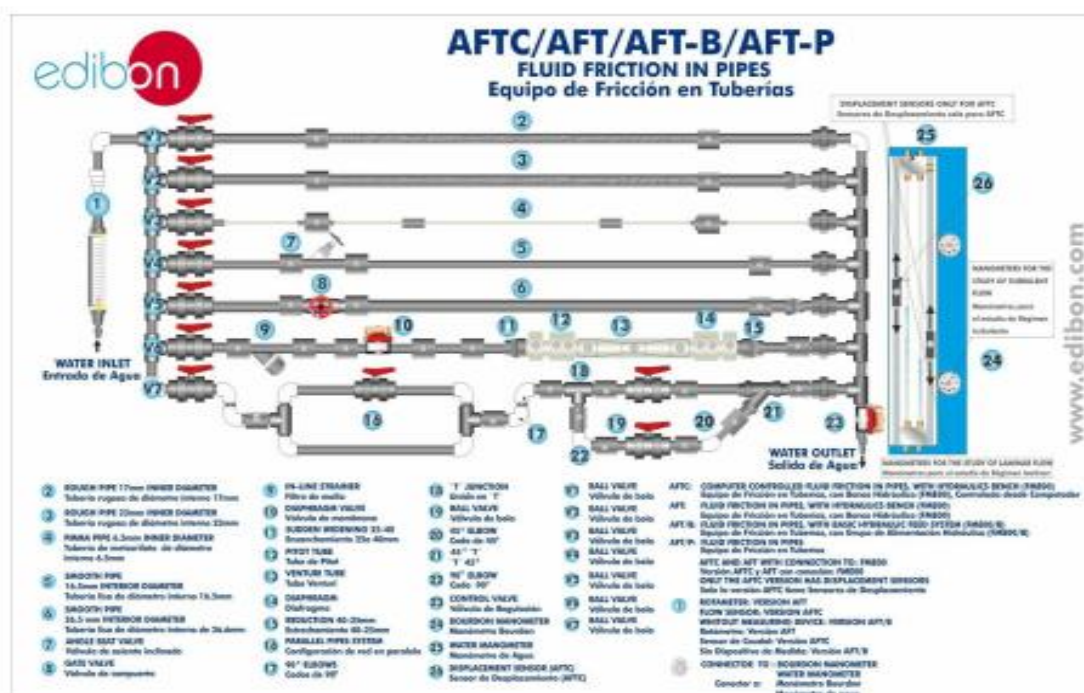
Background

Fluid friction loss in a pipe is a very common occurrence. Friction loss can occur based on a few factors: the viscosity of the fluid, the size of the inner pipe diameter, the internal roughness of the inner surface of the pipe, and sometimes the elevation between the ends of the pipe and defined when the gas flow expels as much air as possible (air blows as hard as it can) and no more air can enter the column because the maximum velocity of air passing through column has been achieved length of pipe in which fluid travels.

Procedure

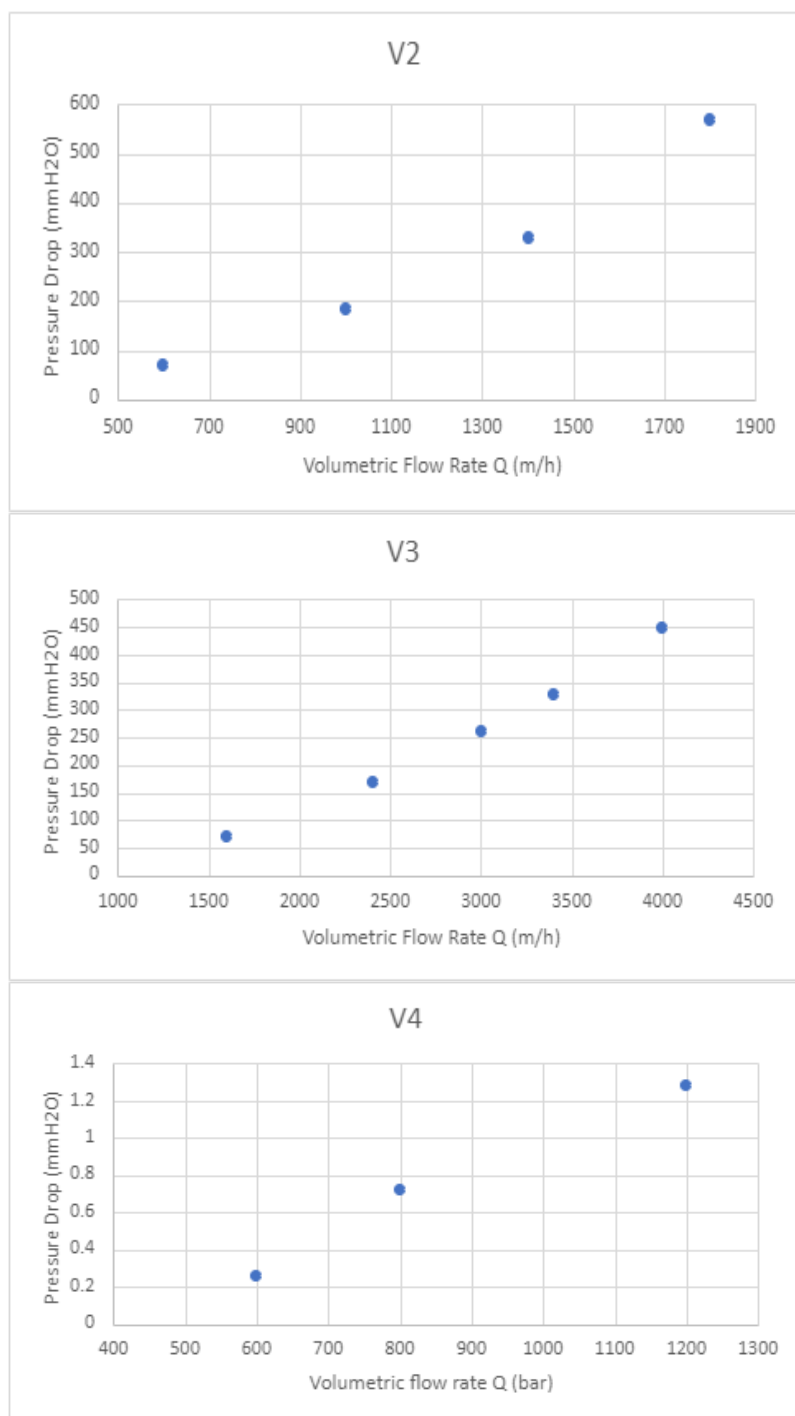
To begin the lab, we familiarized our self with the equipment by checking if everything was set up properly. Next, we connect the unit and switch on the pump. Making sure V1, V2, V3, V4, V5, V6, V7 is closed except for valve 3. We connected the low pressure taps of the corresponding pipe for valve 3. Then we recorded pressure difference for varying volumetric flow rates. To change the flow rates, adjust the regulation valve (valve 23). This process is repeated for Valve 2 with Valve 3 closed. With e V1, V2, V3, V4, V5, V6, V7 closed and valve 4 open connect the high pressure taps to the corresponding pipe for valve 4. Then we recorded pressure difference for varying volumetric flow rates. Lastly Open valve 5 and connect the low-pressure tabs to the pipe corresponding valve. Then we recorded pressure difference for varying volumetric flow rates. To change the flow rate, start with valve 4 fully open and begin to slowly close it in fourths.

Schematic Diagram



Results & Discussion

Treatment of Data



When calculating the friction loss for each pipe at different volumetric flow rates and roughness the friction loss decreased.

Discussion

There were various combinations used in the experimentation processes. The results of the relationship between the volumetric flow rate and the pressure drops for each case linearly increased in all cases. From these results, it is evident that the flow rate increases as the pressure drop decreases. The accuracy in this experiment was ensured through repetition where the results were consistent, which implies high accuracy.

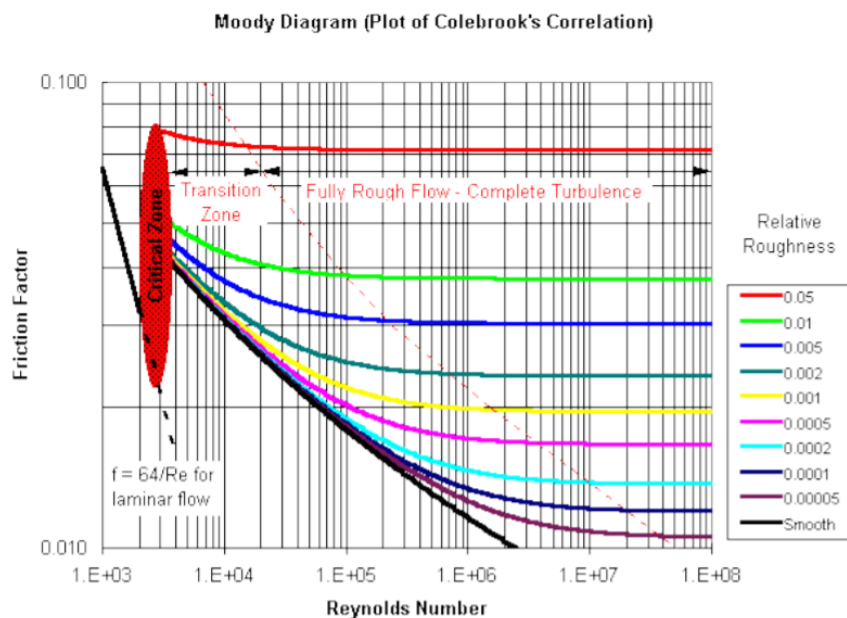
Conclusion

From this experiment, we were able to compare our friction loss within the different pipes and the gate valve using the table of results in the appendix. The friction loss in each pipe decreased with the volumetric flow rate. The data that we collected during the experiment showed that there was a direct relationship between our flow rates and pressure drops across the pipes.

References

6. Billet, R. and Schultes, M. "Modelling of Pressure Drop in Packed Columns," *Chem. Eng. Tech.*, **14**, 89-95, 1991.
7. Billet, R. and Schultes, M. "Prediction of Mass Transfer Columns with Dumped and Arranged Packings: Updated summary of the Calculation Method of Billet and Schultes," *Trans. IChemE*, **77A**, 498-504, 1999.
8. Geankopolis, Christie John "Transport Processes and Separation Process Principles", 4thEd. (Prentice Hall).
9. Perry's Chemical Engineers Handbook.

Appendix



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V3						
	Q	Velocity	pressure drop(mmH2O)	e/D	f	hL
	4000	2.67	450	0.000065	0.018	0.28
	3400	2.27	328	0.000065	0.019	0.22
	3000	2.01	260	0.000065	0.019	0.17
	2400	1.6	170	0.000065	0.02	0.11
	1600	1.07	72	0.000065	0.021	0.05
V2						
	1800	2.2	570	0.000088	0.02	0.29
	1400	1.71	330	0.000088	0.021	0.18
	1000	1.22	186	0.000088	0.022	0.1
	600	0.73	70	0.000088	0.025	0.04
V4			bar			
	1200	10	1.28	0.00023	0.021	16.5
	600	5.02	0.26	0.00023	0.023	4.54

	800	6.7	0.72	0.00023	0.022	7.34
V5						
	fully open		12			
	3/4 open		35			
	1/2 open		140			
	1/4 open		472			
	closed					

CHEMICAL ENGINEERING LAB. II
FALL 2021

FINAL PRESENTATION

TOPICS COVERED IN FINAL PRESENTATION

Final Presentation covers the following topic:

1. Safety in the lab.
2. Design of experiments.
3. Oral and written communication.

**CHEMICAL ENGINEERING LAB. II
FALL 2021**

Rubric and Grading Scheme used to grade the final presentation.

**Design of Experiments CHEG 4101 PO1 & PO3
Laboratory Grading Sheet
Monday 11/29/2021**

Group I

a). Writing

Maximum Grade

1. Organization	<u>5</u>	_____
2. Scientific Language	<u>5</u>	_____
3. Grammar	<u>5</u>	_____
4. Completeness	<u>5</u>	_____

b). Scientific Content

1. Abstract	<u>5</u>	_____
2. Theory	<u>5</u>	_____
3. Results	<u>5</u>	_____
4. Conclusions	<u>5</u>	_____

c). Design Content

1. Concept	<u>5</u>	_____
2. General	<u>5</u>	_____
3. Specific	<u>5</u>	_____
4. Conclusions	<u>5</u>	_____

Total: _____

Average: _____

ABOVE AVERAGE

Lab #3: Fluid Flow Across a Packed Column

Group 3: Tiarra Rodrigues, Doron Montgomery,
Shimere Gregory, Reema Matti, Cinthia Sahin

Abstract

Purpose

The purpose of this lab was to have an understanding of concurrent flow through a packed bed system.

3

Key Findings

- For a packed tower of a given size, packing and liquid flow rate, there is an upper flowrate of gas.
- Gas-liquid pressure must be higher at the bottom of the column
- At low gas velocities, when the gas flow rate is increases, the pressure drop also increases.
- At the loading point, the gas flow rate starts to impede the liquid flow through the packing.
- At the flooding point, the liquid flow through the packing completely stops and is instead blown out with the gas.

4

Major Conclusions Drawn

- Raschig rings create an efficient mass transfer system
- Countercurrent flow in the system receives the highest driving force of concentration between the two phases



Theory

Introduction

- Packed bed towers are commonly used in the Chemical Engineering industry
- Various unit operations are seen in packed bed towers
- We will discuss, the packed bed absorption tower

7

Objectives

- Compare measurements to literature
- Determine the void fraction
- Determine the effects of liquid holdups on the column
- Figure out what the flooding point is within the different conditions
- Measure pressure drops as function for three flowrates

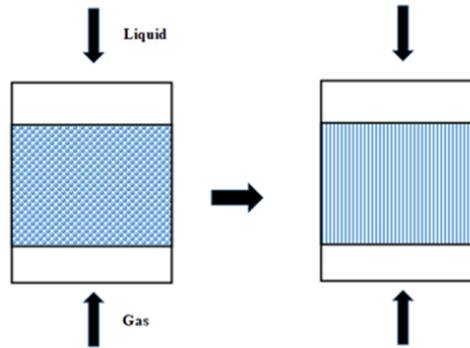


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Background

$$\frac{\Delta P \rho D_p}{G_0^2 L} \frac{\theta^3}{1 - \theta} = 150 \frac{1 - \theta}{N_{Re}} + 1.75$$

- The Ergun Equation (used theoretically)
 - Derived theory from straight tubes
- Assumptions
 - Random packing
 - No channeling



9

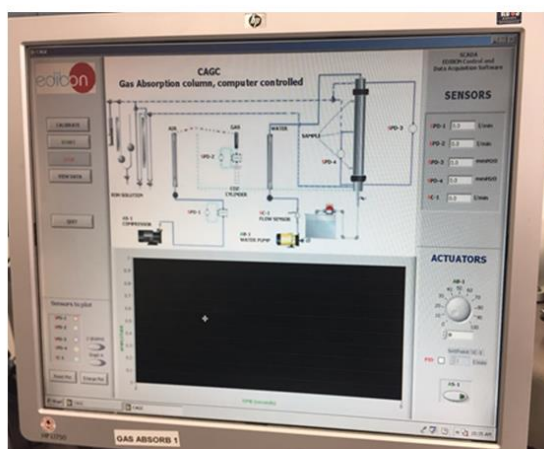
Schematic Diagram



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Procedure

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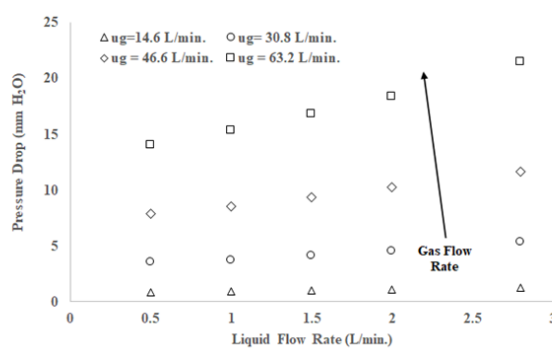
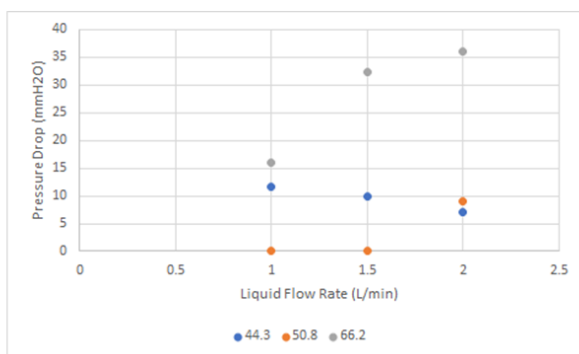


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Results and Discussion

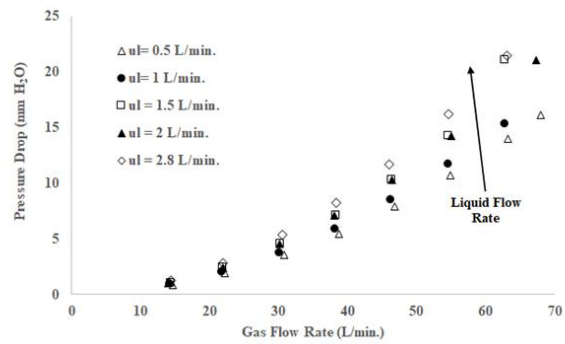
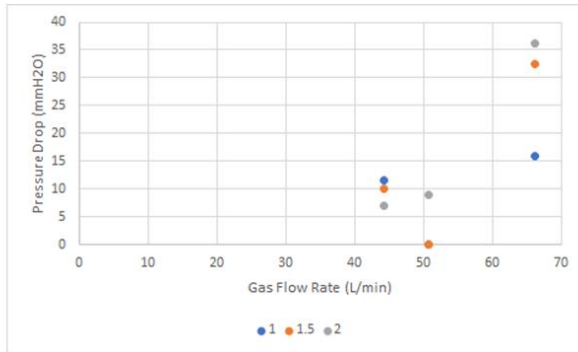
13

Treatment of Data



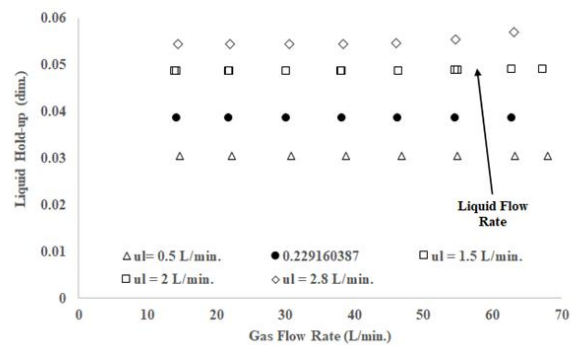
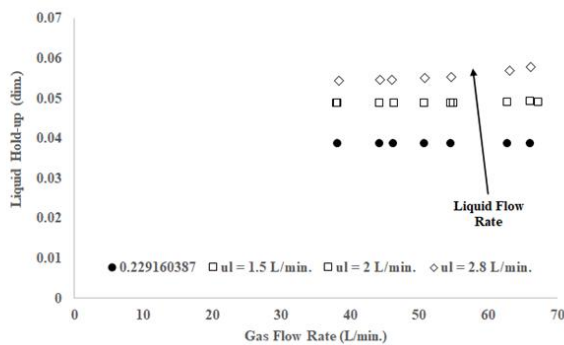
14

Treatment of Data



15

Treatment of data



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Discussion

- As the gas flow rate increases, the liquid flow through the packed bed is impeded
- Higher liquid flow rates also results in higher liquid hold-ups
- The rate at which the pressure drops decreases as the gas flow rate decreases.
- The packing factor is given

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Conclusion

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Conclusion

- Measured pressure drops for all 3 water rates
- With change in liquid and gas flow rates, pressure drop across the column increases.
- However, increase in pressure drop is significant in the case of change in gas flow rate. For change in liquid flow rate from 1 L/min to 2 L/min, pressure drop is increased from 0.9 mmH₂O to 1 mmH₂O.
- While, with change in gas flow rate from 14.6 L/min to 46.6 L/min, pressure drop is increased from 1.28 mmH₂O to 11.69 mmH₂O.

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References

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References

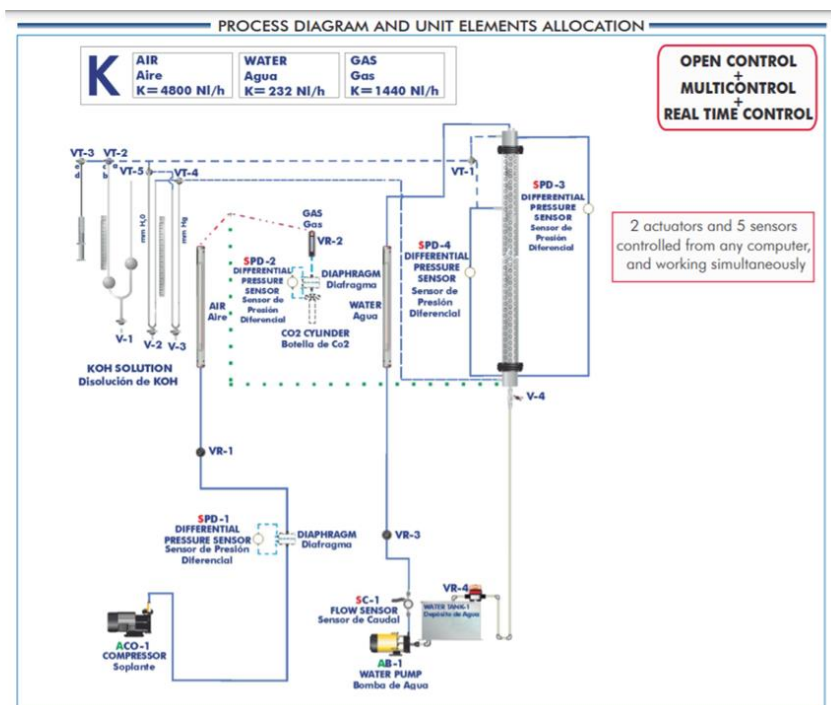
- Antoine, Keisha, director. *CAGC in Action*, 19 Oct. 2020, www.youtube.com/watch?v=t-oVHwwSL1Q. Accessed 27 Sept. 2021.
- Billet, R. and Schultes, M. "Modelling of Pressure Drop in Packed Columns," *Chem. Eng. Tech.*, **14**, 89-95, 1991.
- Billet, R. and Schultes, M. "Prediction of Mass Transfer Columns with Dumped and Arranged Packings: Updated summary of the Calculation Method of Billet and Schultes," *Trans. IChemE*, **77A**, 498-504, 1999.
- "Transport Processes and Separation Process Principles", 4thEd. (Prentice Hall), Christie John Geankoplis.
- Perry's Chemical Engineers Handbook.

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Acknowledgements

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Appendix



AVERAGE



FRACTIONATION: DISTILLATION COLUMN EFFICIENCY

Prairie View A&M University - Chemical Engineering
Department
Dr. Jorge Gabitto - Team 2

Chiebuka Ejimadu
Katelynn Inman
Tyree Madison
Caleb Myers
Xavier Williamson



Presentation Outline

- Introduction
 - Background
 - Objectives&Purpose
- Procedures
- Data Analysis
 - McCabe-Thiele Method
 - Results
- Conclusion





Background

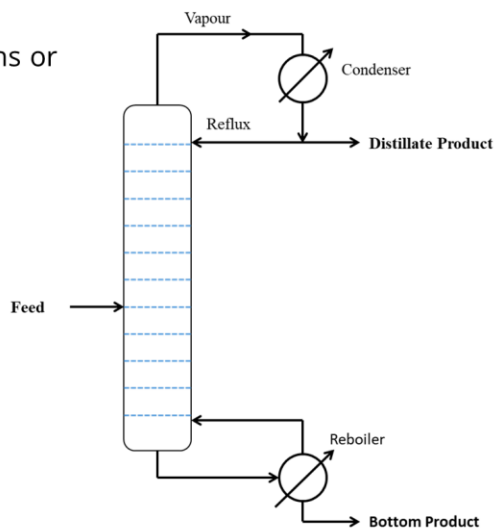
Fractional distillation is a separation of multicomponent mixtures into individual fractions or components based on their volatilities.

Refractive Index is the ratio of the velocity of light in a vacuum against its velocity in a specific mixture

$$n = \frac{c}{v}$$

Column Design Considerations

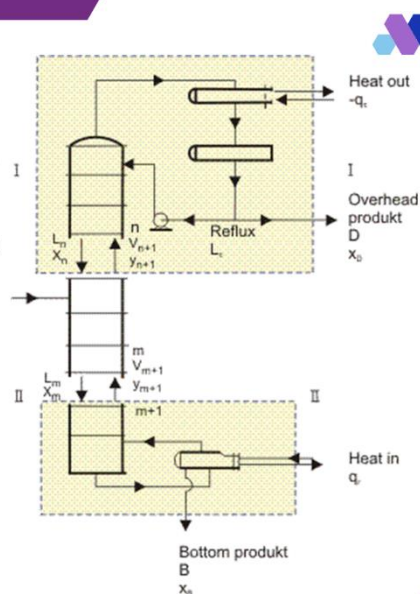
- Flow rates of distillate and bottoms streams
- Reflux rate
- Heat duties of Condenser and Reboiler
- Number of theoretical stages required



Objectives & Purpose

To separate the equimolar component mixture...

- Use refractive index vs. mol. % Ethanol graph
- Calculate the mass balance of the system
- Determine the column efficiency using the McCabe-Thiele method
- Calculate the global energy balance required for the equipment.
- Suggest efficiency improvement ways



Procedures

Column Preparation

- Add a mixture of a desired chemical solution in reboiler can be heated up
- Turn off the Reflux Ratio Timer on the timer so the column can operate at total reflux
- Set the heat controller temperature high then reduce it so the reflux feed can bubble over the column trays at a steady rate
- Allow the column to heat through reboiler for 30 minutes minimum before collecting data



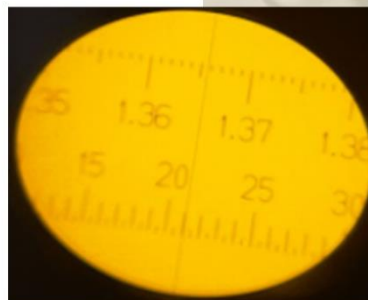
Data Collection (Feed Rates)

- Begin the experiment by calculating the volumetric flow rate of distillate and bottoms streams
- To measure, open the appropriate valve for either stream and set up a volumetric cylinder under the tubing
- Once set up, record the time it takes to fill at desired volume and repeat 3 times for accuracy
- Calculate volumetric flow rate using the times and repeat steps for the next stream (depending on where you began measurement)
- Save small amount of solution from each stream to calculate mole percentage

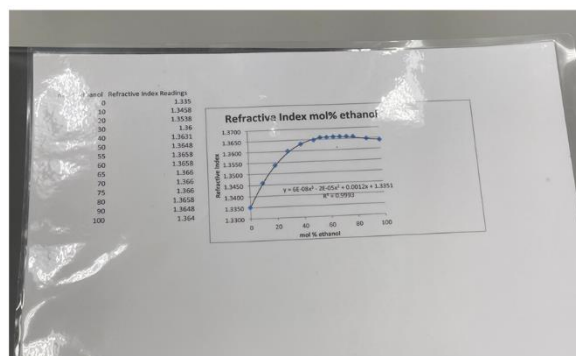
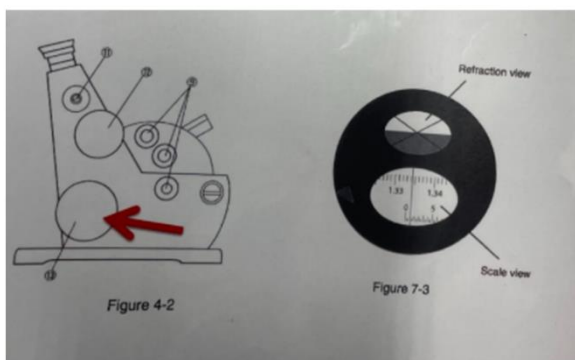


Data Collection (Refractometer)

- Take Solution from sample and place under refractor prism
- Close/tighten the prism and adjust measurement knob until boundary line appears
- When seen adjust the color compensator knob until the line is free of red or blue tint
- Once clear set boundary line to the intersection
- Once this is set, record the number and compare it to the refractive index to get mole percentage of Ethanol in the desired stream (Distillate or Bottoms)



Data Collection (Molar Percentage)





McCabe-Thiele Method

Enriching Section

Reflux Ratio, $R = 5$

$$y[n+1] = (Rx[n] / R+1) + (x[D] / R+1)$$

$$y[n+1] = 5/6 x[n] + 1/6 x[D]$$

Stripping Section

$$y[m+1] = (L[m]x[m] / V[m+1]) + (Bx[B] / V[m+1])$$

$$y[m+1] = 0.91x[m] + 0.089x[B]$$

Feed Section (q-line)

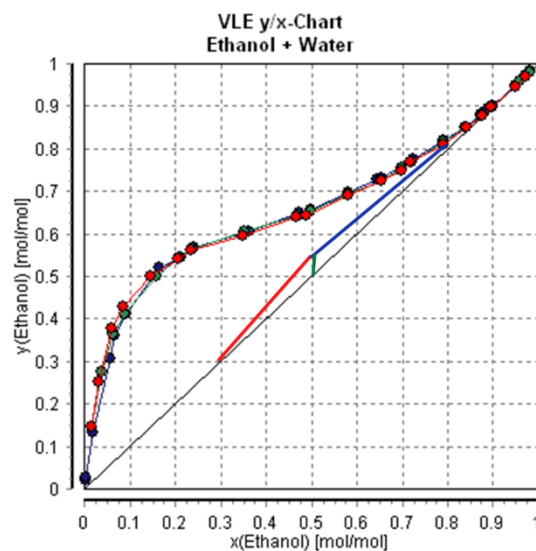
$q > 1$ for subcooled mixtures

$$q = (\lambda + c[p](T[b] - T[F])) / \lambda$$

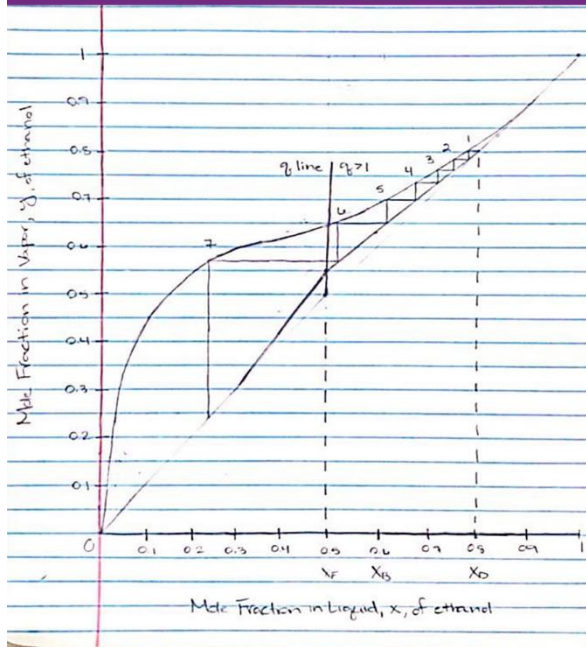
$$q =$$

$$y = (qx / q-1) - (x[F] / q-1) \quad 1.021$$

$$y = 49.25x - 48.25x[F]$$



Results



Overall Mole Balance:

$$F = D + B$$

Ethanol Mole Balance:

$$F x_F = D x_D + B x_B$$

Overall Energy Balance:

$$\Delta H = Q$$

$$Q = Q[C] + Q[R]$$

$E[O] = 7$ theoretical trays / 8 actual trays

Column Efficiency = $E[O] = 0.875$



Conclusion

Conclusion

The efficiency of a distillation column that separates an equimolar mixture of water and ethanol was analyzed by graphing data generated using a refractor prism.

Results

Column Efficiency : 87.5%
 Distillate Composition: 80%
 Actual Column Trays: 8
 Theoretical Column Trays: 7



$$\begin{aligned} \rho_D &= \text{density of distillate} = x_D \rho_E + (1-x_D) \rho_W \\ &= (0.8)(0.789) + (0.2)(1) \\ &= 0.8312 \text{ g/mL} \\ \rho_B &= \text{density of bottoms} = x_B \rho_E + (1-x_B) \rho_W \\ &= (0.6)(0.789) + (0.4)(1) \\ &= 0.8734 \text{ g/mL} \\ M_D &= \text{molar mass of distillate} = x_D M_E + (1-x_D) M_W \\ &= (0.8)(46) + (0.2)(18) \\ &= 40.4 \text{ g/mol} \\ M_B &= \text{molar mass of bottoms} = x_B M_E + (1-x_B) M_W \\ &= (0.6)(46) + (0.4)(18) \\ &= 34.8 \text{ g/mol} \\ D &= \left(\frac{0.644 \text{ mL}}{s} \right) \left(\frac{0.8312 \text{ g}}{1 \text{ mL}} \right) \left(\frac{1 \text{ mol}}{40.4 \text{ g}} \right) = 13.25 \text{ mmol/s} \\ B &= \left(\frac{0.269 \text{ mL}}{s} \right) \left(\frac{0.8734 \text{ g}}{1 \text{ mL}} \right) \left(\frac{1 \text{ mol}}{34.8 \text{ g}} \right) = 6.473 \text{ mmol/s} \end{aligned}$$



Areas of Improvement

- Heat reboiler prior starting the experiment
- Heat reboiler temperature to desired temperature
- Decrease amount of trays in distillation column for better efficiency



Data Collection (Feed Rates)

- Begin the experiment by calculating the volumetric flow rate of distillate and bottoms streams
- To measure, open the appropriate valve for either stream and set up a volumetric cylinder under the tubing
- Once set up, record the time it takes to fill at desired volume and repeat 3 times for accuracy
- Calculate volumetric flow rate using the times and repeat steps for the next stream (depending on where you began measurement)
- Save small amount of solution from each stream to calculate mole percentage



Questions



BELOW AVERAGE

Centrifugal Pump Characteristics Lab

By: Group 1
Alessia Williams
Amiya Rogers
Chinenye Ihe
Taylon Owens
Franck Nangomoko



1

Outline

**ABSTRACT****BACKGROUND****OBJECTIVE****THEORY****PROCEDURES****RESULTS****DISCUSSION****CONCLUSION**

2

Abstract

- Characteristic curves show the performance & operating regions of a centrifugal pump which helps increase pump life
- The goals of this experiment were to:
 1. Investigate the characteristic curves for a single centrifugal pump
 2. Compare the behavior of pumps in parallel against pumps in series
- TecQuipment Two-Stage Series and Parallel Pumps – H83 was used to find the characteristics of centrifugal pumps working alone or in series or parallel
- As flowrate increased, total head decreased and as flowrate increased, power increased

Objectives

1

Obtain head, power,
efficiency graphs

2

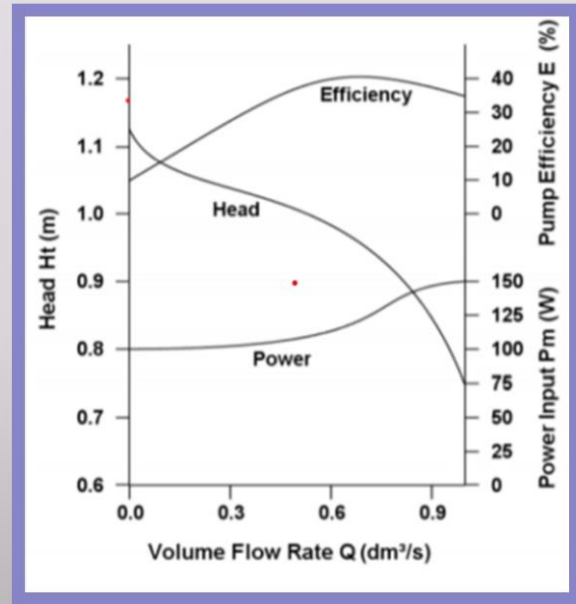
Determine maximum
efficiency and
flowrate at which it
occurs

3

Compare with given
curves

Background

- Efficiency is important when selecting pumping system
 - Ratio of hydraulic power (output) to mechanical power (input)
 - Energy and Cost savings
- No pump is 100% efficient



Reference Performance Curves

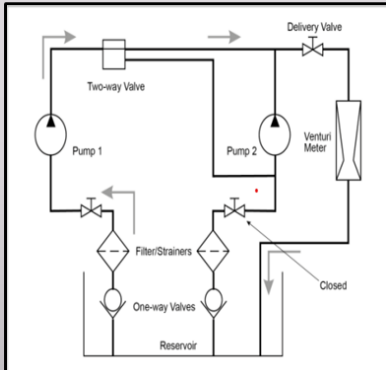
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Applications

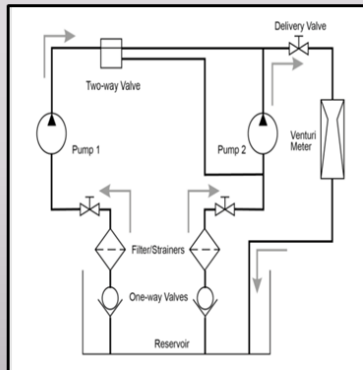
- Energy and oil industries
- Wastewater treatment systems
- Chemical and Petrochemical productions
- Industrial and fire protection



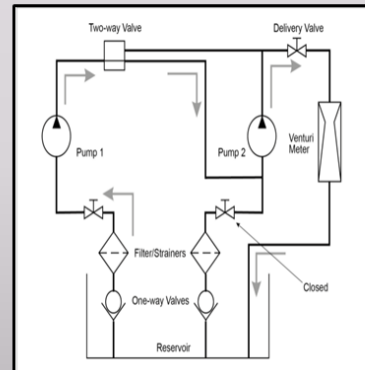
Theory



Single Stage Pump



Parallel Stage Pumps



Series Stage Pumps

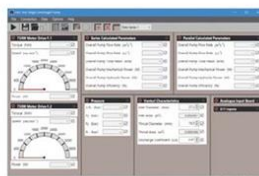
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Calculations

- Total Head:
 - $H_T = H_s + H_v + H_e$
 - $H_{Tseries} = H_1 + H_2$
 - $H_{Tparallel} = H_1 = H_2$
- Flow
 - $Q_{Tseries} = Q_1 = Q_2$
 - $Q_{Tparallel} = Q_1 + Q_2$
- Power (mechanical and hydraulic):
 - $P_m = 2\pi n t$
 - $P_h = H_T Q \rho g$
- Efficiency:
 - $E = 100 \left(\frac{P_h}{P_m} \right)$
- Parallel Pumps:
 - $Q \approx 2Q_{single} @ \text{constant Head}$
- Series Pumps:
 - $H_T \approx 2H_{Tsingle} @ \text{constant Flow}$



Lab Equipment



TecQuipment Two-Stage Series and Parallel Pumps – H83 is used to find the characteristics of centrifugal pumps working alone or in series or parallel



Procedure

Series Pump

1. Create a blank results table by clicking on the icon with the pencil
2. Use both pumps for series configuration. Switch off both motor drive isolators.
3. Open Pump 1 inlet valve. Close Pump 2 inlet valve. Set the two-way valve to direct flow straight to the inlet of Pump 2. Fully open the delivery valve.
4. Switch on both Motor Drive isolators. Start the pump motors and run them to below maximum speed
5. Adjust the motor speed for pumps 1 and 2 by turning the black dial on each pump console to the speed required for the experiment. Record readings for pressure and flow for various dial settings. Make sure to take 3 replicates for each pump dial setting by clicking on the acquire data button 3 times. Try to record data for the pumps having the same rpms.

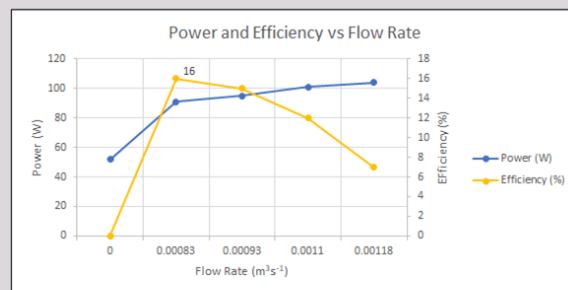
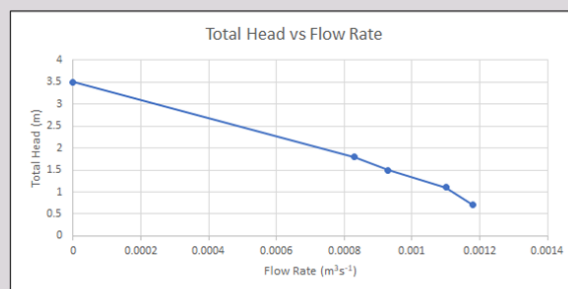
Parallel Pump

1. Create a blank results table
2. Use both pumps for parallel configuration. Switch off both motor drive isolators.
3. Open both inlet valves and set the two-way valve to direct flow straight to the delivery pipe. Fully open the delivery valve.
4. Switch on both motor drive isolators. Start the pump motors and run them to below maximum speed.
5. Adjust the motor speed for pumps 1 and 2 by turning the black dial on each pump console to the speed required for the experiment. Record readings for pressure and flow for various dial settings. Make sure to take 3 replicates for each pump dial setting by clicking on the acquire data button 3 times. Try to record data for the pumps having the same rpms.

Single Pump

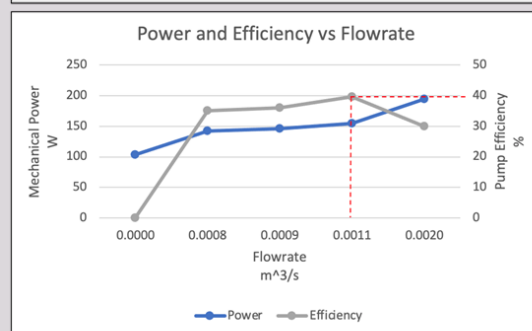
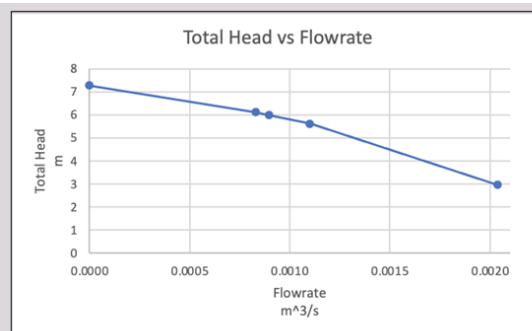
1. Create a blank results table
2. Take readings using the VDAS on Pump 1 only.
3. Switch off both motor pump isolators.
4. Close pump 2 inlet valve and set the 2-way valve to direct flow straight to the delivery pipe. Fully open pump 1 inlet and the delivery valve.
5. Start the pump motor and run it to below maximum speed.
6. Adjust the motor speed for pump 1 by turning the black dial to the speed required for the experiment. Record readings for pressure and flow for various dial settings. Make sure to take 3 replicates for each pump dial setting by clicking on the acquire data button 3 times.

Single Pump Results



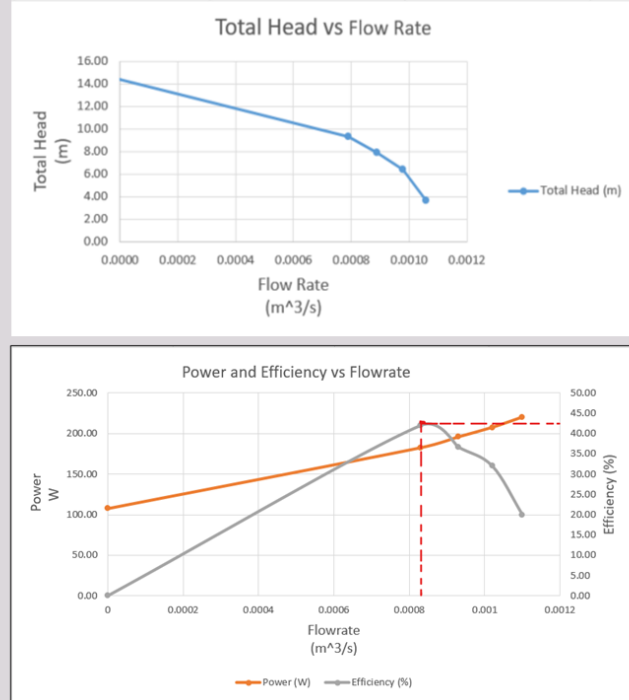
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Parallel Pumps Results



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Series Pumps Results



Discussion & Conclusion

Flowrate and Power are Directly Proportional

Flowrate and Total Head are Inversely Proportional

Greatest Efficiency is in Series

No Pump is 100% Efficient

- Single v Dual Pump Operation

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QUESTIONS?

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