

BINDER FOR OUTCOME "6"

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

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

**BINDER CONTAINING REPRESENTATIVE
ASSIGNMENTS FROM ALL COURSES USED TO ASSESS
OUTCOME "6"**

Last 3 Academic Years

09/15/2022 Revision

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- 3. List of courses used to assess this outcome**
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 - CHEG 4101 Chemical Engineering Laboratory I**
 - CHEG 4104 Chemical Engineering Laboratory II**

2. Description of Outcome "6" and its Performance Criteria

Outcome 6:

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

Sub-Outcomes and Performance Criteria

- 6.1: Ability to develop experiments
- 6.2: Ability to conduct experiments
- 6.3: Ability to analyze and interpret experimental data
- 6.4: Demonstrate the use of engineering judgement to draw conclusions.

3. List of Courses Used to Assess the Outcome

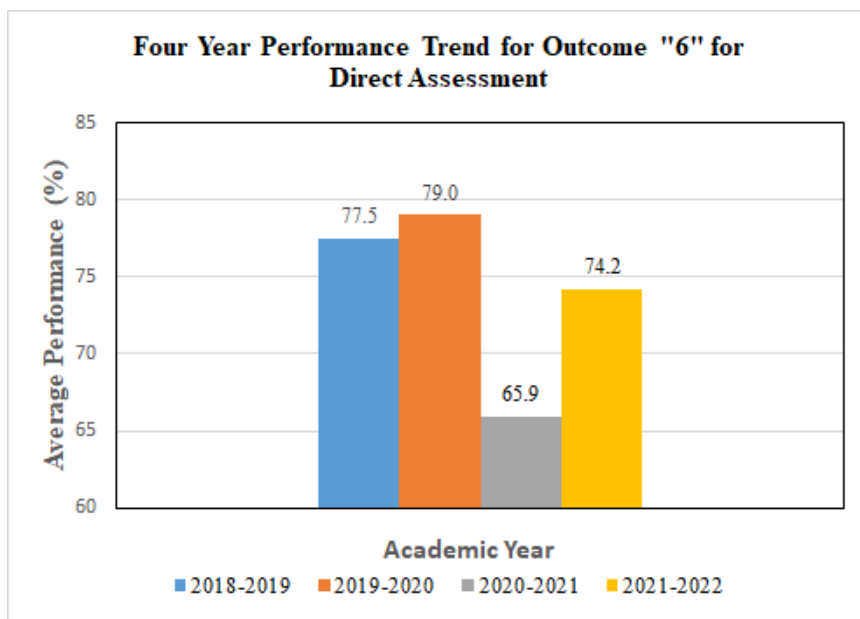
Outcome 6 is assessed in the following courses:

CHEG 4101 Chemical Engineering Laboratory I

CHEG 4104 Chemical Engineering Laboratory II

4. Summary Assessment Results and Continuous Improvements for Outcome "6" over the Assessment Years.

The average performance for all students in the 2 courses used to assess outcome 6 for the past three academic years are shown below



Problems identified and recommended actions to be taken to address problems

1. At the course level

Problems Identified in the Various Courses	Recommended Actions Taken	Basis for Action
1. The students are competent in following equipment SOP and the laboratory manual to obtain their data. Data analysis and data manipulation using tools like EXCEL need improvement. Poor data analysis leads to poor conclusions. There is still a gap in their ability to make insightful connections between collected data and theoretical concepts.	1. The department agreed at the meeting of the faculty that Instructors teaching the required courses should continue to demand the students to clearly present the following in their reports: (1) the response of the dependent variable as the as the independent variable was changed, 2. (2) comparison of the experimental results the results predicted by theory and the reasons for an deviations from the theory, (3) estimation of experimental error, and (4) conclusions based on the objectives and results. The department also agreed at the meeting of the faculty that Instructors should provide assignments using the process simulation software such as ASPEN/HYSYS and function-based programming language such as MATLAB and POLYMATH.	During the 2019-2020 academic year the following practices were implemented: Two new lecturers were added to the faculty for more effective course instruction. A senior lab coordinator was hired and this enabled the lab to be managed by a dedicated resource. A graduate student worked closely with the senior lab coordinator to commission equipment, to prepare the labs, and to participate during lab sessions. Practice sessions were given in the laboratory describing procedures for data acquisition and analysis. Design of Experiments (DOE). The two laboratory classes both contain DOE components, where the student teams must conceptualize a lab exercise in keeping with the theme of the lab course. An executive summary of the proposed lab exercise is provided to the instructor for feedback and evaluation. A final presentation is given by the student teams at the end of the semester for evaluation.

2. At Department Level

Going forward, the following are proposed for the 2020-2021 academic year:

1. Continue to focus on data analysis and the use of data analysis tools. Linking data analysis to the interpretation of results, the development of the discussion and conclusion sections in the technical report.
2. Continue DOE exercises to bolster student averages for this outcome.

Basis of Action:

The result of these actions was that the average for Outcome 6 was 82%, which exceeded the target average of 75%. This was an increase over 2018-2019 average of 61%.

6. Sample Assignments and Justification of suitability of assignment for measuring the outcome in:

CHEG 4011 Chemical Engineering Laboratory I
CHEG 4031 Chemical Engineering Laboratory II

**OUTCOME “6” SPECIFIC ASSIGNMENTS USED TO
ASSESS THE OUTCOME IN**

CHEMICAL ENGINEERING LABORATORY I

CHEMICAL ENGINEERING
OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET
CHEG 4011 CHEMICAL ENGINEERING LABORATORY
II
FALL 2019

Instructor: Dr. Keisha Antoine

Title of Assignment

McCabe-Thiele Method of Calculation for Number of Theoretical Stages

Outcome Measured Using this Assignment

Outcome 6

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

Check the communication problem characteristics related to this assignment

Ability to develop experiment Requires students to	
☒	Identify the appropriate parameters or variables and relationships (independent, dependent and control variables),
☒	Identify and select appropriate equipment or components for measuring the parameters
☒	Provide steps for setting up and conducting the experiment and
☒	Identify data collection method to support experiments (if needed)
Ability to conduct experiments Requires students to	
☒	Conduct experiment while maintaining all safety precautions
☒	Demonstrate knowledge of how to use the equipment safely
☒	Collect and record data using appropriate units of measurement and significant figures
Ability to analyze and interpret experimental data Requires students to	
☒	Present the data (raw /derived) in tabular or graphical form to meet the objectives and to aid in interpretation
☒	Use appropriate statistical analysis methods to analyze and interpret data
☒	discuss the raw and derived data/graphs and assess the validity of the results
Demonstrate the use of engineering judgement in the development and analysis of the experiment Requires students to	
☒	Draw appropriate conclusions and recommendations using engineering judgement.

Brief justification of why this assignment is suitable for this outcome

This is a laboratory experiment which in its nature, tests the outcome outlined above.

CHEG 4011 CHEMICAL ENGINEERING LABORATORY II
FALL 2019

ASSIGNMENT STATEMENT/QUESTIONS

**GRADING SCHEME FOR MCCABE-THIELE METHOD OF
CALCULATION FOR NUMBER OF THEORETICAL STAGES**

McCabe-Thiele Method of Calculation for Number of Theoretical Stages

Objective

To calculate the theoretical number of stages for an equimolar ethanol-water mixture using the McCabe-Thiele method.

Procedure

You will need to measure or record: Reflux ratio, R , x_D , x_F , x_B , the temperatures of each stage, volumetric flow rates of the distillate, D using valve ____ and the bottoms, L using valve _____. You will use these flow rates to determine the molar flow rates. Use the calibration curve for the pump vs. feed flow to determine the volumetric flow rate of the feed.

Equipment Required

Armfield UOP3CC Distillation column

Armfield interface device

Windows™ PC with Armfield UOP3CC software installed

Theory

During rectification (fractionation) or stage distillation, the liquid and vapor products from each stage flow countercurrent to each other. In the ideal case, the vapor stream, V and the liquid stream, L leave each stage in equilibrium.

For countercurrent contact with multiple stages, the material balance on component A is given by the operating line equation:

$$V_{n+1}y_{n+1} + L_{n-1}x_{n-1} = L_nx_n + V_ny_n \quad (11.4-2)$$

The total material balance is given by:

$$V_{n+1} + L_{n-1} = V_n + L_n \quad (11.4-1)$$

V_{n+1} is mol/h of vapor from tray $n+1$, L_n is mol/h liquid from tray n , y_{n+1} is mole fraction of A in V_{n+1} , and so on. Fig. 1 shows the vapor and liquid streams entering and leaving a sieve tray at equilibrium.

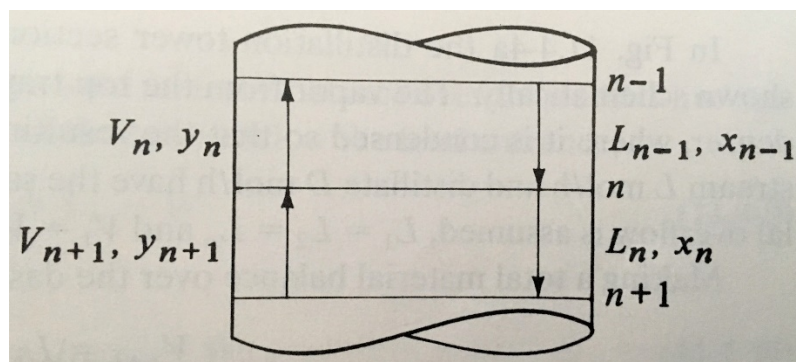


Fig. 1. A representation of the vapor and liquid streams arriving and leaving a sieve tray. The vapor and liquid streams are at equilibrium.

In a distillation, the stages are known as sieve plates or trays, which are arranged vertically in a tower (see Fig 2 below). The feed enters the column somewhere near the middle of the column. Vapor enters

the tray and bubbles through the liquid on this tray as the entering liquid flows across. The vapor and liquid entering the tray are essentially in equilibrium. The vapor continues up to the next tray where it is again contacted with a downflowing liquid. In total, the vapor becomes enriched with the more volatile component (lower boiling component, A) as it ascends the column. The downflowing liquid becomes more and more enriched with the higher boiling point component, B.

The final vapor product coming overhead is condensed in a condenser and a portion of the liquid product, called the distillate is removed, which contains a high concentration of A. The reflux is the remaining liquid that is not withdrawn from the condenser, instead, it is returned as a liquid to the top tray.

The liquid leaving the bottom tray enters the reboiler, where it is partially vaporized, and the remaining liquid, which is lean in A or rich in B, is withdrawn as liquid product. The vapor from the reboiler is sent back to the bottom tray.

NOTE: In a theoretical tray, the vapor and liquid leaving are in equilibrium. The reboiler can be considered as a theoretical stage or tray.

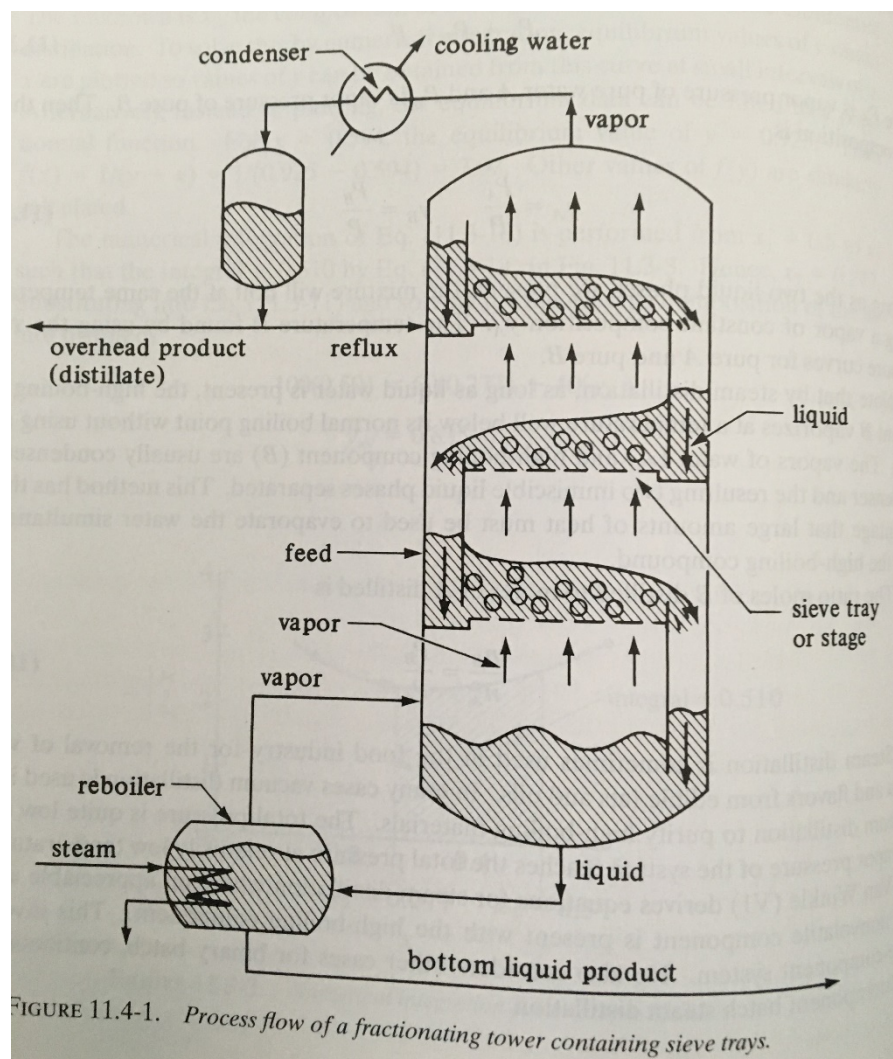


FIGURE 11.4-1. Process flow of a fractionating tower containing sieve trays.

Fig. 2. Schematic of a distillation column containing sieve trays.

For the enriching section,

The theoretical stages are determined by starting at x_D and stepping off the first plate to x_1 .

Equipment Setup

The equipment will be set up for you. Use a reflux ratio of 5:1, i.e., $R = 4$.

Treatment of Data

Review section 11.4A, B for information on the calculation on the number of theoretical stages.

Equations 11.4-1 to 11.4-11 in "Transport Processes and Separation Process Principles", C.J. Geankoplis, 4th Ed.

The diagram illustrates a distillation process for separating a mixture of benzene and toluene. The system includes a reboiler at the bottom, a distillation column in the center, and a condenser at the top. A heater is connected to the reboiler. A manometer is attached to the column. The column has eight trays labeled T1 through T8. The condenser is connected to a decanter. The decanter has a reflux valve and a product receiver. The product receiver is connected to a feed tank. The feed tank is connected to a feed pump. The feed pump is connected to a heat exchanger. The heat exchanger is connected to the reboiler. The heat exchanger is also connected to a cooling water system. The cooling water system is connected to a vacuum pump. The vacuum pump is connected to a vent. The diagram also shows a top product receiver and a bottom product receiver. The top product receiver is connected to a feed tank. The bottom product receiver is connected to a feed tank. The feed tanks are connected to a feed pump. The feed pump is connected to a heat exchanger. The heat exchanger is connected to the reboiler. The heat exchanger is also connected to a cooling water system. The cooling water system is connected to a vacuum pump. The vacuum pump is connected to a vent. The diagram also shows a top product receiver and a bottom product receiver. The top product receiver is connected to a feed tank. The bottom product receiver is connected to a feed tank. The feed tanks are connected to a feed pump. The feed pump is connected to a heat exchanger. The heat exchanger is connected to the reboiler. The heat exchanger is also connected to a cooling water system. The cooling water system is connected to a vacuum pump. The vacuum pump is connected to a vent.

3

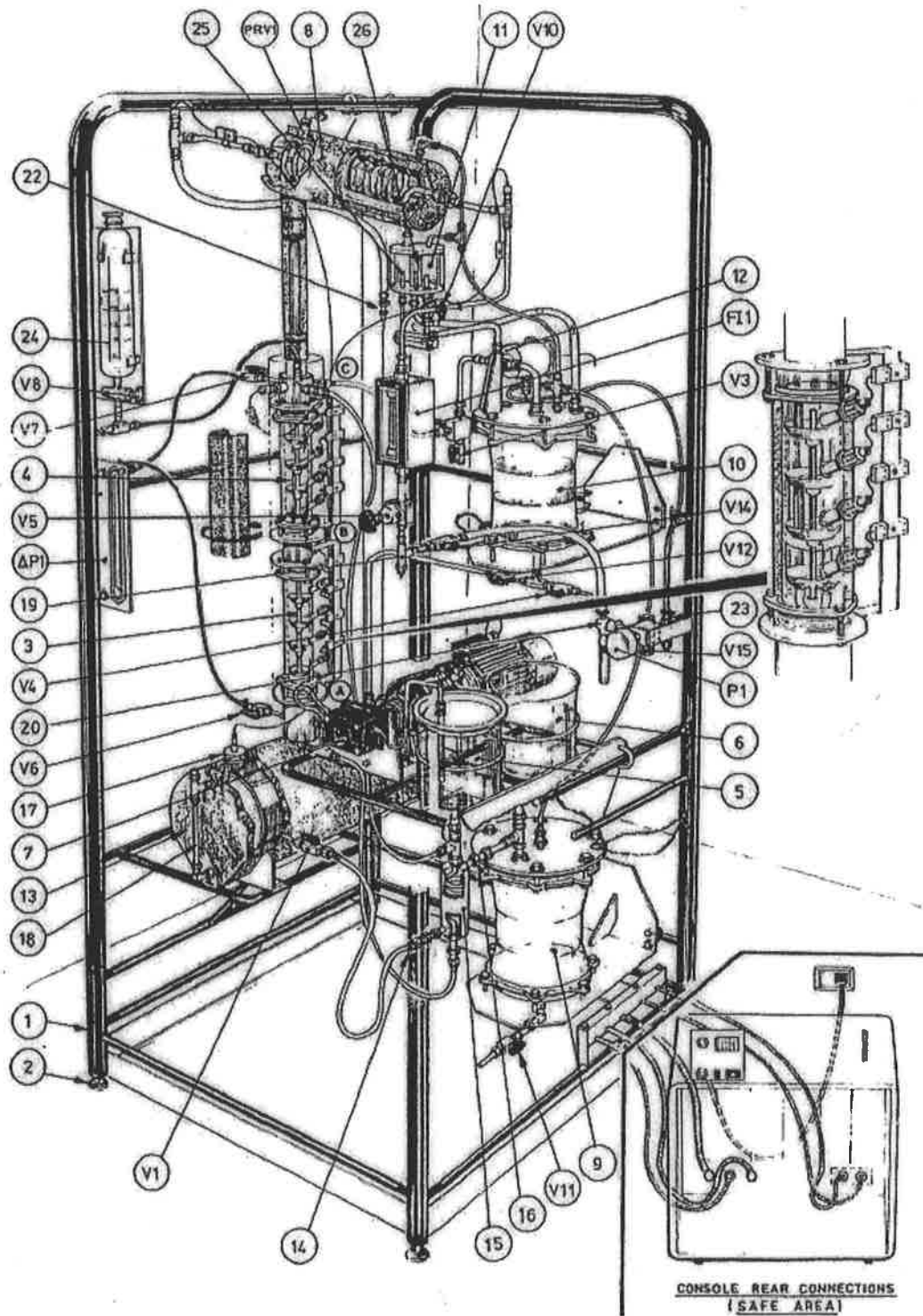
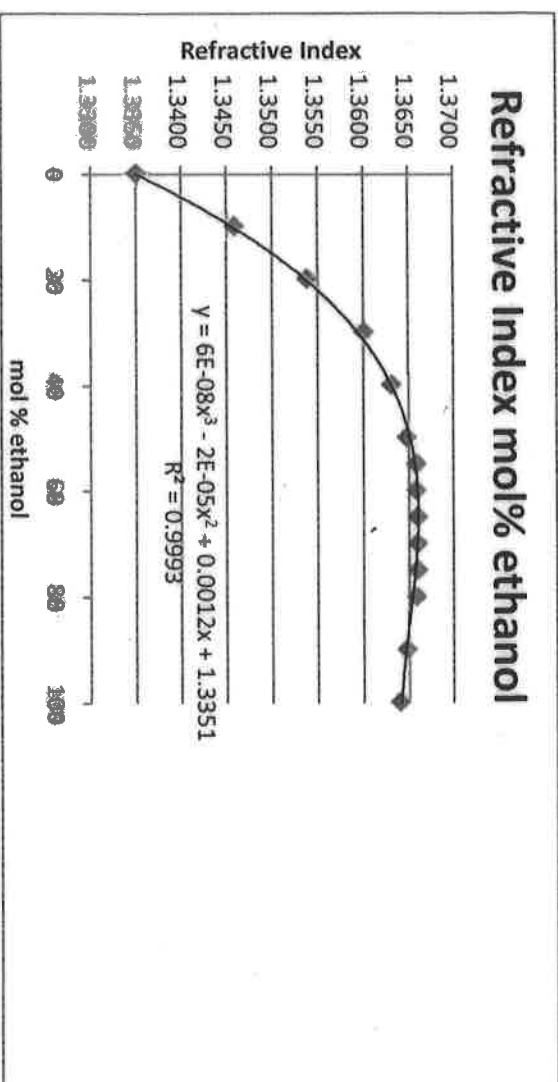


Figure 3: UOP3CC Process Unit

mol % ethanol Refractive Index Readings

0	1.335
10	1.3455
20	1.3508
30	1.35
40	1.3524
50	1.3548
55	1.3558
60	1.3558
65	1.356
70	1.356
75	1.356
80	1.3588
90	1.3648
100	1.364



mol ethanol	Mass
0.1	4.607
0.2	9.214
0.3	13.821
0.4	18.428
0.5	23.035
0.55	25.339
0.6	27.642
0.65	29.946
0.7	32.249
0.75	34.553
0.8	36.856
0.9	41.463
1	46.07

mol % water	mass
0.9	16.2135
0.8	14.412
0.7	12.6105
0.6	10.809
0.5	9.0075
0.45	8.10675
0.4	7.206
0.35	6.30525
0.3	5.4045
0.25	4.50375
0.2	3.603
0.1	1.8015
0	0

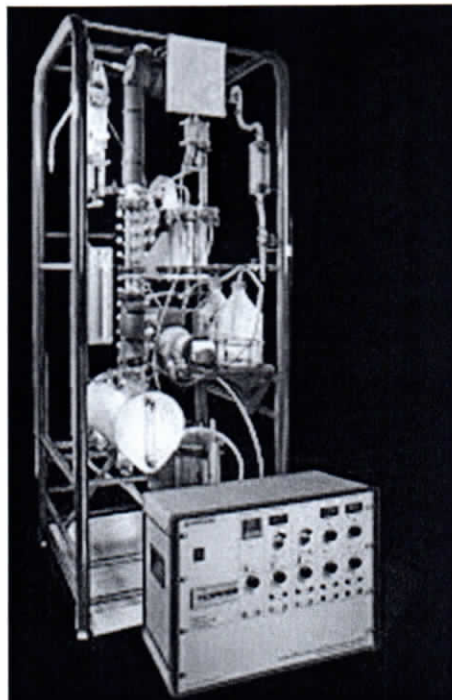
total mass
20.8205
23.626
26.4315
29.237
32.0425
33.44525
34.848
36.25075
37.6535
39.05625
40.459
43.2645
46.07

% ethanol
22.12723037
38.99940743
52.28988139
63.02972261
71.88889756
75.761132
79.32162534
82.60656676
85.64675263
88.46855497
91.09468845
95.83607808
100

Sample Graded Student Work

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

95
100



Rec'd 11/4
4:57pm

CHEG 4011- P03

Chemical Engineering Laboratory II

Lab #3:

McCabe-Thiele Method of Calculation for Number of Theoretical Stages

Date Due: November 4, 2019

Submitted by

Heaven McCray

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Submitted to

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Abstract

Fractional distillation is one of the critical separation operations utilized by the chemical industry. It is used in several sectors such as petroleum refineries, chemical plants, and natural gas processing plants, to purify and separate many organic compounds. A typical example of fractional distillation in industries is the separation of various components of crude oil.

The focus of the experiment was to determine the composition and flow rate of the distillate and bottoms. With the composition and flow rate available, the McCabe Thiele method is used to calculate the number of theoretical stages. A comparison of theoretical and actual steps was conducted to yield the overall efficiency of the column. Readings and data obtained through sampling allowed the tray temperatures, feed pump speed, and pressure drop to be detected. This *you haven't yet stated what the process is.* process was carried out with the Armfield UOP3CC Distillation column and a refractometer. Results should show a higher concentration of ethanol in the distillate in comparison to the bottoms. Overall, the experiment was successful as the objective was fulfilled, consistent results were obtained, and laboratory equipment was operated correctly and understood.

Tech	Engl
4	5

Tech / Eng
10 / 4
10 / 5

Theory

The purpose of this experiment was to calculate the theoretical number of stages for an equimolar mixture using the McCabe-Thiele method in a fractional distillation column.

Distillation involves a feed mixture of two or more components being separated into two or more products (Geankoplis 2003). Distillation is a cheap and efficient method for separating a liquid into its components. However, if the difference between the volatilities is small, ^{or} a mixture is very corrosive or extremely fouling, or a compound is thermally unstable, distillation is not a feasible prospect (Geankoplis 2003). Light components flow upward as a vapor, and heavy components

flow to the bottom of the column as a liquid. There are two types of distillation processes. There can be flash distillation or fractional distillation. For this experiment, fractional distillation was utilized to separate an equimolar ethanol-water mixture.

What is flash distillation? Define it to illustrate the difference between the 2 types of distillation

The three main characteristics to be studied in this experiment include the flow rate of the distillate, the flow rate of the bottoms, and the composition of the distillate and the bottoms in a distillation tower of a given size ^f eight sieve trays. By knowing this information, the theoretical number of stages can be obtained, and the overall efficiency can be calculated. Typically, the three factors that can affect the efficiency of a distillation column are liquid flow rates, gas flow rates, and the number of stages in the column. Figure 1 illustrates a conventional apparatus of a fractional distillation column.

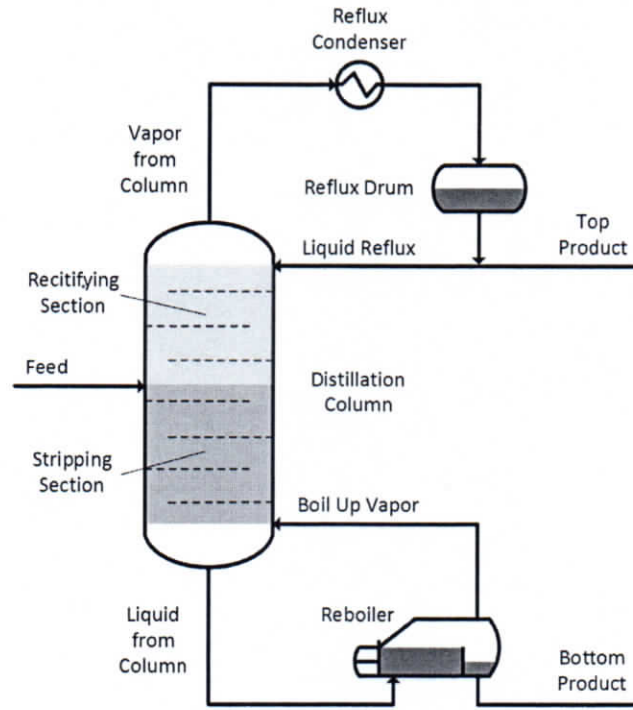


Figure 1. Basic Illustration of Fractional Distillation [“Mass Transfer Distillation” 2018]

Distillation towers are comprised of a rectification section, feed, and a stripping section. The rectification section involves the stages and equipment above the feed line, while the stripping section involves the stages and material below the feed line. Stages are known as sieve plates or trays. They are arranged vertically in the tower. Feed enters the side of the column, typically in the middle. The vapor enters the tray and bubbles through the liquid on the plate as the entering liquid flows across (“CHEG 4011 Laboratory Manual”). Vapor continuously ascends each tray, and it is continually contacted with down-flowing liquid. The vapor becomes enriched with the more volatile component, and the liquid is enriched with the high boiling point component (“CHEG 4011 Laboratory Manual”). At the top of the column, vapor exits and then enters an overhead condenser. Following the condenser, the overhead liquid separates into

distillate and reflux. The distillate is removed as the product, and the reflux is returned to the top tray. The reflux ratio is the ratio of reflux to the distillate. It is common for distillation columns to be operated with a fixed reflux ratio to obtain a desired concentration of product. Liquid leaving the final plate enters the reboiler at the bottom of the column to be partially vaporized. The partial reboiler is considered a theoretical stage (Geankoplis 2003). The liquid bottom product, which is rich in the high boiling point component, is removed. The vapor from the reboiler is returned to the bottom tray in the tower ("CHEG 4011 Laboratory Manual").

In fractional distillation, the liquid and vapor products flow countercurrent to each other. For the McCabe Thiele method, a few assumptions are made. The assumptions are listed below (Geankoplis 2003).

1. The vapor leaving the stage is in equilibrium with the liquid leaving the stage.
2. Liquid and vapor flow rates do not vary from stage to stage.
3. The mixture has a constant heat of vaporization, and the sensible heat and heat of mixing effects are negligible.

The steps to calculate the theoretical number of stages will be presented later in the report.

The total material balance for the tower is given by Equation 1.

$$V_{n+1} + L_{n-1} = V_n + L_n \quad (\text{Equation 1})$$

where,

V_{n+1} = vapor from tray n+1, mol/hr

L_{n-1} = liquid from tray n-1, mol/hr

V_n = vapor from tray n, mol/hr

L_n = liquid from tray n, mol/hr

The material balance for the more volatile component (component A) is given by the operating line equation, Equation 2.

$$y_{n+1}V_{n+1} + x_{n-1}L_{n-1} = x_nL_n + y_nV_n \quad (\text{Equation 2})$$

where,

y_{n+1} = mole fraction of A in V_{n+1}

x_{n-1} = mole fraction of A in L_{n-1}

x_n = mole fraction of A in x_n

y_n = mole fraction of A in V_n

For the rectifying section, the slope of the operating line is readily related to the reflux ratio, R. This is presented in Equations 3-6.

$$V = L + D \quad (\text{Equation 3})$$

where,

V = Vapor leaving column/entering condenser *molar flow*

L = Reflux *molar flow*

D = Distillate *molar flow*

$$\frac{L}{V} = \frac{L}{L+D} = \frac{L/D}{L/D + D/D} = \frac{R}{R+1} \quad (\text{Equation 4})$$

$$\frac{D}{V} = \frac{D}{L+D} = \frac{D/D}{L/D + D/D} = \frac{1}{R+1} \quad (\text{Equation 5})$$

The most useful form of the operating line for the rectifying section is presented in Equation 6.

$$y = \left(\frac{R}{R+1} \right) x + \left(\frac{1}{R+1} \right) x_D \quad (\text{Equation 6})$$

For the stripping section, the material balance is presented in Equations 7-9.

$$x_m \bar{L} = y_{m+1} \bar{V} - x_B B \quad (\text{Equation 7})$$

$$y_{m+1} = \frac{\bar{L}}{\bar{V}} x_m - \frac{B}{\bar{V}} x_B \quad (\text{Equation 8})$$

$$y = \frac{\bar{L}}{\bar{V}} x - \frac{B}{\bar{V}} x_B \quad (\text{Equation 9})$$

where,

B = Bottoms flow rate

x_B = mole fraction of A in the bottoms

$\bar{L}$ = liquid flow rate from bottoms

$\bar{V}$ = vapor flow rate from bottoms

The liquid and vapor flow rates in the stripping section may differ from the liquid and vapor flow rates from the rectifying section due to feed addition (Geankoplis 2003).

Feed conditions are another critical factor when using the McCabe-Thiele method. There are five possible feed conditions. The conditions include subcooled liquid, saturated liquid, mixture of vapor and liquid, saturated vapor, and superheated vapor. The condition of the feed, q , varies depend on the state of the feed. The feed line equation is presented in Equation 10.

$$y = \left(\frac{q}{q-1} \right) x - \left(\frac{x_F}{q-1} \right) \quad (\text{Equation 10})$$

where,

x_F = composition of the feed, mol %

The condition of the feed is calculated by Equation 11 below.

$$q = \frac{H_V - H_F}{H_V - H_L} \quad (\text{Equation 11})$$

Ethanol and water are an interesting separation mixture. The two components form an azeotrope. An azeotrope is a non-ideal system. It is defined as a mixture of two or more liquids in such a ratio that its composition cannot be changed by simple distillation (Geankoplis 2003). Ethanol-water is considered a minimum boiling point azeotrope at the composition of the liquid and vapor phase is the same at minimum temperature. *not clear*

The overall efficiency for the entire column can be calculated using the theoretical number of stages. This is demonstrated by Equation 12. This calculation for plate efficiency is simple, but it is the least fundamental. *explain*

$$\eta_0 = \frac{\text{number of ideal plates}}{\text{number of actual plates}} \quad (\text{Equation 12})$$

Procedure

Figure 2 shows the schematic diagram of the equipment layout.

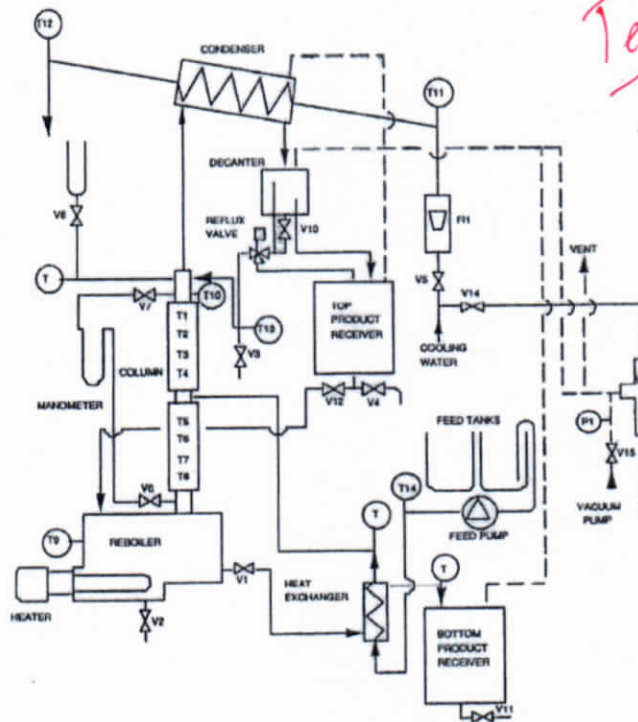


Figure 2. Schematic Diagram of the Armfield Column ["CHEG 4011 Laboratory Manual"]

The steps for the experiment are presented below.

1. Analyze entire column to locate the feed entrance, components of the rectifying section, and components of the stripping section.

2. Review the Armfield interface device to determine the pump setting. The volumetric flow rate of the feed will be determined using a calibration curve for the pump setting versus feed flow.
3. After letting the column reach steady state, record the tray temperatures displayed on the Armfield software.
4. Before collecting samples from each section, drain the entire system to ensure the accurate collection of results.
5. Begin collecting samples of the distillate by opening valve, V3, to allow flow from the overhead condenser.
6. Collect 3 samples of 50 mL. Make sure to record time while filling up the graduated cylinder from 0 to 50 mL. This will be used to determine the flow rate of the overhead and distillate.
7. Take the 3 samples to the refractometer to obtain the refractive index and temperature of each sample.
8. Take the average of all three refractive index values to aid in determining the concentration of ethanol in the distillate.
9. Open valve, V1, to begin obtaining samples from the stripping section.
10. Repeat steps 6-8 for the stripping section

The average refractive index values calculated in step 8 for the distillate and bottoms will be used on the refractive index graph to determine composition of ethanol in both sections.

Tech / Engl
28 / 30
NA

Data and Results

For this experiment, the objective was to calculate the number of theoretical stages, the feed flow, the distillate flow rate, the bottoms flow rate, and the composition of the distillate and bottoms. Table 1 lists constant variables and other information given in the laboratory manual and lab setup.

Table 1. Constant Variables Given by Laboratory Manual and Laboratory Equipment Setup

Parameter	Value
Pump Setting	1.3
Reflux Ratio	5
Feed Location	Between stage 4 and 5
Number of Actual Trays	8
Pressure Drop in Column (during normal operation)	83 mmH ₂ O
Pressure Drop in Column (during distillate sampling)	75 mmH ₂ O
Pressure Drop in Column (during bottoms sampling)	80 mmH ₂ O
Feed Composition, x_F	0.5 mol

x_F - define ~~off~~
wrt component

Good use of Table

The temperature for each tray is presented in Table 2.

Table 2. Temperature of Each UOP3CC Column Tray

Tray No.	Temperature (°C)
1	77.9
2	78.2
3	78.7
4	78.9
5	79.3
6	79.4
7	79.9
8	80.4
Reboiler	83.0

An increase in tray temperature is present as fluid flows further down the column. This is due to the reboiler being located at the bottom of the column and the condenser being at the top of the column.

Using the pump calibration equation (Equation 13), the feed pump speed can be determined. The calculation is shown below.

$$y = 1.304 x - 0.6333 \quad (\text{Equation 13})$$

where,

y = Flow Rate (L/hr)

x = Pump Setting

$$y = 1.304 (1.3) - 0.6333 = 1.0619 \text{ L/hr}$$

The results obtained from the experiment are presented below in Table 3.

Table 3. Experimental Data Obtained from Sampling and Refractometer Analysis

Sample Location	Sample No.	Volume (L)	Time (hr)	Refractive Index	Refractometer Temperature (°C)
Distillate	1	0.05	0.029	1.363	22.3
	2	0.05	0.029	1.367	22.3
	3	0.05	0.029	1.365	22.2
Average:		0.05	0.029	1.365	22.3
Bottoms	4	0.05	0.069	1.361	22.3
	5	0.05	0.070	1.360	22.4
	6	0.05	0.070	1.359	22.5
Average:		0.05	0.070	1.360	22.4

The distillate flow, D:

$$\frac{0.05 \text{ L}}{0.029 \text{ hr}} \times \frac{1}{5} = 0.3434 \text{ L/hr}$$

The value is divided by five because the reflux ratio is five. Five parts return to the column while one part is stored in the distillate product container.

The bottoms flow, B:

$$\frac{0.05 \text{ L}}{0.070 \text{ hr}} = 0.7187 \text{ L/hr}$$

Verifying the overall mass balance,

$$F = D + B$$

$$0.3434 + 0.7187 = 1.0621 \text{ L/hr} \approx 1.0619 \text{ L/hr} \quad +$$

*You need to convert
to a molar flow rate*

Figure 3 shows the refractive index that was used to determine the composition of the distillate and the bottoms product.

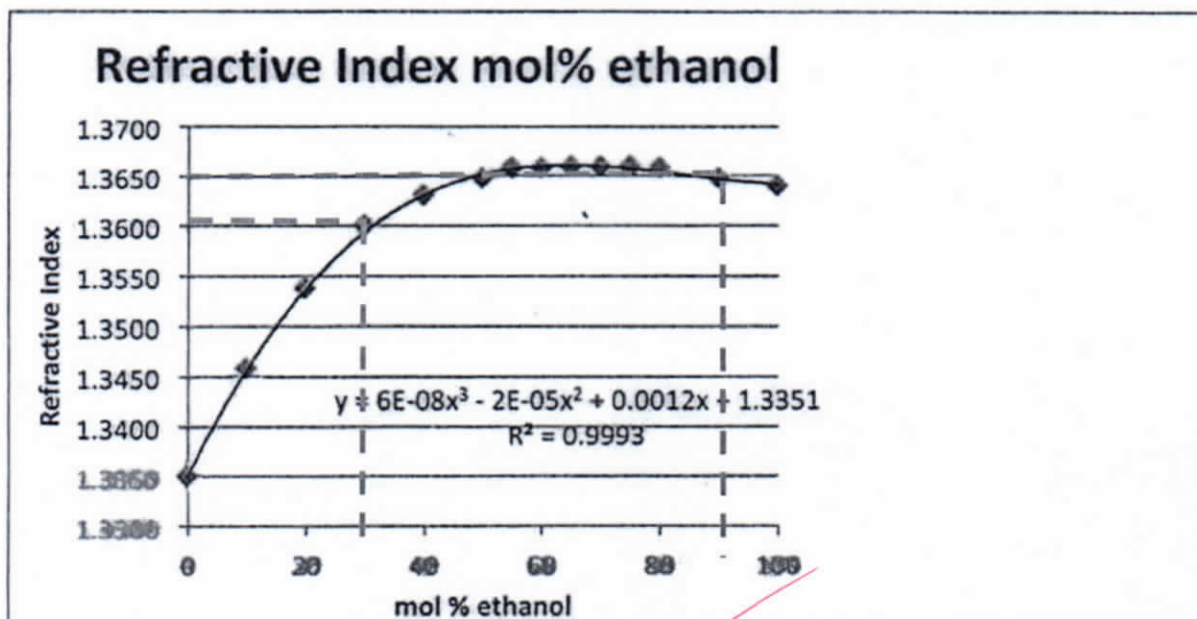


Figure 3. Refractive Index for Mole Percent of Ethanol ["CHEG 4011 Laboratory Manual"]

For the distillate, x_D :

The equation presented on Figure 3 does not yield a reasonable value for the refractive index obtained. To obtain a composition, interpolation was conducted. The distillate composition is estimated to be between 80 and 100 mol % of ethanol since 45 mol % is close to the feed composition. Therefore,

$$\frac{x_D - 80}{100 - 80} = \frac{1.365 - 1.3658}{1.364 - 1.3658}$$

$$x_D = 88.89 \text{ mol \% ethanol}$$

For the bottoms product x_B :

Similar to the distillate composition, interpolation was conducted to obtain the value. The bottoms composition is estimated to be between 20 and 40 mole % of ethanol. Therefore,

$$\frac{x_B - 20}{40 - 20} = \frac{1.360 - 1.3538}{1.3631 - 1.3538}$$

$$x_D = \mathbf{33.33 \text{ mol \% ethanol}}$$

Using an ethanol-water Txy diagram at 1.013 kPa, at a feed temperature of 79°C and a composition of 50 mol% ethanol, the feed is considered a subcooled liquid. This means the

condition of the feed is greater than 1. An enthalpy concentration graph was used to obtain the proper values.

$$q = \frac{H_V - H_F}{H_V - H_L} \quad (\text{Equation 11})$$

$$= \frac{320 \text{ k cal/kg} - 80 \text{ k cal/kg}}{320 \text{ k cal/kg} - 90 \text{ k cal/kg}} = 1.04$$

With the necessary parameters defined and evaluated, the number of theoretical stages can be calculated.

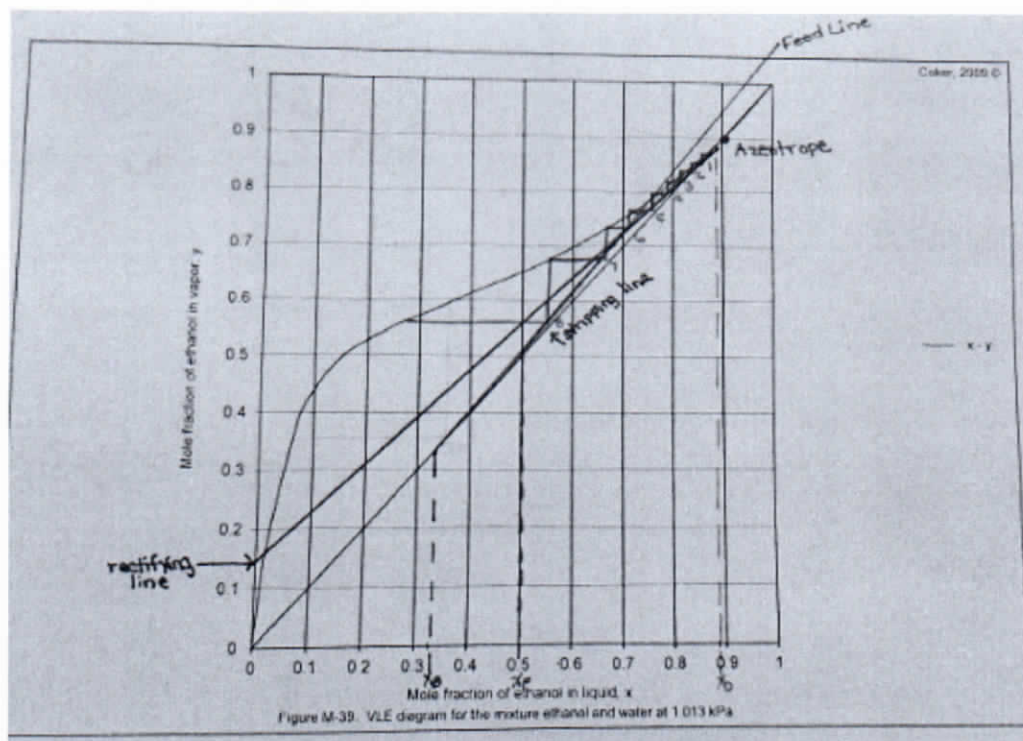
Rectifying operating line:

$$y = \left(\frac{5}{5+1} \right) x + \left(\frac{1}{5+1} \right) 0.889 = \frac{5}{6} x + 0.148$$

Feed line equation:

$$y = \left(\frac{q}{q-1} \right) x - \left(\frac{x_F}{q-1} \right) = y = \left(\frac{1.04}{1.04-1} \right) x - \left(\frac{0.5}{1.04-1} \right) = 26x - 12.5$$

Figure 4 shows the McCabe Thiele method for calculating the theoretical number of stages.



Copy the graph directly and make annotations on the graph using the drawing feature in the software

Figure 4. Theoretical Results using the McCabe Thiele Method

The theoretical number of stages is 8 minus 1 for the reboiler, so there are 7 stages. *okay*

The overall efficiency is calculated below using Equation 12.

$$\eta_0 = \frac{\text{number of ideal plates}}{\text{number of actual plates}} \quad (\text{Equation 12})$$

$$\eta_0 = \frac{7}{8} = 0.875 = 87.5\% \quad \text{okay}$$

Discussion

The Armfield UOP3CC Distillation column is a small scale distillation column used for basic experiments to simulate separation technology. The Scientific Cat No.FS1396410 is an instrument used to measure the temperature and refractive index of a solution within the analysis.

*Tech/Engl
15/5*

These two pieces of equipment are used for determining the flow rate and composition of the distillate and bottoms. Using the calculated flow rates and concentrations, the number of theoretical stages is obtained using the McCabe Thiele method. The software determined the temperature of each tray. The temperature was the highest in the last plate since it was the closest to the reboiler. The higher the tower ascends, the lower the temperature. It is essential to know that the boiling point of water is 100°C , and the boiling point of ethanol is 78.4°C . With ethanol having the lower boiling point, it ascends the tower as a vapor while liquid concentrates in the bottoms.

The results obtained from the experiment, including the findings of the solutions refractive index and temperature, are averaged to yield a single value. The refractive index was determined by a calibration curve provided by the laboratory instructor. The equation for the refractive index was not able to yield a consistent result, so interpolation was used to obtain the mole percent of ethanol in the distillate and bottoms. The McCabe Thiele method required knowledge of the rectifying section, the feed line, and the stripping section. The Armfield UOP3CC Distillation column had eight actual trays. Results showed that there were seven theoretical stages. The overall efficiency of the column was 87.5%. The azeotrope was also able to be identified on the VLE diagram.

Conclusions

In conclusion, the overall efficiency of the distillation column for the ethanol-water mixture is 87.5% As shown in Figure 4, from calculating the theoretical stages of the distillation column, which is eight but due to the reboiler one is subtracted leaving seven theoretical stages.

run on sentence

Tech	Engl
9/10	NA

The tray temperature was determined using the Armfield software, and the refractometer yielded refractive ^{indices} indexes that evaluated the composition of the distillate and bottoms. Overall, the experiment was successful, as each objective was able to be understood and addressed. Principles surrounding the fundamental equations and concepts of distillation columns were effectively used to complete the experiment.

Human factor was a possible cause of the error when determining the flow rates and refractive indexes. These were both based on the human eye and hand coordination measurements. A possible improvement would be to configure the software so that the values can be more accurately calculated to yield more precise results.

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Jan. 2018, [https://www.thegatematrix.com/today-](https://www.thegatematrix.com/today-dcb.php?date=MjAxOC0wMS0xNQ)

[dcb.php?date=MjAxOC0wMS0xNQ](https://www.thegatematrix.com/today-dcb.php?date=MjAxOC0wMS0xNQ).

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There are zero ABOVE AVERAGE student samples available.

CHEMICAL ENGINEERING
OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET
CHEG 4011 CHEMICAL ENGINEERING LABORATORY
II
FALL 2019

Instructor: Dr. Keisha Antoine

Title of Assignment

Introduction to Pump Characteristics and Performance

Outcome Measured Using this Assignment

Outcome 6

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

Check the communication problem characteristics related to this assignment

Ability to develop experiment Requires students to	
☒	Identify the appropriate parameters or variables and relationships (independent, dependent and control variables),
☒	Identify and select appropriate equipment or components for measuring the parameters
☒	Provide steps for setting up and conducting the experiment and
☒	Identify data collection method to support experiments (if needed)
Ability to conduct experiments Requires students to	
☒	Conduct experiment while maintaining all safety precautions
☒	Demonstrate knowledge of how to use the equipment safely
☒	Collect and record data using appropriate units of measurement and significant figures
Ability to analyze and interpret experimental data Requires students to	
☒	Present the data (raw /derived) in tabular or graphical form to meet the objectives and to aid in interpretation
☒	Use appropriate statistical analysis methods to analyze and interpret data
☒	discuss the raw and derived data/graphs and assess the validity of the results
Demonstrate the use of engineering judgement in the development and analysis of the experiment Requires students to	
☒	Draw appropriate conclusions and recommendations using engineering judgement.

Brief justification of why this assignment is suitable for this outcome

This is a laboratory experiment which in its nature, tests the outcome outlined above.

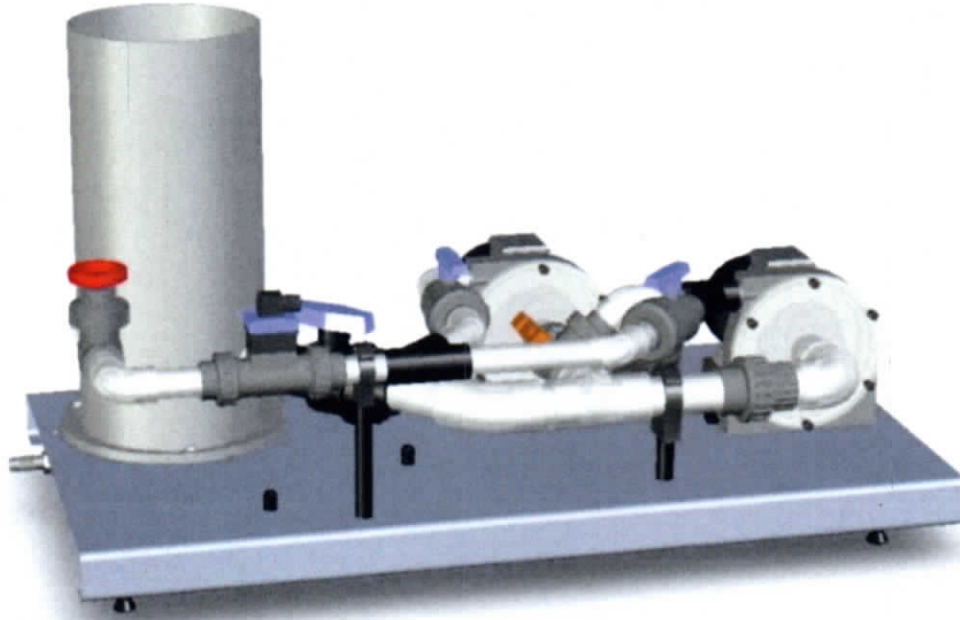
CHEG 4011 CHEMICAL ENGINEERING LABORATORY II
FALL 2019

ASSIGNMENT STATEMENT/QUESTIONS
GRADING SCHEME FOR INTRODUCTION TO PUMP
CHARACTERISTICS AND PERFORMANCE

Sample Graded Student Work

62/100

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



CHEG 4011- P03

Chemical Engineering Laboratory II

Lab #1:

Introduction to Pump Characteristics and Performance

Date Due: October 7, 2019

Submitted by

Heaven McCray

Jordan Smith

Christen Augustine

Chantel Robinson

Submitted to

Dr. Keisha Antoine

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Tech / Eng
4/5 | 5/5

Abstract

Centrifugal pumps are commonly used for pumping water, solvents, organics, and oils in industrial, agricultural, and domestic applications. The use of centrifugal pumps is paramount when dealing with separations and fluid mechanics such as transporting fluids throughout a plant from one place to another.

The purpose and focus of the experiment were to obtain head, power and efficiency graphs for a centrifugal pump. Readings were obtained from the centrifugal pump and associated sensors across a range of flow rates through the pump for the data.

Some critical findings that were discovered during the experiment were that as pressure increased within the system, the total head generated, and the efficiency of the pump increased, but the pump hydraulic power remained constant.

Results also suggest that some of the equipment in the experiment is defective as the software used to conduct the experiment did not calculate a torque value which is necessary to figure out the power input to the pump. With these limitations, the power input could still be calculated by hand and with that, all parameters in the experiment that were unknown could be found.

Tech / Eng
9 / 5

Theory

The purpose of this experiment was to study the performance **and** characteristics of a centrifugal pump. Ideally, five parameters should be monitored and analyzed to understand how well a pump is performing: suction pressure, discharge pressure, flow, pump speed, and power (Kernan).

The three main characteristics to be studied in this experiment include total head, pump efficiency, and pump mechanical power. These are the most commonly used graphical representation of pump performance (*Armfield Ltd Instruction Manual*). Pump performance curves are primarily used to predict the variation of the differential head across the pump as the flow fluctuates. The curves help users to understand characteristics such as variation of differential head, power requirement, NPSH requirement and pump efficiency, along with variation of operating flow ("Theory and Equations for the Centrifugal Pumps"). Figure 1 illustrates the basic layout of a centrifugal pump.

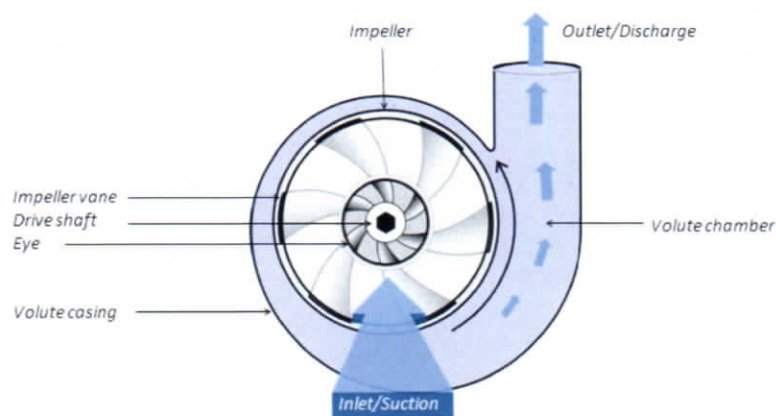


Figure 2. Volute case design

Figure 1. Basic Illustration of a Centrifugal Pump ["Useful Information on Centrifugal Pumps"]

Pump head describes pressure in terms of distance. Pressure can be converted between units of distance and units of force per unit area by the conversion of 2.31 ft of head to 1 psi for water (Wakefield 2019). This conversion is different for different fluids. Total head includes changes in static head, velocity head, and elevation. The change in total head produced due to the work done by the pump can be calculated by Equation 1. The equations listed in this section were obtained from the laboratory manual provided for the course.

how else can you do this conversion?

$$H_t = H_s + H_v + H_e \quad (\text{Equation 1})$$

where,

H_s = Change in static head, m

H_v = Change in velocity head, m

H_e = Change in elevation, m

Equation 1 mirrors Bernoulli's equation as a conservation of energy principle. The Bernoulli equation cites the lowering of fluid pressure when the fluid speed increases ("Bernoulli Equation"). Bernoulli's equation is presented in Equation 2 below.

Good

$$P_1 + \frac{1}{2}\rho V_1^2 + \rho gh_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho gh_2 \quad (\text{Equation 2})$$

where,

ρ = density

g = gravity

This eq'n neglects pump work and friction loss and you should state this

The variables P_1 , V_1 , and h_1 refer to the pressure, speed, and height of the fluid at an initial point, and the variables P_2 , V_2 , and h_2 refer to the pressure, speed, and height of the fluid at a secondary point.

In rotodynamic machine technology, it is practical to express the Bernoulli equation in terms of head ("Bernoulli's Equation" 2007). When the Bernoulli equation (Equation 2) is divided by gravity and rearranged, the following equation (Equation 3) is developed.

$$\underbrace{\frac{P_1}{\rho g}}_1 + \underbrace{\frac{1}{2} \frac{V_1^2}{g}}_2 + \underbrace{h_1}_3 = \frac{P_2}{\rho g} + \frac{1}{2} \frac{V_2^2}{g} + h_2 \quad (\text{Equation 3})$$

Equation 3 expresses the relationship between static head (1), velocity head (2), and potential head (3). Frictional loss and shaft work were not included in the Bernoulli equations above. *You state it here*

The change in elevation is defined as the vertical distance between the inlet and outlet (*Armfield Ltd Instruction Manual*, November 2015). For this experiment, the H_e value was 0.075 m. Static head measures the total vertical distance that a pump raises water (Wakefield 2019). It is comprised of static lift and static discharge. The change in static head, H_s , is calculated by Equation 4.

$$H_s = \frac{P_{OUT} - P_{IN}}{\rho g} \quad (\text{Equation 4})$$

where,

ρ = density, kg/m^3

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

P_{IN} = fluid pressure at inlet, Pa

P_{OUT} = fluid pressure at outlet, Pa

The change in velocity head, H_V , is calculated by Equation 3.

$$H_V = \frac{(V_{OUT}^2 - V_{IN}^2)}{2g} \quad (\text{Equation 5})$$

where,

V_{IN} = Fluid velocity at inlet, m/s

V_{OUT} = Fluid velocity at outlet, m/s

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

The mechanical power input to the pump is determined by the product of rotational force and angular distance. The formula is shown as Equation 6.

$$P_m = \text{rotational force} \times \text{angular distance} = 2\pi nt \quad (\text{Equation 6})$$

where,

n = rotational speed of pump, revolutions per second

t = shaft torque, Nm

Torque is defined as a measure of the force that can cause an object to rotate about an axis ("Torque").

Pump efficiency measures the efficiency with which the pump transfers useful work to the fluid (“Centrifugal Pumps”). Pump efficiency can be determined by Equation 7.

$$E = 100 \times \frac{P_h}{P_m} \quad (\text{Equation 7})$$

where,

P_h = hydraulic power imparted to the fluid, W

P_m = mechanical power absorbed by pump, W

The hydraulic power, P_h , can be calculated by Equation 8, shown below.

$$P_h = H_t \times Q \times \rho \times g \quad (\text{Equation 8})$$

where,

H_t = change in total head, m

Q = volumetric flow rate, m^3/s

ρ = density, kg/m^3

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

It is important to mention that each of the above listed parameters is measured at a constant rotational pump speed of 1440 rev/sec. The main three characteristics discussed are plotted against the volumetric flow rate to analyze pump performance. An example of the graphical representation will be presented later in the report (Figure 6).

Tech / Eng 1
8 / 3.5
10 / 5

7

Procedure

To obtain head, power, and efficiency data for a centrifugal pump, the FM51 Series and Parallel Pump Demonstration Unit and water was used. The relationship between the three factors was determined by obtaining several readings from a centrifugal pump and associated sensors across a range of flow rates. Figure 2 offers a schematic of the fluid flow throughout the experiment.

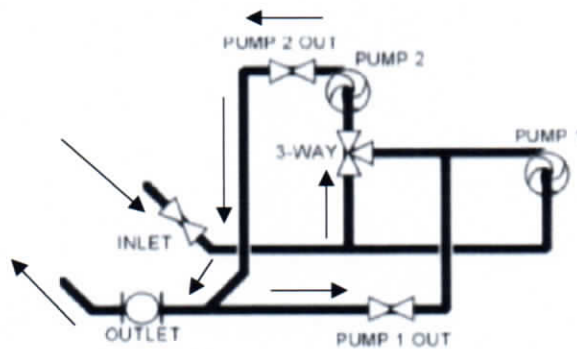


Figure 2. Schematic of Piping, Valve and Pump Layout [“Armfield Ltd Instruction Manual”]

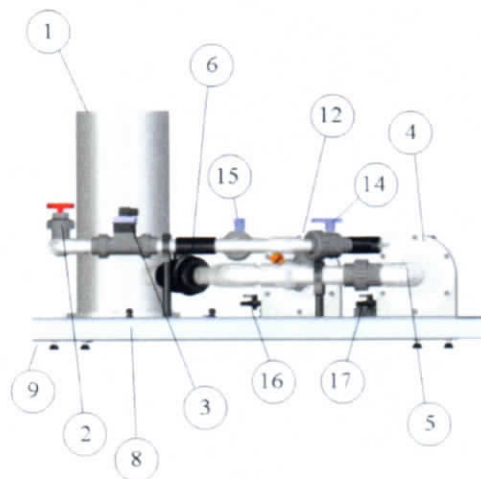


Figure 3. Front View of FM51 Series and Parallel Pumps Demonstration Unit [“Armfield Ltd Instruction Manual”]

Table 1 identifies the numbered equipment pictured in Figure 2.

Table 1. Equipment Identification for the FM51 Pumps Demonstration Unit

Equipment No.	Equipment Name
1	Reservoir
2	Outlet
3	Flow Sensor
4	Pump 1
5	Pressure Sensor
6	Inlet
8	Base Plate
9	Drain Valve
12	Pump 2 with Flow Sensor
14	Pump 1 Outlet
15	Pump 2 Outlet
16	Drain Valve
17	Drain Valve

Pump 2 was driven at a fixed speed of ¹⁰⁰80% of a ⁶⁰50 Hz electrical supply. The flow rate through the pump was manually controlled using the ^{not listed in your table}gate valve, causing the back pressure on the pump; therefore, the head is being forced to do work. This is significant in creating variations within the data so that flow rate, power, and efficiency can be calculated. The flow rate was not controlled by the inlet valve to avoid damaging the system. When adjusting the flow rate, the gate valve was turned in increments of about 25%. The readings for each variable (flow rate, efficiency, power, and head) were recorded several times to obtain an average value. When the gate valve was opened, approximately 30 seconds passed before the data was collected to ensure the sensor was stabilized. The gate valve was opened in the specified increments until the valve was fully open. Concluding the experiment, all data is collected in the programs table and exported as an Excel file for later data analysis.

Are you saying different things?

Tech
25
30

Eg 1
NA

Data and Results

For this experiment, the objective was to measure the head, power, and efficiency of the centrifugal pump (Pump 2) at various flow rates. Table 2 lists constant variables and other information given in the laboratory manual.

Table 2. Constant Variables Determined by Armfield FM51 Software

Parameter	Value
Pump Setting, S	80%
Pump Speed, n	1440 rpm*
Inlet Pressure, P_0	2.7 kPa
Water Temperature, T	23.4 °C
Pump 1 Pressure	1.7 kPa
Density of Water, ρ	997 kg/m ³
Inlet Diameter, d_{IN}	0.0235 m
Outlet Diameter, d_{OUT}	0.0175 m
Change in Elevation Head, H_s	0.075 m
Operating Mode	Single

not important/
not working

*The value should have been 3,000 rpm for 80%, since
(50 rev/sec) $\times$ (60 sec/min) = 3,000 rpm.

$60 \frac{rev}{sec} \times \frac{60 \frac{min}{sec}}{60} = 3600 \frac{rev}{min}$
You should have used your calculated value

Each data point used for analysis is an average of four replicates obtained from the software. The valve that controls the inlet was opened a quarter turn (25%) at a time until the valve is fully opened.

The FM51 Software did not calculate a torque value throughout the experiment. Using the above equation for mechanical power input, P_m , the torque can be calculated as followed:

$$P_m = \text{rotational force} \times \text{angular distance} = 2\pi nt \quad (\text{Equation 4})$$

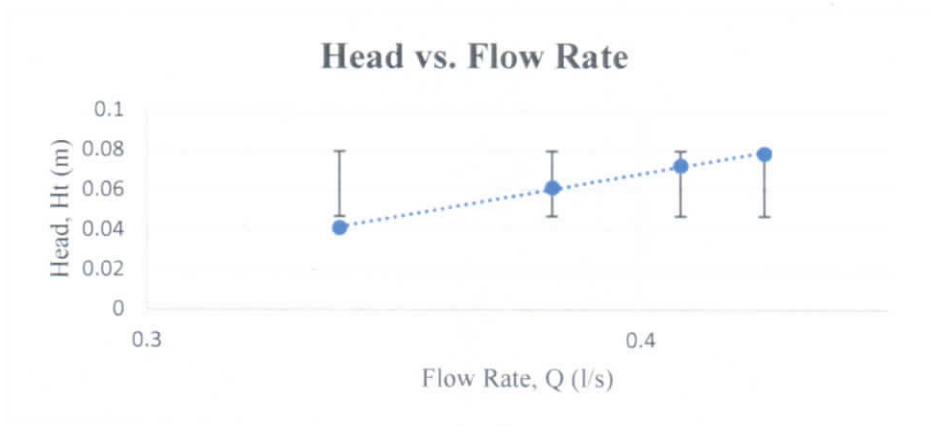
$$P_m = 2\pi nt$$

$$0.5 W = 2\pi(1440 \text{ rpm})t$$

$$0.5 \text{ W} = 2\pi(1440 \text{ rev/min})/(60 \text{ sec/min})t$$

$$t = 3.316 \times 10^{-3} \text{ N.m}$$

Figure 4 shows head versus flow rate while Figure 5 shows mechanical power versus flow rate and flow rate versus efficiency.



Interesting. You didn't observe a max Head?

Figure 4. Head vs. Flow Rate Results

Overall, the results show that the change in head and the flow rate have a directly proportional relationship. How do you know this? Is there a mathematical relationship that shows this?

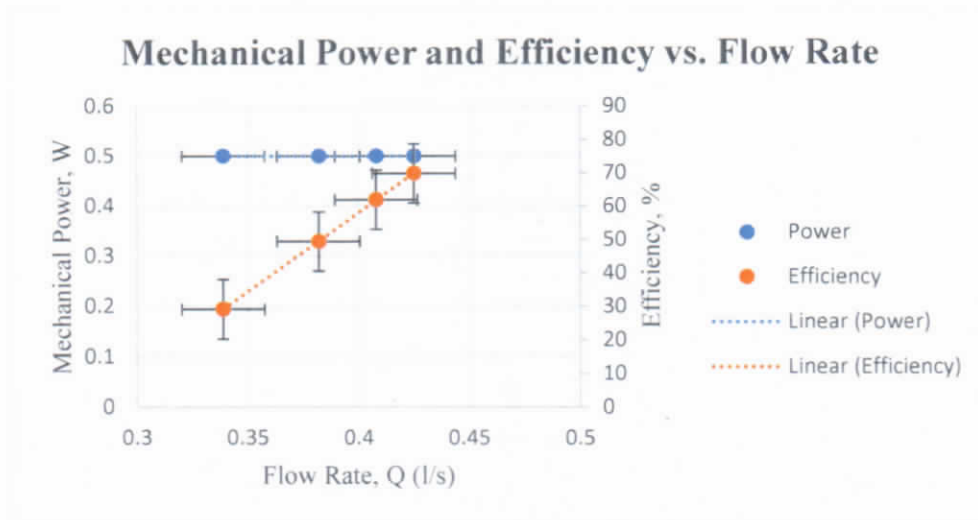


Figure 5. Mechanical Power and Efficiency vs. Flow Rate Results

Overall, the efficiency of the pump and flow rate have a directly proportional relationship. However, the power input remained constant across various flow rates.

Discussion

The FM51 Series and Parallel Pump Demonstration Unit is small scale equipment usually used in all production factories that include a holding of a liquid used during their production process. Most plants always include more than one pump, in which the second is titled as a “back up” ^{to be used in case of} due to complications or maintenance issues (Beebe 2004). The FM51 equipment typically has two pumps, but only Pump 2 was utilized for the experiment due to complications with Pump 1. Figure 6 shows the expected performance results for a centrifugal pump (“Armfield Ltd Instruction Manual”).

Expt only looked at Pump 2 Pump 1 was not a factor for this expt.

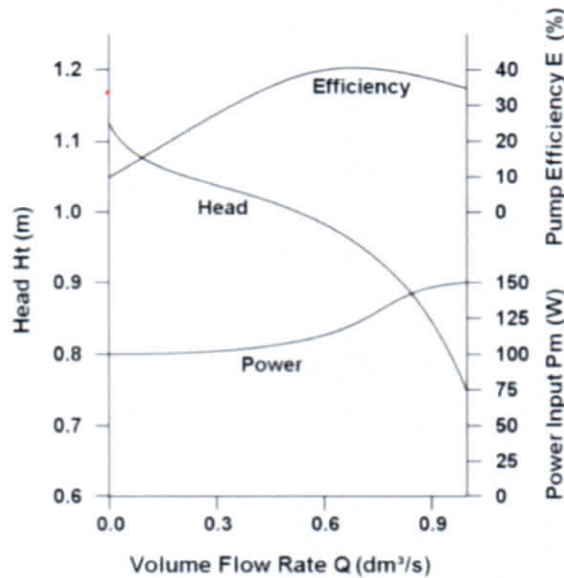


Figure 6. General Performance Curve ["Armfield Ltd Instruction Manual"]

The head curve in Figure 6 correctly shows the relationship between head and flow rate. *'Inverse' and 'proportional' have specific mathematical meanings.*
 The change in head decreases while the flow rate increases, resulting in an inverse relationship.
 However, the results obtained from the experiment (Figure 4) state that head and flow rate are directly proportional. Therefore, there is either a programming issue with the collection of data or an equipment sensor issue. *Or, maybe the Q wasn't over a large enough range.*

The power curve shown in Figure 6 demonstrates the relationship between the power input to the pump and the change in flow rate through the pump. *Hydraulic power, yes. Mechanical power? Not that simple.*
Power should increase with the flow rate; however, results in Figure 5 show that the power input remained constant. The data showed an experimental error in the mechanical pump power due to the value remaining stagnant at 0.5 W. There should be changes due to the results for the pump's efficiency and pump

hydraulic power. After further review, it was determined that mechanical power remained constant because the power supply received remained constant.

Efficiency curves are used to show the pump's capacity at which the pump operates most efficiently. In both Figures 5 and 6, efficiency increased with flow rate. Typically, efficiency changes [?]are the system discharge is throttled. In the experiment, the optimum operating capacity is 0.43 L/s. Possibly, a significant enough flow rate range was not investigated to determine the maximum efficiency of pump 2. When selecting a pump for an application where the typical operating capacity is known, a pump should be chosen so that its optimum efficiency is at or very near that capacity.

Conclusions

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10

Engl
NA

In conclusion, efficiency and power should increase as the volumetric flow rate through the pump increases. Head and volumetric flow rate should be ^{no}inversely proportional. The data obtained showed that efficiency and total head increased with the flow rate, and power remained constant across various flow rates. This can be due to sensor errors and equipment deficiencies. Overall, the experiment was rather unsuccessful as the anticipated correlations for flow rate, head, and power were not demonstrated. However, principles learned in Unit Operations, such as Bernoulli's equation was presented in a real-world application.

After conducting the experiment and discussing the results, there are a few recommendations that can be included in this experiment to produce better results and data. One

proposal that arose for further experimentation would be to ensure that all sensors and pumps are calibrated and operating correctly to ensure adequate measurements and accurate data collection. For example, 50 Hz did not yield the expected 3,000 rpm. With proper data collection, the anticipated results described by engineering literature can be seen and verified. Another recommendation that can potentially enhance this experiment is to vary the pump setting from 80%. With this pump setting variation, a comparison for the three main characteristics (head, efficiency, and power) can be obtained for various rotational pump speeds.

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**OUTCOME “6” SPECIFIC ASSIGNMENTS USED TO
ASSESS THE OUTCOME IN**

CHEMICAL ENGINEERING LABORATORY II

**CHEMICAL ENGINEERING DEPARTMENT
OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET
CHEMICAL ENGINEERING LABORATORY III
SPRING 2020**

Instructor: Dr. Jorge F. Gabitto

Title of Assignment

Design of Experiments Presentation

Outcome Measured Using this Assignment

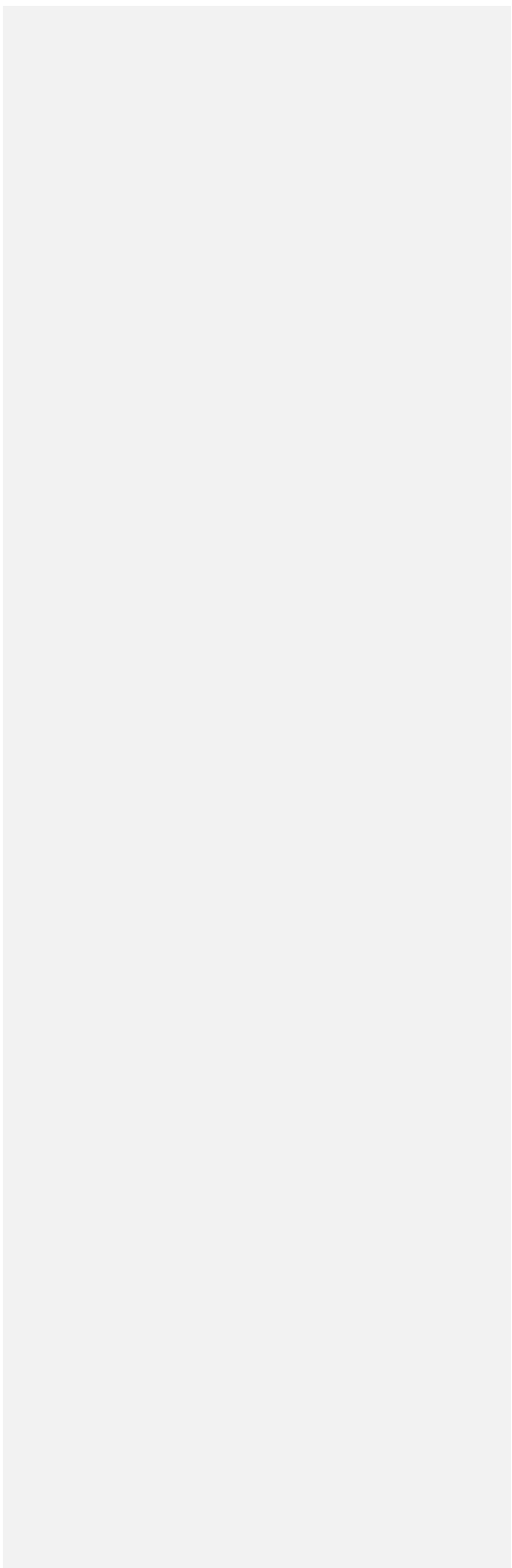
Outcome 6

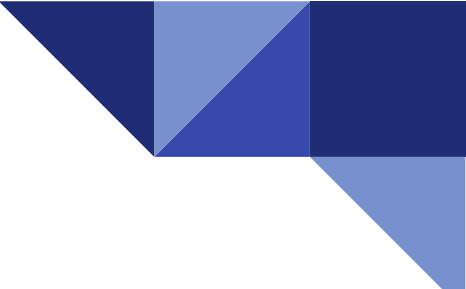
An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

Brief justification of why this assignment is suitable for this outcome

This assignment demonstrates the ability of students to propose a new experiment considering feasibility, safety, cost, other relevant considerations.

Sample Work





Esterification Reaction

By: Ashley Gutierrez

Saidou Niandou Hassane

Patricia Ujeyah

Jaliil Zoundi

Overview

- Problem Statement
- Theory
- Abstract
- Experimental Set-Up
- Procedures
- Expected Results
- Discussion
- Conclusion
- References



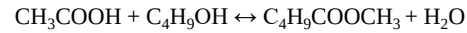
Problem Statement

- Determine the reaction rate constants for the forward and backward reactions for esterification of acetic acid and n-butanol at different temperatures



Theory

Reaction:



Acetic Acid + Butanol $\leftrightarrow$ Butyl Acetate + Water

Kinetic Model:

Among all the models the simplest model is the pseudo homogeneous model given by the following equation;

$$-r_{\text{C}_4\text{H}_9\text{COOH}} = K_1 C_{\text{C}_4\text{H}_9\text{COOH}} C_{\text{C}_4\text{H}_9\text{OH}} - K_2 C_{\text{C}_4\text{H}_9\text{COOCH}_3} C_{\text{H}_2\text{O}}$$

Where K is the reaction equilibrium constant (i.e. k_1/k_2) that can be independently calculated using the following relation:

$$\ln \frac{K}{K^0} = \frac{\Delta H_R^{0(L)}}{R} \left[\frac{1}{T_0} - \frac{1}{T} \right]$$

Where: $K^0 = \exp \left[-\frac{\Delta G_R^{0(L)}}{RT_0} \right]$

Data: $\Delta H_R^{0(L)} = -3.887 \frac{\text{kJ}}{\text{mol}}$, $\Delta G_R^{0(L)} = -8.89 \text{ kJ/mol}$



Abstract

- The synthesis of butyl acetate is done through esterification of acetic acid with-butanol
- Esters has many wide applications, as well as a versatile solvent within the chemical industry
- Within this experiment:-
 - presence of acid catalyst
 - Catalyst- Solid heterogeneous
 - Reactions takes place on the surface of the catalyst



Equipment Set-Up

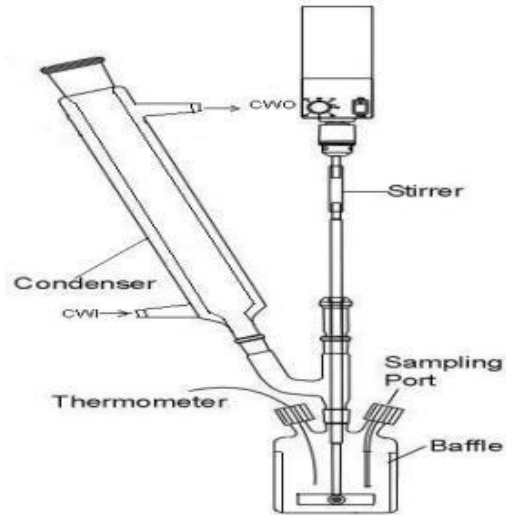


Figure 1: Experimental Set up

Equipment Used:

Thermometer,
Condenser,
Sampling Port,
Stirrer, and Baffle

Procedure

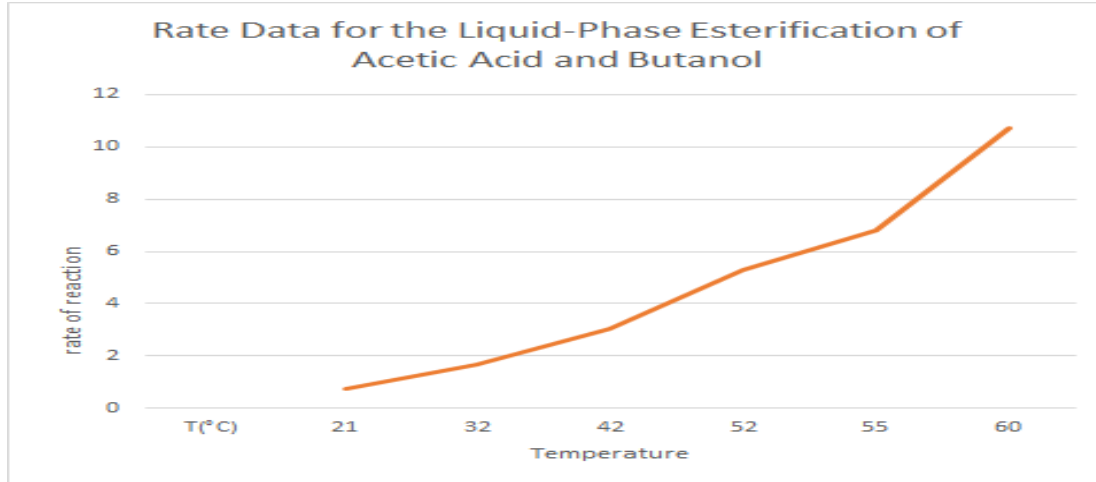
1. Set the temperatures of the heating chambers (at least four) at the desired levels and start heating.
2. Take measured quantities of acetic acid and n-butanol in the two reactors.
3. Place the reactors in the oil baths, start slow stirring and observe the reactor temperature.
4. Once the desired temperature of the reaction mixture is attained, add the measured quantity of cation exchange resin (Amberlyst-15) in the reactor. Consider this time as the zero reaction time.
5. Increase the speed of agitation to 1200 rpm.
6. Remove samples from all the reactors.
7. Keep removing the samples as per the time intervals indicated in the tables.
8. Titrate weighed quantity of the sample against 0.5 M NaOH.
9. Record the titration readings and calculate conversions at every time interval.



Expected Result

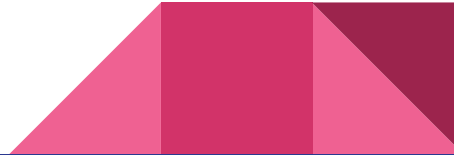
Column1	Column2	Column3
T(°C)	$r_0 * 10^3 {}^a (mol L^{-1} min^{-1})$	$K_{auto} * 10^6 {}^b (L^2 mol^{-1} min^{-1})$
21	0.76	0.97
32	1.68	2.15
42	3.03	3.87
52	5.3	6.77
55	6.83	8.73
60	10.7	13.7

Result Graph



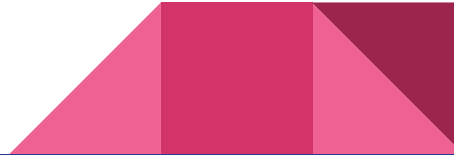
Discussion

- From the result we can observe an increase in the rate of reaction as the temperature increases
- This reaction is therefore temperature sensitive
- To reach a greater yield the temperature needs to be reach 60°C



Conclusion

- Esterification Reaction of Acetic Acid with butanol was successful
- Investigations were conducted with the effect of molar ratios, temperatures, and catalyst
- A stir speed ≥ 800 rpm was found sufficient for eliminating external diffusion
- The conversion of the alcohol increased with increasing temperatures and initial amount of acid



Conclusion cont.

- Safety: Hazard: flammable materials, corrosive material

Risk: Glassware breaking, fire ignition

Mitigation: Rigorous training and extinguisher

- Economics: Condenser- \$50 , Thermometer- \$10, Stirrer- \$400, Sampling Port- \$55 , Baffle- \$130

Total: \$645

- Feasibility: 1-2 hrs experiment, comprehensive material cost
- Sustainability : Maintenance is minimal and affordable

References

- [1]. B. RabindramJermy, A. Pangurangam, "A highly efficient catalyst for the esterification of aceticacid using n- Butyl alcohol", Journal of molecular catalysis, 237(2005), 146-154.
- [2]. S. Ismail, Lirbaslar, UmurBramur,"esterification of acetic acid with ethanol catalyzed by an acidic ion exchange resin", turkJournal of Environmental science, 25(2001),569-579



**CHEMICAL ENGINEERING DEPARTMENT
OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET
CHEMICAL ENGINEERING LABORATORY III
SPRING 2020**

Instructor: Dr. Jorge F. Gabitto

Title of Assignment

Typical Laboratory Report

Outcome Measured Using this Assignment

Outcome 6

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

Brief justification of why this assignment is suitable for this outcome

This assignment involves a written report evaluated on technical content, grammar, professional writing, and report organization. Student ability to conduct proper experimentation, analyze the collected data, and draw appropriate conclusions is demonstrated.

Prairie View A&M University

Roy G. Perry College of Engineering

Department of Chemical Engineering



CHEM 4031 –P01

Chemical Engineering Laboratory III

Spring 2020

Virtual Lab II: Reaction Kinetics of three CSTRs in Series

Submitted By

Abstract	Sabrina Noe
Procedure & Theory	Omar Habib
Results & Discussion	Marvellous Oguejiofor Kinza Rizwan
Conclusion	Sabrina Noe

On Monday, April 27th, 2020

To

Dr. Jorge Gabitto

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Abstract

In this experiment, we will be discussing and understand the reaction kinetics between three CSTRs in series. The objective is to investigate the conversion of reactant in a second-order reaction carried out in the three CSTR configuration. Generally, reactors depend greatly on the efficient mixing of the reactants from the chemical reaction. This experiment will also allow for the study of the dynamic behavior of the reaction occurring in the stirred tank as it approaches steady state conditions. The goal is to estimate the dynamic and steady state fractional conversion of the limiting reactant in the first tank connected to the other tanks using conductivity measurement data and calculate the residence time for the first CSTR. Results showed the conversion of the limiting reactant at steady state behavior is plotted as an ascending exponential until the reaction reaches flat line steady state. A descending exponential plot of concentration of NaOH $C_a(t)$ changes dynamically until the CSTR reaches flat line steady state. The mean residence time for the first tank resulted as 8.75 mins. Many more question are answered about the reaction kinetic behavior of the CSTRs in the rest of this report.

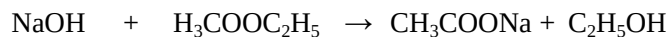
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Theory

This reaction:



Sodium Hydroxide (A) + Ethyl Acetate (B) → Sodium Acetate (C) + Ethyl Alcohol (D)

can be considered equal-molar and first-order with respect to both sodium hydroxide and ethyl acetate – and second-order overall, within the limits of concentration (0 - 0.1M) and temperature (20 - 40°C) studied. It is known that 1 g/mol of ethyl acetate reacts with 1g/mol of NaOH. A mass balance for can be conducted over the reactor (at steady state), in terms of the two molar feed flows (F_A and F_B), resulting in an expression for the fractional conversion of NaOH (component A), X_A , is as follows:

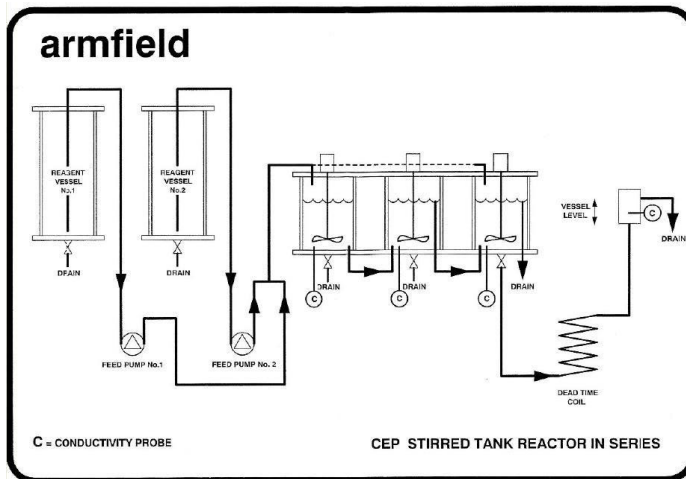
$$X_A = \frac{A \text{ consumed in reactor}}{A \text{ fed to reactor}} = \frac{A \text{ fed to reactor} - A \text{ leaving reactor}}{A \text{ fed to reactor}}$$

Since the concentration of NaOH ($C_{A,\text{feed}}$) is given and known, we see a direct relationship between the fractional conversion of NaOH and the solution conductivity in the CSTR:

$$X_A(t) = \frac{1}{\Lambda_{OH^-} - \Lambda_{COO^-}} \cdot \left[\Lambda_{Na^+} + \Lambda_{OH^-} - \frac{2 \cdot \kappa(t)}{C_{A,feed}} \right]$$

Algebraic manipulation of previous equations from this theory yields a normalized fractional conversion (normalized by the steady-state conversion) in terms of the initial, final, and transient solution conductivities:

$$\frac{X_A(t)}{X_A^{ss}} = \frac{\kappa_0 - \kappa(t)}{\kappa_0 - \kappa_\infty}$$



Experimental Procedure

Figure 1: CEP-MkII Stirred Tank Reactors in Series Experimental Setup

Procedure Steps:

1. Make 5.0-liter batches of 0.1M sodium hydroxide and 0.1M ethyl acetate solutions.
2. Remove lids of the reagent vessels and carefully fill with the reagents to a level approximately 50mm from the top. Then, put the lids back on.
3. Conductivity data will be collected until a steady state condition is reached in the reactor and this will take approximately 45 minutes. It is advisable to set the data collection period to 60 minutes.
4. Using the calibration graph for each of the feed pumps, set the pump speed controls to give 80 ml/min flowrate from each tank.
5. Set the agitator speed controller to 10.0 with 84% max capacity.
6. Turn on both feed pumps and agitator motor and begin taking readings.
7. It has been determined that the degree of conversion of the reagents affects the conductivity of the reactor contents so that recording the conductivity with respect to time using the Armfield data logger can be used to calculate the amount of conversion.

Results & Discussion

According to Anderko and Lencka, the net conductivity of an aqueous solution is dependent on the concentration of all ionic species in the solution (1997). Therefore, the net conductivity can be determined by summing up the product of all their concentrations and molar conductivities. This supports the conductivity expression given in the lab manual. First, the fractional conversion of NaOH is given by the concentration of NaOH and the molar conductivities of the ions in the solution. Once the conversion of NaOH is calculated for each time (t), a plot can be generated as the following:

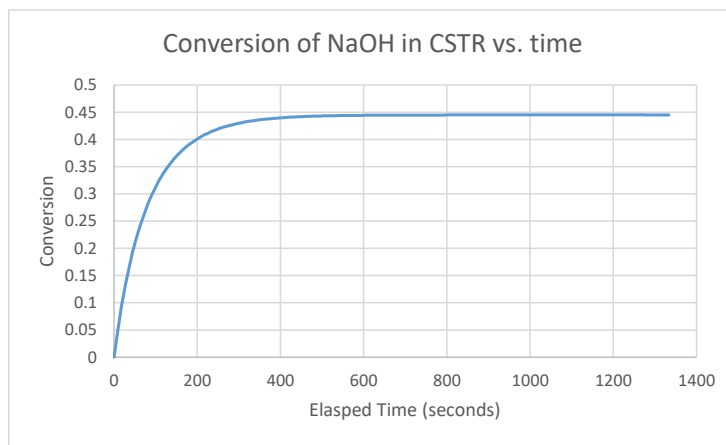


Figure 2: *Conversion of NaOH in CSTR vs. time*

In this plot, the conversion is seen to increase over time till it approaches a value. Once it has reached this value, the conversion remains the same for the remainder of the reaction. This value is known as the steady state conversion and is characterized by the flattening of the conductivity, and as a result conversion, curve. From Figure 2, the steady state conversion: $X_A^{ss} = 0.445$. Next, the change in concentration of NaOH over time as the CSTR approaches steady state will be analyzed. The concentration of NaOH can be calculated by rearranging the conversion equation in the lab manual to solve for concentration. After the concentration is calculated for each time (t), the following plot is generated as the following:

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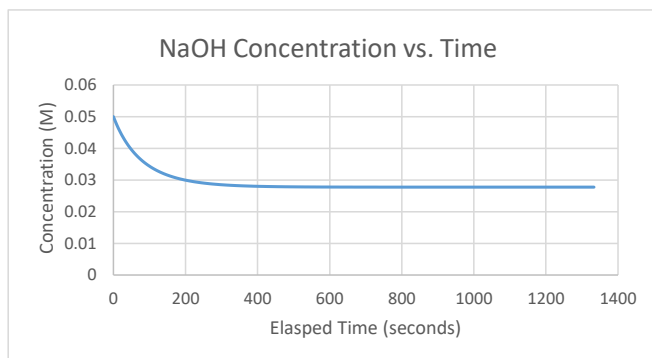


Figure 3: NaOH concentration vs. Time

This plot shows the concentration of NaOH reducing as the reactant is consumed and the reaction progresses. The concentration is seen to sharply reduce, as the conversion increases, till the curve finally flattens out as the reaction reaches steady state.

In the lab manual, the concentration of NaOH in the feed tank, $C_{A,feed}$ is identified to be twice the concentration of NaOH in the first reactor, C_{Ai} . Since the feed from both feed tanks are equimolar, there is twice the number of moles in the first reactor as in the NaOH feed tank. Since the moles of NaOH remained the same from the feed tank to the reactor, the concentration of NaOH in the reactor would be half of what it was in the feed tank.

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From the data, since $X_A^{ss} = 0.445$, 25% of the steady state conversion is $X_A^{0.25,ss} = 0.445 * 0.25 = 0.11$, 50% is $X_A^{0.5,ss} = 0.22$, and 75% is $X_A^{0.75,ss} = 0.33$. The time to reach each conversion is given in the table below:

Table 1: Time to reach steady state conversion

Percent Steady State (%)	Conversion	Elapsed Time (seconds)
25%	$X_A^{ss} = 0.11$	27
50%	$X_A^{ss} = 0.22$	54
75%	$X_A^{ss} = 0.33$	117

The corresponding conductivities can be calculated by rearranging Eq. 3 from the theory to solve for k_{∞} and changing the values of X_A^{ss} to those calculated at 25%, 50%, and 75%. The calculated and measured theoretical conductivities are given in the table below:

Table 2: Conductivities for different percentages of steady state

Percent Steady State (%)	Conversion	Calculated Conductivity (mS/L)	Measured Conductivity (mS/L)
25%	$X_A^{ss} = 0.11$	7.944	7.843
50%	$X_A^{ss} = 0.22$	7.389	7.403
75%	$X_A^{ss} = 0.33$	6.833	6.820
100%	$X_A^{ss} = 0.445$	6.275	6.275

Based on the known values of conductivities, the percentage of steady state achieved by the system can be determined from a plot of the percent steady states vs. measured conductivity.

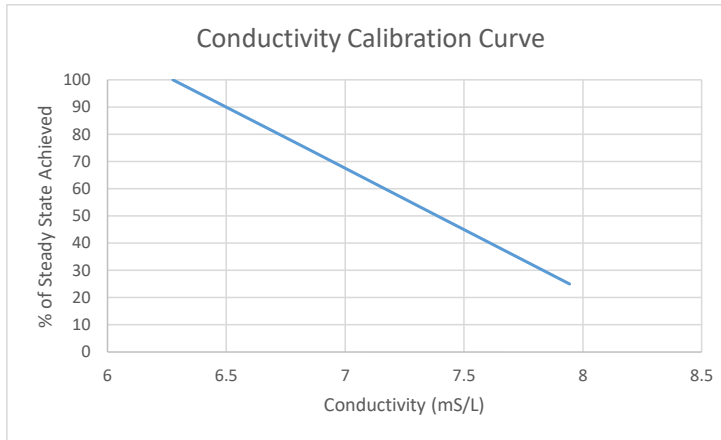


Figure 4: Conductivity Calibration Curve

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From this plot, once a conductivity is measured, it can be plugged in to determine the percentage of steady state achieved at that conductivity.

Finally, the residence time of the first reactor (τ) can be calculated from the volume of the reactor and its volumetric flowrate by the following equation (1).

$$\tau = \frac{\text{total reactor volume}}{\text{total volumetric flow rate}} \quad (1)$$

Therefore,

$$\tau = \frac{700 \text{ ml}}{80 \frac{\text{ml}}{\text{min}}} = 8.75 \text{ min}$$

Conclusion

The data used for this experiment confirmed that we were able to find at least one reference that can support the conductivity equation by the summation of the product of all their concentrations and conductivities. The plot of fractional conversion of NaOH as a function of time resulted as an increasing exponential slope until it reached the steady state condition at around 400 secs at 0.45 conversion. A plot was developed for how the concentration of NaOH changes dynamically as the CSTR approaches steady state showing the concentration slope decreasing exponential over time. This means the NaOH reactant is being consumed as the reaction is progressing over time. According to the lab manual provided, since the feed tanks were equal molar, the first CSTR would have twice the number of moles. Since the moles of NaOH remained the same from the feed tank to the reactor, the concentration of NaOH in the reactor would be half of what it was in the feed tank. The time was measured for the CSTR within 25%, 50% and 75% conversion of its steady state conversion which resulted as: 27 secs, 54 secs, and 117 secs. A calibration curve was created based on known conductivity values to the percentage of steady state showing a linearly descending slope. The residence time was calculated using the total reactor volume over the total volumetric flow rate creating a mean residence time 8.75 mins.

References

1. Fogler, H. Scott. Elements of Chemical Reaction Engineering. Upper Saddle River, N.J.: Prentice Hall PTR, 2016.
2. Anderko, A., & Lencka, M. M. (1997). Computation of Electrical Conductivity of Multicomponent Aqueous Systems in Wide Concentration and Temperature Ranges. *Industrial & Engineering Chemistry Research*, 36(5), 1932–1943. doi: 10.1021/ie9605903

Grading Rubric

Group: Omar Habib, Marvellous Oguejiofor, Sabrina Noe, Kinza Rizwan

Technical Content	Maximum	Grade
Abstract/Objective	5	4
Theory	5	4
Results	5	4
Conclusions	5	4
Total = 16/20	20	16

Writing Content		
Organization	5	5
Language	5	4
Professional content	5	4
Appearance	5	5
Total = 18/20 for 34/40	20	6

ASSIGNMENTS FOR 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.

**CHEMICAL ENGINEERING DEPARTMENT
OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET
Chemical Engineering Laboratory III
FALL 2021**

Instructor: Dr. Jorge F. Gabitto

Title of Assignment

Report 2

Outcome Measured Using this Assignment

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.

Brief justification of why this assignment is suitable for this outcome

The rubric used to grade the report assesses the students planning, organization, and collaborative environment. Student participation is also assessed by private communication related to the activity.



Lab #2 Fluid Friction in Pipes

Shanelle Bryant

Willie Conner

Jevaun Christie

Ryan Livingston

Timothy Waugh

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

- ν : 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...

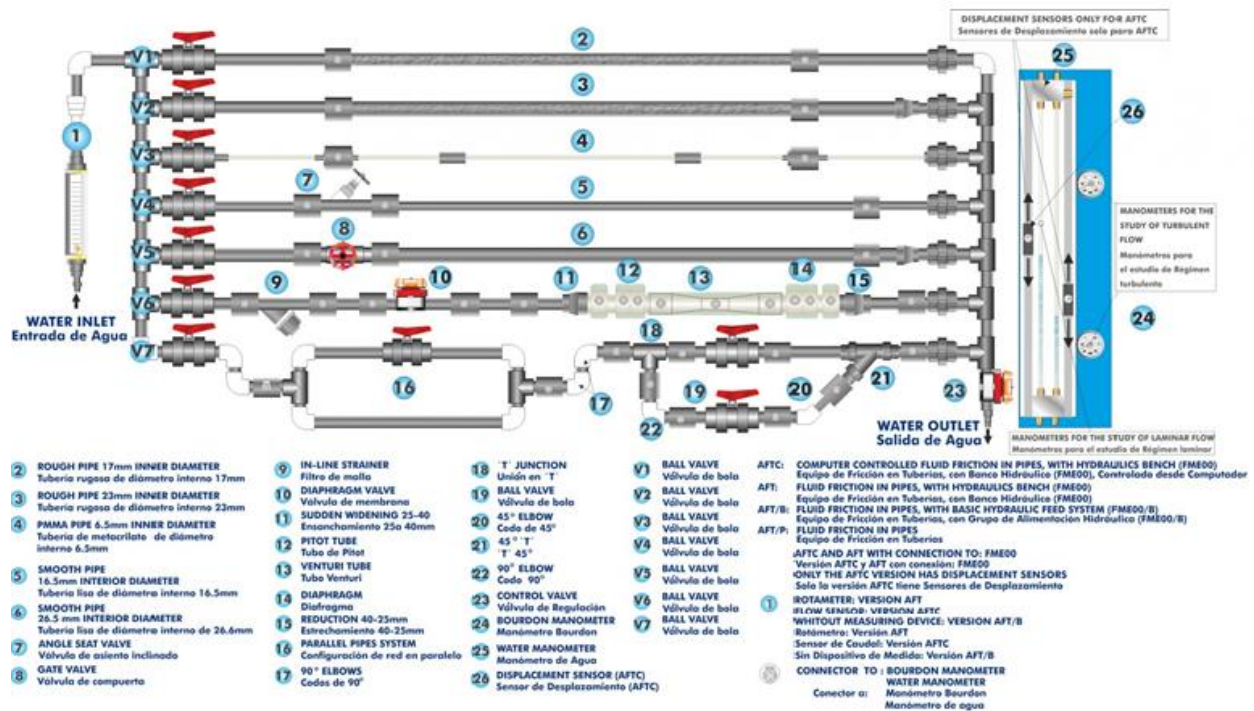
$$h_f / \Delta p = f \frac{L}{D} \times \frac{v^2}{2g} = \frac{8fLQ^2}{gD^5 \pi^2}$$

- 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

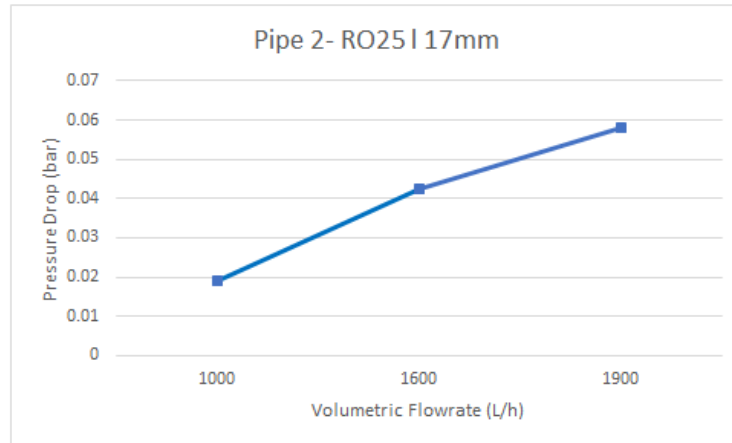


Figure 1: Pressure Drop vs. Volumetric Flow Rate in Pipe 2

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.

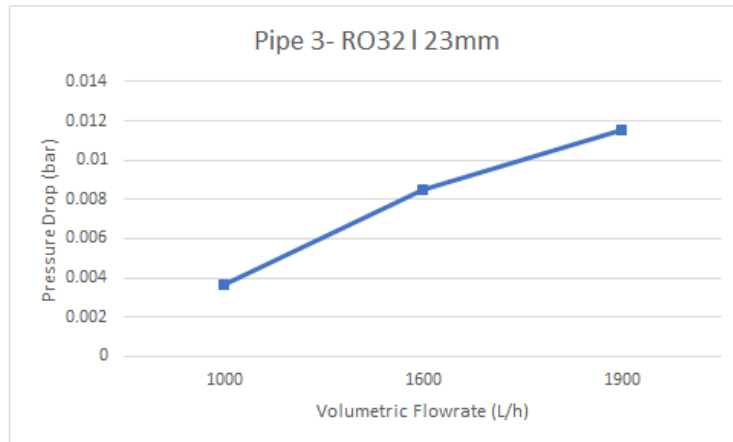


Figure 2: Pressure Drop vs. Volumetric Flow rate in Pipe 3

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.

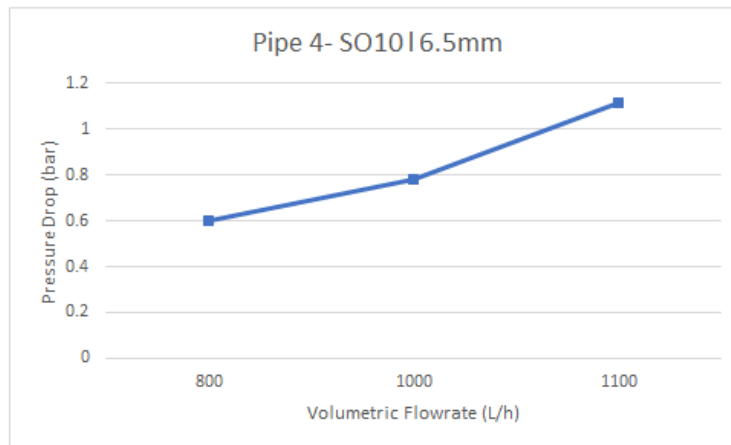


Figure 3: Pressure Drop vs. Volumetric Flow Rate in Pipe 4

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

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

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

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

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

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

Pipe 2- RO25 | 17mm

For 1000 L/h

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

For 1600 L/h

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

For 1900 L/h

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

Pipe 3- RO32 | 23mm

For 1000 L/h

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

For 1600 L/h

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

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

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 DEPARTMENT
OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET
Chemical Engineering Laboratory II
FALL 2021**

Instructor: Dr. Jorge F. Gabitto

Title of Assignment

Report 3

Outcome Measured Using this Assignment

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.

Brief justification of why this assignment is suitable for this outcome

The rubric used to grade the report assesses the students planning, organization, and collaborative environment. Student participation is also assessed by private communication related to the activity.

Prairie View A&M University
Chemical Engineering Department
Lab #3 Gas Absorption
CHEG 4104 - P01



Chiebuka Ejimadu
Katelyn Inman
Tyree Madison
Caleb Myers
Xavier Williamson

Date Conducted: 11/01/ 2021
Submission Date: 11/08/2021

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Abstract

- Purpose
- Key Findings
- Major Conclusion Drawn

Theory

- Introduction
- Objectives
- Background

Procedures

- Schematic Diagram

Results & Discussion

- Treatment of Data
- Discussion

Conclusion

Abstract



Gas absorption is a separation process mostly used at chemical industries for chemical processes and/or sustainability control. Gas-liquid absorption is an extraction technique where one or more components from the gas mixture will be separated and dissolved into the liquid. This method is utilized in power generation and many chemical plants for CO₂ capturing, flue gas purification, off-gas waste treatment and so on. CAGC equipment from Edibon is a type of device used to conduct and simulate such experiments. CAGC stands for Computer Controlled Gas Absorption Column, which is used for examining and testing hydrodynamic and absorption experiments in packed columns. The objectives of this lab are to measure and record the pressure drops within the column as a function of air rate, but at various water flow rates. Also, we need to find the flooding point of the relationships under all the different conditions. The results showed a direct relationship in terms of as the liquid flow rate and gas flow rate increased, pressure drop increased as well.

Theory

In a gas-liquid absorption activity, the two reaching stages are a gas and water. The ideal result is to separate a solute or a few solutes from the gas stage into the fluid stage, to all the more effectively separate the ideal part from its unique combination. In this test arrangement notwithstanding, there is no solute stage. There are two masses, reaching stages, air and water. In this experiment, we have a countercurrent stream of air and water through a loaded section with air streaming vertically and water descending. The segment is loaded with Raschig Rings. There are four ways pressure drop can be calculated;

- In a packed bed, with one fluid phase
- In a packed bed, with gas/liquid counter-operation
- Random packing
- Flooding pressure drop in packed and structured packings

For pressure drop in a packed bed with a one fluid phase flow is caused by kinetic energy and viscous losses, which can be calculated from the Ergun's equation:

$$\left(\frac{-\Delta p}{L}\right)\left(\frac{D_p g_c}{\rho_v u^2}\right)\left(\frac{\varepsilon^3}{1-\varepsilon}\right) = 150\left(\frac{1-\varepsilon}{Re}\right) + 1.75$$

where,

$-\Delta p$ = pressure drop

ρ_v = fluid density

L = package length

u = average superficial velocity of fluid

g_c = conversion factor

D_p which is the effective particle of what Reynolds number is based off of.

$$Re = \frac{D_p G'}{\mu}$$

where,

G' = mass velocity of the fluid based on the tower cross section

μ = fluid viscosity

If the packing is not a spherical shape, the effective particle diameter is found by:

$$D_p = \frac{6V_p}{A_p} = \frac{6(1-\varepsilon)}{A_v}$$

Where,

ε = the fraction of total bed volume that is void

A_v = is the ratio of the total packing surface area in the bed to the total volume of the bed

Pressure drop in a packed bed with gas/liquid counter-current operation there is an upper limit to the flowrate of gas in a packed tower of a given size with a given packing and liquid flow. The column can't operate past this velocity. When gas flow velocities are low, the liquid will flow downward while the flow of the gas hinders the flow of the liquid by a countercurrent flow. The pressure drop is proportional to the increase of gas flow rate to the 1.8 power. At the loading point, a great amount of liquid appears in the packing. At this point the gas will start to rise to a faster rate. The accumulation of liquid increases as the gas flow rate increases. The liquid is no longer able to flow downward through the packing at the flooding point, which then will be solved by being blown out with the gas.

In the flooding pressure drop in a packed and structured packing proper designing is important to be able to infer the flooding pressure drop in columns, which limits the flow rate at flooding. To infer the limiting pressure drop at flooding Kister and Gill created an equation:

$$\Delta p_{flood} = 0.115 F_p^{0.7}$$

where,

Δp_{flood} = H₂O/ft height of packing

F_p the packing factor in ft⁻¹

For pressure drop in random packings is by Strigle. The empirical correlations for different random packings experimental data are used to infer the pressure drop in the gas flow.

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. Ensure that the air blower is connected (to check that the security valve is open).
3. Next, open the VR-1 valve and close the VR-2.
4. Check the air flow and ensure it is fixed by means of the VR-1 valve and after write down the pressure drop (read in the manometers of the panel) that the gas suffers when crossing the column.
5. Next, write down the load losses corresponding to each one of the 10 air flows. Of this form the points of the gas flow-fall of pressure graphic are obtained, corresponding to the dry filling.
6. Connect the water pump and check that the VR-3 valve is open, and fix the desired value for the water flow with the VR-3 valve.
7. For each liquid flow fixed (read directly in the flowmeter), to measure the load losses corresponding to 10 different gas flows.
8. Repeat the points 6 to 9 for other two liquid flows to obtain relationships between gas flow and pressure drop for the corresponding liquid flows.

Results & Discussion

The objective of this lab, as previously stated, was to measure pressure drops as functions of inlet air volumetric flow rate for three different liquid volumetric flow rates of 1.5, 2.0, & 2.5 L/min. Pressure values at SP3 and SP4 were recorded for the various liquid and gas flow rates and tabulated below:

Table 1: Pressure readings for several liquid and gas flow rates into the absorption column

Valve openness	Liquid flow rate [L/min]	Gas flow rate [L/min]	SP3 [in H ₂ O/ft]	SP4 [in H ₂ O/ft]
40%	1.5	34.4	5.5	3.0
60%	1.5	51.1	14.1	10.0
80%	1.5	67.1	26.0	19.1
40%	2.0	33.3	5.2	3.9
60%	2.0	50.1	16.8	14.1
80%	2.0	67.5	40.2	33.9
40%	2.5	33.8	10.1	8.5
60%	2.5	50.7	39.6	36.8
80%	2.5	67.1	55.9	50.4

Pressure drop values were derived from this data by the use of SP3 - SP4 calculations to find the change in liquid pressure between the two points. In order to discover the relationship between gas flow rates and the resulting pressure drops, the two parameters were plotted against each other and the trends analyzed. The graph below displays this information; each line represents data for a particular controlled liquid flow rate:

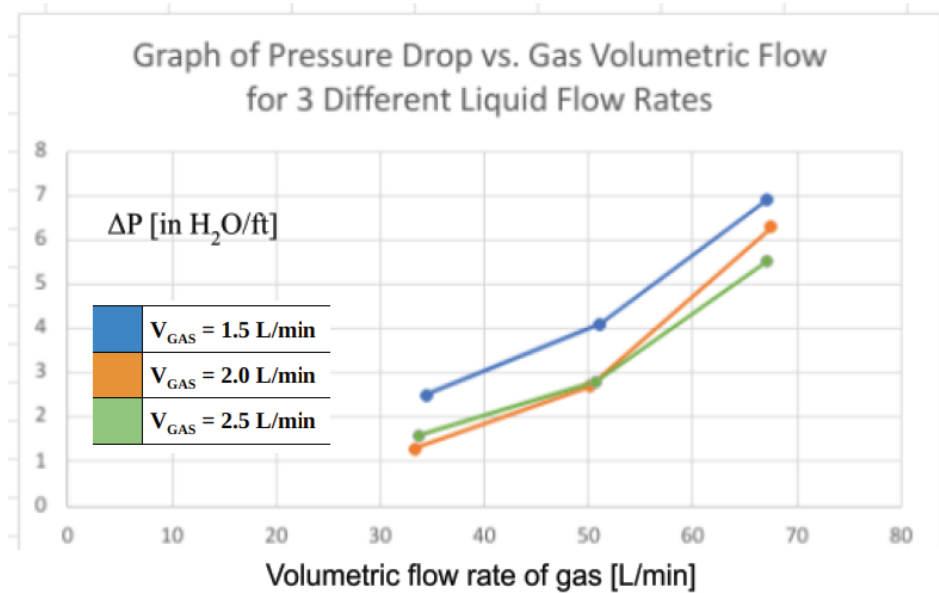


Figure 1: Graph of Pressure Drop vs. Gas Volumetric Flow for 3 Different Liquid Flow Rates

Looking at the trend, it is clear that the liquid flow rate has an effect on the pressure drop along with the gas flow rate. By keeping the liquid flow rates and three different controlled values, this was more easily observed. As the liquid flow rate increased, the pressure drops increased as well. This was also true as the gas flow rate increased, as shown by the increase in y-values as the gas flow rate on the x-axis increased. The pressure drop is shown to be proportional to the flow rate of the gas to the 1.8 power.

Conclusion

In this experiment, the pressure drop, as a function of air rate and three water rates, was measured for several conditions of a 2-phase flow. The results show that as the valve opens more, at a constant liquid flow rate, the pressure increases along with the pressure drop. When comparing the pressure drop of each 3 liquid flow rates at the same valve opening percentage, the pressure drop was highest at the 1.5 L/min liquid flow rate and decreases as the flow rate increases. When collecting the data for SP3 and SP4, an average range was taken due to the large fluctuation of numbers.

ASSIGNMENTS FOR 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.

**CHEMICAL ENGINEERING DEPARTMENT
OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET
Chemical Engineering Laboratory III
SPRING 2022**

Instructor: Dr. Jorge F. Gabitto

Title of Assignment

Report 1

Outcome Measured Using this Assignment

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.

Brief justification of why this assignment is suitable for this outcome

The rubric used to grade the report assesses the students planning, organization, and collaborative environment. Student participation is also assessed by private communication related to the activity.

Roy G. Perry
College of Engineering



CHEG 4104 - Chemical Engineering Lab III

Experiment 1:
Conversion of NaOH in Saponification Reaction in a 3-Series CSTR
Group #2

Due Date: March 30, 2022

Submitted by:
Chad Gardner
Anh Nguyen
Meredith Meyer
Franck Nangomoko

Submitted to:
Dr. Jorge Gabitto

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- Figure 3: Conductivity of 3 CSTRs over Time
- Figure 4: Conversion of NaOH in Tank 1 over Time
- Figure 5: Concentration of NaOH vs Time approaching Steady State Condition

Abstract

A continuous-stirred tank reactor is a common model for the estimation of key unit operation variables with specified output. For this experiment, the Armfield CEP-MkII stirred tank reactors model was used to observe the second-order reaction of 0.1M EtOAc and 0.1M NaOH. The aims of the experiment were to investigate and determine the conversion of a second order reaction in a tank reactor as well as to determine the reaction rate of the reaction. The parameters considered for analysis were conductivity, concentration of NaOH, and residence time. The steady state conversion was obtained as 0.62 at 25°C with the residence time of 264 seconds. The constant rate of reaction was calculated as 0.162L/mol.s. The results were helpful in determining the condition of operating variables to achieve a desirable conversion of the saponification reaction in CSTRs on an industrial scale.

Theory

Reactor is an important equipment in every chemical process. Continuous stirred tank reactors (CSTRs) have proven to be more energy efficient than batch reactors. Since the reaction is continuous, there is no need to go through an empty-fill and heat up cycles. Despite being under further investigations for various processes, these reactor vessels serve as great importance to the chemical industry. A CSTR consists of a tank and an impeller to provide efficient mixing.

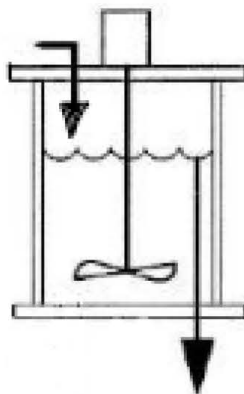


Figure 1: Schematic Diagram of CSTR

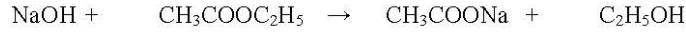
CSTR can be connected in series or in parallel. In this experiment, CEP-MkII Stirred Tank Reactors in Series is used to analyze the steady-state fractional conversion of a limiting reactant in saponification reaction, shown in Figure 2.



Figure 2: CEP-MkII Stirred Tank Reactors in Series

The reactants used in the experiment are sodium hydroxide and ethyl acetate. The reaction is called saponification reaction which its products are used in different fields, such as petroleum, cosmetics, and textile industry.

The reaction is shown below.

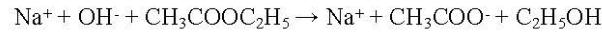


Sodium Hydroxide (A) + Ethyl Acetate (B) $\rightarrow$ Sodium Acetate (C) + Ethyl Alcohol (D)

Sodium hydroxide (NaOH) and ethyl acetate (EtOAc) are fed in equimolar. Each reactant has a concentration of 0.1M. The fraction conversion of limiting reactant is expressed by the change in flow rate of NaOH (component A).

$$X_A(t) = \frac{A_{\text{fed to reactor}} - A_{\text{leaving reactor}}}{A_{\text{fed to reactor}}} = \frac{C_{A,i} - C_A(t)}{C_{A,i}}$$

The saponification reaction occurs in a partially electrolytic solutions, the conversion can be obtained by monitoring the changes in conductivity (κ) of the reacting mixture in steady-state condition, including ionic species Na^+ , OH^- , and CH_3COO^- . The reaction is expressed in ion form:



Since the conductivity $\kappa(t)$ is linearly dependent on the concentration of these three ions, it can be expressed as the sum of ions' concentrations ($C_{\text{Na}^+}, C_{\text{OH}^-}, C_{\text{COO}^-}$) with their molar conductivities ($\Lambda_{\text{Na}^+}, \Lambda_{\text{OH}^-}, \Lambda_{\text{COO}^-}$) which COO^- represents acetate ion.

$$\kappa(t) = C_{\text{Na}^+}(t) \cdot \Lambda_{\text{Na}^+} + C_{\text{OH}^-}(t) \cdot \Lambda_{\text{OH}^-} + C_{\text{COO}^-}(t) \cdot \Lambda_{\text{COO}^-} \quad (1)$$

The concentration of each ion can be expressed in terms of initial concentration of OH^- ($C_{\text{OH}^-}^o$), initial volume of the reactant ($\dot{V}^o$), and conversion (X), equation (1) is equivalent to:

$$\kappa(t) = \frac{\dot{V}^o C_{\text{OH}^-}^o}{2\dot{V}^o} \cdot \Lambda_{\text{Na}^+} + \frac{\dot{V}^o C_{\text{OH}^-}^o (1-X)}{2\dot{V}^o} (t) \cdot \Lambda_{\text{OH}^-} + \frac{\dot{V}^o C_{\text{OH}^-}^o X}{2\dot{V}^o} (t) \cdot \Lambda_{\text{COO}^-} \quad (2)$$

The relationship between conductivity $\kappa(t)$ and conversion (X) is then expressed in equation (3):

$$X = \frac{2\kappa(t) - C_{\text{OH}^-}^o (\Lambda_{\text{Na}^+} + \Lambda_{\text{OH}^-})}{C_{\text{OH}^-}^o (\Lambda_{\text{COO}^-} - \Lambda_{\text{OH}^-})} \quad (3)$$

where Λ_{Na^+} is 50.1 S.cm²/mol, Λ_{OH^-} is 198.6 S.cm²/mol, and Λ_{COO^-} is 40.9 S.cm²/mol [2].

To determine the steady state conversion of the reactor, we look at the conductivity curve in the software. A “flattening” of the curve indicates the steady-state conversion of the reactor.

Additionally, we analyzed the mean residence time (τ) which is the average time that a reactant or product will spend in the reactor.

$$\tau = \frac{\text{Total reactor volume}}{\text{Total volumetric flow rate}} = \frac{V_R}{\dot{V}^o} \quad (4)$$

Rate of saponification reaction (r_A) can then be determined by

$$r_A = k_A C_A C_B$$

where A is NaOH, and B is EtOAc; k_A is the rate constant with respect to A and C is the concentration. Since NaOH and EtOAc are fed in equimolar, the rate of equation can be expressed in terms of initial concentration of NaOH as:

$$-r_A = k_A C_{A0}^2 (1-X)^2 \quad (5)$$

Assuming the reaction is elementary, the component mass balance equation is:

$$F_{A0} - F_A + V_R (r_A) = 0$$

Since the volumetric flow rate is constant ($\dot{V} = \dot{V}^o$), $C_A = F_A / \dot{V}^o$, and $C_A = C_{A0} (1-X)$, the mass balance equation can be written in combining with equation (5) as:

$$\dot{V}^o C_{A0} - \dot{V}^o C_{A0} (1-X) + V_R k_A C_{A0}^2 (1-X)^2 = 0 \quad (6)$$

The reaction rate constant as a function of fractional conversion and the residence time can be written in combining equation (6) with equation (4) as:

$$\tau = \frac{V_R}{\dot{V}^o} = \frac{X}{k_A C_{A0} (1-X)^2} \quad (7)$$

Procedures

As the equipment was already set up, the experiment proceeded in the following steps:

1. Start the Armfield software for CSTR in series
2. Collect conductivity data until all 3 reactors in steady state conditions ("flat" conductivity curve) in approximately 25 minutes
3. Make sure the pump speed controls to give 80mL/min flowrate and the agitator speed controller to 84% max capacity
4. Switch on both feed pumps and agitator motor and click "Go" on the screen to record the data. The data were obtained in a 10-second interval.

Results and Discussion

Feed flow rate of 80 mL/min 0.1M NaOH and 80 mL/min 0.1M EtOAc were used in the experiment. The reaction was carried out at a constant temperature of 25°C and stirrer speed at 54% (6.43 rpm). Ten (10) minutes after the start of the experiment, the steady state conditions were reached. Figure 3 shows the conductivity of CSTRs as time elapses. The conductivity of the reaction mixture decreases as reaction takes place in all three tanks. It is because as the reaction proceeds, the concentration of NaOH reduces resulting in a drop in conductivity values.

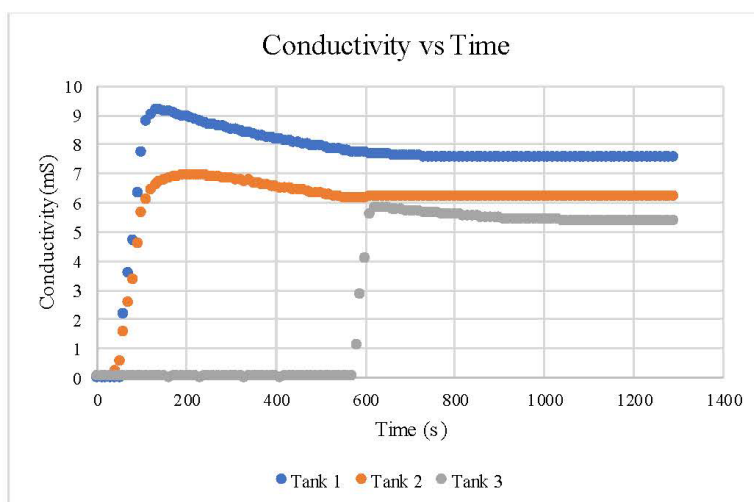


Figure 3: Conductivity of 3 CSTRs over Time

Figure 4 shows the trend of conversion of NaOH in Tank 1 over time as it approaches steady state (starting from 140s). It is determined that the conversion of NaOH at steady state is 0.62. According to Figure 4, it takes 230s (almost 6 minutes) for the CSTR to get 75% of its steady-state conversion.

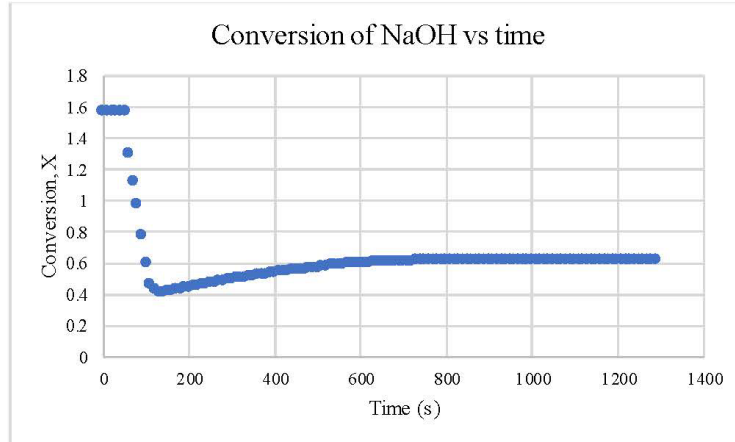


Figure 4: Conversion of NaOH in Tank 1 over Time

Figure 5 shows the dynamically change of the concentration of NaOH $C_A(t)$ as the 1st CSTR approaches a steady state. The concentration reaches a peak of 0.059M (at $t = 130s$) and gradually decreases to a steady state value of 0.038M in 540s (9 minutes).

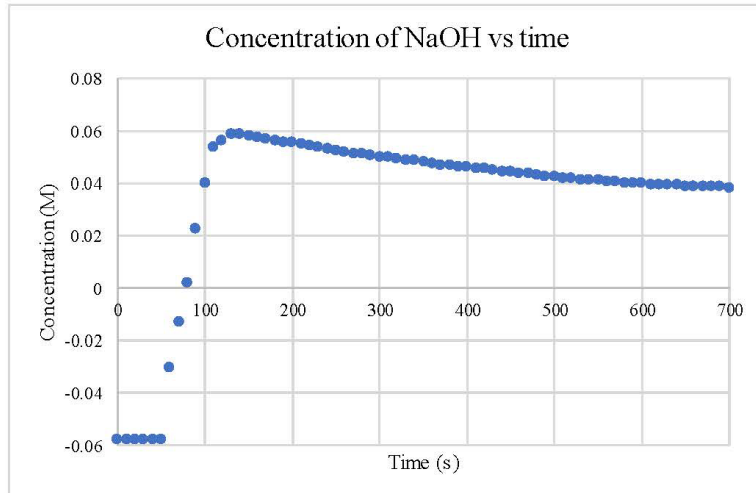


Figure 5: Concentration of NaOH vs Time approaching Steady State Condition

From Figure 3, 4 and 5, it clearly shows that as the reaction proceeds, the conductivity of the solution decreases, the concentration of NaOH decreases, and the conversion of NaOH increases. The three variables, however, will eventually achieve their own steady state value. Those values are important in any chemical processes as it determines the efficiency of the process and desired rate of production.

The mean residence time of the first tank was then calculated using equation (4) to be 4.4 minutes (264 seconds) in which the reactor volume was 0.7L and the total flow rate was 0.16L/min. The reaction rate constant k_A at steady state was found to be 0.162 L/mol.s using equation (7). The reaction rate constant for the saponification reaction would not change over time because the CSTR could be consider as a batch reactor. Therefore, the volumetric flow rate is constant, and the reaction rate constant is constant under this experiment's conditions.

Conclusion

Understanding the conversion of a second-order reaction in a CSTR is crucial in the estimation of unit operation variables with specified output. The steady state conversion of NaOH was 0.62 after about 10 minutes of the experiment running. The steady state concentration of NaOH leaving the 1st reactor was 0.38M. The result showed that as the reaction proceeded the concentration of NaOH reduced resulting in a dropping of the conductivity values; and the conductivity of the reaction mixture decreased as the reaction took place. The overall time to reach steady state conditions was approximately 18 minutes. With different conditions (feed's flow rates, feed's concentration, and temperature), the steady state conversion, the residence time, and the rate constant of the reaction can be varied. Therefore, this experiment can be reconducted at different temperatures and/or the feed stream's conditions to determine the conversion of NaOH.

References

Roy G Perry. Chemical Engineering Department. *Reaction Kinetics in a 3-Series CSTR*. Accessed 2022.

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**CHEMICAL ENGINEERING DEPARTMENT
OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET
Chemical Engineering Laboratory III
SPRING 2022**

Instructor: Dr. Jorge F. Gabitto

Title of Assignment

Report 2

Outcome Measured Using this Assignment

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.

Brief justification of why this assignment is suitable for this outcome

The rubric used to grade the report assesses the students planning, organization, and collaborative environment. Student participation is also assessed by private communication related to the activity.

Roy G. Perry
College of Engineering



CHEG 4104 - Chemical Engineering Lab III

Experiment 2: Reaction Kinetics in PFR Reactor

Instructor: Dr. Jorge F. Gabitto

Team 1 Members:



Jacquelyn Fuller
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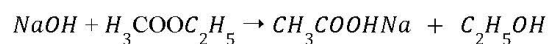
I. Abstract

The continuous stirred tank reactor (CSTR) is the ideal representation of complete mixing in reactor design. A CSTR often refers to a model used to estimate the key unit operation variables when using a continuous agitated-tank reactor to reach a specified output. It is important to consider that there is no CSTR reactor in real life.

This experiment involves a CEP-MkII Stirred Tank Reactor in series. The concentration is kept uniform for each reactor; however a change in concentration is observed as fluid flows from one reactor to the other reactor. This experiment is carried out to determine the conversion of a second order reaction in the tank as well as compare the operation between a real tank reactor and a CSTR (ideal) reactor. Finally, it was concluded that the real tank had a lower conversion rate compared to the ideal CSTR, but there was only a 0.07 difference making the actual experiment feasible.

II. Theory

The reaction taking place in this experiment is the saponification of Ethyl Acetate with Sodium Hydroxide.



This reaction can be considered as equi-molar and first order with respect both to sodium hydroxide and ethyl acetate, and second order overall, within the limits of concentration (0-0.1M) and temperatures between 20°C to 40°C.

The equation above shows that one mole of ethyl acetate reacts with one mole of sodium hydroxide.

The fractional conversion of sodium hydroxide in terms of feed flows can be expressed as:

$$X_A = \frac{A \text{ consumed in reactor}}{A \text{ fed to reactor}} = \frac{A \text{ fed to reactor} - A \text{ leaving reactor}}{A \text{ fed to reactor}} \quad (\text{eq 1})$$

Or can be expressed in terms of concentration as:

$$X_A(t) = \frac{C_{Ai} - C_A(t)}{C_{Ai}} \quad (\text{eq 2})$$

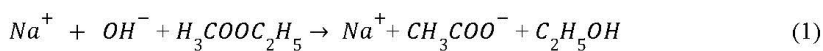
The reaction was carried out in three 0.7 litre tanks connected in series. The tanks eventually reached steady state when a certain conversion of the starting reagents was achieved. The steady state condition of the reaction was observed by observing the changes in the specific electrical conductance or conductivity denoted by the symbol (κ).

It was assumed that the flattening of the conductivity of the conductivity curve of " $\kappa(t)$ vs t " in a tank reactor indicates that the tank has achieved a steady state conversion, X_A^{SS} .

Specific conductivity decreases with a decrease in concentration. Since the

To understand the connection between and, we must first recognize $\kappa(t)$ and $X_A(t)$ that this saponification reaction occurs in a partially electrolytic solution.

Rewriting in terms of its reacting ions, the reaction can be expressed in its charge-balanced form:



The reacting mixture featured a measurable specific conductance due to the presence of the ionic species Na^+ , OH^- , COO^- . and the conductivity, $\kappa(t)$, of the reacting mixture was linearly dependent on the concentration of these ionic species in the solution.

$\kappa(t)$ can be expressed as a sum of the contributions of Na^+ , OH^- , COO^- based on their

respective concentrations and molar conductivity as follows:

$$\kappa(t) = C_{Na^+}(t) \cdot \Lambda_{Na^+} + C_{OH^-}(t) \cdot \Lambda_{OH^-} + C_{COO^-}(t) \cdot \Lambda_{COO^-} \quad (2)$$

$$\kappa(t) = \frac{F_{Na^+}}{\dot{V}} \Lambda_{Na^+} + \frac{F_{OH^-}}{\dot{V}}(t) \cdot \Lambda_{OH^-} + \frac{F_{COO^-}}{\dot{V}}(t) \cdot \Lambda_{COO^-} \quad (3)$$

$$\kappa(t) = \frac{\dot{V}^o C_{OH^-}^0}{2 \dot{V}^o} \Lambda_{Na^+} + \frac{\dot{V}^o C_{OH^-}^0 (1-X)}{2 \dot{V}^o}(t) \cdot \Lambda_{OH^-} + \frac{\dot{V}^o C_{OH^-}^0 X}{2 \dot{V}^o}(t) \cdot \Lambda_{COO^-} \quad (4)$$

$$\kappa(t) = \frac{C_{OH^-}^0}{2} \Lambda_{Na^+} + \frac{C_{OH^-}^0 (1-X)}{2}(t) \cdot \Lambda_{OH^-} + \frac{C_{OH^-}^0 X}{2}(t) \cdot \Lambda_{COO^-} \quad (5)$$

$$\kappa(t) - \frac{C_{OH^-}^0}{2} \Lambda_{Na^+} - \frac{C_{OH^-}^0}{2}(t) \cdot \Lambda_{OH^-} = - \frac{C_{OH^-}^0 X}{2}(t) \cdot \Lambda_{OH^-} + \frac{C_{OH^-}^0 X}{2}(t) \cdot \Lambda_{COO^-} \quad (6)$$

$$X = \frac{\kappa(t) - \frac{C_{OH^-}^0}{2} \Lambda_{Na^+} - \frac{C_{OH^-}^0}{2}(t) \cdot \Lambda_{OH^-}}{\frac{C_{OH^-}^0}{2} (\Lambda_{COO^-} - \Lambda_{OH^-})} = \frac{\kappa(t) - \frac{C_{OH^-}^0}{2} (\Lambda_{Na^+} + \Lambda_{OH^-})}{\frac{C_{OH^-}^0}{2} (\Lambda_{COO^-} - \Lambda_{OH^-})} \quad (7)$$

Figure 1. List of Equations

III. Procedure

The procedure carried out on this experiment is intended to determine the conversion of a second order reaction using a tank reactor; in addition, it compares the operation of a real tank reactor with that of a CSTR reactor. The equipment used in this experiment is the CEP armfield which has a series of stirred tank reactors. The process consists of two feed vessels of which one contains 0.1M of ethyl acetate while the other has the same concentration of sodium hydroxide; both vessels have a volume of 5 liters.

The feed vessels supply into tank reactor 1, which is connected to tank 2 and both are filled at the same rate. Two pumps are used parallel to each other and are connected into the same header that feeds tank 1 and 2. Once these two tanks are completely full, they overflow into tank 3. Samples of the product are taken from tank 1 once steady state is reached. The process is said to be at steady state once the conductivity is no longer increasing or decreasing, if applicable, and the measurement of conductivity is observed from the CEP armfield display. Below is the systematic sequential steps to performed the experiment:

1. Prepare a solution of 0.1M of ethyl acetate, approximately 5 liters
2. Prepare another solution of 0.1M of sodium hydroxide, approximately 5 liters
3. Remove the lid of one of the two feed vessels
4. Fill the vessel with 0.1M solution up to 50mm from the top
5. Put the lid back securely on the vessel
6. For the second feed vessel (empty at this time), use 0.1M solution of sodium hydroxide and repeat steps 3-5
7. Turn on the pump on vessel 1
8. Set the pump's speed to 10 (~ 80ml/min)
9. Set the agitator speed in tank 1 to 10 (~84% its max)
10. Turn on the other pump from the second vessel and respect steps 8-9
11. Observe tank reactors 1 and 2 being filled and watch overflow into tank reactor 3
12. Allow the process to run for approximately 20-30 minutes until it reaches state state (conductivity is stable)
13. Collect the product sample from tank reactor #1
14. Data collection may begin at this point if no computer is used

IV. Results and Discussions

1. A reaction between a strong base such as sodium hydroxide with a weak acid like ethyl acetate produces sodium acetate and ethyl alcohol. The reaction is a partially electrolytic solution because of the free ions such as Na^+ , OH^- , and COO^- (which represents the acetate). Each ion has its own molar conductivity and its own molar concentration. By multiplying the molar conductivity and concentration of each type of ions and adding them up, the conductivity of the solution can be determined.

The equation, $\kappa(t) = C_{Na^+}(t) \cdot \Lambda_{Na^+} + C_{OH^-}(t) \cdot \Lambda_{OH^-} + C_{COO^-}(t) \cdot \Lambda_{COO^-}$, is supported by references like (Lower, 2021) and (Weedmark, 2018).

2. In this experiment, it was asked to plot a graph of the fraction conversion of the NaOH as a function of time. Using the concentration of NaOH and the conductivities of the ions given in the solution. The plot can be then developed after the conversion of NaOH is computed for each time.

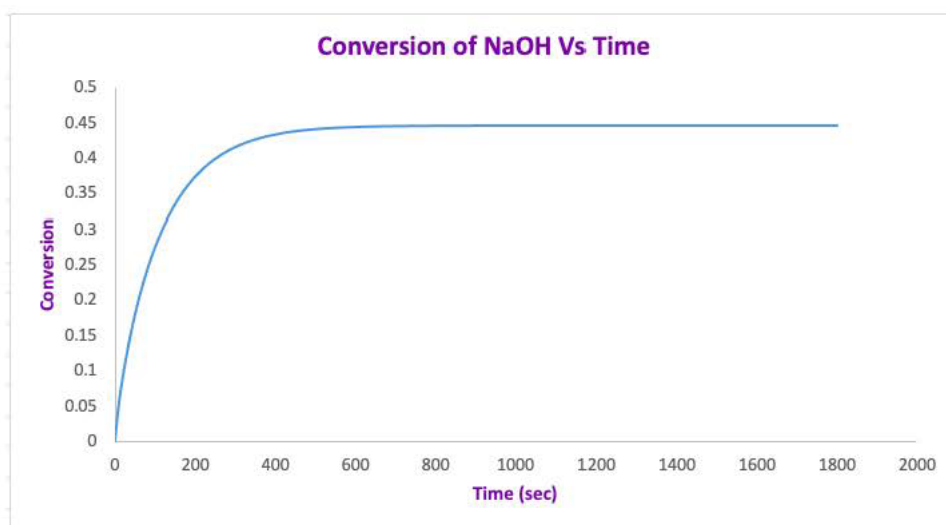


Figure 2. Conversion of NaOH as Function of Time.

As you can observe from the graph above, the conversion rate seems to increase as the time also increases. At a certain conversion rate and time which can be determined to be at 460 sec and 0.439, the rest of the reaction remains the same. At that point, we can consider the reaction reaching steady states and can be indicated by the flattening of the conductivity curves achieved by the tank.

3. The concentration was calculated using the equation provided in the lab manual. The graph below represents the concentration curve developed.

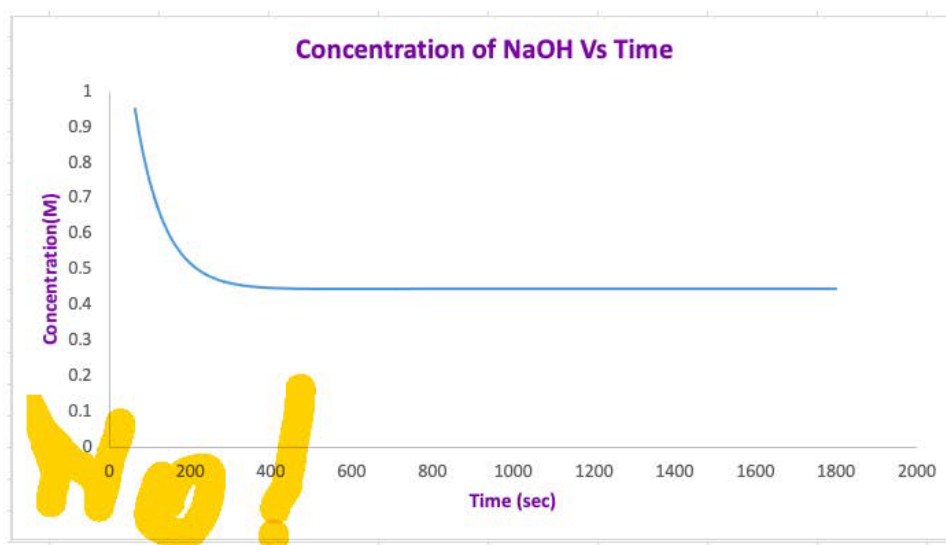


Figure 3. Concentration of NaOH as Function of Time

In this plot, we notice that the concentration decreases as it is being consumed in the first reactor. The reaction does not reach steady state until the curve starts flattening .

4. Below is an analysis based on the configuration and conditions of the experiment that confirms the equation $C_{A,i} = \frac{C_A^\circ}{2}$ where $C_{A,i}$ is the feed concentration of A to the first CSTR and C_A° is the concentration of A in feed tank A.

C_A° is given to be 0.1M. Using the equation, $C_{A,i}$ would be 0.05 M.

In the experiment, the concentration of NaOH in the feed tank (C_A°) and the concentration of ethyl acetate in the feed tank (C_B°) are both given to be 0.1M. An equimolar solution of NaOH (A) and ethyl acetate (B) is fed to the CSTR. Since A and B have the same molar concentration, A and B need to have the same volume to create an equimolar solution. Thus, for a 5.0 L batch, 2.5 L of 0.1 M NaOH and 2.5 L of 0.1 M ethyl acetate will create an equimolar solution that would be fed to the CSTR.

Since there is 2.5 L of 0.1 M NaOH, the moles of NaOH is 0.25. In order to calculate the concentration of NaOH in the 5.0 L solution, 0.25 moles of NaOH is divided by the solution volume, giving 0.05M of NaOH.

The equation $C_{A,i} = \frac{C_A^\circ}{2}$ can be used in this experiment because NaOH and ethyl acetate have the same initial molar concentration that was used to create an equimolar solution.

5. By using equation (7) listed in the lab manual, the conversion was computed and was used to plot a graph. From the graph, we noticed that the steady state is reached at a certain time when the curve starts flattening. The table below represents the steady state conversion given at 25%, 50%, and 75%.

Percentage steady state (%)	Elapsed time (sec)	Conversion	Measured Conductivity (mS/L)	Theoretical Conductivity (mS/L)
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25	297.3	0.426	6.187	6.236
50	594.6	0.446	6.269	6.267
75	891.9	0.446	6.267	6.267

Table 1. CSTR Steady State at Given Percentage.

6. From the values provided in the lab manual, conductivities and the percentage of steady state achieved by the system will be developed by a plot shown below.

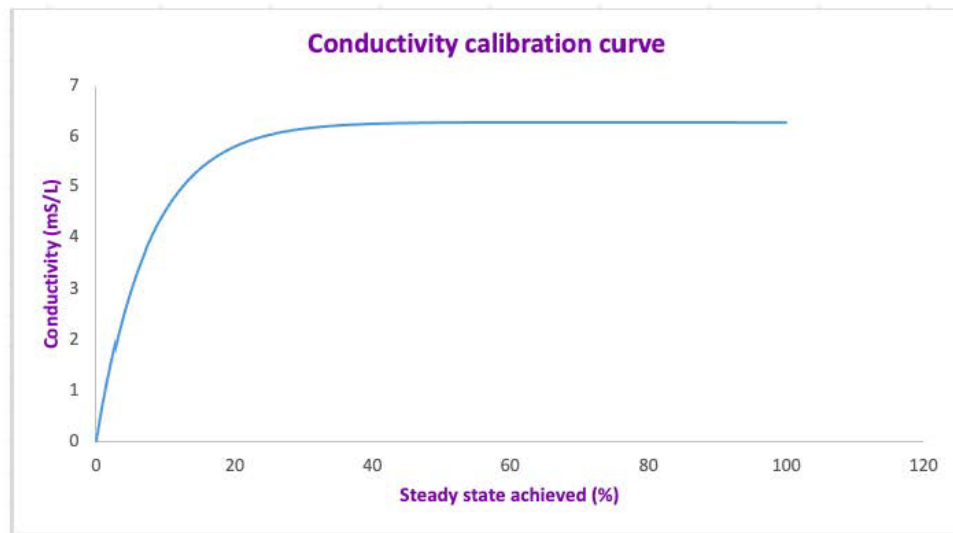


Figure 4. Conductivity Calibration Curve

The plot above demonstrates the curve developed after calibrating the value of the conductivity which starts reaching the steady state at 20%.

7. The mean residence time (τ) of the first reactor can be calculated using the equation:

$$\tau = \frac{\text{Total reactor Volume}}{\text{Total volumetric Flow Rate}}$$

There are 3, 0.7L CSTR tanks connected in series. The volumetric flow rate is 80 mL/min which can be written as 0.0013 L/s.

Using the equation given, the mean residence time for the first reactor is 525 seconds.

V. Conclusion

The main goal of the experiment was to determine the conversion of NaOH in a tank reactor. An equimolar solution of NaOH and ethyl acetate was added into the CEP-MkII Stirred Tank Reactors in Series unit which was compared to a 3-series 0.7L CSTR configuration. The conductivity of the solution was determined using the concentrations of ions and the molar conductivities. The solution's conductivity was then used to determine the conversion of NaOH in the real tank reactor where the conversion was at 0.439. The conversion of NaOH in the ideal CSTR was determined to be around 0.446. In conclusion, the real tank had a lower conversion rate compared to the ideal CSTR, but there was only a 0.07 difference making the actual experiment feasible. Possible ways to increase the conversion of NaOH is to have a higher concentration of NaOH, add an enzyme, larger tank volume, more residence time (if it does not reach equilibrium), and/or have a higher stirring rate.

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