

**OUTCOME “3” SPECIFIC ASSIGNMENTS
USED TO ASSESS THE OUTCOME IN**

**CHEG 4011
CHEMICAL ENGINEERING
LABORATORY II**

**CHEMICAL ENGINEERING
OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET
CHEG 4011 CHEMICAL ENGINEERING LABORATORY**

II

FALL 2019

Instructor: Dr. Keisha Antoine

Title of Assignment

DOE Presentation

Outcome Measured Using this Assignment

Outcome 3

**An ability to communicate effectively with a range of audiences
(Oral Communication)**

Check the communication characteristics related to this assignment

X	Involves ability to organize, plan, design/prepare and use appropriate visual aids for communication/presentation to a range of audiences (executives, technical and non-technical).
X	Involves ability to demonstrate technical knowledge and understanding of the subject, prepare and display prototypes or models when they are necessary, respond clearly to questions in a professional manner
X	Requires use of correct grammatical English and technical terms appropriate to technical area and audience type; ability to speak with clarity and confidence, maintain good posture and eye contact with the audience
X	Geared to diverse groups of stakeholders (students and industrial representatives, etc.)

Brief justification of why this assignment is suitable for this outcome

The DOE Presentation is a group project assigned for the purpose of evaluating students' communication skills.

CHEG 4011 CHEMICAL ENGINEERING LABORATORY II
FALL 2019

ASSIGNMENT STATEMENT/QUESTIONS
GRADING SCHEME FOR DOE PRESENTATION

DEPARTMENT OF CHEMICAL ENGINEERING
CHEG 4031
CHEMICAL ENGINEERING LAB. II

DESIGN OF EXPERIMENTS PROJECT

During the course students are expected to design and operate, or simulate, a typical course experiment. The experiment will be chosen by the students from a provided list or students' suggestions. The subject matter should be relevant to the subjects dealt with in the specific laboratory. The work will be done by the same groups performing experiments. The chosen experiment will be defended in an open presentation by the end of the semester. A written report may be also required.

Procedure

The students should follow the following procedure:

1. Subject selection.
2. Define the goals and objectives of the experiment.
3. Research any relevant theory and previously published data from similar experiments.
4. Select dependent and independent variable(s) to be measured or controlled.
5. Describe an appropriate procedure for the experiment.
6. Select appropriate chemicals for the experiment to be conducted safely.
7. Select appropriate methods for measuring/independent variables.
8. Propose appropriate equipment and instrumentation.
9. Select the proper range of the independent variable(s).
10. Design a method to process the results.
11. Indicate what kind of conclusions you expect.

Students will be graded accordingly to how well they address the previous issues.

Deliverables

By mid-term the students should provide a one page summary including

1. Title.
2. Goals (one paragraph).
3. Abstract (one or two paragraphs).
4. Brief description of experimental procedure (one or two paragraphs).
5. Expected results (one or two paragraphs).

Final Presentation

On final week, or any suitable agreed upon time, each group of students will present their design NEW experiment orally. The presentation will contain the same elements as a formal laboratory report listed below:

1. Abstract.
2. Theory.
3. Procedure.
4. Results and Discussion.
5. Conclusions.

Students should include either simulated data or data from similar experiments as example of what results are expected from the experiment and how the results should be handled. These manipulations should include error and statistical analysis.

A discussion about the suitability of the experiment and the estimated accuracy should be included in the discussion.

Prepared by: Dr. Jorge Gabitto

Date: January, 2019

ABOVE AVERAGE

(Note: All Pages shown in Light Blue should be printed on Light Blue Paper)

Above Average Student Original Graded Assignment

There are zero ABOVE AVERAGE student samples available.

AVERAGE

Average Student Original Graded Assignment

Design of Experiments

The Study of Cooling Tower Operations and Performance

CHEG 4011P03: Dr. Antoine

Prepared By:
Heaven McCray
Christen Augustine
Jordan Smith
Chantel Robinson

Agenda

- Goals ➤ Conclusions
- Abstract ➤ References
- Theory
- Experimental Procedure
- Results

➤ Discussion

Goals

- Study the performance of cooling towers by varying inlet water temperature
- Complete the energy balance of the system
- Create a successful experiment where classroom fluid mechanic and separation topics are applied by Prairie View Students in the Unit

Operations Lab



Abstract

- Industrial cooling towers are used to remove surplus heat from water.
- They function as heat exchangers based on the counter flow principle.
- Primarily uses latent heat of vaporization (evaporation) to cool process water.



Abstract

- Major Factors of Cooling Tower Performance:
 - Water Flow Rate
 - Water Inlet Temperature
 - Water Outlet Temperature
 - Wet Bulb Temperature
- Cooled water is below the dry-bulb temperature and above the wet bulb temperature of air.



Theory

$$H = U + PV.$$

This equation is used to calculate the enthalpy of the system, which is referenced from tables depending on the fluid used:

- Water
- Air

$$\Delta H = H_{in} - H_{out}.$$

This is the general method to conduct an energy balance for the cool water output. Generation and accumulation are

not considered in this equation.

$$\Delta H = C_p \Delta T \text{ (3)}$$

Although the enthalpy of air can be calculated using the general method, since air is at low pressure it is treated as an ideal gas and be

calculated with the equation.

$$\Delta H_{Water} + \Delta H_{Air} = 0$$

When the two values are added together, the result should be zero, showing the first law of thermodynamics.

$$\Delta H_{Water} = \Delta H_{Air}$$

The change in the enthalpy of water and the enthalpy of air should have opposite signs to show the heat transfer among the two fluids.

Theory

- **Humidification:** the process of increasing the water vapor content of air
- **Dehumidification:** the process of decreasing the water vapor content of air
- **Wet Bulb Temperature:** the lowest temperature that water theoretically can reach by evaporation

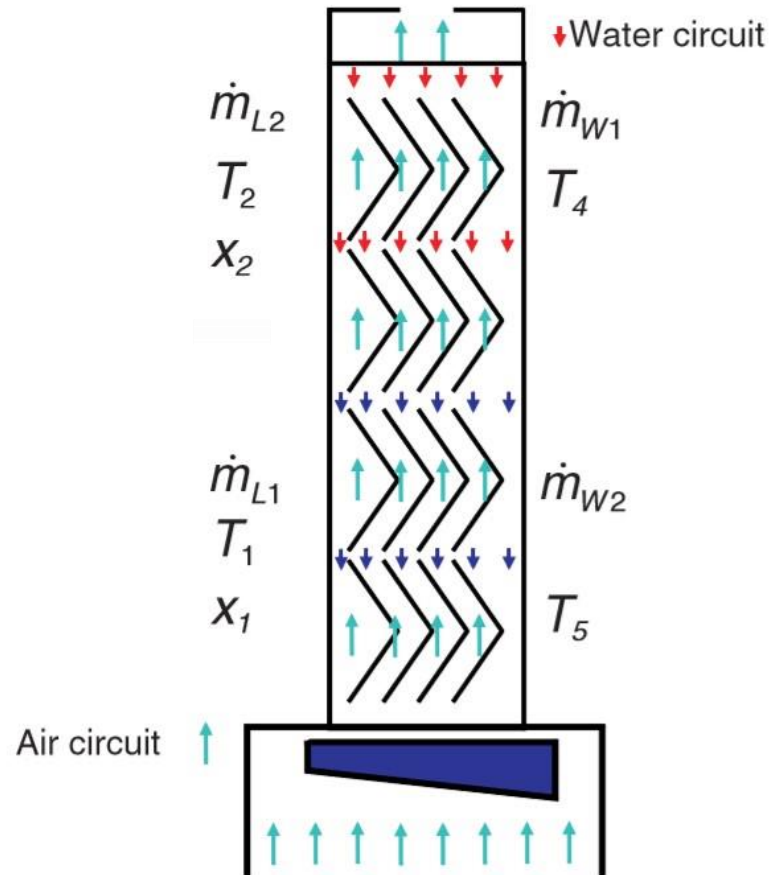
Theory



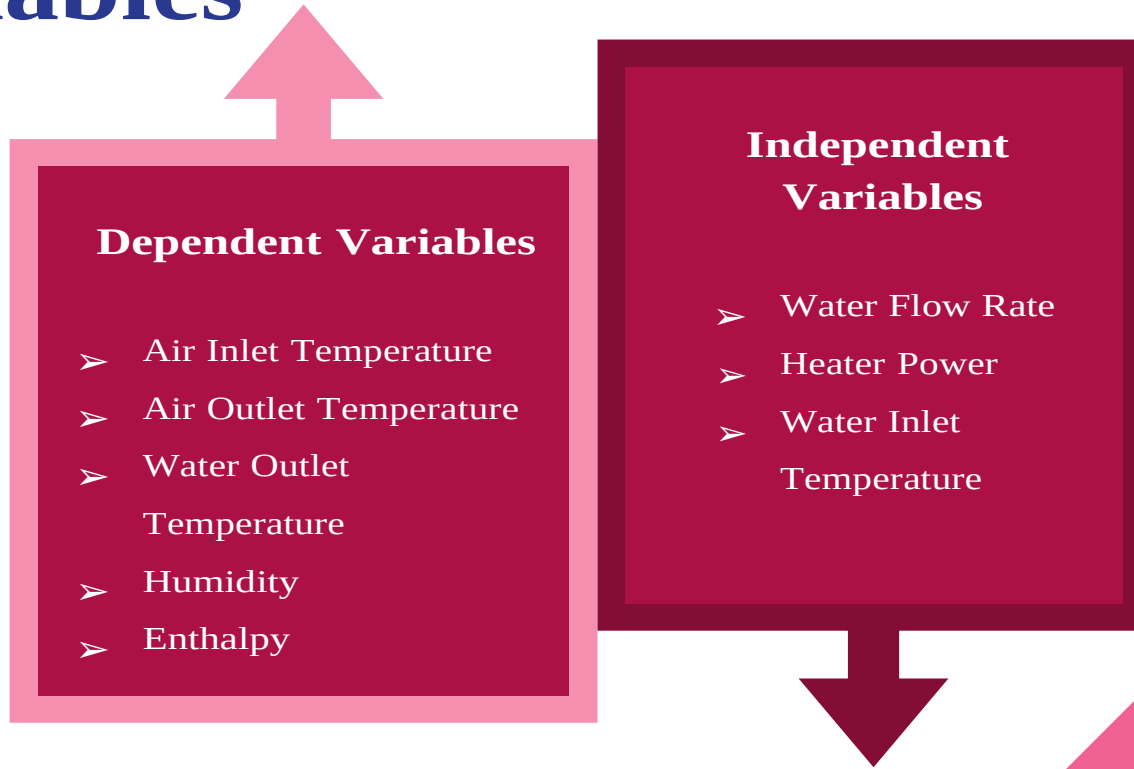
- **Dry Bulb Temperature:** the temperature of the air
- **Dew Point Temperature:** the temperature at which water vapor starts to condense
- **Cooling Load:** the rate at which heat is removed from the water
- **Cooling Range:** the difference between the water temperature at entry to and exit from the tower

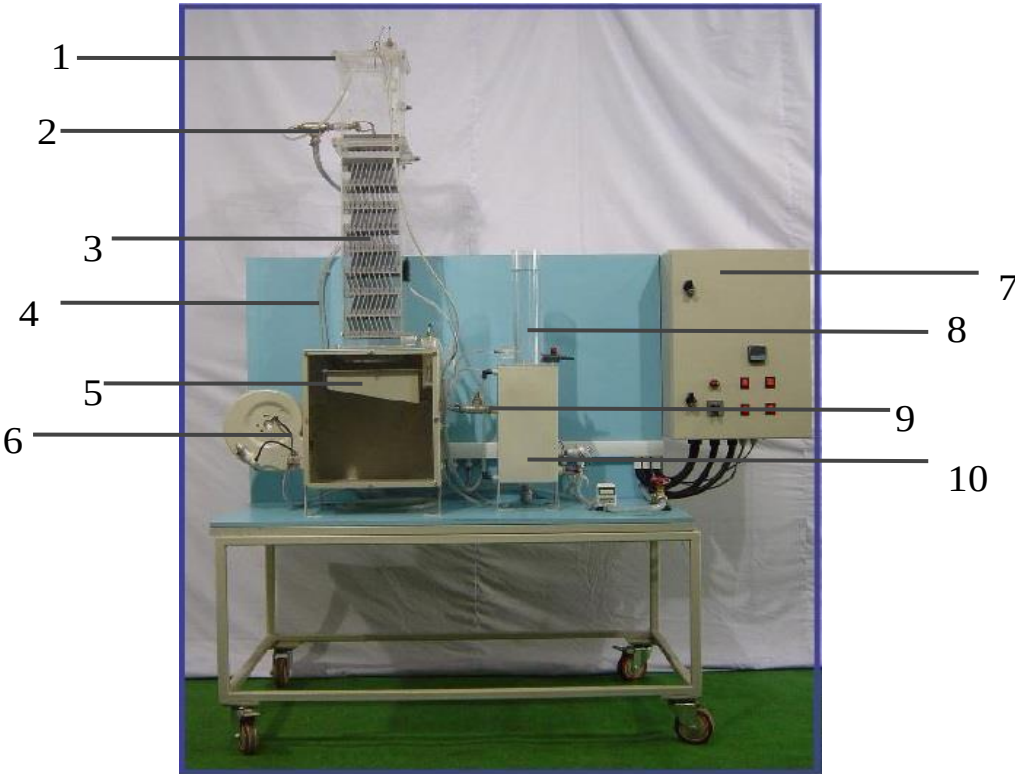


Theory



Variables





2. Water Distributor
3. Packing Column
4. Flow Meter
5. Basin
6. Air Blower
7. Control Panel
8. Make-Up Tank
9. Differential Pressure Transmitter
10. Load Tank

1. Orifice

Experiment Setup

1. Ensure that the valves are checked and are closed.
 2. Fill the load tank with deionized water (or tap water) up to the zero mark.
 3. Add deionized water to the wet bulb sensor reservoir.
 4. All appropriate tubing was connected to the differential pressure sensors.
- 

5.Ensure appropriate cooling tower packing was installed for the experiment.

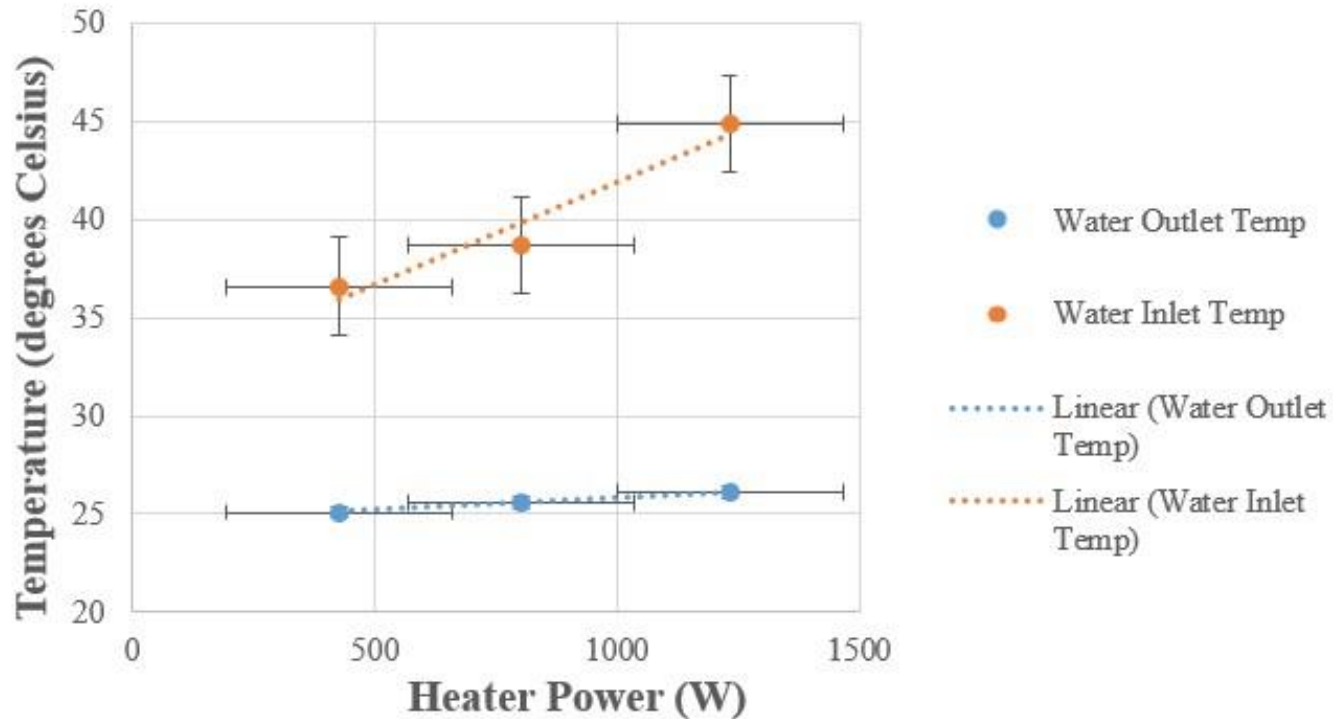
Experimental Procedure

- 1.Set temperature of temperature controller to 45°C. Switch on the 1.0 kW water heater and heat to 40°C.
 - 2.Switch the pump on and slowly open the control valve (V1) to adjust the water flow rate.
 - 3.Fully open the damper and turn on the fan blower.
 - 4.Run the system for 20 minutes to ensure float valve correctly adjusted the level in the load tank.
 - 5.The damper and the water flow rate were set to be constant to determine effect of heater power on water outlet temperature.
- 

Experimental Procedure cont.

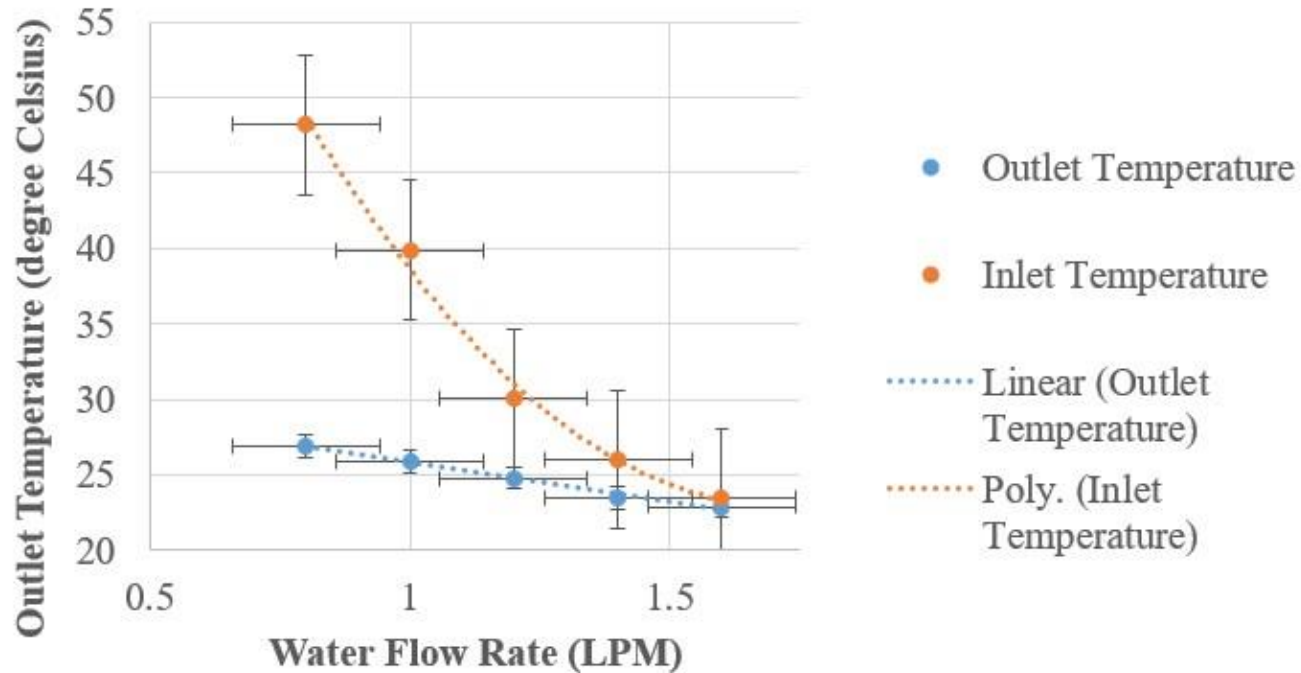
6. Switch off the 1.0 kW water heater and set the power as 0 kW.
 7. Record all the data required after 10 minutes to ensure the unit stabilized for the first trial and another 10 minutes for second trial.
 8. To measure the differential pressure across the orifice, valves V4 and V5 were opened while valves V3 and V6 were closed.
 9. To measure the differential pressure across the column, valves V3 and V6 were opened while V4 and V5 were closed.
 10. Set water heater to 0.5 kW, 1.0 kW, and 1.5 kW. Collect data.
 11. Finally, turn off the heaters and let water circulate through the system for 3-5 minutes until cool.
- 

Heater Power vs. Water Temperature



Results (Cont.)

Water Temperature vs. Water Flow Rate



Discussion

For Experiment 1

- ❖ Investigated the effect of different heater powers (0.5 kW - 1.5 kW) to determine changes in outlet temperature.
- ❖ When the value of the heater power fluctuated, it resulted in the values of 25.1°C, 25.6°C, and 26.1 °C, showcasing that increasing the value of heater power will decrease the amount of heat transfer.

Discussion



For Experiment 2

- Investigate the effect of various water flow rates (0.8 - 1.6 LPM) on the outlet water temperature.
- From the data we can conclude that increasing the water flow rate will reduce heat transfer in the cooling system.



Discussion

➤ Safety:

- Non-hazardous materials.
- Moderately low temperature and pressure. ➤

Equipment: Benchtop Cooling Tower

- Cost - \$2,800
- Low maintenance and minimal care required.

➤ Timing

- Approximately 25 minutes per experiment.
- Can be completed within the allotted class time.

Conclusion

- This experiment was successfully conducted



- The experiment is recommended for the PVAMU CHEG 4011 curriculum.

Experiment 1

- As the value of the power heater increases, the cooling range increase.

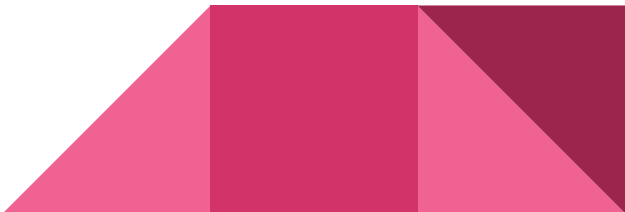
Experiment 2

- The higher the water flow rate, the lower the energy in the form of heat transfer is released.
- The higher the power, the lower the energy transfer.

References

Ahmed, Noaman. “Cooling Towers - An Extensive Approach.” *LinkedIn SlideShare*, 8 Jan. 2015,

<https://www.slideshare.net/NomanAhmed1/cooling-towers-an-extensive-approach>.



“Bench Top Cooling Tower.” *Didac International*, <https://www.didacinternational.com/bench-top-cooling-tower-3511570.html>.

“Dry Bulb, Wet Bulb and Dew Point Temperatures.” *Engineering ToolBox*, https://www.engineeringtoolbox.com/dry-wet-bulb-dew-point-air-d_682.html.

Hao, Sem Yong. “Cooling Tower Lab Report.” *Academia.edu*,

References

Lewis, Sharon, et al. *Cooling Tower Experiments*. University of Tennessee at Chattanooga , 17 Sept. 1996,
<http://chem.engr.utc.edu/webres/435F/3T-CT/3T-CT.html>.

Skool, Azlan. “Cooling Tower Full Report.” LinkedIn SlideShare, 15 Nov. 2014,
<https://www.slideshare.net/azlan.skool/cooling-tower-full-report>.

“Und

e

https://www.academia.edu/28948993/Cooling_Tower_Lab_Report?auto=downl

standing Wet Bulb Temperatures and How It Affects Cooling Tower Performance: Manufacturers of Cooling Towers & Systems: Delta Cooling Towers, Inc.” *Manufacturers of Cooling Towers & Systems by Delta Cooling Towers, Inc.*, 27 Oct. 2017, <https://deltacooling.com/resources/news/understanding-wet-bulb-temperatures-and-how-it-affects-cooling-tower-performance>.

BELOW AVERAGE

Below Average Student Original Graded Assignment

There are zero BELOW 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

McCabe-Thiele Method of Calculation for Number of Theoretical Stages

Outcome Measured Using this Assignment

Outcome 3
An ability to communicate effectively with a range of audiences
(Written Communication)

Check the communication problem characteristics related to this assignment

Ability to prepare an executive summary for the report	
Requires students to:	
	Prepare an executive summary of 5 to 8 pages
Ability to organize, plan and properly format a written technical report	
Requires students to:	
x	Organize report by chapters, major sections, subsections and paragraphs
x	Provide Title Page, and Table of Contents, list of Figures, and List of Tables properly formatted.
x	Provide figure and table numbers with titles and reference and discuss each table and figure in accord with standard practice.
x	Properly cite references in the report and provide well formatted reference list at the end.
x	Prepare the written report in accord with standard report formatting Manual
Ability to compose original texts and properly apply the conventions of written language.	
Requires students to:	
X	Properly apply capitalization, punctuation, and penmanship, to communicate clearly and spell proficiently,
X	Apply standard grammar and usage to communicate clearly and effectively in writing using complete sentences , good subject-verb agreement, pronoun referents, and parts of speech, properly using adjectives, adverbs, prepositional phrases appropriately, conjunctions to connect ideas to make writing vivid and precise, and use available technology to support aspects of creating, revising, editing, spell checking, and publishing the report.
Ability to provide appropriate discussion, conclusions and recommendations	
Requires students to	
X	summarize the goals, objectives, and indicate whether they were met.
X	summarize the report chapter by chapter
X	summarize constraints and codes and indicate whether they were met for design reports Summarizes how issues relating to public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors were considered/addressed for design reports.
X	Provide logical conclusions Provide logical conclusions and recommendations (including strengths and weaknesses)

Brief justification of why this assignment is suitable for this outcome

The lab report is a requirement that demonstrates the students' capability for written communication.

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.

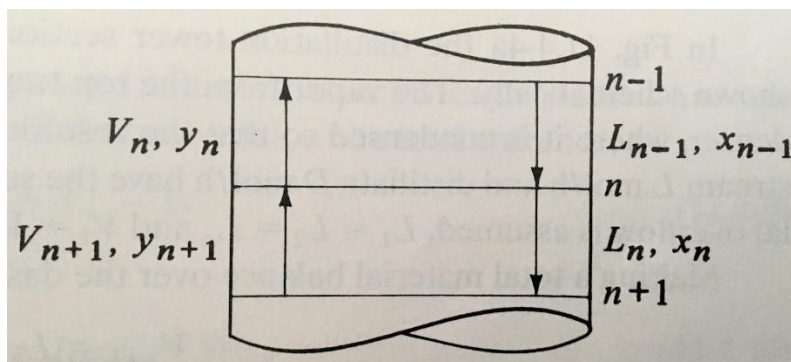
For countercurrent contact with multiple stages, the material balance on component A is given by the operating line equation:

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

The total material balance is given by:

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

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.



PVAMU CHEG 4011 – Chemical Engineering Laboratory II
Separations & Fluid Mechanics

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.

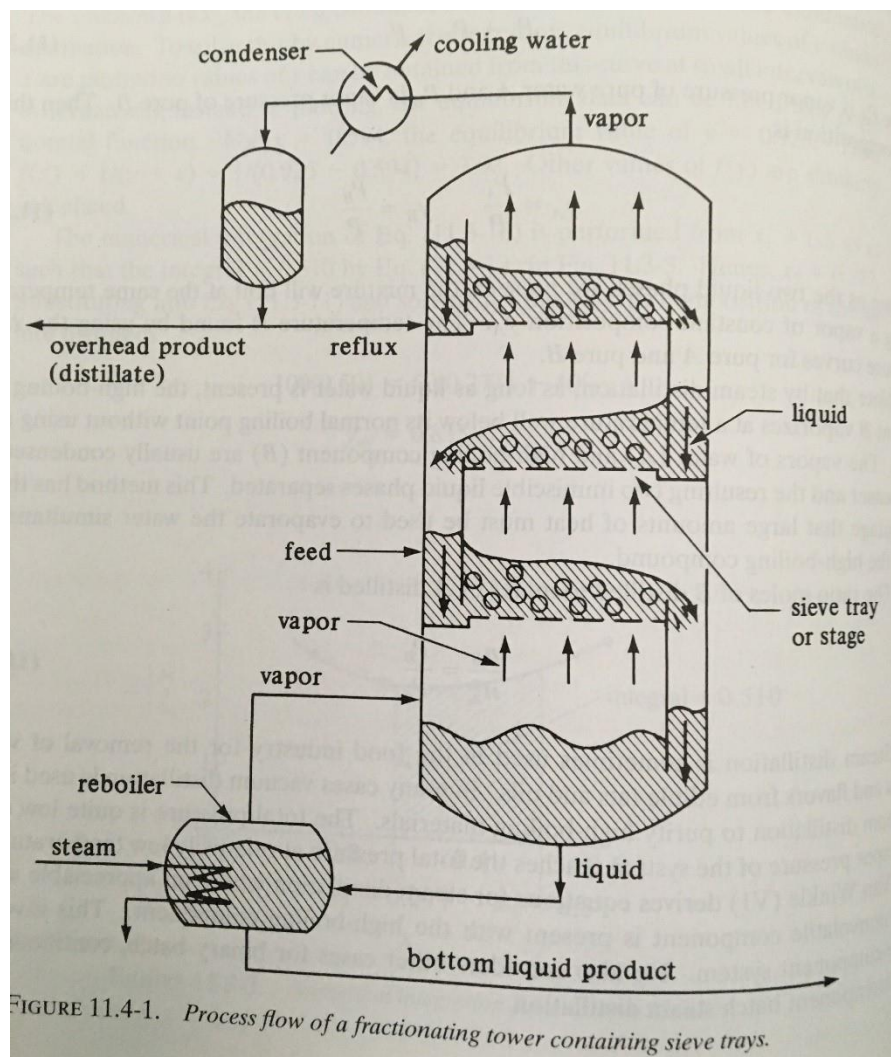


Fig. 2. Schematic of a distillation column containing sieve trays.

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.

Equipment Diagrams

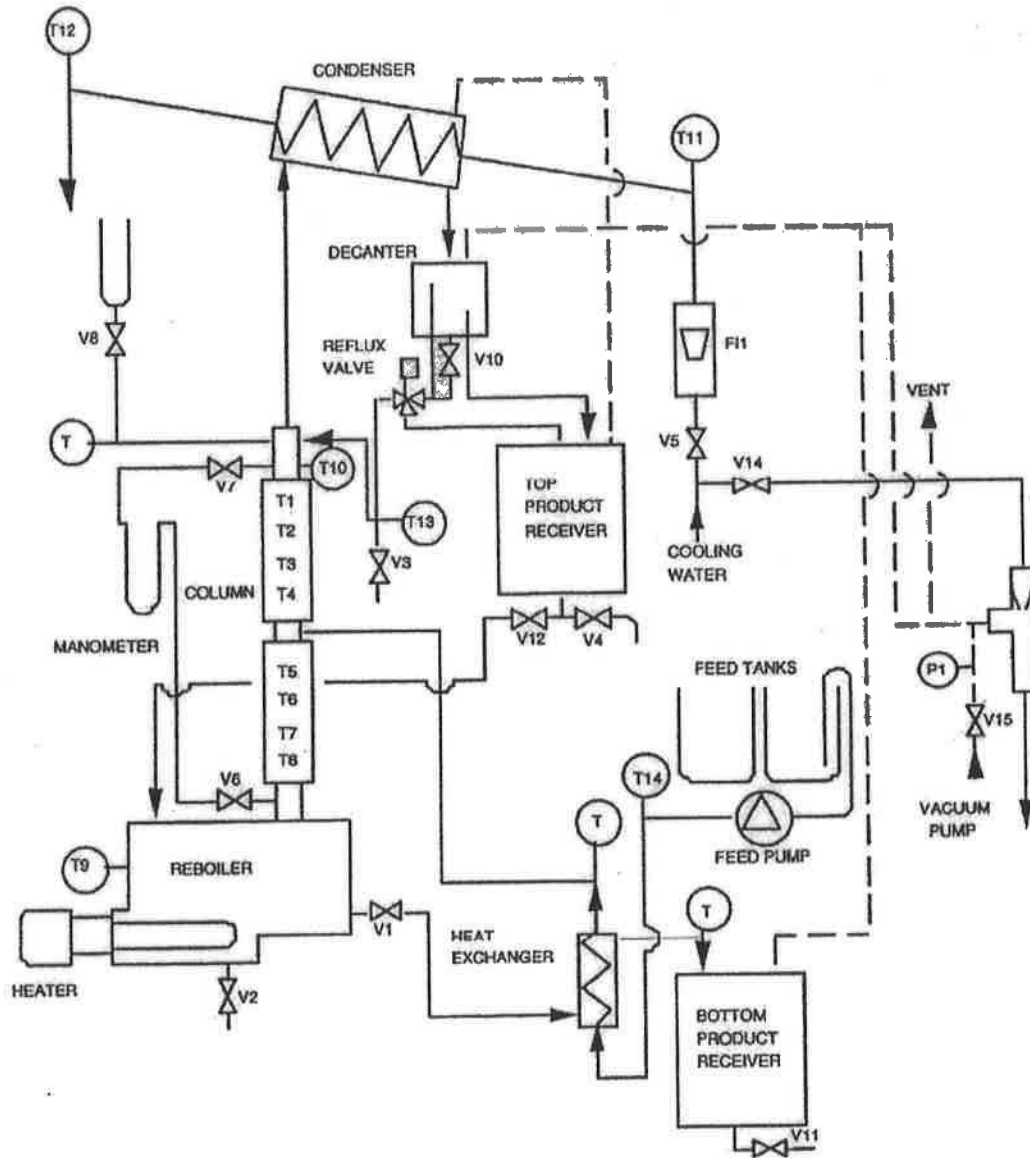


Figure 1: Schematic Diagram

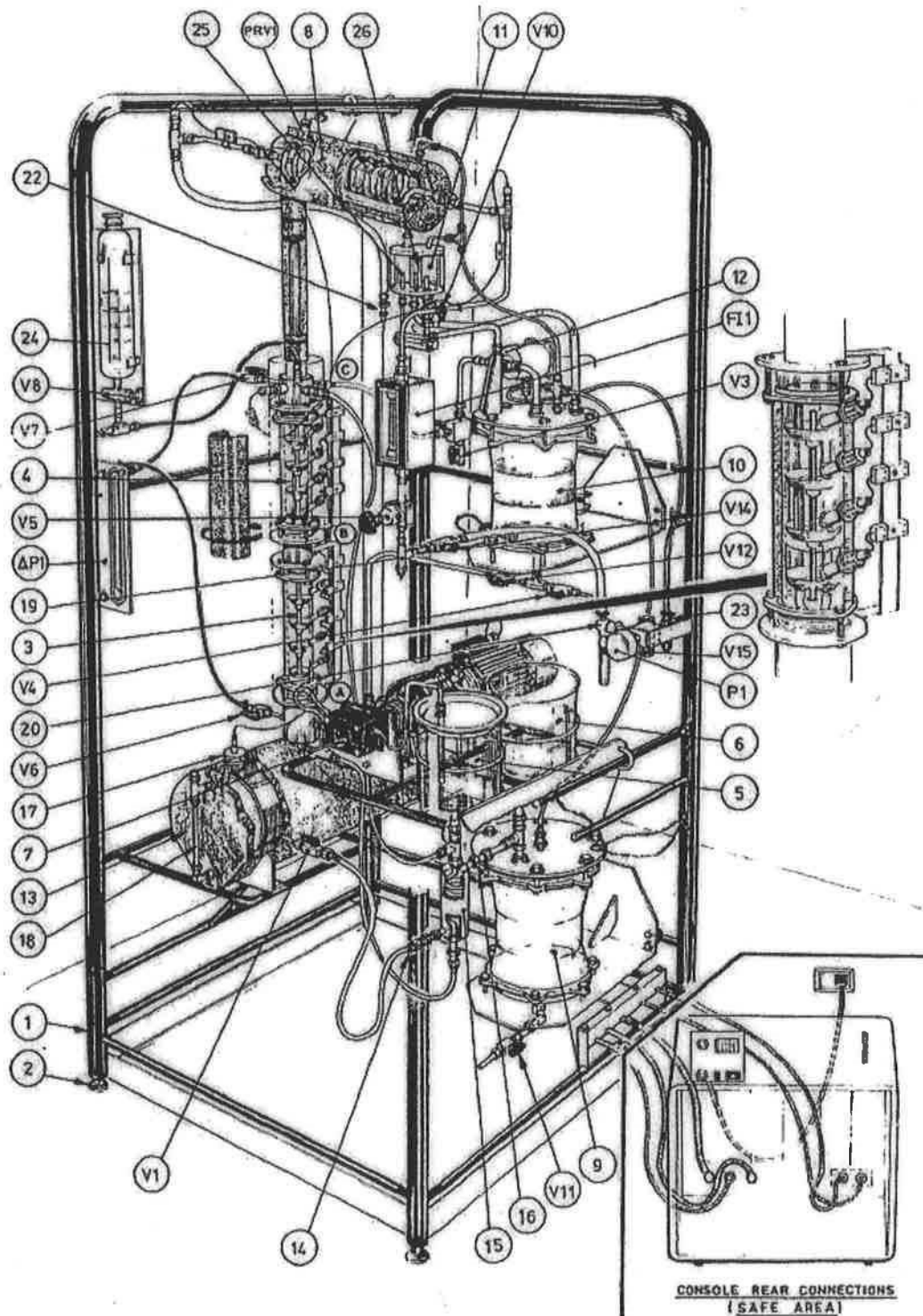
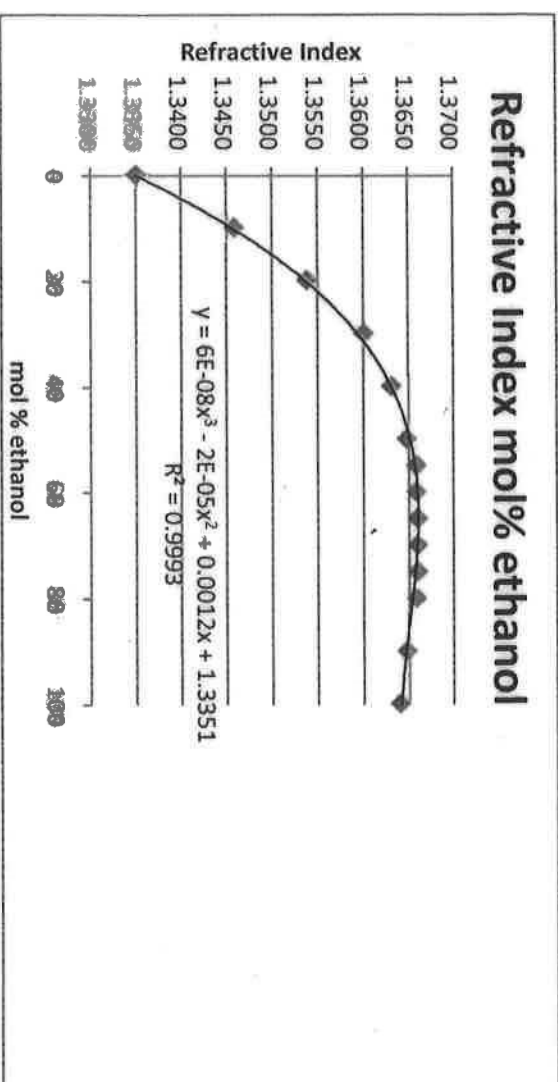


Figure 3: UOP3CC Process Unit

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	1.3568
65	1.356
70	1.355
75	1.355
80	1.3558
90	1.3548
100	1.354



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

ABOVE AVERAGE

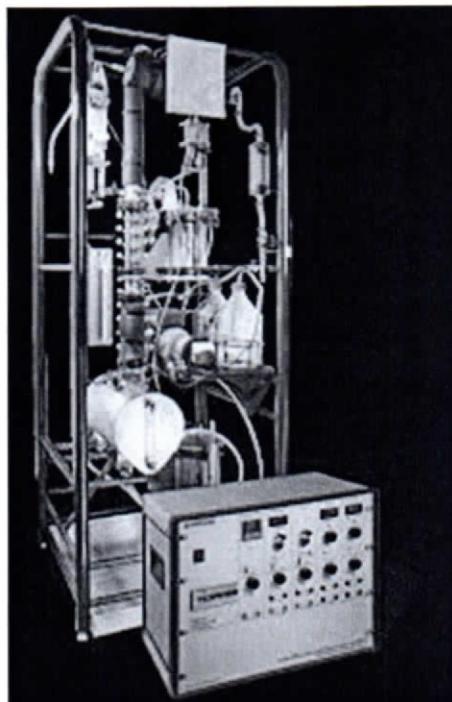
(Note: All Pages shown in Light Blue should be printed on Light Blue Paper)

Above Average Student Original Graded Assignment

Page T4

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

Jordan Smith

Christen Augustine

Chantel Robinson

Submitted to

Dr. Keisha Antoine

Table of Contents

Abstract.....	1
Theory.....	2
Procedure.....	8
Data and Results.....	10
Discussion.....	16
Conclusions.....	17
References.....	19

List of Illustrations

Figures

Figure 1. Basic Illustration of Fractional Distillation	3
Figure 2. Schematic Diagram of the Armfield Column.	8
Figure 3. Refractive Index for Mole Percent of Ethanol.	13
Figure 4. Theoretical Results using the McCabe Thiele Method.	16

Tables

Table 1. Constant Variables Given by Laboratory Manual and Laboratory Equipment Setup.	10
Table 2. Temperature of Each UOP3CC Column Tray.	10
Table 3. Experimental Data Obtained from Sampling and Refractometer Analysis.	11

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.

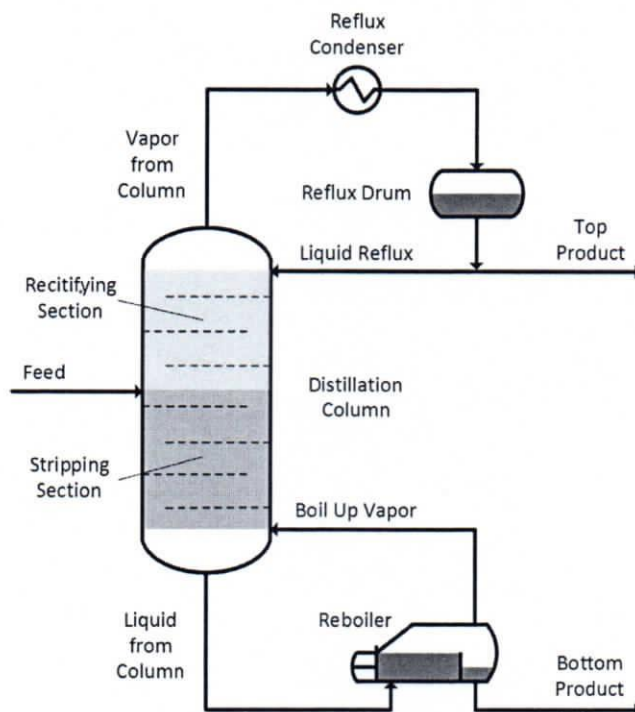


Figure 1. Basic Illustration of Fractional Distillation [“Mass Transfer Distillation” 2018]

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.

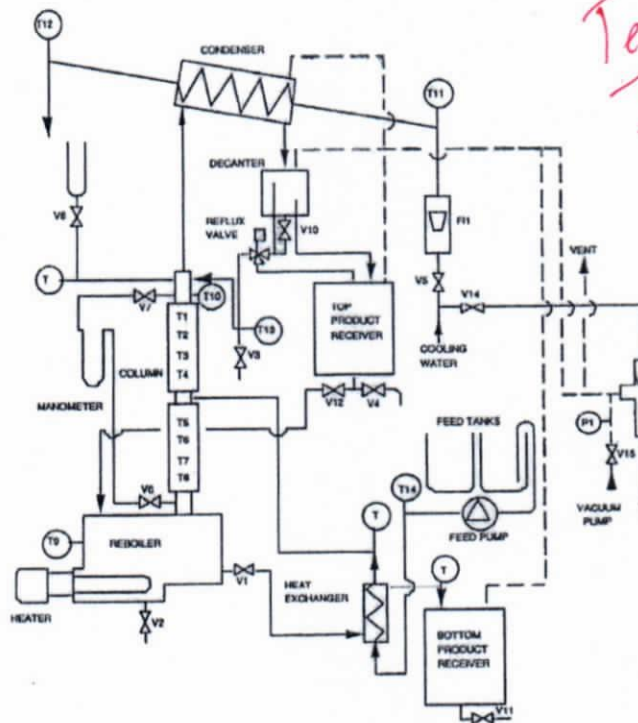


Figure 2. Schematic Diagram of the Armfield Column ["CHEG 4011 Laboratory Manual"]

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 ~~with~~ 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.

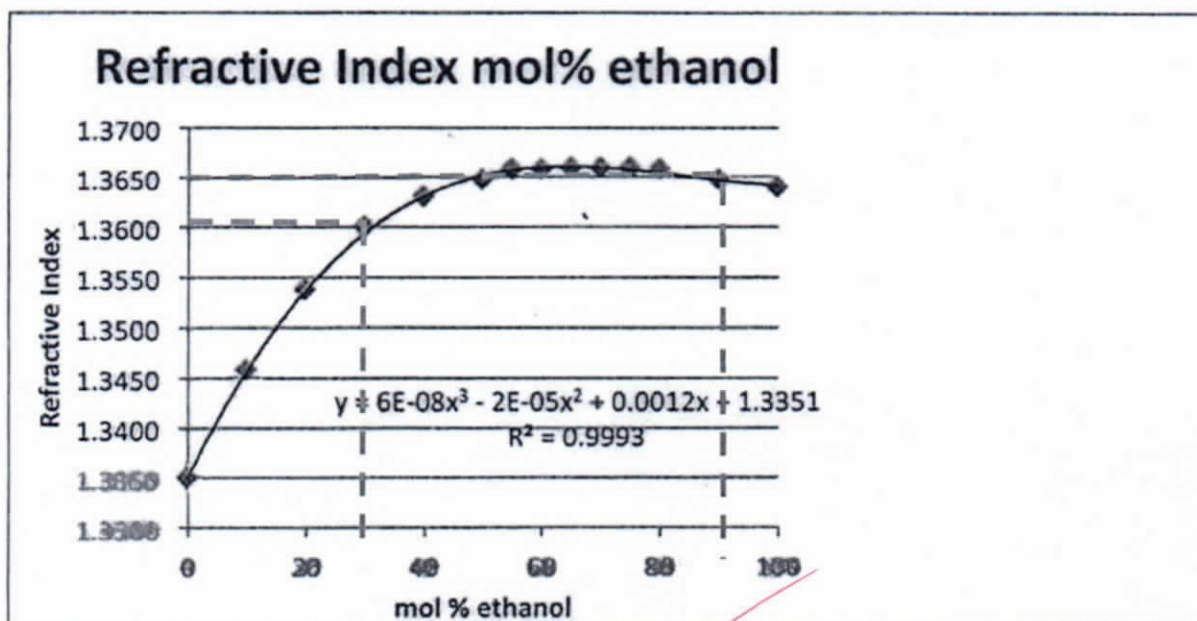


Figure 3. Refractive Index for Mole Percent of Ethanol ["CHEG 4011 Laboratory Manual"]

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.

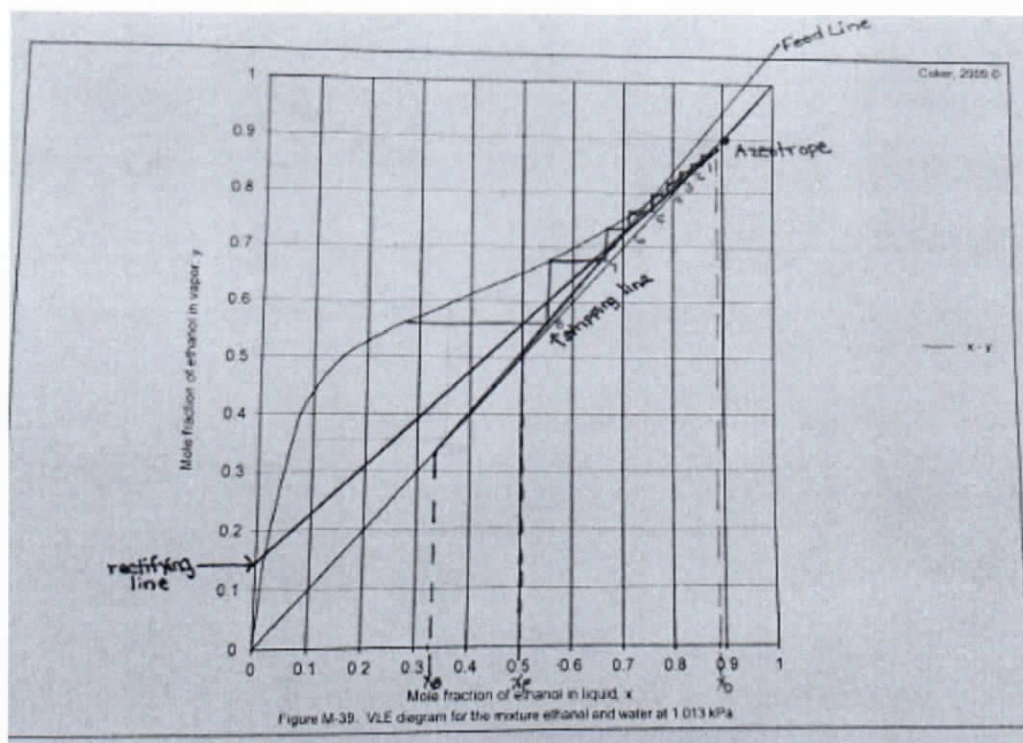
Rectifying operating line:

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

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
15/15*

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.

References

“CHEG 4011 Laboratory Manual.” Prairie View.

“Mass Transfer Distillation.” Chemical Engineering: Mass Transfer, The Gate Matrix, 15

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).

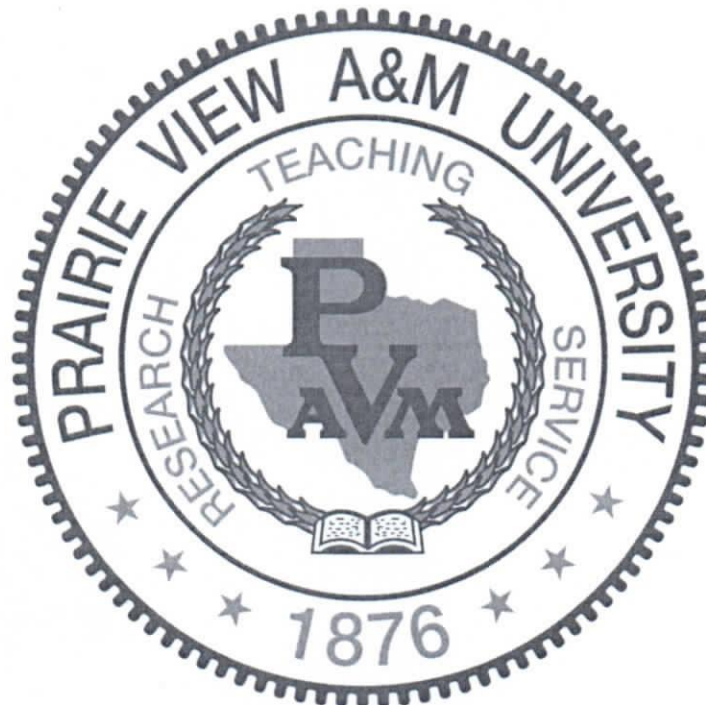
Geankoplis, Christie John. *Transport Processes and Separation Process Principles*. 4th ed., Prentice Hall, 2003.

There are zero ABOVE AVERAGE student samples available.

AVERAGE

Average Student Original Graded Assignment

70.5
100



**Lab 2: McCabe-Thiele Method of Calculation for Number of
Theoretical Stages**

Performed by: Habibat Kadri, Charles Kellum, Hiba Nadeem, Waleed
Siddiqui

Experiment performed on: October 14, 2019

Due Date: October 21, 2019

Tech	Engl
$\frac{7}{10}$	$\frac{3}{5}$

Abstract:

The purpose of this experiment is to fully understand and comprehend the McCabe-Thiele method of calculating the number of theoretical stages. Utilizing the ^{Armfield} UOP3CC continuous distillation column, the main factors that need to be accounted for with the McCabe-Thiele method are Reflux ratio [R], x_D , x_F , x_B . The key results from this experiment are that the reflux ratio is 5, $x_D = 0.74$, $x_B = 0.24$, $x_F = 0.5$, and the number of theoretical stages is 5.6. The mole fraction in the distillate shows that there is mainly ethanol at the top, a very minimal amount of ethanol at the bottom (mainly water at the bottom).

do you need both these words that mean the same thing?

these are supposed to be subscripts. You made the font so small it is difficult to read.

is not a result; you were told that are these?

Tech	Engl
$\frac{3}{5}$	$\frac{3}{5}$

Theory:

Distillation is a system of separation utilizing volatility to separate binary or multicomponent streams. A distillation column is used for this process, and is composed of trays, a reboiler, condenser as primary components. The trays in the system serve to maximize mass transfer between the liquid and vapor as the two phases come into contact with one another. A reboiler reheats liquid to maximize the phase change of the substance needed to be separated. The condenser does the opposite and condenses the vapor stream to maximize separation. For the condenser, in particular, the product liquid (the condensed vapor) is called the distillate and some of the condensed liquid that is fed back into the column is called the reflux. The ratio between those two liquids is called reflux ratio. - show eq'n.

Please explain

Please explain

To better [?]under how the separation occurs the concept of volatility must be understood.

Volatility is the tendency for a variable or substance to evaporate, and given that varying substances have higher or lower boiling temperatures separation can occur by temperature manipulation. In binary systems you have two components, the substance with the lower boiling temperature and the substance with the higher boiling temperature. These components are known as the light key and heavy key, respectively.

different boiling T's

exploiting the temp difference

there are

each having different boiling T's

low boiling T
high boiling T

The primary application of the McCabe-Thiele method is to help with the design of a distillation column. The main conditions that are needed to satisfy the McCabe-Thiele method are that it is a binary distillation (two components are being fed into a distillation column) and that the VLE (vapor-liquid equilibrium) data for the light-key are provided.

The McCabe-Thiele method is considered the simplest method for analysis of binary distillation. The composition of each equilibrium stage is completed by the mole fraction of one of the two components and is based on the assumption of constant molar overflow which requires that: the molar heats of vaporization of the feed components are equal to each other, for the mole of the liquid vaporized, the mole vapor is condensed.

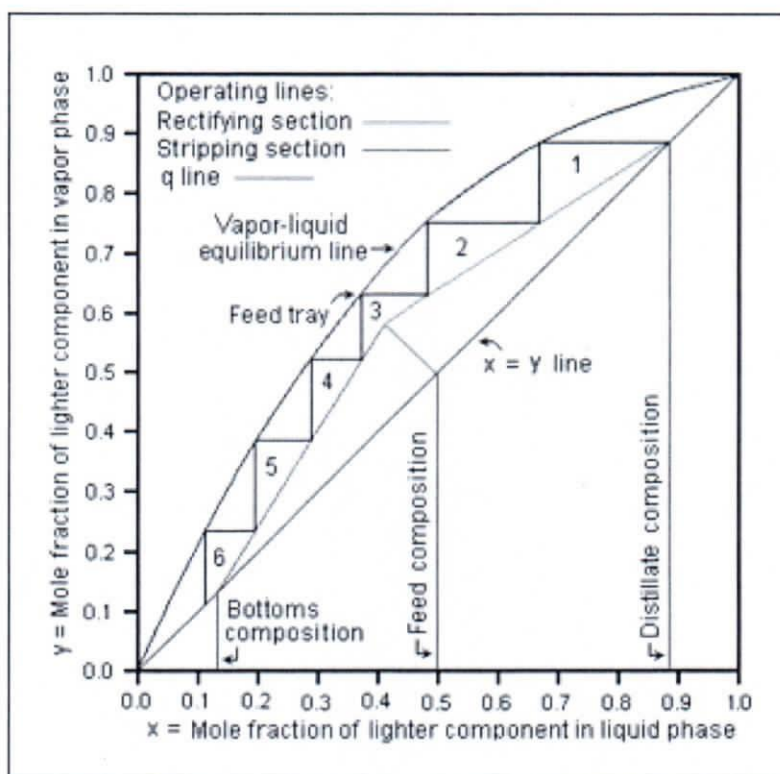


Figure 1: McCabe-Thiele diagram for distillation of a binary feed

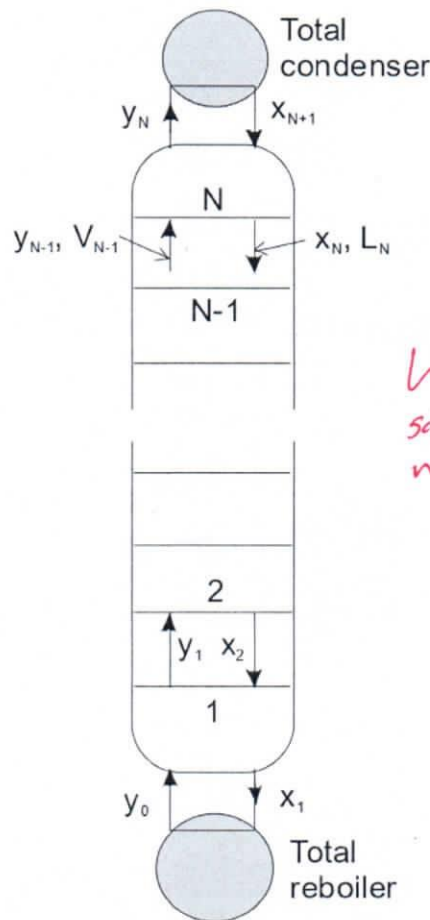
During stage distillation, the liquid and vapor products from each stage flow are countercurrent to each other. Usually, the vapor stream, V and the liquid stream, L leave each stage in equilibrium.

This is an assumption, a goal one, but an assumption nevertheless

To calculate the reflux ratio:

$$\text{Reflux ratio} = \frac{\text{liquid}}{\text{distillate}} \quad (\text{Equation 1})$$

molar flow rate (pointing to liquid)
molar flow rate (pointing to distillate)



Why did gaeshaw this schematic? It wasn't mentioned in the Theory

Figure 2: The distillation column operation at total reflux

reference?

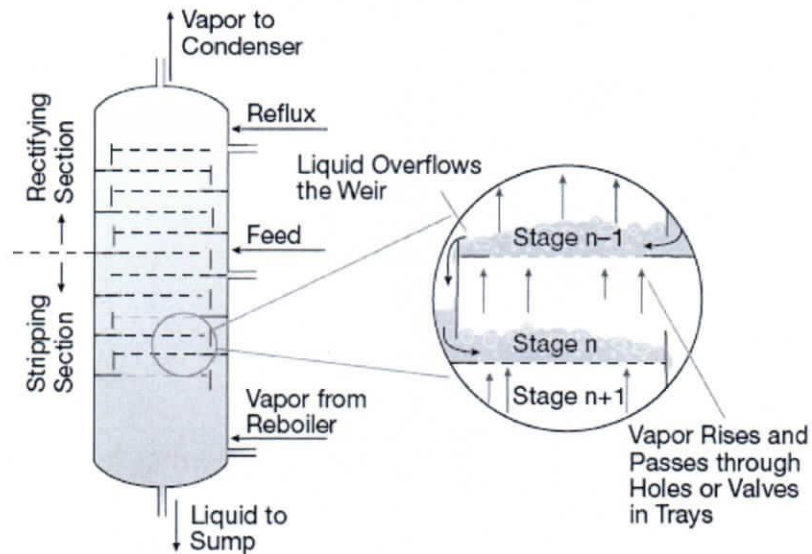


Figure 3: Portrayal of stage behavior within the distillation column

reference?

During stage distillation, the liquid and vapor products from each stage flow are concurrent to each other. Usually, the vapor stream (V) and the liquid stream (L) leave each stage in equilibrium. For concurrent contact with multiple stages, the material balance on component A is given by the operating line equation:

$$V_{n+1}Y_{n+1} + L_{n-1}X_{n-1} = L_nX_n + V_nY_n \quad (\text{Equation 2})$$

The total material balance is:

$$V_{n+1} + L_{n-1} = V_n + L_n \quad (\text{Equation 3})$$

- V_{n+1} is mol/h of vapor from the tray $n+1$
- L_n is mol/h liquid from tray n

- Y_{n+1} is mole fraction of A in V_{n+1}

Solving Y_{n+1} , the enriching-section operating line is

$$Y_{n+1} = \frac{L_n}{V_{n+1}} X_n + \frac{Dx_D}{V_{n+1}} \quad (\text{Equation 4})$$

Since $Y_{n+1} = L_n + \frac{Dx_D}{V_{n+1}} = \frac{R}{R+1}$ and equation 4 becomes:

$$Y_{n+1} = \frac{R}{R+1} x_n + \frac{x_D}{R+1} \quad (\text{Equation 5})$$

Solving for Y_{m+1} , the stripping section operating line is

$$Y_{m+1} = \frac{L_m}{V_{m+1}} + \frac{Wx_W}{V_{m+1}} \quad (\text{Equation 6})$$

Procedure: — *Bold or Italics or Underline*

Tech / Egl
70 / 3
5

The first step of this experiment is to allow the system to flow for a couple minutes in order to make sure that flow is constant throughout the entire system. Once the system has been active for a few minutes, you must take samples from two specific locations in the system, the reboiler and V3. The first area where samples need to be extracted from is V3, so the first thing to do is to disconnect the pipe from the receiver and have a flask to collect excess mixture and check to see if the flow coming out of the pipe is constant. Once the flow is constant, grab a 100 mL graduated cylinder and time to see when the mixture fills 50 mL of the 100 mL

graduated cylinder. Record the time and repeat this step two more times to ensure that the

no; it is to get an average, which is more accurate than 1 reading.

times are about the same. Next, mixture samples from the reboiler need to be obtained. Repeat

the same steps from V3, however, handle with caution and be sure to wear gloves because the

temperature of the mixture coming out will be ~77°C. Once the samples are obtained, it is

important to send them to a refractometer.

Different
sense from
sentence
before and
after it.

why?
The second part of this process requires taking the samples from V3 and the reboiler to a refractometer. The first step with the refractometer is to rotate the primary and secondary prisms open take an alcohol wipe and clean them. Take the first sample from V3 and use a transfer pipet to place 2-3 drops on the primary prism. Next, lower the secondary prism and rotate the prism open and shut the knob away from you in order to encase the sample between the primary and secondary prism. Turn the measurement knob until the boundary line appears in the field of view. Once the line appears, turn the color compensator to make sure there isn't a red or blue tinge and it is clear to your field of vision. Next, turn your measurement knob to set the boundary line to the intersection of the cross hairs. Right underneath the cross hairs, there are two different scales that should be there, the top showing the Refractive index, and the lower showing the Brix percent. Record these values and repeat these steps for the multiple samples remaining. *wasn't used in your results*

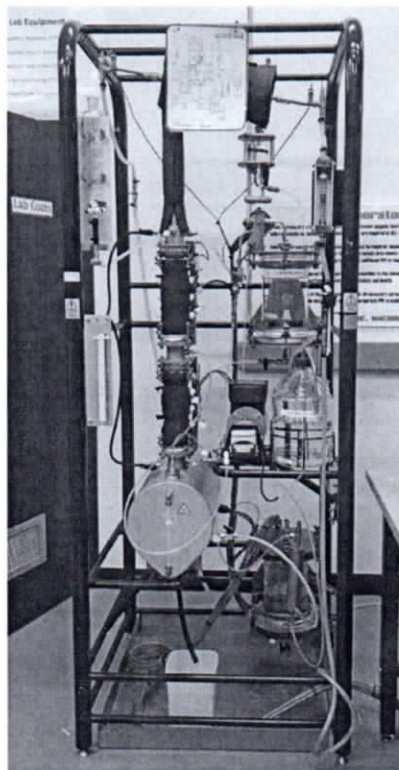


Figure 4: Frontal view of UOP3CC Process Unit



Figure 5: V3 Pipeline going into Receiver

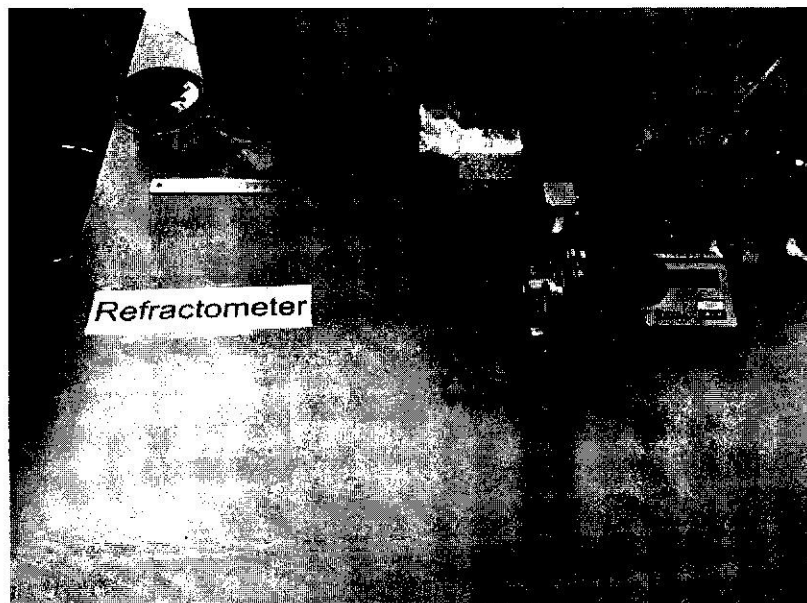


Figure 6: Refractometer setup

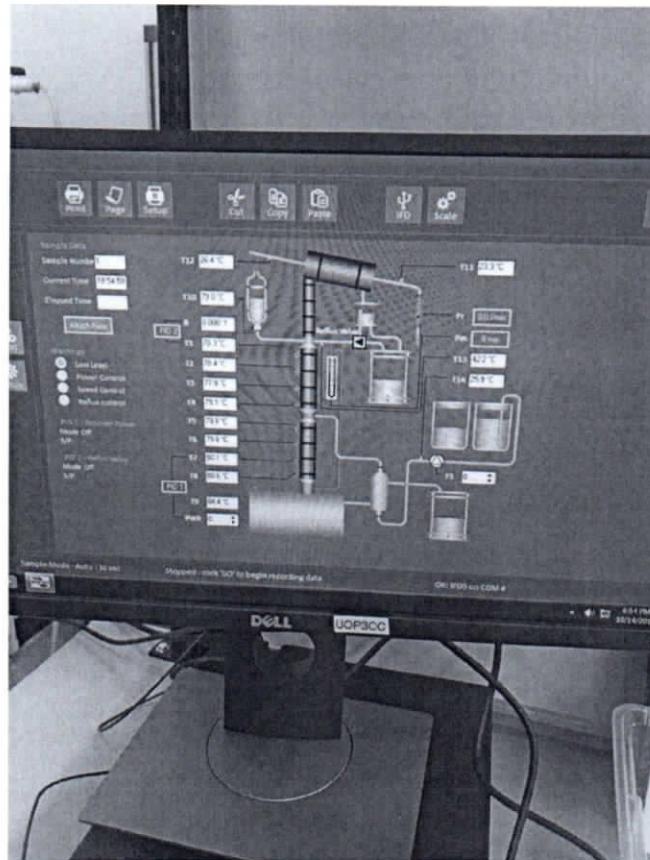


Figure 7: Computer Data showing the temperatures within the system

Discussion and Results:

Data + Results
Tech 25/30
Engl 10/15
W/OX

Discussion
Tech 10/15
Engl 3.5/5

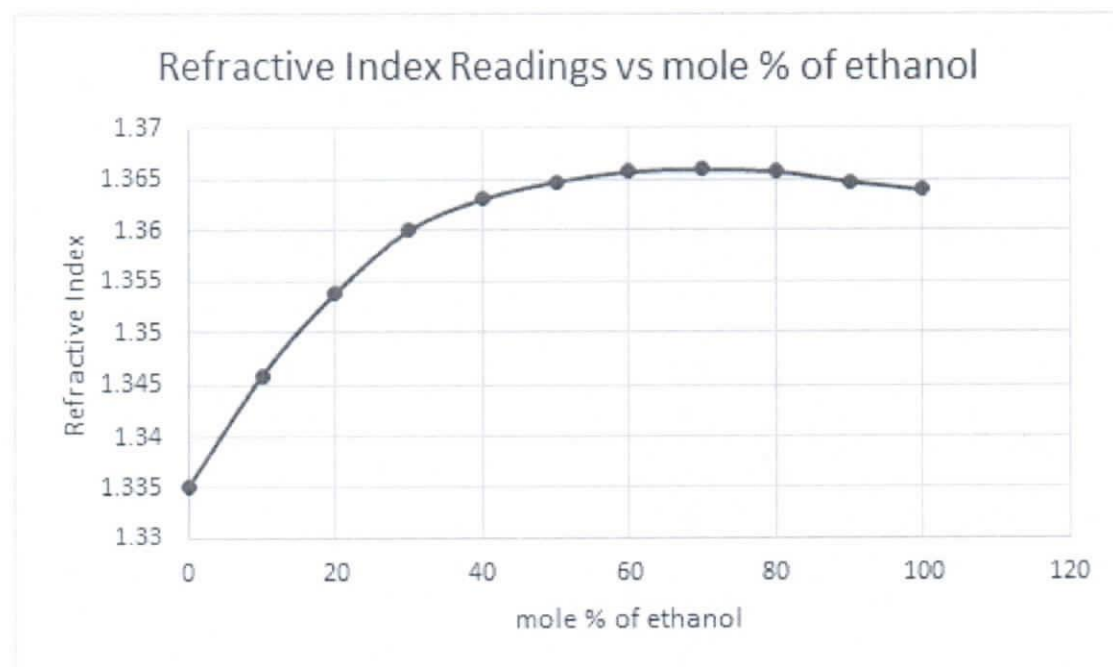
In our system, ethanol has a boiling temperature of 78.4°C and water 100°C . This means that ethanol is our light-key and water is the heavy-key, of the system. Also, because distillate is usually the product of interest in distillation, ethanol is the point of reference in calculations.

To ensure that volumetric flow was accurate throughout the system the overall flow balance of the feed was calculated using a calibration curve of the feed pump. That value came

out to be roughly 1.23 mL/s. To calculate flows, of the top (D) and bottom (B), time was measured as a graduated cylinder was filled to 50mL. Dividing that volume over the measure time, allowed for estimating flow rates of those two streams. Understanding that F must equal B and D , we could add both volumetric flows (B and D) to analysis if they matched up to the feed flow. *no. B is molar flow rate, Distillate flow rate. Also mass flows are conserved*

Overall the flow of B and D combined was 1.16 mL/s, which doesn't deviate too much to the feed flow given the opportunity for human error.

Our feed was entering as equimolar (50:50 ethanol to water) meaning x_F was found to be 0.5 mole percent. To find the molar compositions of ethanol sampling of distillate and bottom was needed to estimate the x_D and x_B . To determine the concentration of the streams refractive index readings were used, and the results were obtained by using the refractometer as shown in Figure 3. Three trials of sampling concluded that the average refractive index of distillate (valve V3) was 1.365 at 22.6 C, and 1.356 for bottom (valve V1) at 22.9 C.



Graph 1: Relationship of Refractive Index Readings to Mole % of ethanol

Is this Figure 3? show on the graph x_D , x_F , x_B

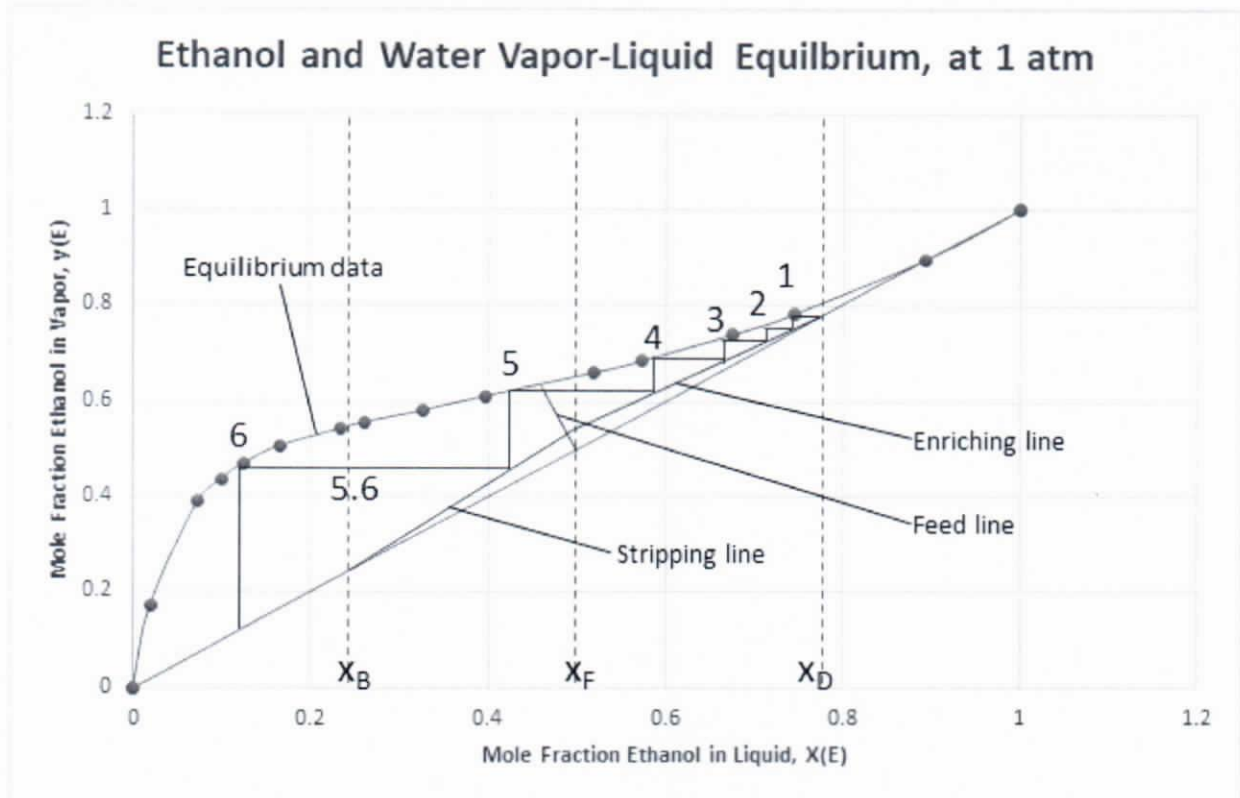
where is this?

For translating the refractive index results to molar composition tabular data of Figure. 7, was used. The values of our average refractive index readings could be interpolated to get more exact values of molar composition of ethanol. It was concluded that for the molar composition from the valve V3 was 0.78% ethanol, and 0.24% for valve V1. These results make sense given that there should be a higher concentration of ethanol that is vaporized and less remaining in liquid phase.

To find the theoretical number of stages needed for distillation, the McCabe-Thiele method can be used. This method utilizes specific variables and operating lines needed for accurate calculation of stages; these values include mole percentage of the most volatile component in the feed (x_f), distillate (x_o), and in bottom (x_b). To generate the number of stages the enriching line or stripping line, along with feed line of the system must be established.

The feed separates the enriching and stripping portion of the distillation column, their define operating lines of each are separated by the feed line. For our feed line we assumed 50% vapor and 50% liquid feed to get slope of the feed line equal to -1. The enriching line (the operating line of the distillate portion in distillation column) is formed by using **Equation 5**. This line was formed using that equation with reflux (R) equal to 5, until values meet the feed line. Once the intersection of those two lines were formed the respective stripping line must meet the same point from x_b . Starting from x_b on the 45° line ^{why?} the number of theoretical stages can be drawn as shown in **Graph 2** below.

Figure, not Graph



Graph 2: shows ethanol and water equilibrium data at atmospheric pressure.

can't see color, so you must find other ways to demonstrate what you mean

Each red vertical line shown in **Graph 2**, indicates one full stage. Given that knowledge,

it was concluded that the theoretical number of stages was 5.6 stages. For real application the

number of stages cannot be partial so the number of stages would actually be 6, with feed

entering between stages 4 and 5. Our actual system has 8 stages, therefore there is some

relevant variance between actual and theoretical values. *What about heat loss?*

This is likely due to the assumption of equilibrium being reached on each of the theoretical stages. *it is*

Also, its relevant to note that the theoretical feed location of the stages is concurrent with actual feed location.

Conclusion:

Tech 6 / Engr NA

The experiment helped in understanding how the feed and the output streams can be calculated using standard compositions of a mixture. The boil up rate revealed how the reflux ratio has a consequence on the distillation column's operation effectiveness. The higher the

reflux ratio the more efficient the separation process. Understanding this method of designing a distillation column can help outline how the engineers cut costs by determining what is optimal for a process under favorable mass transfer and conditions. Utilizing the McCabe-Thiele method can be helpful in knowing a rough estimate of designing parameters and being able to use it appropriately can cut cost and raise efficiency of distillation processes.

References

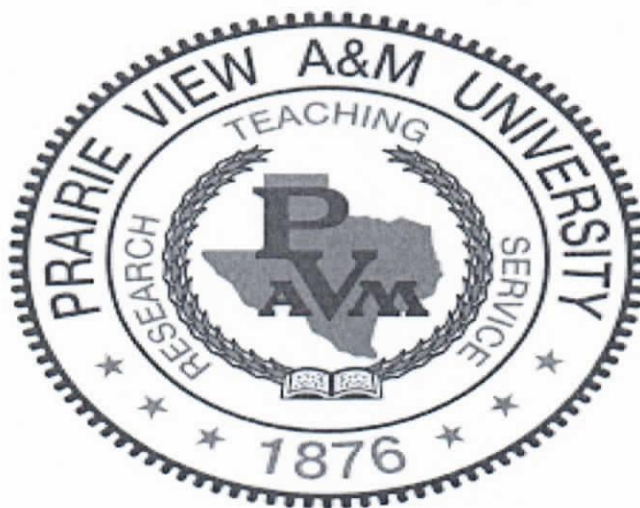
1. Geankoplis, Christie John. *Transport Processes and Separation Process Principles: (Includes Unit Operations)*. Prentice Hall PTR, 2009.
2. GmbH, DDBST. "Vapor-Liquid Equilibrium Data." *Vapor-Liquid Equilibrium Data of Acetone + Ethanol from Dortmund Data Bank*, www.ddbst.com/en/EED/VLE/VLE%20Acetone%3BEthanol.php.
3. "McCabe-Thiele Method(Construction and Use of the McCabe-Thiele Diagram, Assumptions,q-Line Slope)." *McCabe-Thiele Method(Construction and Use of the McCabe-Thiele Diagram, Assumptions,q-Line Slope)*, engineeringoperations.blogspot.com/2010/12/mccabe-thiele-methodconstruction-and.html.
4. *Factors Affecting Distillation Column Operation*, www.rccostello.com/distil/distilop.htm.
5. Steffen, Vilmar, and Edson Antonio da Silva. "Steady-State Modeling of Equilibrium Distillation." *IntechOpen*, IntechOpen, 28 June 2017, www.intechopen.com/books/distillation-innovative-applications-and-modeling/steady-state-modeling-of-equilibrium-distillation.
6. Geankoplis, Christie J, A A. Hersel, and Daniel H. Lepek. *Transport Processes and Separation Process Principles*. , 2018. pp. 806-32.

BELOW AVERAGE

Below Average Student Original Graded Assignment

Prairie View A&M University
Department of Chemical Engineering

Rec'd 11/18
16:40



43
100

Lab #4: McCabe-Thiele Method of Calculation for Number of Theoretical Stages



[2]

Lab Members:

Sabrina Noe, Kameron Flournoy,

Jerrick Shepherd, Faryal Fatima

Dr. Keisha Antoine

Due Date: November 18th, 2019

TABLE OF CONTENTS

Title page.....	1
Table of Contents.....	2
Abstract.....	3
Theory.....	4-6
Procedure.....	7
Data & Results.....	8-9
Conclusion.....	9
References.....	10

ABSTRACT

awkward phrasing

The purpose of this experiment is to study the behavior of a distillation column containing ethanol-water mixture with countercurrent flow. The objective is to calculate the theoretical number of stages for an equimolar ethanol-water mixture using the McCabe-Thiele method. This calculation is important for distillate^{ion} columns because the sieves or trays inside the column *a this sentence doesn't demonstrate the importance of this calculation.* effect the flow of both the vapor and liquid streams in the system. The McCabe-Thiele method uses operating line equations for both the *what are these?* enriching and stripping sections to determine the theoretical stages within the column. The vapor stream should become more enriched with more volatile components as it ascends to the top of the column. The liquid stream will become more enriched as it descends into the bottom of the column with higher boiling point components. Results are that *? not clear* the composition of the distillate stream should be larger than the bottom stream due to ethanol being a more volatile component, the component that will readily enter the vapor phase first. The amount of time for the bottom stream to flow should be faster than the distillate stream since it is moving in a downward direction in favor with gravity. *?*

Tech	Engl
$\frac{3}{5}$	$\frac{3}{5}$

THEORY

A distillation column uses stages known as sieve plates or trays, which are arranged vertically throughout the column. The liquid and vapor streams move from each stage in a countercurrent flow to each other. A feed stream can be entered anywhere in the middle of the column. The vapor moves through the trays and bubbles through the liquid stream flowing across the trays. *This is an assumption. Reference?* Both the vapor and liquid entering the tray are at equilibrium. Vapor continues to move throughout the column *not clear* contacting the liquid downstream moving across each stage. The vapor becomes enriched with more volatile components as it ascends ~~up~~ the column. The liquid becomes more enriched with higher boiling point components as it descends ~~through~~ the column.

The final vapor is condensed in a condenser at the top of the column and the liquid product ^{the} is distillate removed from the column. The liquid leaving the bottom tray enters a reboiler where it is partially vaporized, and *no!* the remaining liquid is the distillate product. The vapor from the reboiler is sent back into the bottom tray. Since the vapor and liquid leaving are in equilibrium, the reboiler can be considered as a theoretical stage or tray. *Okay* For the enriching *explain what this is* section, the theoretical stages are determined by the starting liquid distillate composition stepping off the first plate. The reflux is the remaining liquid that is not withdrawn from the condenser but is recycled back into the tray. The figure below shows the process flow of a sieve tray distillation column:

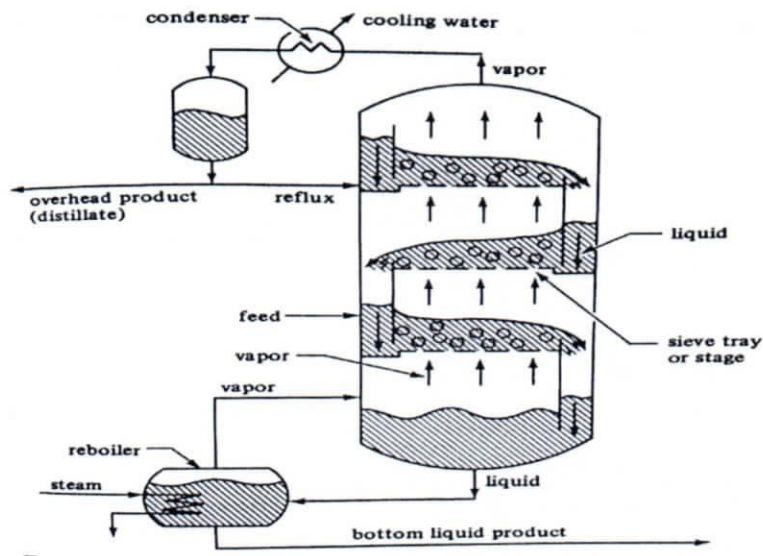


Fig. 1: Process flow of a fractionating tower containing sieve trays [1]

For countercurrent contact with multiple stages, the material balance on the component A *is A the high melting T or low melting component?* is given by the following equation (1):

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

The total material balance is given by equation (2):

$$V_{n+1} + L_{n-1} = V_n + L_n \dots\dots\dots(2)$$

In which:

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

L_n = liquid from tray n (mol/hr)

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 L_n

n = mole fraction of A in V_n

The representation of the vapor and liquid streams arriving and leaving the sieve tray are shown in the figure below:

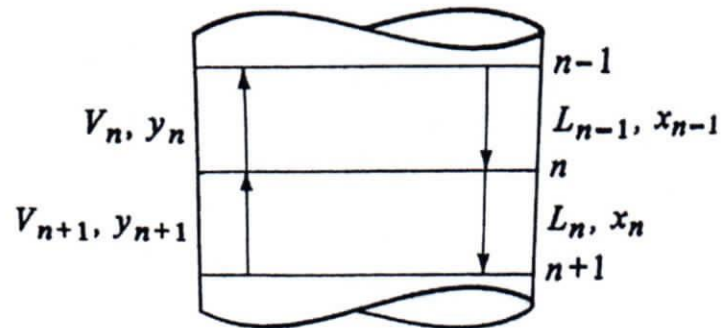


Fig. 2: Representation of liquid and vapor streams arriving and leaving the sieve trays [1]

Tech	Engl
$\frac{6}{10}$	$\frac{3}{5}$

EXPERIMENTAL PROCEDURE

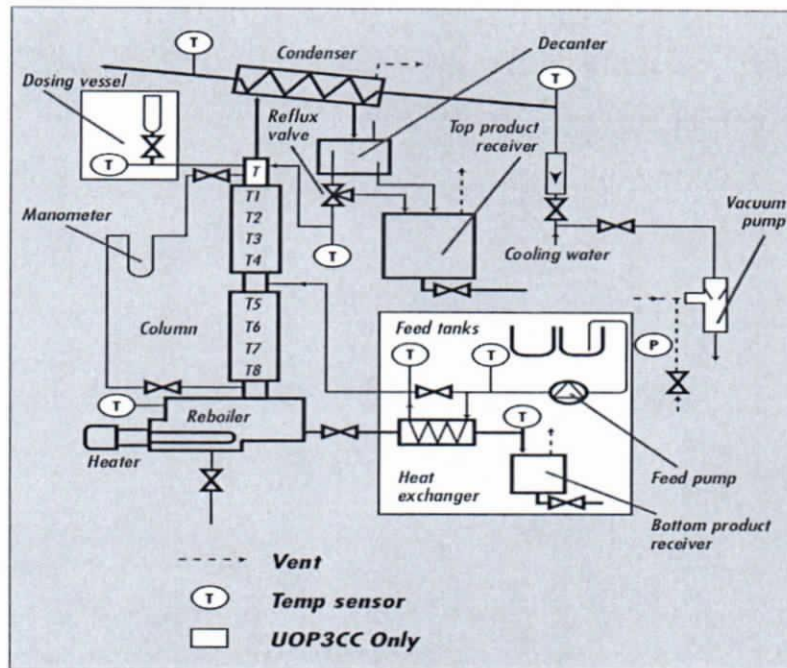


Fig. 3: Schematic of Armfield Distillation Column Equipment [2]

not clear The procedure required to measure the reflux ratio, all the liquid and vapor compositions in the stream (distillate, bottom, feed), the temperatures of each stage, volumetric flow rates of the distillate. The reflux ratio ^{is} set up on the equipment to be 5:1. The volumetric flow rate of the distillate and bottom were measured at constant rate for each trial. The temperature was recorded for the condenser and reboiler. As the stream was flowing, the time was recorded once it reached the set constant volumetric flow rate. The compositions for the distillate and bottom streams were measured by putting samples of the streams into a refraction machine. This experiment was repeated three times for both distillate and bottom stream measures.

Overall the procedure as written is unclear

Time / Engl

$$\frac{6}{10} \div \frac{3}{5}$$

DATA & RESULTS

Teeth | Engt
15 | NA
30

In the experiment ~~the~~ we measured the bottoms and distillate flow rate to be 0.07 and 0.03 kilo-moles per hour, respectively. Using an overall material balance

$$F = D + B, \dots \dots \dots (3)$$

where F is the feed, D is the distillate, and B is the bottoms flow rate, the feed flowrate was

measured 0.10 kilo-moles per hour. The bottoms and distillate mol fraction of ethanol were found

to be 0.2 and 0.77 using the refractometer. *How? Calibration curves* The feed was assumed to be equimolar therefore the mol *why? You could have measured this*

fraction of ethanol in the feed was 0.5. The q-line is 1 due to the feed being a liquid at the boiling

point. The slope of the stripping line is plotted as

*what is the temp of the feed? If $< T_b$
 $\Rightarrow q > 1$*

$$m = \frac{B + 1}{B}$$

Intercepting at $x_b = 0.2$ and the q line. The slope of rectifying line is plotted as

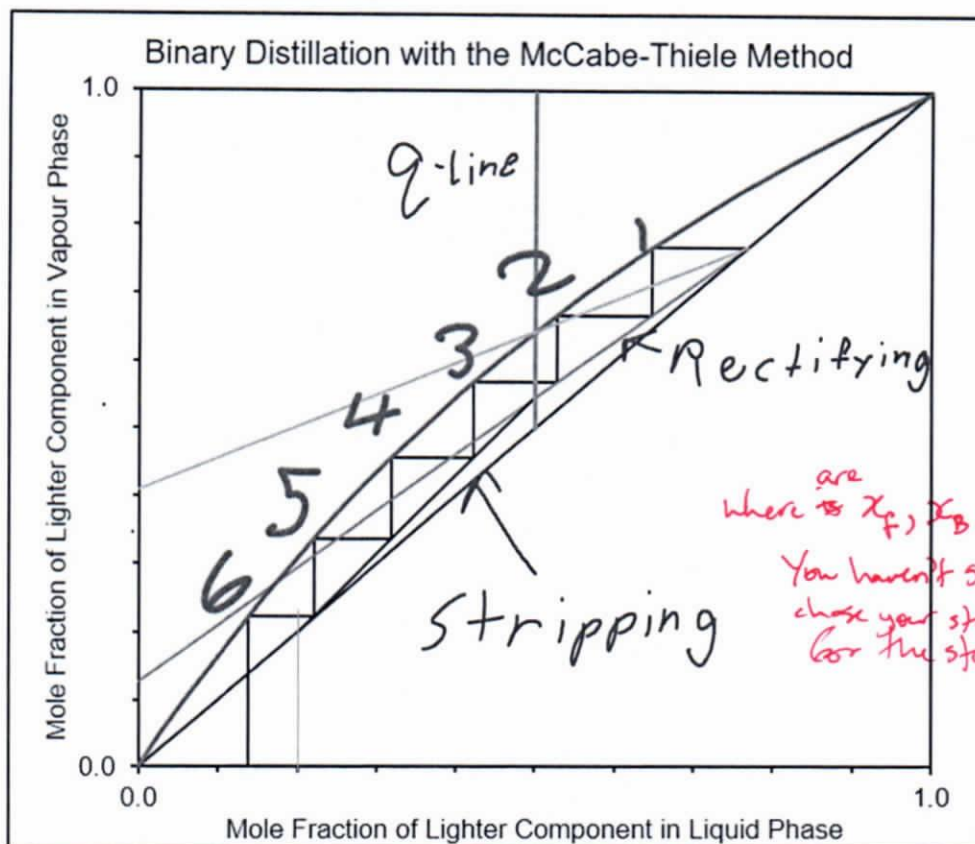
$$m = \frac{R}{R + 1}$$

*Define R and
Define x_b, x_f, y_f, q*

Intercepting at $y_f = 0.5$

Our stages using the McCabe-Thiele method came out be roughly 5 adding in the reboiler it *okay* would be 6. The actual stages in the distillation column is 8.

So what is the theoretical efficiency?



Missing Discussion - 20

CONCLUSION

Task	Engl
40	NA

To sum up, [?] the is a good rough estimate of the actual required number of stages. 6 stages were calculated although there are 8 actual stages. Main sources of error could have come from the measuring the mole fraction with the refractometer, general calculations, and noise from measurement techniques.

REFERENCES

- [1] Geankoplis, Christie John, et al. "Transport Processes and Separation Process Principles".
Prentice Hall, 2018.
- [2] Jenkins, J.D. "UOP Series: Heat and Mass Transfer Operations Distillation Columns".
Discover Armfield, 2013, discoverarmfield.com/media/transfer/doc/uop3.pdf.

**OUTCOME SPECIFIC ASSIGNMENTS
USED TO ASSESS OUTCOMES**

ASSIGNMENTS FOR OUTCOME 3

An ability to an ability to communicate effectively with a range of audiences.

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

Instructor: Dr. Jorge F. Gabitto

Title of Assignment

Report 4

Outcome Measured Using this Assignment

Outcome 3

An ability to an ability to communicate effectively with a range of audiences.

Brief justification of why this assignment is suitable for this outcome

The rubric used for grading this assignment measures the students' ability to express themselves using written communication. Organization and professional language are also measured.

Prairie View A&M University

Roy G. Perry College of Engineering

Department of Chemical Engineering



CHEG 4031 – Y01 Chemical Engineering Laboratory III

Virtual Lab IV- Tubular Reactor

Spring 2021

Submitted By

Constantino Mansogo

Indira Ribeiro

Joel Kakona

Lilia Yang

Paul Danjuma

On Thursday, April 29th 2021

To Dr. Gabitto

Table of Contents

Abstract	3
Theory	3
Procedure	5
Results and Discussion	6
Figure 1. Plot of Time vs Conductivity	6
Figure 2. Plot of Position vs Concentration A at a Given Time	7
Figure 3. Plot of Position vs CA	8
Conclusion	9
References	10

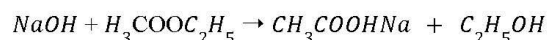
I. Abstract

A tubular reactor is a vessel through which the flow is continuous, usually at a steady state, and configured so that conversion of the chemicals and other dependent variables are functions of position within the reactor rather than time. Typical industrial uses of tubular reactors are in gasoline production, oil cracking, synthesis of ammonia from its elements, and the oxidation of sulfur dioxide to sulfur trioxide; tubular reactors can also be used as bioreactors or for small scale production.

This experiment is carried out to study and determine the conversion factor X of the solution for a given set of conditions in a tubular reactor, the effect of the reaction rate constant, and the conductivity and conversion of NaOH. The two samples (sodium hydroxide and ethyl acetate) had less contact time, resulting in a reduction in the conversion of the products (ethanol and sodium acetate). In the results session of this report, three graphs represent the experimental finding. The first graph, which is a plot of time versus conductivity, depicts that the plug flow reactor is close to the ideal behavior of an ideal reactor. The second graph shows a plot of position versus concentration A at a given time, which represents that as the fluid moves in the plug flow reactor, the concentration increases. Finally, the third graph represents a plot of the position versus the concentration of substance A , which shows that the plug flow reactor is not far from an ideal reactor. In sum, the experimental step is shown to be close to its ideal step thus suggesting that the real plug flow reactor produces near ideal behavior.

II. Theory

The reaction:



can be considered equi-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 mol of ethyl acetate reacts with 1mol 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:

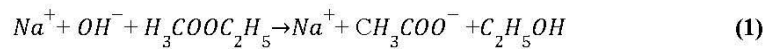
$$X_A = \frac{A \text{ consumed in reactor}}{A \text{ fed to reactor}} = \frac{A \text{ fed to reactor} - A \text{ leaving reactor}}{A \text{ fed to reactor}}$$

Or,

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

The reaction is carried out in the tubular reactor which will eventually reach steady state when a certain conversion of the starting reagents is achieved. A steady-state condition for this saponification reaction can be observed by continuously monitoring changes in the specific electrical conductance or conductivity (κ) of the effluent that are caused by changes in the concentrations of ions present in the effluent. It is assumed that a “flattening” of the conductivity curve - $\kappa(t)$ vs. t - in a tank reactor indicates that the tank has achieved its steady state conversion, X_A^{ss} .

To understand the connection between $\kappa(t)$ and $X_A(t)$, we must first recognize that this saponification reaction occurs in a partially electrolytic solution. Rewritten in terms of its reacting ions, the reaction can be expressed in its charge balanced form:



The reacting mixture features a measurable specific conductance due to the presence of the ionic species Na^+ , OH^- , and COO^- (representing acetate.) And the conductivity, $\kappa(t)$, of the reacting mixture is linearly dependent on the concentration of these ionic species in solution, and additive. As such, $\kappa(t)$ can be expressed as a sum of the contributions of Na^+ , OH^- , and COO^-

based on their respective concentrations (C_{Na^+} , C_{OH^-} , and C_{COO^-}) and molar conductivities (Λ_{Na^+} , Λ_{OH^-} , and Λ_{COO^-}) as follows:

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

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

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

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

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

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

III. Procedure

1. Make 3 liters of 0.1 M of NaOH and 3 liters of 0.1M of EtOAc.
2. Start the Edibon Software, select QRFT, and input a filename to save your data.
3. Switch on both pumps AB1 and AB2 using the software and adjust (if necessary) the flow rates to ~6 L/Hour for each feed; check that the product discharges into the product bottle.
 - a. Note that for our actual experiment, AB-1 is set at ~ 50 and AB-2 is set at ~55, approximately pumping fluid at ~5L/Hour.
4. Click on the icon for Take data and change the periodic time to 5 seconds.
5. Let the reaction run for 15-25 minutes or until the reactor has reached a steady state.
 - a. Note the flow rates of NaOH and EtOAc, and the conductivity readings.
6. Write down the steady-state conductivity value and use eq. (7) in the theoretical section to calculate the value of the limiting reactant conversion.

IV. Results and Discussion

In this experiment, we utilized the conductivity and time to develop the plot for the tubular reactor by using the Edibon's QRFT and QRUBI.

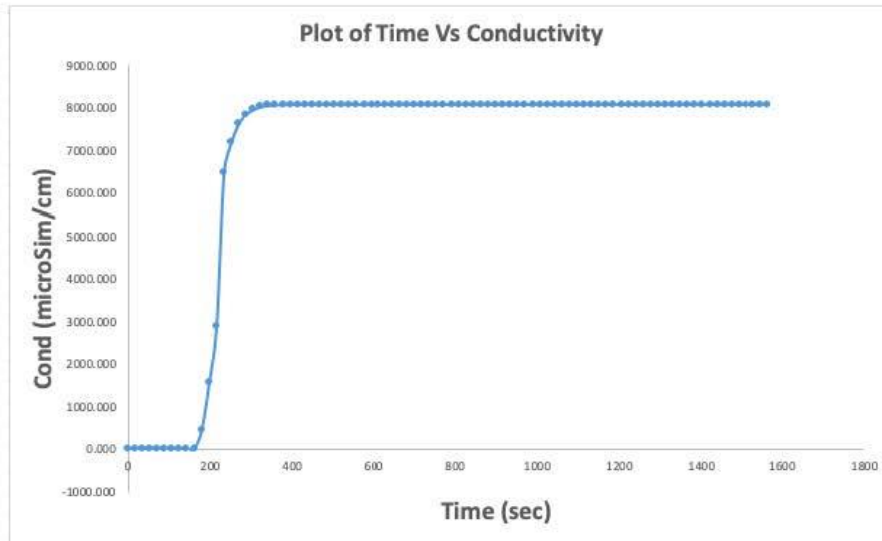


Figure 1. Plot of Time vs Conductivity

The plot above is represented by a curve of conductivity and time. As we can see from the graph, at time zero to about 194 sec, the conductivity is maintained at zero. Then the conductivity increases rapidly before reaching steady state at about 504 sec and 8079.4 microSim/cm with a conversion of 0.5577. This plot can be compared to a representation of a step response but in this case the step response is not ideal because it has an inclination and is not instantaneous. However, the inclination shows that the plug flow reactor is close enough to the ideal behavior of an ideal reactor. Thus, the experimental step is very close to its ideal step.

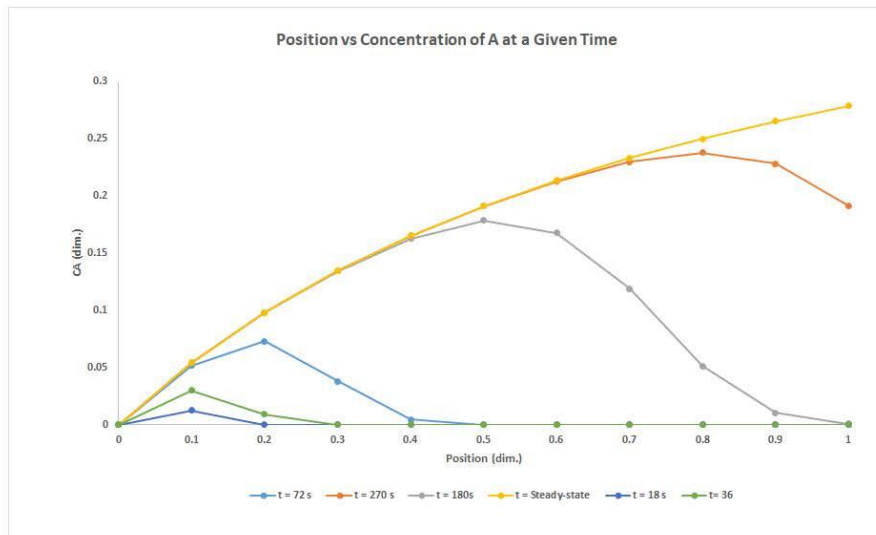


Figure 2. Plot of Position vs Concentration A at a Given Time

In Figure 2., the graph shows that as the concentration moves in the plug flow reactor, the concentration increases. At 72 seconds, the concentration produced was about 0.06M when it reached the position of 0.2 in the plug flow reactor. At position 0.3, the concentration produced was about 0.05M. As the time increases, the position in the plug flow reactor gets closer to its output of the reactor. The yellow line represents the steady-state of the reaction. As the time increases, the reaction follows the steady-state line more closely. For example, at 180 seconds, as the concentration moves further in the plug flow reactor to position 0.5, the concentration increases to about 0.16M. From position 0 to 0.4, the line follows the steady-state curve before deviating.

The next graph below will represent the concentration C_A versus position in the plug flow reactor experiment.

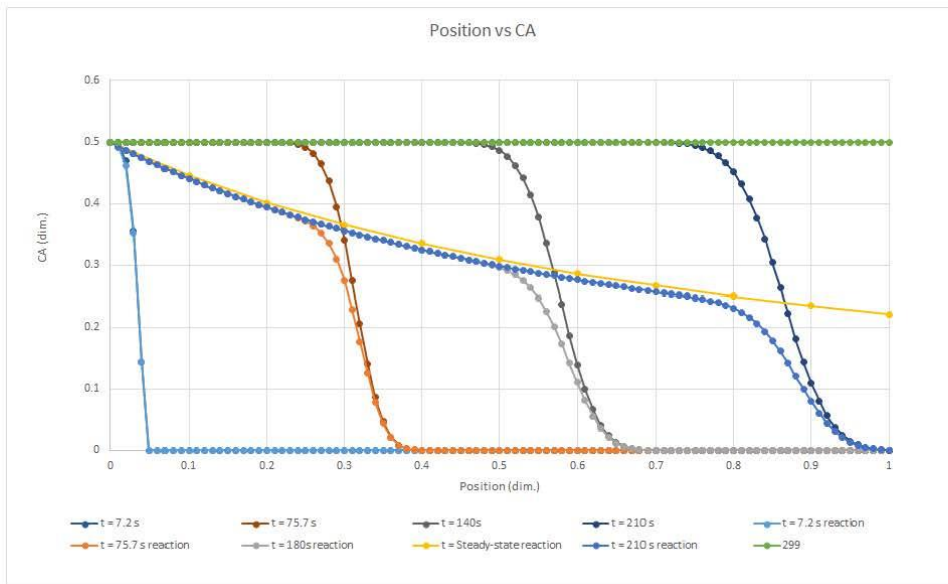


Figure 3. Plot of Position vs C_A

Figure 3. Plot of Position vs C_A shows the concentration and the position change of a plug flow reactor. From position zero to one, we have, respectively, the input and output of the reaction of the reactor. At 7.2 sec, the position of the plug flow reactor has not really changed. At 75.7 sec, the position of the plug flow reactor moved from 0.38. At 140 sec, the position of plug flow reactor keeps moving to the output of the plug flow reactor to reach 0.65. At 210 sec, the position reaches 0.98.

The green line “299” remains at a concentration of 0.5M. This line shows that there is no reaction occurring as the concentration passes through the plug flow reactor. Line $t=7.2$ s, line $t=75.7$ s, line $t=140$ s, and line $t=210$ s represent the concentration moving in the plug flow reactor without reacting. The plug flow reactor is indicated to be a real reactor because these lines have a slope or inclination towards the end of where they stop in the plug flow reactor at their particular times. However, since these lines have a slope near a vertical line, the plug flow reactor is not far from an ideal reactor.

The line labelled as t =steady-state reaction is the curved line that represents the steady state at which a reaction is occurring. Line $t=7.2$ s reaction, line $t=75.7$ s reaction, line $t=140$ s reaction, and line $t=210$ s reaction represent the concentration moving in the plug flow reactor while a reaction is occurring. As the concentrations move through the plug flow reactor, the reactant concentrations decrease since the reaction consumes the reactant to produce the product. The area between the horizontal line (line 299) and curve line (line t =steady state reaction) is the amount of limited reactants consumed. The more the concentration moves through the plug flow reactor, the more of the reactants are consumed.

V. Conclusion

The experiment was carried out using a tubular reactor to study and determine the conversion factor of the solution. 3 liters of 0.1 M of sodium hydroxide and 3 liters of 0.1M of ethyl acetate were used to make sodium acetate and ethanol. The conversion of NaOH was determined to be 0.557 at 504 seconds with a conductivity of 8079.4 microsim/cm. As the concentrations move through the plug flow reactor, the concentrations of the products increase and the concentrations of the reactants decrease. When the two reactants had less contact time in the plug flow reactor, there was a reduction in the conversion. The experimental data shows that the plug flow reactor is not an ideal reactor due to the step response having an inclination instead of being instantaneous. However, the experimental step is shown to be close to its ideal step thus suggesting that the real plug flow reactor produces near ideal behavior.

VI. References

Etherington, Sachie M. "QRFT Introduction to the Equipment". Youtube. Apr. 12, 2021. Video. Accessed 4/27/2021. <https://www.youtube.com/watch?v=-OHnTwLN85M>

Lower, Stephen. "8.10.9B: The nature of ions in aqueous solution" Chemistry LibreTexts. Mar. 3, 2021. Web. Accessed 3/31/2021. [https://chem.libretexts.org/Bookshelves/General_Chemistry/Book%3A_Chem1_\(Lower\)/08%3A_Solutions/8.10%3A_Ions_and_Electrolytes/8.10.9B%3A_8.10.9B%3A_The_nature_of_ions_in_aqueous_solution](https://chem.libretexts.org/Bookshelves/General_Chemistry/Book%3A_Chem1_(Lower)/08%3A_Solutions/8.10%3A_Ions_and_Electrolytes/8.10.9B%3A_8.10.9B%3A_The_nature_of_ions_in_aqueous_solution)

Weedmark, David. "How to Calculate Conductivity Due to Concentration". Sciencing. Mar. 9, 2018. Web. Accessed 3/31/2021. <https://sciencing.com/calculate-conductivity-due-concentration-2691.html>

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

Instructor: Dr. Jorge F. Gabitto

Title of Assignment

Final Presentation

Outcome Measured Using this Assignment

Outcome 3

An ability to an ability to communicate effectively with a range of audiences.

Brief justification of why this assignment is suitable for this outcome

The rubric used for grading this assignment measures the students' ability to express themselves using oral communication. Presentation organization and professional language are also measured.

CHEMICAL ENGINEERING LAB III

GROUP 2

LAB 1

Effect of PID Controller Parameters on Level Control

FOR

CHEG 4031

By:

Iwinosa Omo-Ojo, Dorinda Ntim, Jesse McDowell,
Lawankilea Juste Ki, Patmarvis Akunna

By Iwinosa



This photo by Unknown Author is licensed under CC BY-NC-ND



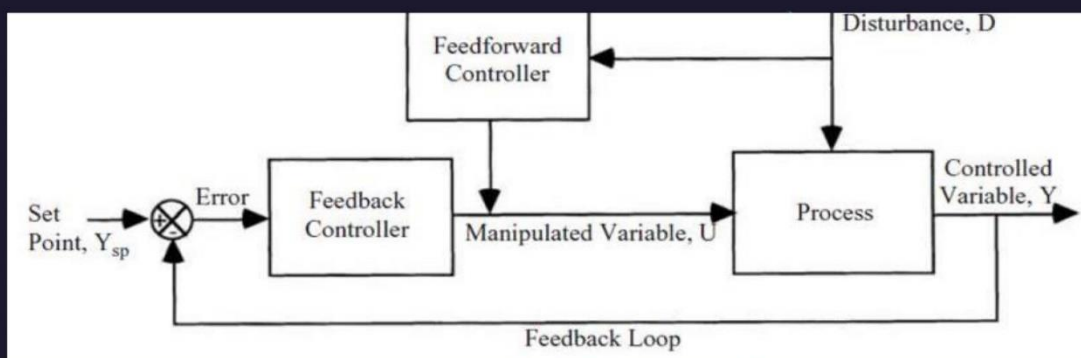
Table of Contents

- Abstract
- Theory
- Procedures
- Results
- Discussion
- Conclusion

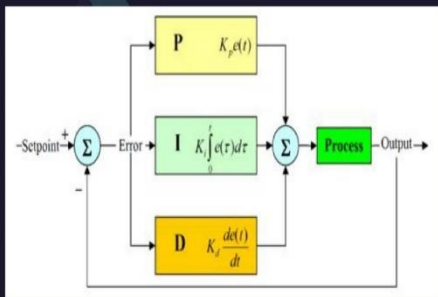
By Dorinda

ABSTRACT

The goal of this lab is to perform a qualitative review of the effect of proportional, integral, and derivative (PID) settings on the level control for the UCPN. Taking into consideration the P, PI and PID methods, we determined which method gives the best control and why. We also regulated the set point or level by using a PID controller which operates the control valve. Furthermore, determined what happened when we decreased or increased the gain, was able to compare time to the measurement signal, and finally the set point against the process variable.



THEORY



- Proportional-integral-derivative controller (PID controller)
 - generic control loop feedback mechanism widely used in industrial control systems.
- PID controller attempts to continuously correct the error ($e(t)$)
 - measure process variable (PV) and,
 - a desired setpoint (SP)
- By calculating, then outputting a corrective action based on
 - proportional,
 - integral, and
 - derivative that can adjust the process consequently.

By Juste

PROCEDURE



By Jae

This experiment was done using a Computer Controlled Process Control System.

- Open the software and hit start.
- After selecting the PID control option, select the element that is being used. Enter a set point, as well as a PID constant.
- Turn on data save and select graph configuration for the program to record.

RESULTS & DISCUSSION

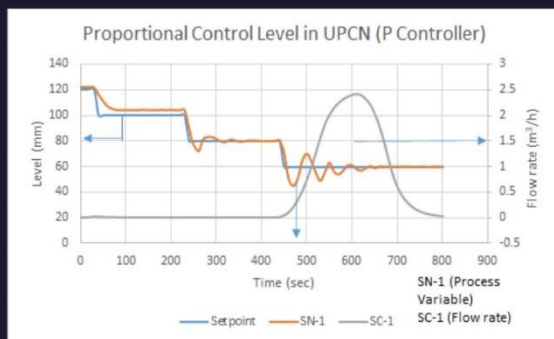


Figure 1: Proportional Control Level in UPCN (P Controller)

Figure 1 is a graph plotted to analyze the time dependence of two variables.

That is the flowrate and the fluid level in the superior tank.

The result is analyzed as both the flowrate and the level approaches the set value.

Fluid level and flowrate data is plotted against time for a P controller.

RESULTS & DISCUSSION

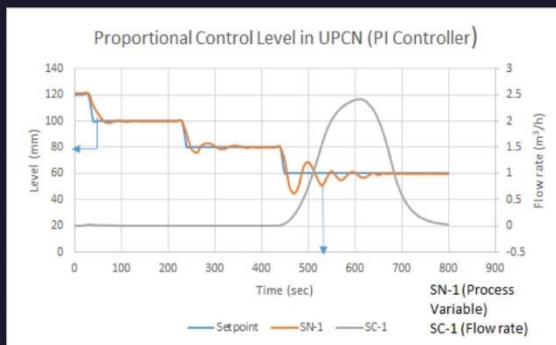


Figure 2: Proportional Control Level in UPCN (PI Controller)

- Figure 2 is also a graph plotted to analyze the time dependence of two variables as well.
- That is the flowrate and the fluid level in the superior tank.
- The result is analyzed as both the flowrate and the level approaches the set value.
- Fluid level and flowrate data is plotted against time for a PI controller.

By Pat

RESULTS & DISCUSSION

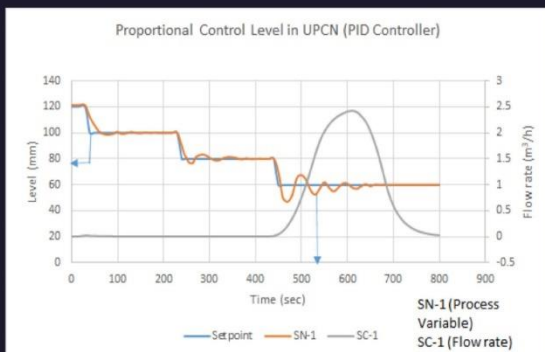


Figure 3: Proportional Control Level in UPCN (PID Controller)

- Figure 3 is a graph plotted to analyze the time dependence of two variables.
- That is the flowrate and the fluid level in the superior tank.
- The result is analyzed as both the flowrate and the level approaches the set value.
- Fluid level and flowrate data is plotted against time for a PID controller.

CONCLUSION



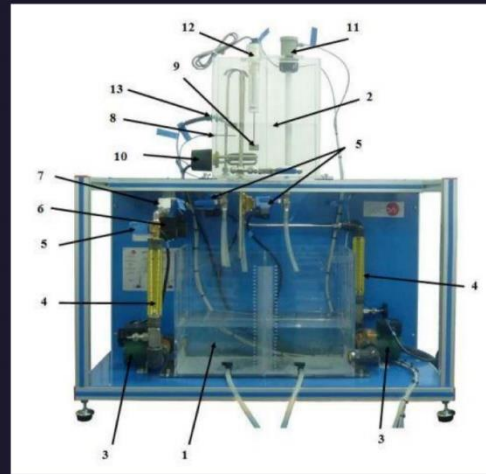
By Jae

- From the goal to perform a qualitative review of the effect of proportional, integral, and derivative (PID) settings on the level control for the UCPN, we have concluded that:
- Regulation of the set point controls the flow rate from the data received
- The application of all three (proportional, integral, and derivative) are the best method of control.
 - All three controllers have their individual strengths and weaknesses.
 - They are mostly combined to maximize their strengths while minimizing their weaknesses.
 - Increasing the systems gain decreases the steady-state error.



Schematic of the Equipment Setup

- 1. A main tank and collector with an orifice in the central dividing wall ($2 \times 25 \text{ dm}^3$), and drainage in both compartments (made of methacrylate).
- 2. A dual process tank ($2 \times 10 \text{ dm}^3$), interconnected through an orifice and a ball valve and an overflow in the dividing wall (methacrylate); a graduate scale and a threaded drain of adjustable level with bypass (metallic).
- 3. AB-1 and AB-2: Two centrifugal pumps.
- 4. C-1 and C-2: Two variable area flowmeters ($0.2\text{-}2 \text{ l/min}$, and $0.2\text{-}10 \text{ l/min}$), and with manual valve (VR-1 and VR-2).



- 5. Line of on/off regulation valves (solenoid). There is one normally opened (AVS-1) and two normally closed with different Cv (AVS-2 and AVS-3); and manual drainage valves of the upper tank.

- 6. AVP-1: A motorized control valve (piston type) with rotation indicator.

- 7. SC-1: A flow sensor, fixed, turbine type.

- 8. ST-1: A temperature sensor.

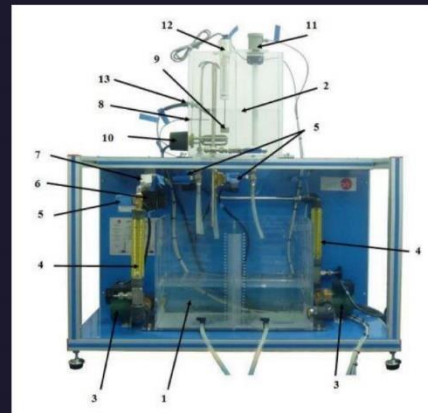
- 9. AA-1: A helix agitator.

- 10. AR-1: An electric heating element (0.5 KW), fixed.

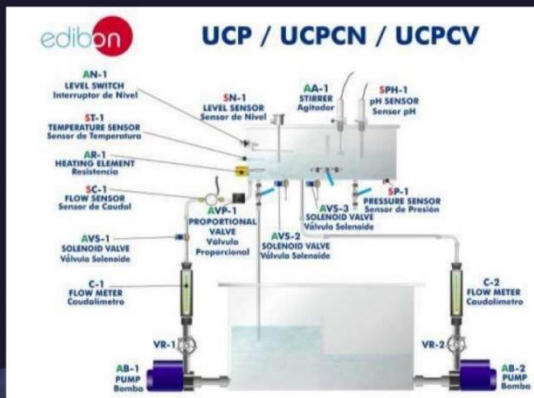
- 11. SN-1: Level sensor 0-300 mm (capacitive and immersion level sensor, 4-20 mA); it can be dismantled.

- 12. SPH-1: pH sensor (glass electrode, ddp (V)), removable (tank/effluent).

- 13. AN-1: On/off level switch. This sensor determines the performance of the immersion heating element.



Process Description



- This unit consists of a hydraulic circuit with a bottom tank (1) and an upper process tank (2), both dual, two centrifugal pumps (3), two flowmeters with manual control valve (4), three on/off solenoid valves (5), and a motorized proportional valve (infinitely variable) (6). Of course, it includes the appropriate tubes, elbows, connections, bulkheads, stopcocks and drains for the circuit operation. All the above[1] mentioned is set on a support frame designed to be placed on a work bench. Additional fixed elements include a flow sensor that is installed in one of the upward lines of flow (7), and a temperature sensor located in the process tank (8) together with an electric heating coil (10). The interchangeable additional elements in the unit are a stirrer (9), the immersion level sensor located in the process tank (11), and the pH sensor (electrode) which can be placed in the process tank or in the bottom tank (12) to study the effect of the time out.

ACKNOWLEDGEMENT

Special Thanks to:

- Dr. Gabitto
- Dr. Antoine
- Ms. Etherington

By Juste



QUESTIONS?



**OUTCOME SPECIFIC ASSIGNMENTS
USED TO ASSESS OUTCOMES**

ASSIGNMENTS FOR OUTCOME 3

An ability to an ability to communicate effectively with a range of audiences.

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

Instructor: Dr. Jorge F. Gabitto

Title of Assignment

Report 4

Outcome Measured Using this Assignment

Outcome 3

An ability to an ability to communicate effectively with a range of audiences.

Brief justification of why this assignment is suitable for this outcome

The rubric used for grading this assignment measures the students' ability to express themselves using written communication. Organization and professional language are also measured.

Roy G. Perry
College of Engineering



CHEG 4011 Chemical Engineering Lab II
Lab 3: Experiment 4 On Pumps in Parallel and Series

Group 2

Oluwatoyosi Idowu
Mohamed Akinotcho
Ike Anaghara
Utomwen Irabor
Laura Ukpede

Table of Contents

Abstract	3
Theory	3
Procedure	4
Result/Discussion	6
Conclusion	8
References	8

Abstract

Centrifugal pumps assembled in series or in parallel are used in a wide range of applications in the processing industry. The objective of this lab was to investigate the characteristic curves for a single centrifugal pump. Also, compare the behavior of 2 centrifugal pumps in parallel against two in series. The pump characteristics curves were developed for a single pump, two pumps in series, and two pumps in parallel by measuring flow rate, power, and head & pump efficiency using the experimental apparatus. The apparatus consists of a tank and pipework which delivers water to and from two identical centrifugal pumps. The assembly of the pumps was constructed in a way that the valves can be adjusted accordingly to activate an individual single pump, series pump, and parallel pump. For two identical pumps in a series, the head will be twice the head of a single pump, whereas pumps in parallel are expected to have twice the flow rate of a single pump for a given head. The mechanical power of the pump increases, and the flow rate increases which causes the total head to decrease. The pump efficiency peaks and decreases afterward.

Theory

According to Pumpwork.com, “the term pumping in series means that 1 pump acts as a booster to feed another pump” (1). They also added that the purpose of pumps operating in series is that, at the same flow rates, the differential pressure or head of both pumps is additive” (2). The three most used graphical representations of pump performance include the change in total head produced by the pump, the power input to the pump, and the pump efficiency. In this experiment, we also compared the behavior of two centrifugal pumps in parallel against two in series. To accomplish these, we are to utilize certain unit operation equations. Total Head is the addition of the suction head and the delivery head. The total head can also be calculated by adding the change in static head to the change in velocity head and change in elevation. That is, $H_t = H_s + H_v + H_e$. In this equation, the change in the static head (H_s) = $\frac{(P_{out} - P_{in})}{\rho g}$ where P_{in} is the fluid pressure at the inlet in pascal. While the change in velocity head (H_v) = $\frac{(V_{out} - V_{in})^2}{2g}$. Where V_{in} is the fluid velocity at the inlet stream and the V_{out} is the fluid velocity at the outlet. The change in elevation (H_e) = vertical distance between inlet and outlet. It is zero on the TQ H83 equipment. The power input (P_m) is the mechanical power input to the pump. $P_m = \text{rotational force} \times \text{angular distance}$. The efficiency of the pump is the division of the hydraulic power imparted to the fluid by the mechanical power absorbed by the pump.

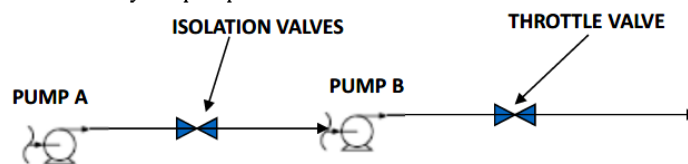


Figure 1: Schematic of two identical pumps connected in Series

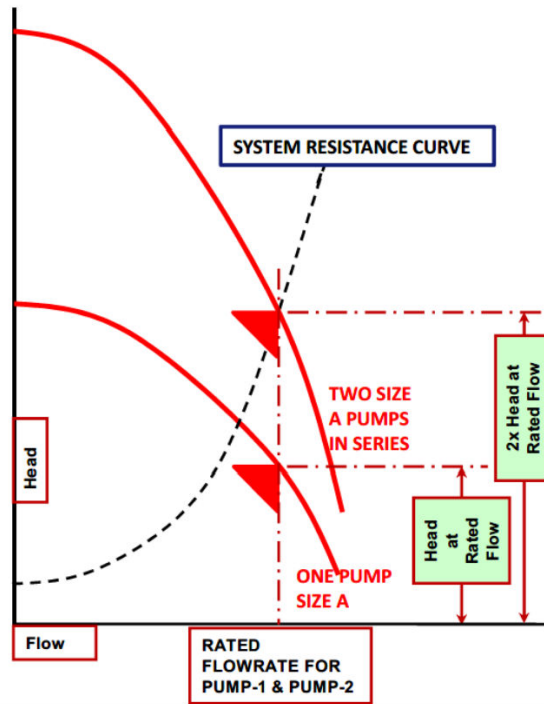


Figure 2: A Schematic showing the Head and Flow Curves plotted for pump A and the Series Curve which is plotted by totaling the Heads of Pump A and Pump B at the same flow rate.

Procedure

This experiment was carried out utilizing the TQ H83 series and parallel pump test set unit, the TecQuipment Versatile Data Acquisition System (VDAS), and venturi tubes to measure the head of the pump. The objective was to analyze and evaluate the efficiency, power, and total head; these steps were taken for a single centrifugal pump, pump in parallel, and pump in series respectively.

Single Pump:

- We started the pump motor and run it to maximum speed.
- Then used the bleed line to bleed all pressure gauges.
- Adjusted the motor speed for the pump by turning the black dial to the speed required for the experiment.
- Switched off both motor pump isolators.
- Closed pump 2 inlet valve and set the 2-way valve to direct flow straight to the delivery pipe.
- Fully open pump 1 inlet and the delivery valve.

- Step 5 - Record readings for pressure and flow for various dial settings.

Parallel Pumps:

- We started the pump motor and run it to maximum speed.
- Then used the bleed line to bleed all pressure gauges.
- Adjusted the motor speed for the pump by turning the black dial to the speed required
- Switched off both motor pump isolators.
- Open both inlet valves and set the two-way valve to direct flow straight to the delivery pipe
- Fully open the delivery valve. Switch on both motor drive isolators.
- Start the pump motors and run them to maximum speed. Bleed all pressure gauges.
- Adjust the motor speed both pumps by turning the black dial console to the speed required.

Series:

- We started the pump motor and run it to maximum speed.
- Then used the bleed line to bleed all pressure gauges.
- Adjusted the motor speed for the pump by turning the black dial to the speed required
- Switched off both motor pump isolators.
- Open Pump 1 inlet valves. Close Pump 2 inlet valve. Set the two-way valve to direct flow straight to the inlet of Pump 2. Fully open the delivery valve.
- Switch on both Motor Drive isolators. Start the pump motors and run them to maximum speed.
- Adjust the motor speed for pumps 1 and 2 by turning the black dial on each pump console to the speed required for the experiment.

Result & Discussion

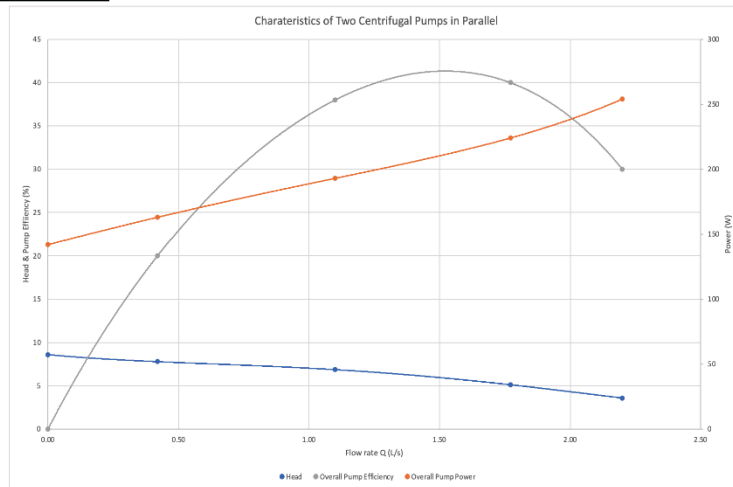


Figure 3: Graphical Representation of Characteristics of Two Centrifugal pumps in Parallel

When two or more pumps are arranged in parallel their resulting performance curve is obtained by adding the pump flow rates at the same head. Centrifugal pumps in parallel are used to overcome larger volume flows than one pump can handle alone. Figure 3 illustrates the flow rate of centrifugal pumps in parallel going from 0 L/s to 2.20 L/s.

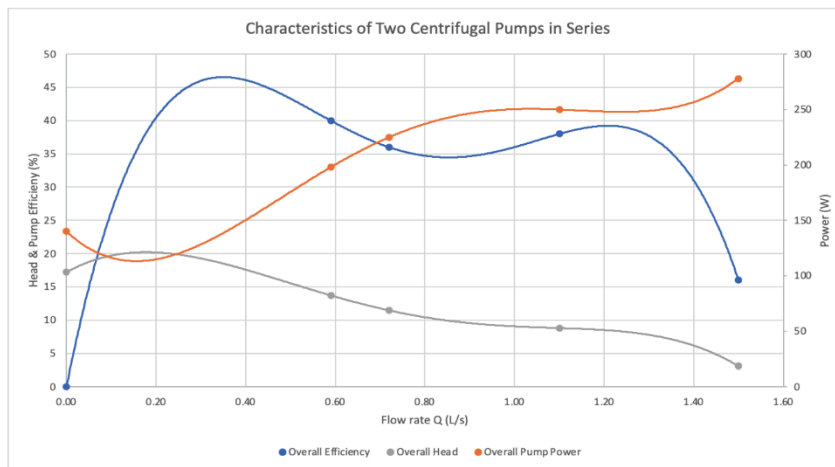


Figure 4: Graphical Representation of characteristics of Centrifugal Pumps in series

When two (or more) pumps are arranged in series their resulting pump performance curve is obtained by adding their heads at the same flow rate. Centrifugal pumps in series are used to overcome larger system head loss than one pump can handle alone. For two identical pumps in series, the head will be twice the head of a single pump at the same flow rate. Pumps in series will give higher head and pumps in parallel would give steady discharge.

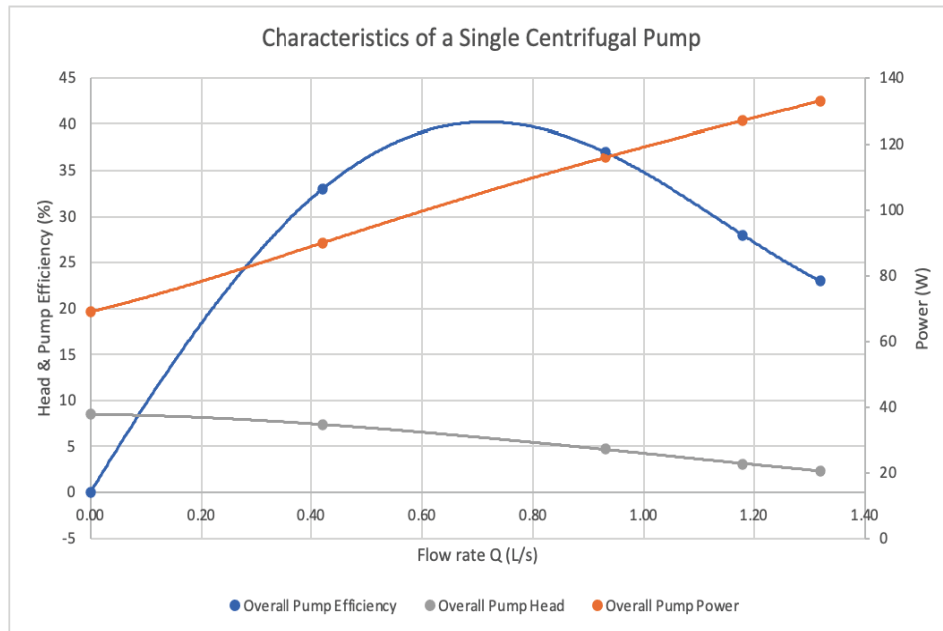


Figure 5. Graphical representation of characteristics a single centrifugal pump

For the pumps in parallel the head decreases while the pump efficiency increases and decreases, the power increases, and the volumetric flow rate increases which is different from the pump in series. In series the overall head increases as the efficiency and the overall pump increase, then start decreasing regardless of how the others are behaving. The overall head for a single pump is behaving the same as the overall head for pumps in parallel. Secondly, the overall power is increasing as the volumetric flow rate and the Pump efficiency increase or decrease in some cases for all the different pump arrangements, however, for a single pump and pumps in parallel, we have an ascending line while for pumps in series we have an oscillator graph. Lastly, the overall pump efficiency increases to a certain point as the overall pump power and the volumetric flow rate increase then starts decreasing as the others keep increasing for pumps in parallel and single pump, while for pumps in series it oscillates regardless of how the others are behaving. It increases to a certain point while the overall head and the overall pump increase, and decreases while the overall decreases and the overall pump power increases

Conclusion

When we compare the two or more parallel pumps versus the singular pump in parallel, we can see from the graph that the slope is steeper meaning that two or more parallel pumps are more efficient than one. In reference to the pumps arranged in series we can see that it is more efficient than pumps in parallel whether more than one or singular.

References

Roy G. Perry Department of Chemical Engineering. "TQ H83 - Understanding Series & Parallel Centrifugal Pumps."

Roy G. Perry Department of Chemical Engineering. "SOP H83."

<https://www.pumpworks.com/operating-two-pumps-series/>

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

Instructor: Dr. Jorge F. Gabitto

Title of Assignment

Final Presentation

Outcome Measured Using this Assignment

Outcome 3

An ability to an ability to communicate effectively with a range of audiences.

Brief justification of why this assignment is suitable for this outcome

The rubric used for grading this assignment measures the students' ability to express themselves using oral communication. Presentation organization and professional language are also measured.

Centrifugal Pump Characteristics Lab

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



1

Outline



ABSTRACT



BACKGROUND



OBJECTIVE



THEORY



PROCEDURES



RESULTS



DISCUSSION



CONCLUSION

2

Abstract

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

Objectives

1

Obtain head, power, efficiency graphs

2

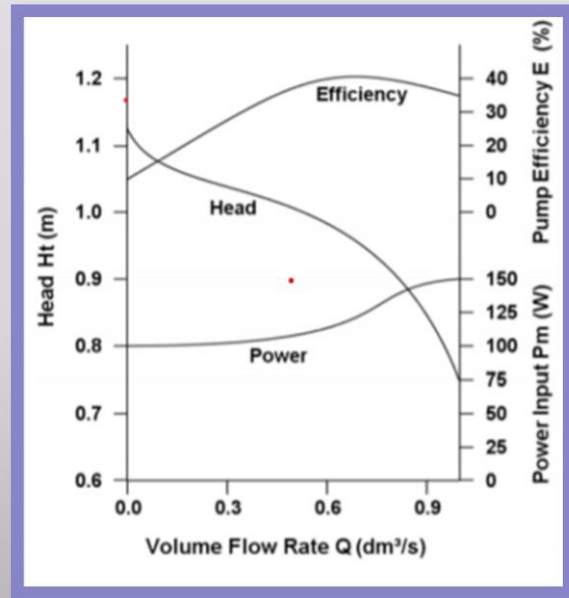
Determine maximum efficiency and flowrate at which it occurs

3

Compare with given curves

Background

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



Reference Performance Curves

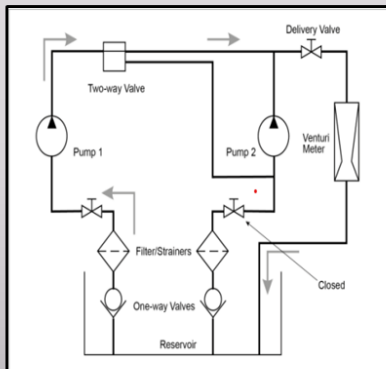
5

Applications

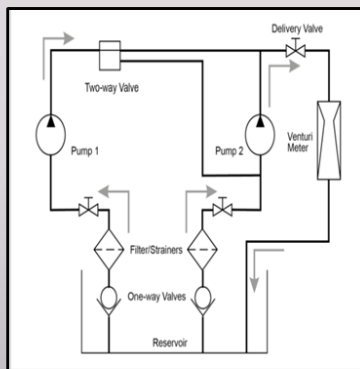
- Energy and oil industries
- Wastewater treatment systems
- Chemical and Petrochemical productions
- Industrial and fire protection



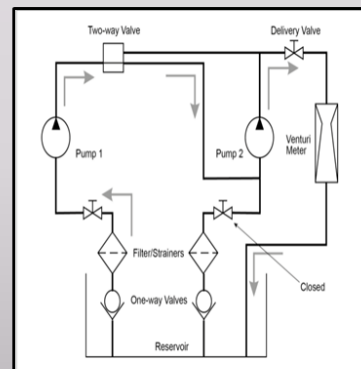
Theory



Single Stage Pump



Parallel Stage Pumps



Series Stage Pumps

7

Calculations

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



Lab Equipment



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



Procedure

Series Pump

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

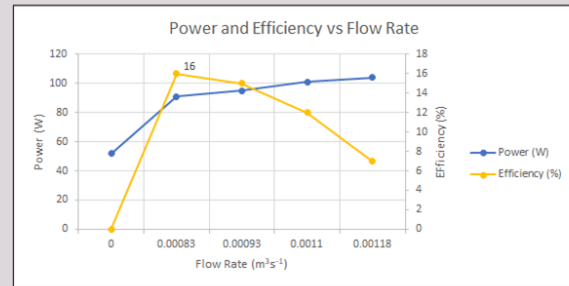
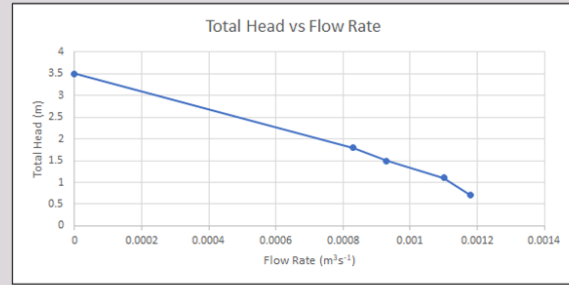
Parallel Pump

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

Single Pump

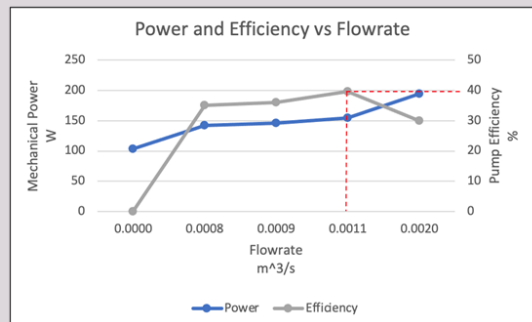
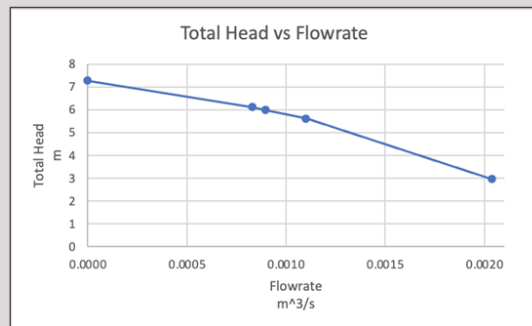
1. Create a blank results table
2. Take readings using the VDAS on Pump 1 only.
3. Switch off both motor pump isolators.
4. Close pump 2 inlet valve and set the 2-way valve to direct flow straight to the delivery pipe. Fully open pump 1 inlet and the delivery valve.
5. Start the pump motor and run it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

Single Pump Results



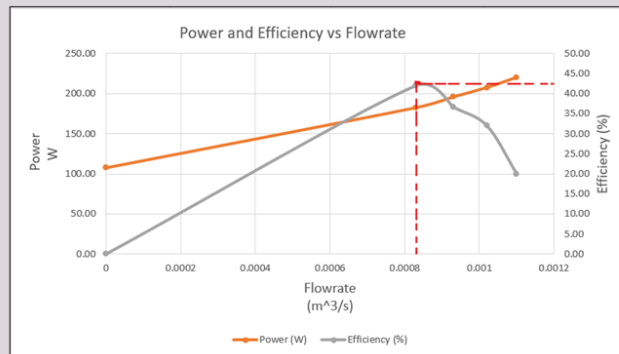
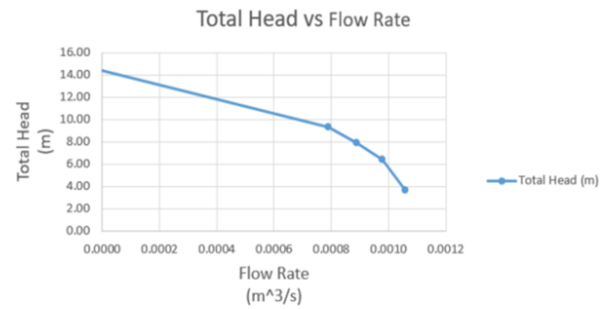
11

Parallel Pumps Results



12

Series Pumps Results



Discussion & Conclusion

Flowrate and Power are Directly Proportional

Flowrate and Total Head are Inversely Proportional

Greatest Efficiency is in Series

No Pump is 100% Efficient

- Single v Dual Pump Operation

Acknowledgements

**Dr. Gabitto
Dr. Antoine
Dr. Martin
Sachie Etherington
Roy G. Perry College of Engineering Faculty &
Staff**

15

QUESTIONS?

16

**OUTCOME SPECIFIC ASSIGNMENTS
USED TO ASSESS OUTCOMES**

ASSIGNMENTS FOR OUTCOME 3

An ability to an ability to communicate effectively with a range of audiences.

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

Instructor: Dr. Jorge F. Gabitto

Title of Assignment

Report 4

Outcome Measured Using this Assignment

Outcome 3

An ability to an ability to communicate effectively with a range of audiences.

Brief justification of why this assignment is suitable for this outcome

The rubric used for grading this assignment measures the students' ability to express themselves using written communication. Organization and professional language are also measured.

Roy G. Perry
College of Engineering



CHEG 4104 - Chemical Engineering Lab III

Experiment 4:
Level Control using PID Controller

Group #2

Due Date: April 13, 2022

Submitted by:

Chad Gardner

Anh Nguyen

Meredith Meyer

Franck Nangomoko

Submitted to:

Dr. Jorge Gabitto

Table of Contents

Abstract.....	2
Theory.....	2
Procedures.....	4
Results and Discussion	4
Conclusion	6
References.....	7

Table 1: Controller Constant Values

Figure 1: Schematic of the UPCN Equipment
Figure 2: General Control Loop Components and Setup
Figure 3: Proportional (P) Setting Results
Figure 4: Proportional-Integral (PI) Setting Results
Figure 5: Proportional-Integral-Derivative (PID) Setting Results

Abstract

PID Control is a fundamental aspect of chemical engineering that serves as significant importance in industrial control applications to regulate flow, pressure, temperature, and other process variables. In a proportional-integral-derivative (PID) control, three essential terms are used, to be controlled with precision, i.e., P, I and D, where each term produces an output value that is proportional to current value, integral with past value and estimated future value, respectively. For this experiment, we utilized the Edibon UCPCNCV software model to analyze the behavior of a PID control settings for level control of two tanks of water. The behavioral changes were observed by inputting a variation of proportional, integral, and derivative constants in three settings: P, PI, and PID. The behavior changes of all three control system settings are direct and converged. However, the oscillatory or monotonic behavior is varied. It is determined that the behavior of the PID controller is examined to develop an understanding of parameters set by the control mechanism.

Theory

Process Control is an engineering discipline and statistic that deals with architectures, algorithms, and mechanisms for maintaining the output of a specific process within desired parameters. This is done to achieve a production level of consistency, economy, and safety which cannot be achieved purely by human control. Figure 1 is the EDIBON UPCN, equipment used for analyzing the effect of Proportional-Integral-Derivative controller.

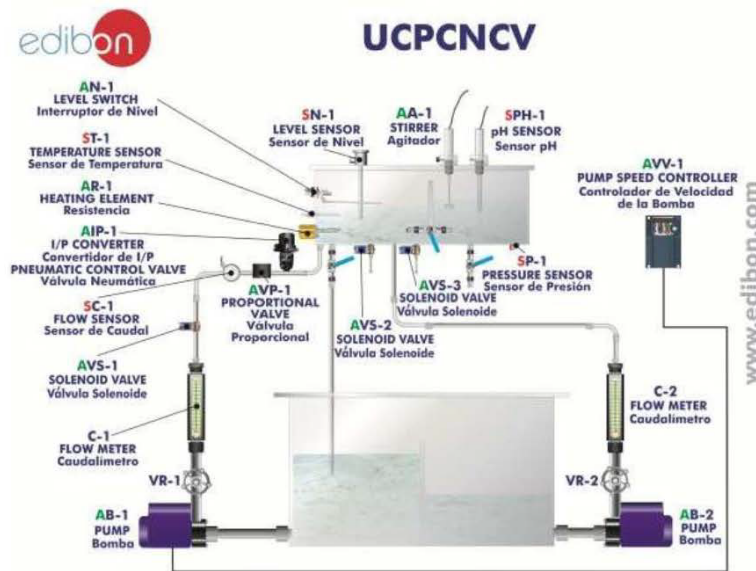


Figure 1: Schematic of the UPCN Equipment

Within this discipline and on an industrial scale, PID controllers serve as receptive and accurate measures to regulate safe and stable operations of a specific processing unit. These systems assist engineers in developing a line of communication of feedback within a control mechanism to identify the occurrence of an error and provide an action in place to mitigate a responsive solution in a safe manner. Figure 2 displays the general components of a control loop.

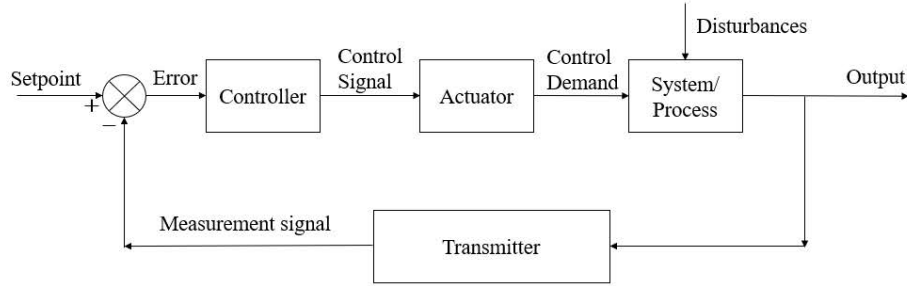


Figure 2: General Control Loop Components and Setup

Within a PID controller, a closed-loop feedback system is used to generate an error signal by evaluating the difference between the feedback variable and the given setpoint, resulting in altering the system output. The process starts by sending an error signal to a controller, which sends a control signal to an actuator. The actuator then sends a control demand to the system to alter the output variables. The output is measured by a transmitter and the measurement signal is sent back to the summing point, where the error signal is generated by the difference of setpoint and measured value. This procedure will continue until the error reaches zero, else the value of the feedback variable becomes equivalent to the specified setpoint.

The PID controller uses the three terms of proportional, integral, and derivative influence on the controller output. The proportional component depends only on the current difference between the set point and the process variable. The integral component accounts for past values of the setpoint-variable error and integrates them over time. Lastly, the derivative component estimates the future trend of setpoint-variable error and effectively controls the output by generating the control influence using the rate of error change. The output variable value $u(t)$ is given by:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt} \quad (1)$$

where K_p , K_i , and K_d are the proportional, integral, and derivative constants, respectively; $e(t)$ is the error of setpoint and measured value; t is the instantaneous time; τ is the variable of integration.

The transfer function in the Laplace domain of the PID controller is derived from equation (1) is:

$$G(s) = k_p + \frac{k_i}{s} + k_d s \quad (2)$$

where s is the complex frequency.

Different settings can be used for PID control system, includes P, I, D, PI, PD, and PID. The PID mode is considered as providing the most efficient control output as it accounts for past, present, and future changes in that system.

Procedures

This lab experiment was carried out virtually. The equipment was already set up and connected. The experiment would be carried out as follows:

1. Press Start in the top left corner of the Edison UCPCNCV software
2. Add the name of the file to the dialog box that pops up, where the data was recorded
3. Input the set values for P, I, and D parameters for the PID1 controller as shown in Table 1 for run 1 and setpoint value of 120mm

Table 1: Controller Constant Values

Controller	Run (action)	Setpoint (mm)	K_p	K_i	K_d
P	1	100	1	0	0
	2	80	2	0	0
	3	60	5	0	0
PI	1	100	1	5	0
	2	80	1	2	0
	3	60	1	0.5	0
PID	1	100	1	5	0.2
	2	80	1	5	0.5
	3	60	1	5	1

4. Press record and change the interval for the measured data to seconds
5. Change the set point listed in Table 1
6. Run the experiment until steady state was reached
7. Change the value of K_p , K_i , K_d for other two values
8. After the third set, press STOP and retrieve the data file
9. Repeat the whole procedure for the other two types of controllers (PI and PID)

Results and Discussion

The result for each type of controller P, PI, and PID output was obtained and graphed, shown in Figure 3, Figure 4, and Figure 5. Three graphs share a similar trend of output variables. For the first set point changes from 120mm to 100mm, the change in water level slowly decreases. For the second setpoint (100mm to 80mm) and third setpoint (80mm to 60mm), there are oscillatory behaviors. Particularly, for the third setpoint, the water flow rate increases dramatically from almost 0 L/min at 450s to about 2.4 L/min at 610s and then decreases to 0 L/min at 800s. All

changes in water level are converged to the given setpoint, except the first change in Proportional Setting Control is higher than the setpoint of 100mm.

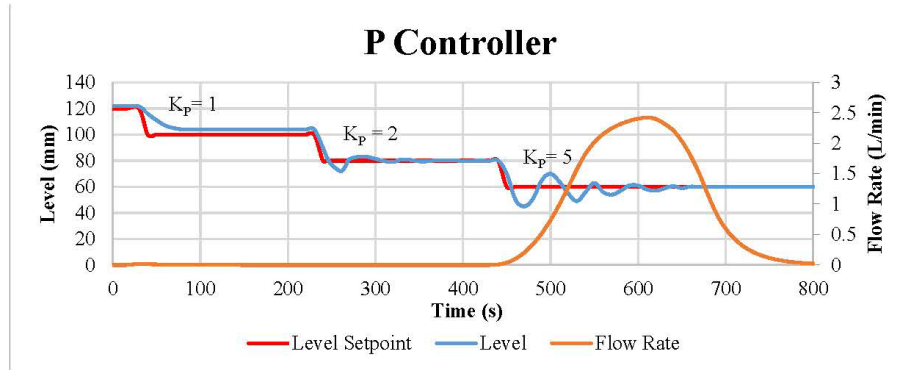


Figure 3: Proportional (P) Setting Results

Figure 3 shows the level readings and flow rate versus the recording time for the proportional setting. The chosen proportional constants K_p are 1, 2, and 5. When $K_p = 1$, the behavior is direct, monotonic, and converged. However, there is still an offset for this K_p . For $K_p = 2$, the behavior is direct, slightly oscillatory, and converged. For $K_p = 5$, the behavior is direct, highly oscillatory, and still converged. The high oscillatory behavior can be spotted as the water flow rate increases dramatically.

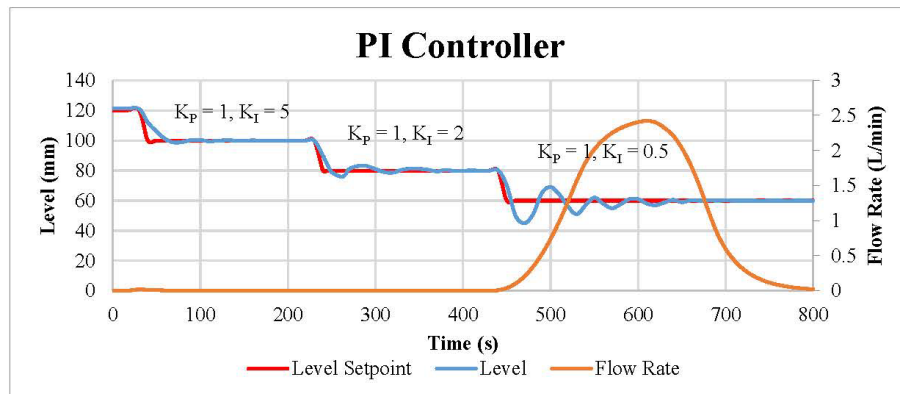


Figure 4: Proportional-Integral (PI) Setting Results

Figure 4 shows the level readings and flow rate versus the time for the effect of the proportional-integral (PI) setting on the system. The proportional constant K_p is kept constant at 1 while the integral constant K_i are 5, 2, and 0.5, respectively. When $K_i = 5$, the behavior is direct, slightly oscillatory, and converged. When $K_i = 2$, the behavior is direct, moderately oscillatory, and converged. When $K_i = 0.5$, the behavior is direct, highly oscillatory, and again converged.

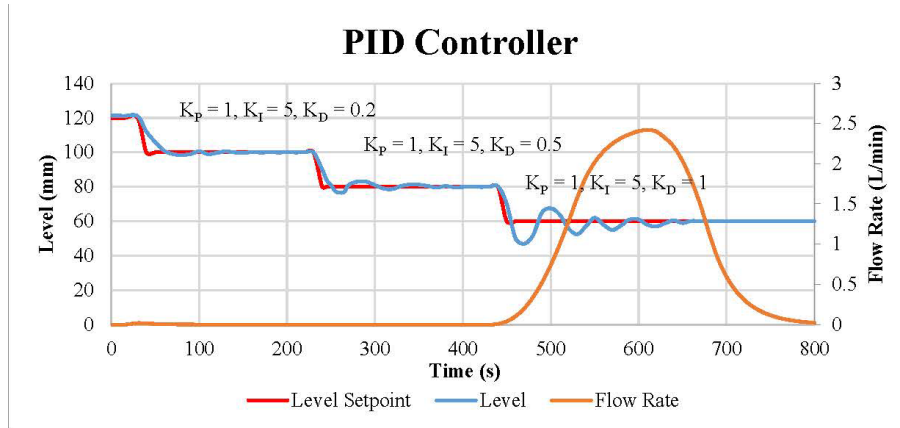


Figure 5: Proportional-Integral-Derivative (PID) Setting Results

Figure 5 shows the effect of the proportional-integral-derivative (PID) setting for the level readings and flow rate vs time. The values for K_i and K_p remain constant at 1 and 5, respectively while the derivative constant K_d increases from 0.2, 0.5, and 1, respectively. For $K_d = 0.2$, the behavior is direct, slightly oscillatory, and converged. For $K_d = 0.5$, the behavior is direct, moderately oscillatory, and converged. For $K_d = 1$, the behavior is direct, highly oscillatory and converged.

Based on the direct behavior we obtained from all the runs, this proves that the roots of the numerator of equation (2) are less than zero. Since the behavior of majority of the results are oscillatory, this means that the roots of the denominator of equation (2) are complex or imaginary numbers. And since the denominator roots are complex, the roots will be converged if the real part of the roots are negative.

Conclusion

PID Controls is an important element in any industries because of its function of regulating flow, pressure, temperature, and other process variables. With the software EDIBON UCPCNCV, the behavior of a P, PI, and PID control settings for level control of the upper tank of water. All control settings show direct and converged behavior. The oscillatory or monotonic behavior is varied depend on the proportional, integral, and derivative constants. With the given K_p , K_i , and K_d , the PI and PID control systems provide a similar efficiency in term of time and oscillation for water level to be converged. Even though the experiment brought in an insight into PID control settings and helped determine the best constants for future use, it should be reconducted with different set of K_p , K_i , and K_d to verify the most efficiency of PID control system.

References

Virtual Lab: Effect of PID Controller Parameters on Level Control. Roy G Perry, Chemical Engineering Department. Accessed 2022.

UCP: Computer Controlled Process Control System (With Electronic Control Valve). Youtube. Edibon International, 2013. <https://www.youtube.com/watch?v=UBMPMaJM3Qo>

PID Controller. Wikipedia. Accessed 2022.
https://en.wikipedia.org/wiki/PID_controller#Control_damping

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

Instructor: Dr. Jorge F. Gabitto

Title of Assignment

Final Presentation

Outcome Measured Using this Assignment

Outcome 3

An ability to an ability to communicate effectively with a range of audiences.

Brief justification of why this assignment is suitable for this outcome

The rubric used for grading this assignment measures the students' ability to express themselves using oral communication. Presentation organization and professional language are also measured.



Level Control Using PID Controller

CHEG 4014-P01

DR. GABITTO

GROUP 1

OLUWATOYOSI IDOWU, CHIEBUKA EJIMADU, CHINENYE IHE, TYREE MADISON



Table of Contents

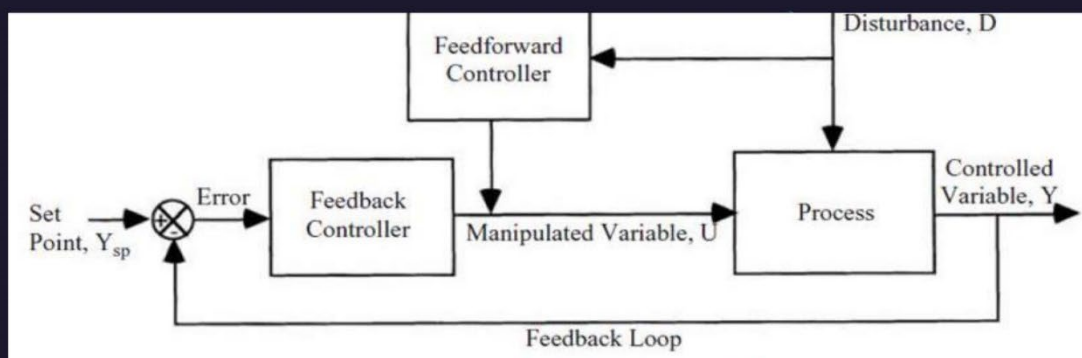
- Abstract
- Theory
- Procedures
- Results
- Discussion
- Conclusion

By Dorinda

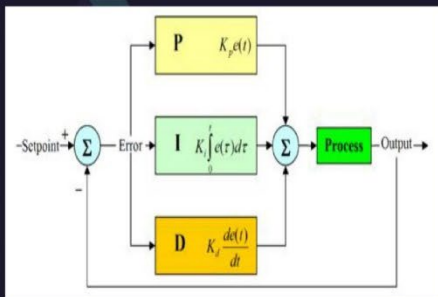
ABSTRACT

The goal of this lab is to perform a qualitative review of the effect of proportional, integral, and derivative (PID) settings on the level control for the UCPN. Taking into consideration the P, PI and PID methods, we determined which method gives the best control and why. We also regulated the set point or level by using a

PID controller which operates the control valve. Furthermore, determined what happened when we decreased or increased the gain, was able to compare time to the measurement signal, and finally the set point against the process variable.



THEORY



- Proportional-integral-derivative controller (PID controller)
 - generic control loop feedback mechanism widely used in industrial control systems.
- PID controller attempts to continuously correct the error ($e(t)$)
 - measure process variable (PV) and,
 - a desired setpoint (SP)
- By calculating, then outputting a corrective action based on
 - proportional,
 - integral, and
 - derivative that can adjust the process consequently.

By Juste

PROCEDURE



By Jae

This experiment was done using a Computer Controlled Process Control System.

- Open the software and hit start.
- After selecting the PID control option, select the element that is being used. Enter a set point, as well as a PID constant.
- Turn on data save and select graph configuration for the program to record.

RESULTS & DISCUSSION

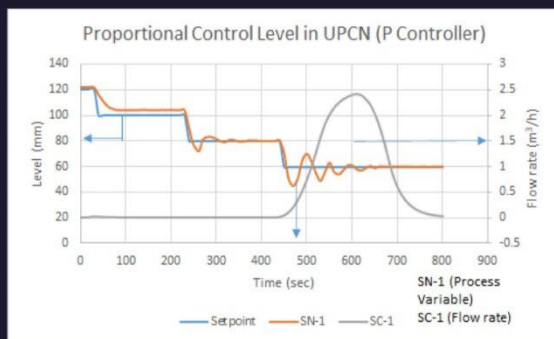


Figure 1: Proportional Control Level in UPCN (P Controller)

Figure 1 is a graph plotted to analyze the time dependence of two variables.

That is the flowrate and the fluid level in the superior tank.

The result is analyzed as both the flowrate and the level approaches the set value.

Fluid level and flowrate data is plotted against time for a P controller.

RESULTS & DISCUSSION

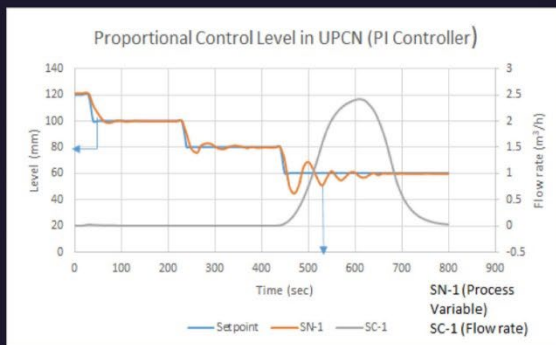


Figure 2: Proportional Control Level in UPCN (PI Controller)

- Figure 2 is also a graph plotted to analyze the time dependence of two variables as well.
- That is the flowrate and the fluid level in the superior tank.
- The result is analyzed as both the flowrate and the level approaches the set value.
- Fluid level and flowrate data is plotted against time for a PI controller.

By Pat

RESULTS & DISCUSSION

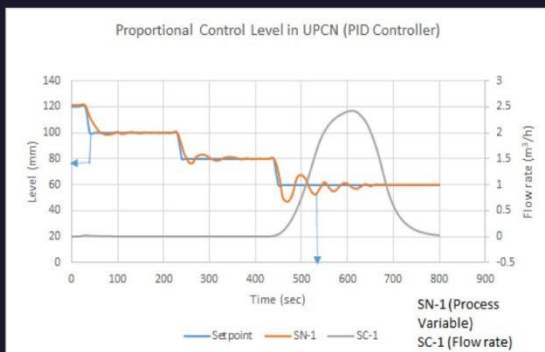


Figure 3: Proportional Control Level in UPCN (PID Controller)

- Figure 3 is a graph plotted to analyze the time dependence of two variables.
- That is the flowrate and the fluid level in the superior tank.
- The result is analyzed as both the flowrate and the level approaches the set value.
- Fluid level and flowrate data is plotted against time for a PID controller.

CONCLUSION



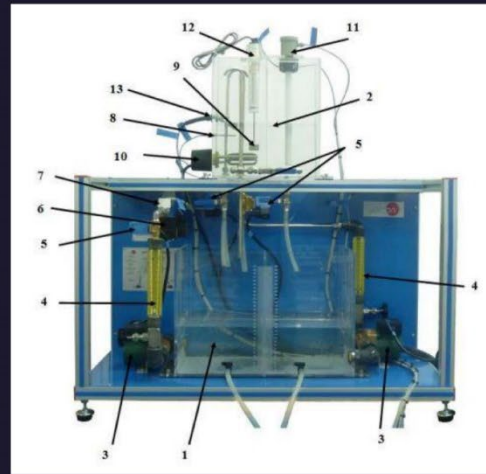
By Jae

- From the goal to perform a qualitative review of the effect of proportional, integral, and derivative (PID) settings on the level control for the UCPN, we have concluded that:
- Regulation of the set point controls the flow rate from the data received
- The application of all three (proportional, integral, and derivative) are the best method of control.
 - All three controllers have their individual strengths and weaknesses.
 - They are mostly combined to maximize their strengths while minimizing their weaknesses.
 - Increasing the systems gain decreases the steady-state error.



Schematic of the Equipment Setup

- 1. A main tank and collector with an orifice in the central dividing wall ($2 \times 25 \text{ dm}^3$), and drainage in both compartments (made of methacrylate).
- 2. A dual process tank ($2 \times 10 \text{ dm}^3$), interconnected through an orifice and a ball valve and an overflow in the dividing wall (methacrylate); a graduate scale and a threaded drain of adjustable level with bypass (metallic).
- 3. AB-1 and AB-2: Two centrifugal pumps.
- 4. C-1 and C-2: Two variable area flowmeters ($0.2\text{-}2 \text{ l/min}$, and $0.2\text{-}10 \text{ l/min}$), and with manual valve (VR-1 and VR-2).



- 5. Line of on/off regulation valves (solenoid). There is one normally opened (AVS-1) and two normally closed with different Cv (AVS-2 and AVS-3); and manual drainage valves of the upper tank.

- 6. AVP-1: A motorized control valve (piston type) with rotation indicator.

- 7. SC-1: A flow sensor, fixed, turbine type.

- 8. ST-1: A temperature sensor.

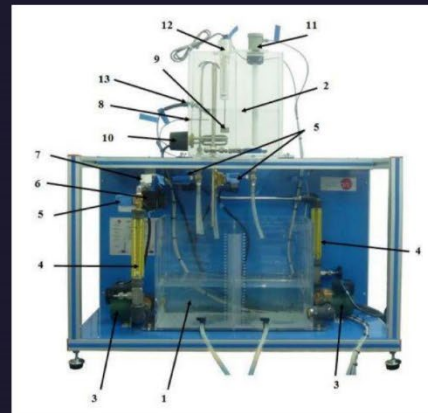
- 9. AA-1: A helix agitator.

- 10. AR-1: An electric heating element (0.5 KW), fixed.

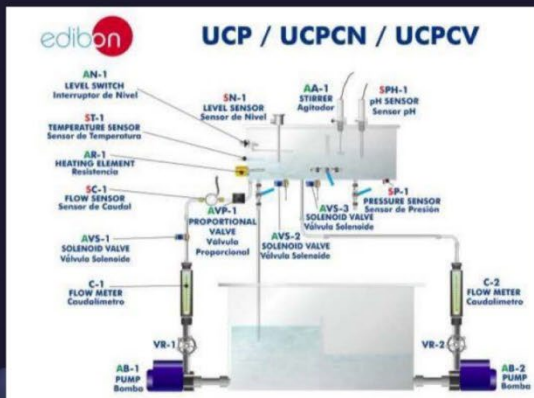
- 11. SN-1: Level sensor 0-300 mm (capacitive and immersion level sensor, 4-20 mA); it can be dismantled.

- 12. SPH-1: pH sensor (glass electrode, ddp (V)), removable (tank/effluent).

- 13. AN-1: On/off level switch. This sensor determines the performance of the immersion heating element.



Process Description



- This unit consists of a hydraulic circuit with a bottom tank (1) and an upper process tank (2), both dual, two centrifugal pumps (3), two flowmeters with manual control valve (4), three on/off solenoid valves (5), and a motorized proportional valve (infinitely variable) (6). Of course, it includes the appropriate tubes, elbows, connections, bulkheads, stopcocks and drains for the circuit operation. All the above[1] mentioned is set on a support frame designed to be placed on a work bench. Additional fixed elements include a flow sensor that is installed in one of the upward lines of flow (7), and a temperature sensor located in the process tank (8) together with an electric heating coil (10). The interchangeable additional elements in the unit are a stirrer (9), the immersion level sensor located in the process tank (11), and the pH sensor (electrode) which can be placed in the process tank or in the bottom tank (12) to study the effect of the time out.

ASSIGNMENTS FOR OUTCOME 3

**An ability to communicate effectively with a range of audiences
(Written and Oral, Demonstrated by Parts of Final Project Report &
Presentation Slides)**

**CHEMICAL ENGINEERING DEPARTMENT
OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET
SENIOR DESIGN & PROFESSIONALISM II
SPRING 2022**

Instructor: Dr. Emmanuel A. Dada

Title of Assignment

Final Project Powerpoint Presentation

Outcome Measured Using this Assignment

Outcome 3

An ability to communicate effectively with a range of audiences

Check the communication problem characteristics related to this assignment

Ability to prepare an executive summary for the report	
Requires students to:	
	Prepare an executive summary up to 3 pages
Ability to organize, plan and properly format a written technical report	
Requires students to:	
x	Organize report by chapters, major sections, subsections and paragraphs
x	Provide Title Page, and Table of Contents, list of Figures, and List of Tables properly formatted.
x	Provide figure and table numbers with titles and reference and discuss each table and figure in accord with standard practice.
x	Properly cite references in the report and provide well formatted reference list at the end.
x	Prepare the written report in accord with standard report formatting Manual
Ability to compose original texts and properly apply the conventions of written language.	
Requires students to:	
X	Properly apply capitalization, punctuation, and penmanship, to communicate clearly and spell proficiently,
	Apply standard grammar and usage to communicate clearly and effectively in writing using complete sentences , good subject-verb agreement, pronoun referents, and parts of speech, properly using adjectives, adverbs, prepositional phrases appropriately, conjunctions to connect ideas to make writing vivid and precise, and use available technology to support aspects of creating, revising, editing, spell checking, and publishing the report.
Ability to provide appropriate discussion, conclusions and recommendations	
Requires students to	
X	summarize the goals, objectives, and indicate whether they were met.
X	summarize the report chapter by chapter
X	summarize constraints and codes and indicate whether they were met for design reports Summarizes how issues relating to public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors were considered/addressed for design reports.
X	Provide logical conclusions Provide logical conclusions and recommendations (including strengths and weaknesses)

Brief justification of why this assignment is suitable for this outcome

Grading Scheme

The students are assessed by external evaluators who are professional engineers for their skills in presenting their projects and defending their projects via a powerpoint presentation mode. The students are graded based on some rubrics detailed below. The students written report as attached for outcome 2 above are graded based on the below grading rubrics.

The grading rubrics for evaluation of the Senior Design II projects CHEG 4248 (a continuation of the fall 2021 Senior Design I CHEG 42472) are presented below. The students are to be evaluated as outlined in the rubrics with emphasis on the following:

- Justification of plant location and capacity
- Provide a process description and Process Flow Diagram (PFD) for the plant showing the major items of equipment, and indicating the materials of construction and the operating temperatures and pressures
- Material and energy balances with summary table for the process with streams information showing a mass balance for each major equipment
- A complete HYSYS/ASPEN simulation report of the process
- Chemical engineering design of major equipment such as (i) reactor(s), (ii) absorption column(s) and (iii) distillation columns
- Estimates of the Major Equipment Capital Cost (Capex)
- Estimates of Operating Cost (Opex)
- Preparation of a net present value and investor's rate of return analysis for the investment over a 15-year life, assuming the company's current capital hurdle rate is 15%.
- Preparation of a project milestone schedule
- Preparation of a P&ID for a section of the process showing the control scheme to ensure safe operation of the unit, and carrying out a HAZOP analysis of the section of the process selected
- Preparation of a safety report indicating the safety measures required for the plant bearing in mind any toxic and flammable materials handled

In addition, the names of the presenters for each design project have been included in the rubrics to enable each presenter to be evaluated as well.

References:

1. Gael D. Ulrich and Palligarnai T. Vasudevan, "Chemical Engineering : Process Design and Economics, A practical Guide", second edition, 2004, Process Publishing, New Hampshire, USA, ISBN 0-9708768-2-3

2. Gavin Towler and Ray Innot, "Chemical Engineering Design : Principles, Practice and Economics of Plant and Process Design" Butterworth-Heinemann, ISBN 978-0-08-096659-5, second edition, 2013

3. Perry's Chemical Engineering Handbook, sixth edition or latest

4. Turton, R., Bailie, R., Whiting, W., and Shaeiwits, J. A. "Analysis, Synthesis, and Design of Chemical Processes," 4th Edition Prentice-Hall PTR, Upper Saddle River, New Jersey 07458, 2008.

5. "Plant Design and Economics for Chemical Engineers" by Peters, M.S., K.D. Timmerhaus and R.E. West, 5th edition, 2003, McGraw-Hill, ISBN 0—07-239266-5.

DEPARTMENT OF CHEMICAL ENGINEERING
SENIOR DESIGN & PROFESSIONALISM II CHEG 4248
COURSE ASSESSMENT GRADING & OUTCOME
ASSESSMENT SHEET FOR SPRING 2022 SEMESTER

ABET Student Learning Outcome 3: An ability to communicate effectively with a range of audiences (Written Technical Communication)

Assignments that test competency in written communication will include problems that test the student's ability to logically arrange information, use correct grammar, use appropriate format, use discipline specific conventions including citations, and use acceptable graphical conventions.

Name: _____

Title of Assignment: _____ Due Date _____

Competency Area	Points Assigned	Points Received
1. Ability to prepare an executive summary for the report	10	
Students are able to prepare an executive summary of 5 to 8 pages	10	
2. Ability to organize, plan and properly format a written technical report	80	
(i) Students are able to organize report by categorizing ideas for the report into well and logically organized chapters, major sections, subsections and paragraphs blended within the larger units.	20	
(i) Students are able to organize report by categorizing ideas for the report into well and logically organized chapters, major sections, subsections and paragraphs blended within the larger units.	20	
(ii) Students provide Title Page, and Table of Contents, list of Figures, and List of Tables properly formatted.	12	
(iii) Students provide figure number and title for each figure in the report, reference each figure, and completely discuss each figure in the report in accord with standards in the project manual.	12	
(iv) Students provide table number and title for each table in the report in accord with standards in the project manual, reference each table, and completely discuss each table in the report.	12	
(v) Students properly cite references in the report and provide well formatted reference list at the end.	12	
(vi) Students prepare the written report in accord with standard report formatting provided in the Senior Projects Report Manual.	12	
3. Ability to compose original texts and properly apply the conventions of written language	50	

(i) Properly apply capitalization, punctuation, and penmanship, to communicate clearly.	15	
(ii) Spell proficiently	10	
(iii) Apply standard grammar and usage to communicate clearly and effectively in writing including • using complete sentences, varying the types such as compound and complex to match meanings and purposes • properly employing standard English usage in writing for audiences, including subject-verb agreement, pronoun referents, and parts of speech • properly using adjectives (comparative and superlative forms) and adverbs appropriately to make writing vivid or precise • properly using prepositional phrases to elaborate written ideas • properly using conjunctions to connect ideas meaningfully	20	
(vi) Use available technology to support aspects of creating, revising, editing, spell checking, and publishing the report.	5	
4. Ability to provide appropriate discussion, conclusions and recommendations	60	
(i) Summarize the goals, objectives, and indicate whether they were met.	10	
(ii) Summarize the results.	30	
(iii) Summarize constraints and codes and indicate whether they were met.	10	
(iv) Provide logical conclusions and recommendations (including strengths and weaknesses).	10	
Total	200	

SENIOR DESIGN & PROFESSIONALISM II CHEG 4248

Oral Design Presentation Evaluation Form

Title of Presentation:
Date of Presentation: April 23, 2022
Name of Examiner/Appraiser:

Performance Criteria	Not Acceptable (0-59.9%)	Below Expectations (60-69.9%)	Average meets minimal expectations 70-79.9	Very Good Meets Expectations (80-89.9%)	Excellent Exceeds Expectations (90- 100%)
1. Ability to Organize, Plan, Design/Prepare and Use Appropriate Visual Aids for communication/Presentation**	20 40 59	60 65 69	70 75 79	80 85 89	90 95 99
Presentation is organized in well structured logical sequence making it easy for audience to follow the content with clear understanding.	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Slides are well prepared and are effective in helping					

audience to understand (<i>adequate and relevant technical content and view graphs that are legible, completely labeled, annotated, dimensioned to illustrate important features of the work being presented</i>)	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Modern presentation techniques are used (<i>may include visually enhanced transitions, animations, video, and sound clips</i>).	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Average for this Performance Criteria					
2. Ability to Articulate Subject Knowledge (Technical Content)*					
Client identification and recognition of need	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Project goals and objectives, and planning	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Process screening and selection, PFD and process description	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Process chemistry, and material and energy balances	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Quality of chemical engineering design/and analysis, and design constraints	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Design within economic, societal and environmental constraints(including contemporary issues and broader impact on society)	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Hazard and Safety considerations****	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Questions are responded to in a clear professional manner after restating questions to audience	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Average for this Performance Criteria					
3. Appearance and Ability to Provide Good Oral Delivery**					
Correct grammatical English and technical terms appropriate to technical area and audience are used; and presenters speak with clarity and confidence	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Good posture and eye contact with the audience are maintained (<i>should not read from prepared notes</i>) and elicits the attention of the audience	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Presenters dress appropriately for the occasion.	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Efforts of all group members/Group dynamics***	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Average for this Performance Criteria					
OVERALL AVERAGE GROUP PERFORMANCE					
NAME OF PRESENTER	OVERALL PERFORMANCE OF PRESENTER				
	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐

	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐

*ABET Student Outcome 2 ; **ABET Student Outcome 3; *** ABET Student Outcome 5; ****Program Criterion 9b

INSERT A SAMPLE STUDENT'S COPY OF THE POWERPOINT PRESENTATION

PRODUCTION OF DIMETHYL ETHER

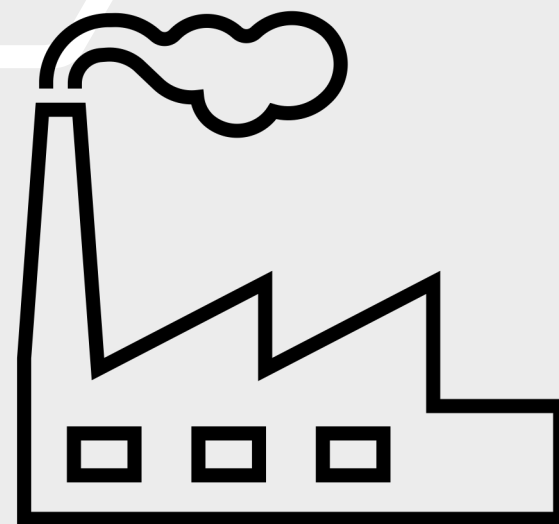
DADA TEAM 4

Amiya Rogers — 88%

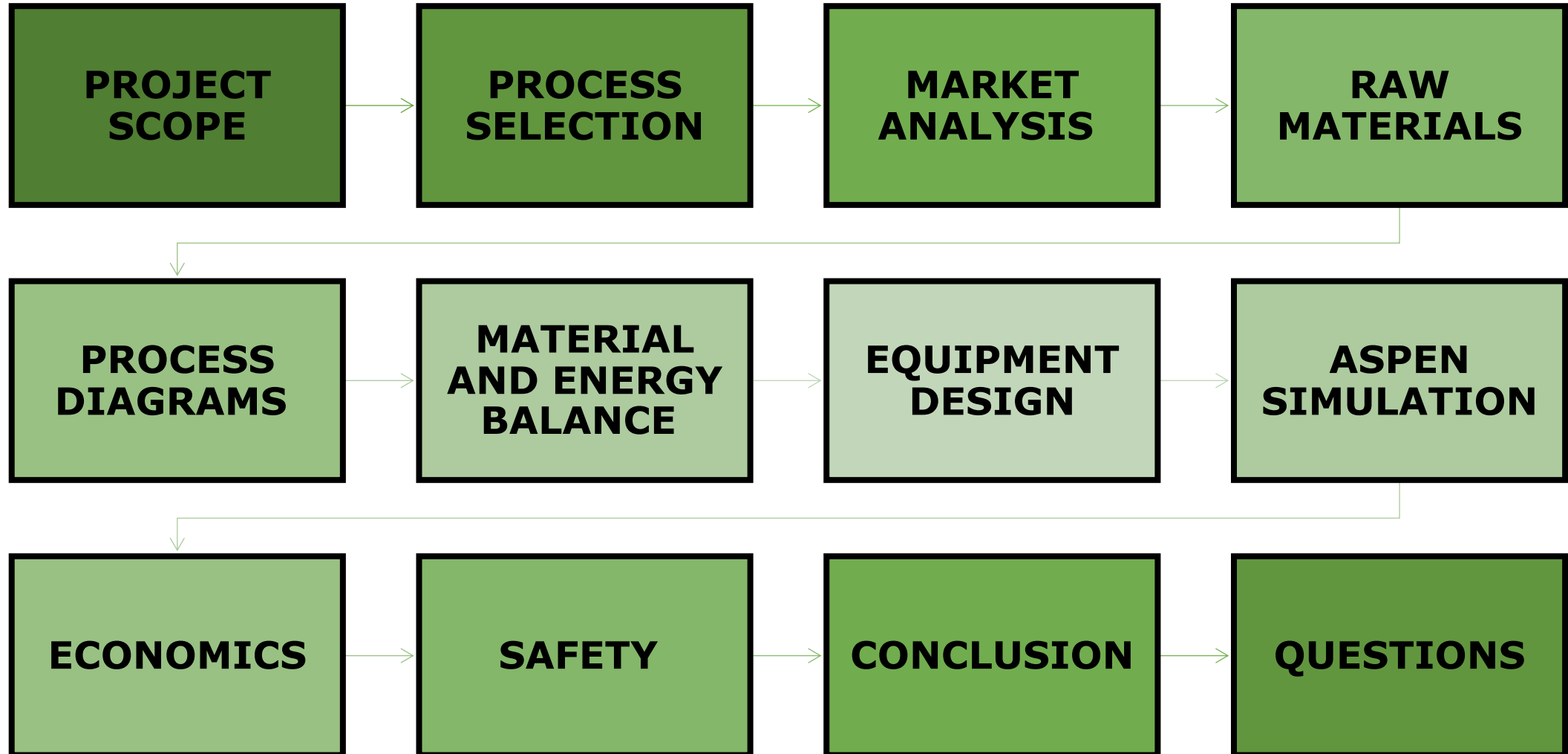
Cinthia Sahin — 88%

Laura Ukpede — 87%

Taylon Owens — 90%



OUTLINE



PROJECT SCOPE

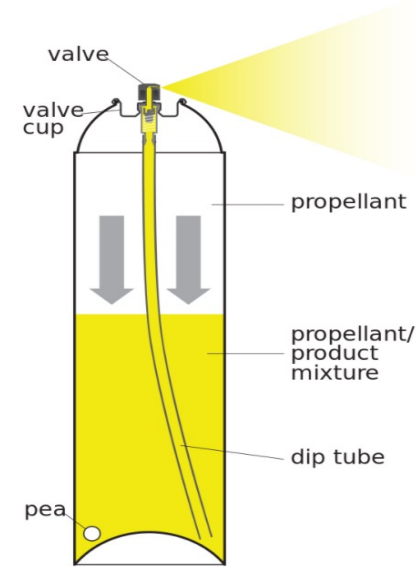
PROBLEM STATEMENT

The purpose of this project is to design a system that produces Dimethyl Ether (DME) at the required 99.9% purity.



PRODUCT USES

- Refrigerant (R-E170)
- Solvent
- Propellant in industrial aerosol products.
- Potential use for transportation fuel, domestic use, and power generation



PROCESS SELECTION

PROCESSES CONSIDERED

ALTERNATIVE	PROCESS	PROS	CONS
1	Methanol Dehydration	- Consumes less time and cost of equipment - Relatively simpler process flow - Catalyst deactivation occurs at relatively high temperature (400 C).	- Requires more downstream separation technologies. - Sourcing of methanol may present challenges. - Marginally lower DME yield.
2	Indirect Synthesis from biogas feedstock	- Marginally higher DME yield. - Water build up in the process is alleviated. - Energy efficiency is maximized.	- Sourcing of biogas feedstocks presents a challenge. - Process requires more equipment. - Relatively costly and time consuming
3	Direct Synthesis from Natural Gas Feed Stock	- Higher Yield of DME. - Low production cost. - Abundantly available feedstock	- Highly exothermic. - Low production rate - Higher operating temperature.

PROCESS SELECTION MATRIX

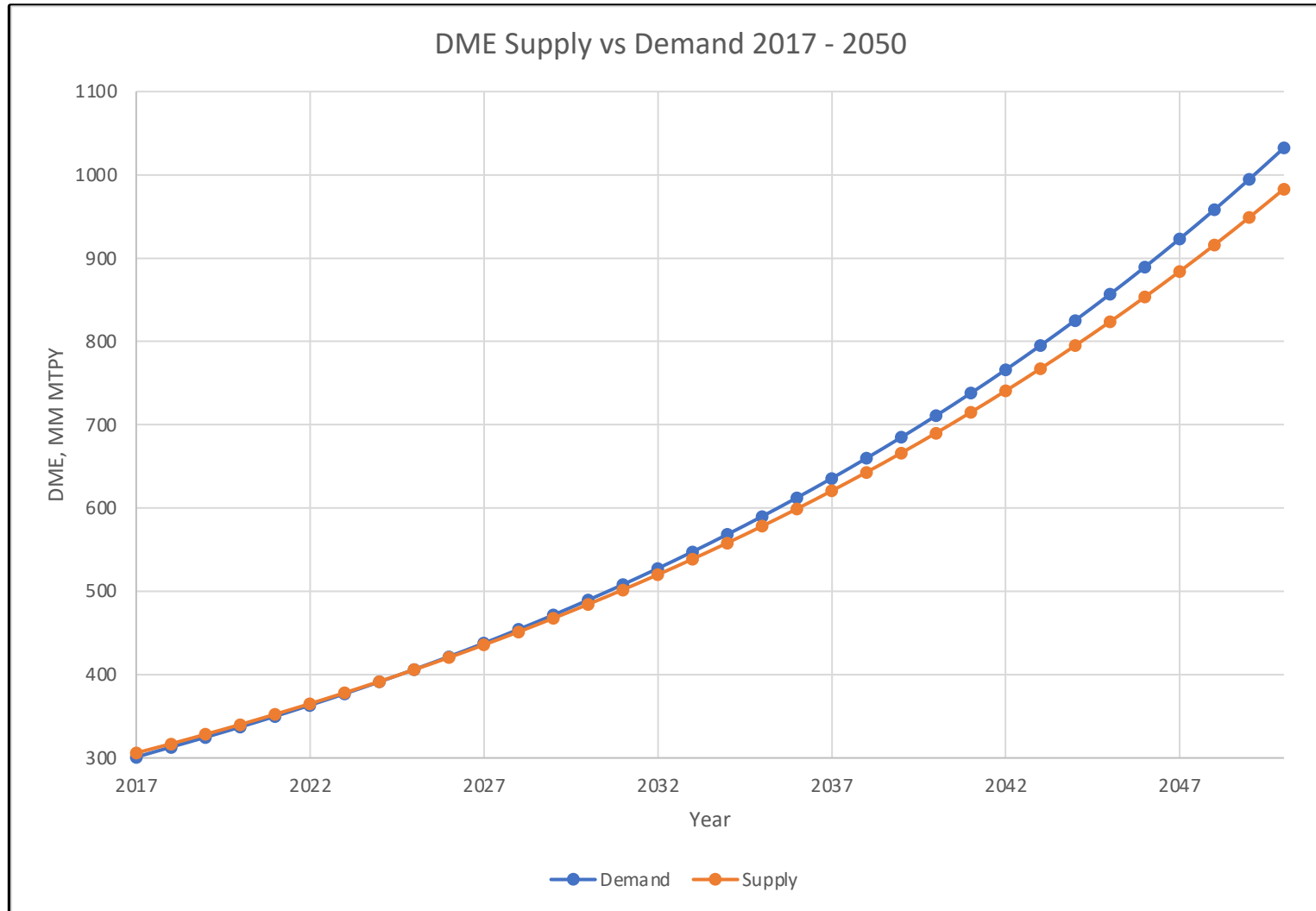
CONSIDERATIONS	ALTERNATIVE 1 Methanol Dehydration	ALTERNATIVE 2 Indirect Synthesis from biogas feedstock	ALTERNATIVE 3 Direct Synthesis from Natural Gas Feed Stock	WEIGHT
Economics	18	10	12	40%
Environmental	13	16	20	25%
Location	14	13	9	25%
Safety	13	13	16	10%
Total	<u>15.25</u>	12.5	13.65	100%

PROJECT PLANNING (GANTT CHART)

PROJECT TITLE:		PRODUCTION OF DIMETHYL ETHER (DME)																																																				
Project start		2/18/2022																																																				
Display Week		0																																																				
TASKS AND SUB-TASKS			OWNER	START DATE	END DATE	DURATION																																																
HYSYS/ASPEN Simulation of Process																																																						
Include Small Equipment	All	18-Feb-22	25-Feb-22	1 week																																																		
Verify Recycle Stream	All	18-Feb-22	25-Feb-22	1 week																																																		
Converge	All	18-Feb-22	25-Feb-22	1 week																																																		
Chemical Engineering Design																																																						
Design of Major Equipment	All	28-Feb-22	28-Mar-22	4 weeks																																																		
Detailed Unit P&ID (Reactor)	Taylon & Amiya	28-Feb-22	28-Mar-22	4 weeks																																																		
Listing Equipment and Specification	Laura & Cinthia	28-Feb-22	28-Mar-22	4 weeks																																																		
Economic Evaluation																																																						
Cost of Major Equipment Using CAPCOST Software	Cinthia and Laura	30-Mar-22	13-Apr-22	2 weeks																																																		
Fixed Capital Costs	Taylon	30-Mar-22	13-Apr-22	2 weeks																																																		
Utilites	Taylon	30-Mar-22	13-Apr-22	2 weeks																																																		
Fixed Capital Investments	Taylon	30-Mar-22	13-Apr-22	2 weeks																																																		
Manufacturing Production costs Peters and Timmerhaus	Amiya	30-Mar-22	13-Apr-22	2 weeks																																																		
Complete Economic Anylasis/ Cash Flow Diagram	All	30-Mar-22	13-Apr-22	2 weeks																																																		
Safety and HAZOP Analysis																																																						
Methanol Safety/Hazards	Laura	30-Mar-22	13-Apr-22	2 weeks																																																		
Reactor & Catalyst Safety/Hazards	Taylon	30-Mar-22	13-Apr-22	2 weeks																																																		
DME Safety/Hazards	Amiya	30-Mar-22	13-Apr-22	2 weeks																																																		
Specific Unit Breakdown (Distillation)	Cinthia	30-Mar-22	13-Apr-22	2 weeks																																																		
Startup/Shutdown HAZOP	Amiya	30-Mar-22	13-Apr-22	2 weeks																																																		
Finish Report																																																						
Complete Rough Draft	All	9-Apr-22	16-Apr-22	1 week																																																		
Complete Final Draft	All	9-Apr-22	16-Apr-22	1 week																																																		
Visual & Oral Presentation																																																						
Complete Presentation	All	9-Apr-22	16-Apr-22	1 week																																																		
Presentation Practice	All	9-Apr-22	16-Apr-22	1 week																																																		

MARKET ANALYSIS

MARKET ANALYSIS



PLANT STARTUP:

2026

2 Year Build-Time

DEMAND BASIS:

50,000 Metric Tons Per Year
(5% of 1MM Gap)

DEMAND BASIS:

90% Utilization

CLIENT IDENTIFICATION



PLANT LOCATION

LOCATION:

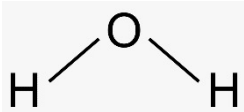
Plaquemine, Louisiana

Plaquemine Cogeneration Facility: Steam and Power
Port of Plaquemines for Cooling Water



RAW MATERIALS

CHEMICAL CONDITIONS

Conditions	Methanol	Dimethyl Ether	Water
Molecular Weight	0.071 lb/mol	0.102 lb/mol	0.039 lb/mol
Chemical Formula	CH ₃ OH	CH ₃ OCH ₃	H ₂ O
Chemical Structure	$ \begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{O}-\text{H} \\ \\ \text{H} \end{array} $	$ \begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{O}-\text{C}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array} $	
Boiling Point	148.46 ° F	-11.2°F	212°F
Melting Point	-138.28°F	-221.8°F	32°F
Flash Point	49.46°F	-41.98°F	-
Density	0.029 lb/in ³	0.071 lb/in ³	0.036 lb/in ³

RAW MATERIALS



A (Methanol)

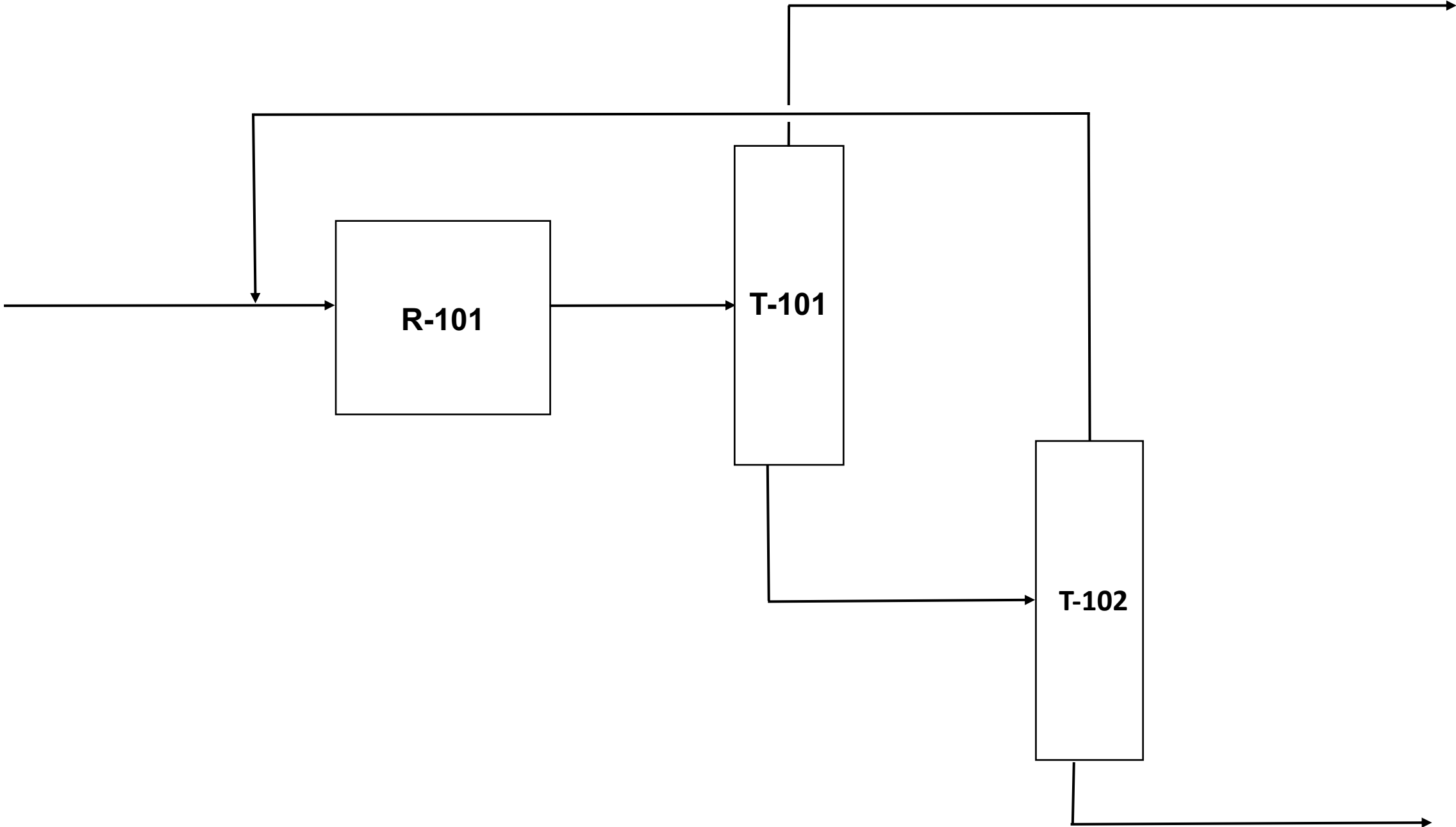
B (DME)

C (Water)

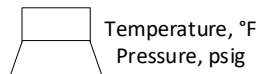
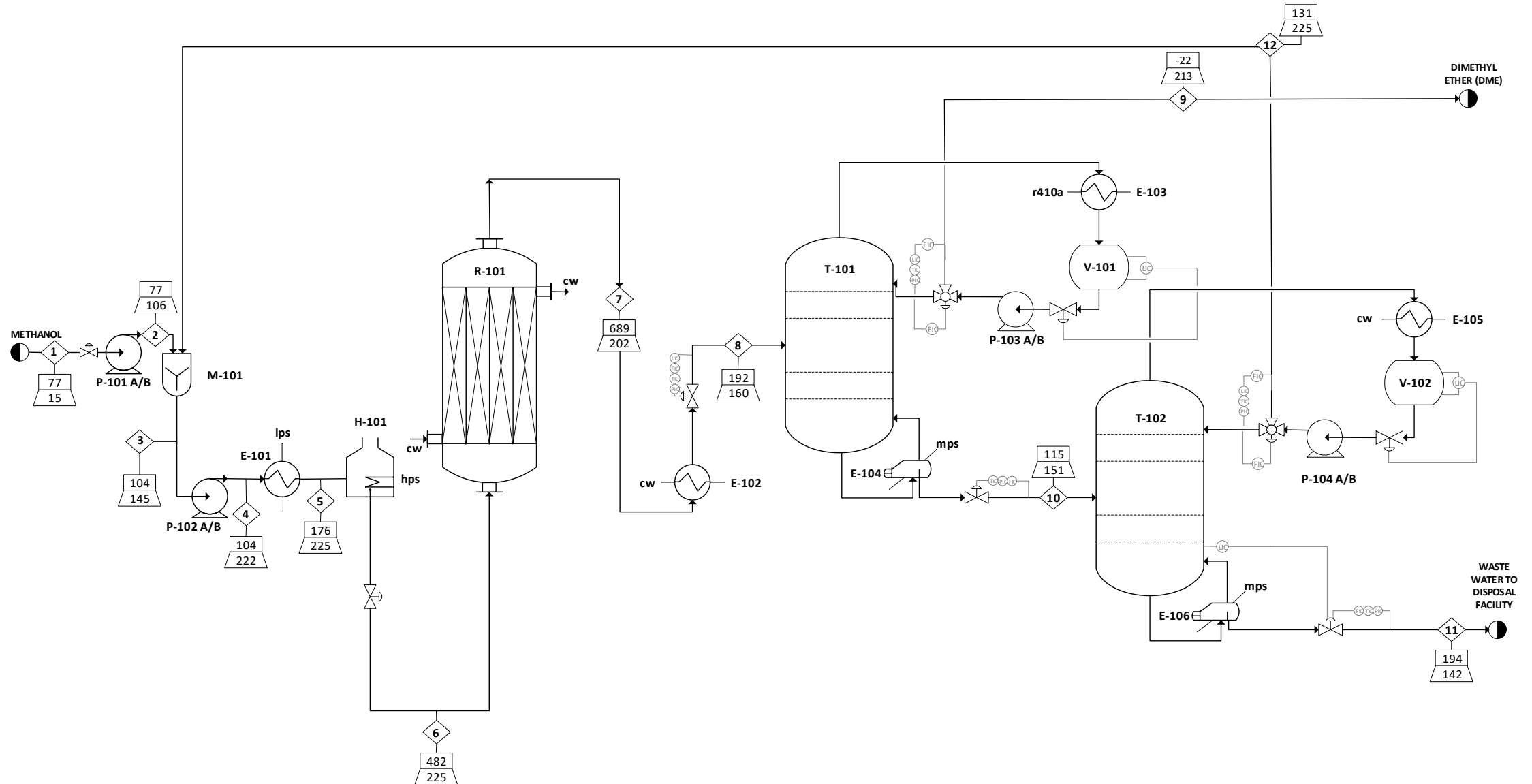
	A	B	C
mol	2	1	1
Molecular Weight lb/mol	0.071lb/mol	0.102 lb/mol	0.040 lb/mol
lb	0.141 lb	0.102 lb	0.040 lb
lb/lb DME	3.06 lb	2.20 lb	.862 lb
cents/lb	\$0.16	\$0.41	\$0.24

PROCESS DIAGRAMS

BLOCK FLOW DIAGRAM

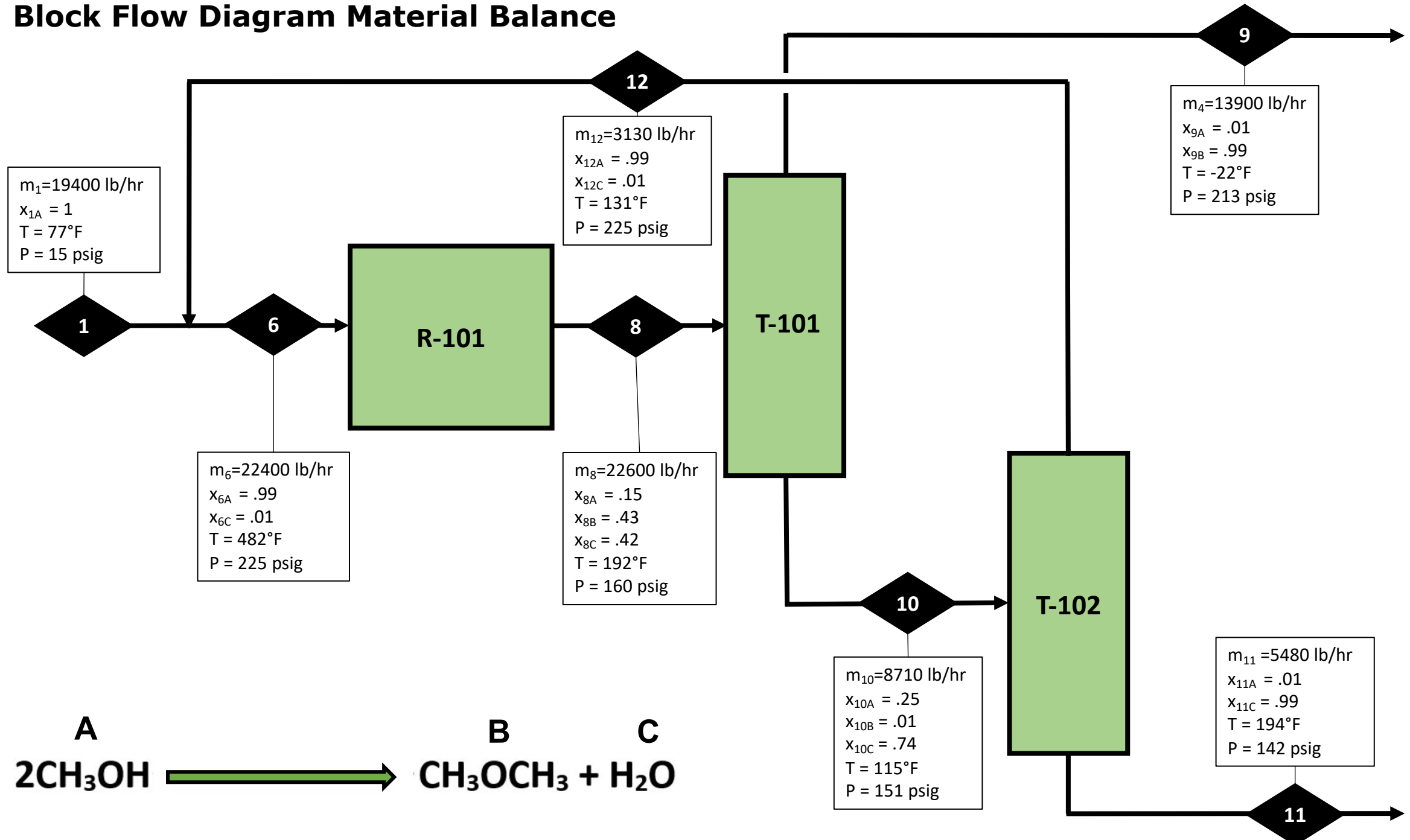


PROCESS FLOW DIAGRAM



MATERIAL AND ENERGY BALANCE

Block Flow Diagram Material Balance



MATERIAL BALANCE

STREAM CONDITIONS

Stream Description	Pure Methanol to Pump	Pure Methanol to Mixer	Mixed Stream to P-102	Methanol to Vaporizer	Combined Methanol to Furnace	Combined Feed to R-101	Reactor Effluent to Cooler	Methanol+ DME + Water to T-101	Dimethyl Ether Product	Methanol + Water to T-102	Wastewater to Disposal	Recycled Methanol to Mixer
Steam Number	1	2	3	4	5	6	7	8	9	10	11	12
Temperature (F)	77	77	104	104	176	482	689	192	-22	115	194	131
Pressure (psig)	15	106	145	222	225	225	202	160	213	151	142	225
Methanol Mole Fraction	1	1	.99	.99	.99	.99	.15	.15	.01	.25	.01	.99
DME Mass Fraction	0	0	0	0	0	0	.43	.43	.99	.01	0	0
Water Mass Fraction	0	0	.01	.01	.01	.01	.42	.42	0	.74	.99	.01
Mass Flow (lb/hr)	19352	19352	Methanol 22268	Methanol 22268	Methanol 22268	Methanol 22268	Methanol 3374	Methanol 3374	Methanol 97	Methanol 3203	Methanol 97	Methanol 3107
			Water 126	Water 126	Water 126		Water 126	Water 5307	DME 13907	DME 13776	DME 184	

ENERGY BALANCE

Methanol Dehydration R-101	
Temperature	689°F
R-101 Duty	-1.36×10^7 BTU/hr
E-101 Duty	9.67×10^6 BTU/hr
H-101 Duty	5.40×10^6 BTU/hr
E-102 Duty	-1.14×10^7 BTU/hr

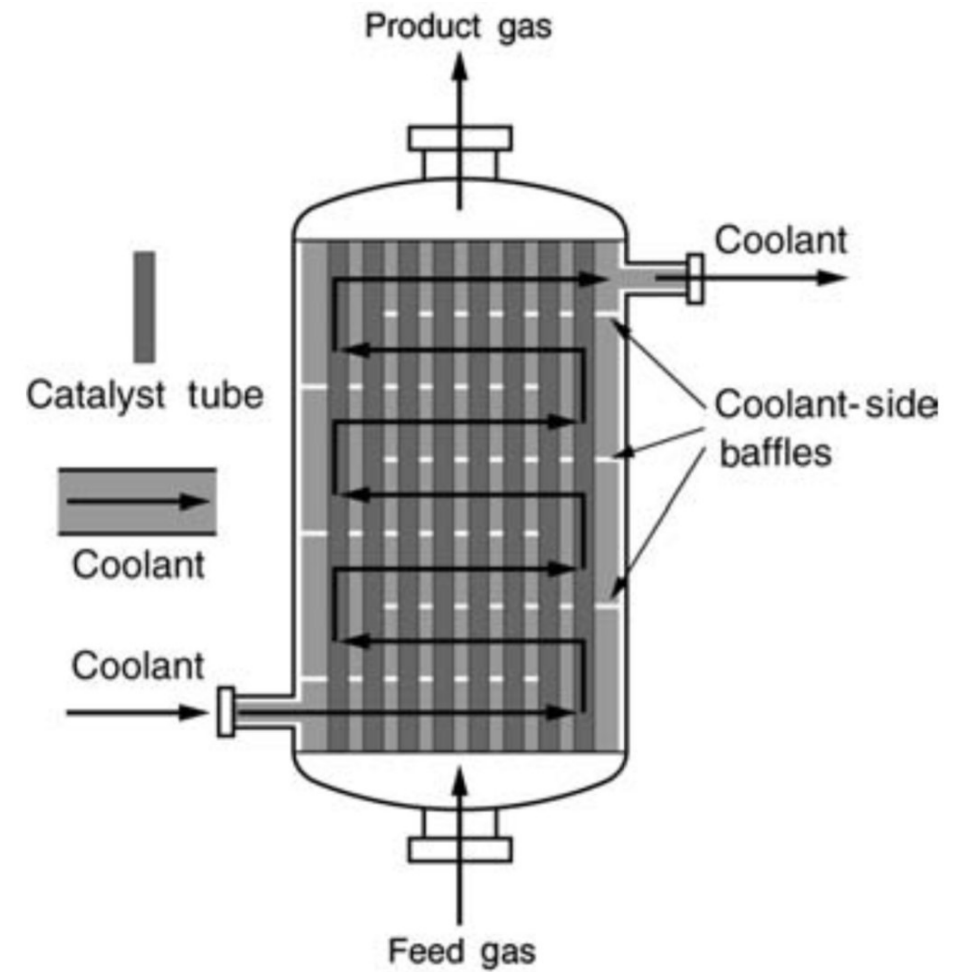
DME Distillation T-101	
Temperature	86°F/114.8°F
E-103 Duty	-3.39×10^6 BTU/hr
E-104 Duty	2.36×10^6 BTU/hr

Methanol Distillation T-102	
Temperature	158°F/194°F
E-105 Duty	-1.18×10^7 BTU/hr
E-106 Duty	1.14×10^7 BTU/hr

EQUIPMENT DESIGN

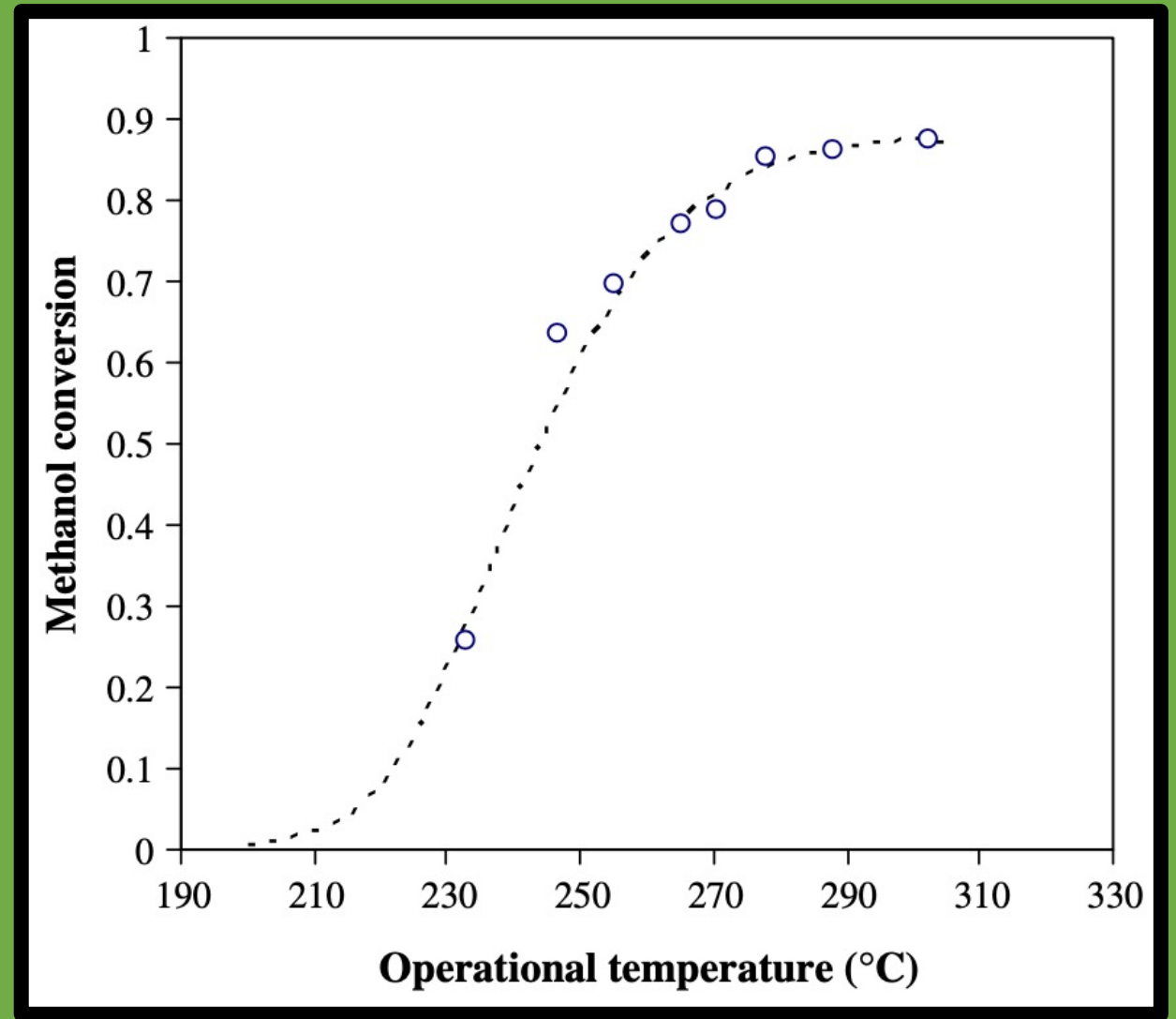
REACTION KINETICS

- Reaction: Methanol Dehydration
- Reactor Type: Catalytic Packed Bed Reactor
- Catalyst: $\gamma\text{-Al}_2\text{O}_3$
- Conversion: 90%
- Exothermic Reaction



CATALYST: γ -Al₂O₃

- Operates at high pressure
- Commonly used catalyst for Methanol Dehydration
- High activity
- Increase temperature ensures increased conversion



R-101 Specifications Sheet

Identification	
Item	Catalytic Packed Bed Reactor
Item No	R-101
Function	Dehydration of methanol to produce DME and water
Operation	Continuous
Catalyst	γ -Al ₂ O ₃
Catalyst Weight	54900 lbs

Materials Handled	In	Out
Mass Flow (lb/hr)	22400	22600
Mole flow (lbmol/hr)	702	702
Component Flow lbmol/hr		
Dimethyl Ether	0	302
Methanol	695	105
Water	7	295
Temperature (°F)	482	689
Pressure (psig)	225	202
Vapor Fraction	1.0	1.0

Design Data	
Diameter (ft)	4.36
Overall height (ft)	14.7
Number of Tubes	34
Maximum Pressure rating (psig)	218
Combined Tube Volume ft ³	62.3
Area (ft ²)	40.7
Construction of Material	Carbon Steel
Utilities (CW)	28600
Duty (Btu/hr)	-1.36x10 ⁷
Comments	-Temperature maintained by cooling water. - Shell side Methanol -Tube Side Water

T-101 Specifications Sheet

Identification	
Item	1 st distillation column
Item No	T-101
No. Required	1
Function	Separates DME from methanol and water
Operation	Continuous
Material Of Construction	Carbon Steel

Design Data	
Number of actual trays	22
Total tower height (ft)	52.5
Column diameter (ft)	2.62
Maximum Pressure rating (psig)	218
Reflux ratio	1.7
Tray Spacing (ft)	2.00

Materials Handled	Feed Methanol + DME + Water	Liquid Distillate Methanol + DME	Liquid Bottoms Methanol + Water
Mass Flow (lb/hr)	22600	13900	8710
Mole flow (lbmol/hr)	702	302	400
Component Flow lbmol/hr			
Dimethyl Ether	302	299	400
Methanol	105	3.02	100
Water	295	0.00	296
Temperature (°F)	192	86	115
Pressure (psig)	151	165	162
Vapor Fraction	1	1	0.0

Associated Components					
Condenser (E-103)	CW = 185000 lb/hr	A = 330 ft ²	Q = 3.21 x 10 ⁶ Btu/hr	- Fixed Head - Carbon Steel	Max Pressure = 145 psig
Reboiler (E-104)	mps = 2770 lb/hr	A = 72.2 ft ²	Q = 2.24.10 ⁶ Btu/hr	- Floating Head -Carbon Steel	Max Pressure = 160 psig
Reflux Drum (V-101)	L = 9.48 ft	D = 3.74 ft	Carbon Steel	Max Pressure = 149 psig	
Reflux Pump (P-102 A/B)	Power = 5.2 kW	Efficiency = 40 %	ΔP = 66.7 psig	Centrifugal/Carbon Steel	

T-102 Specifications Sheet

Identification	
Item	2 nd distillation column
Item No	T-102
No. Required	1
Function	Separates methanol from water
Operation	Continuous
Materials Of Construction	Carbon Steel

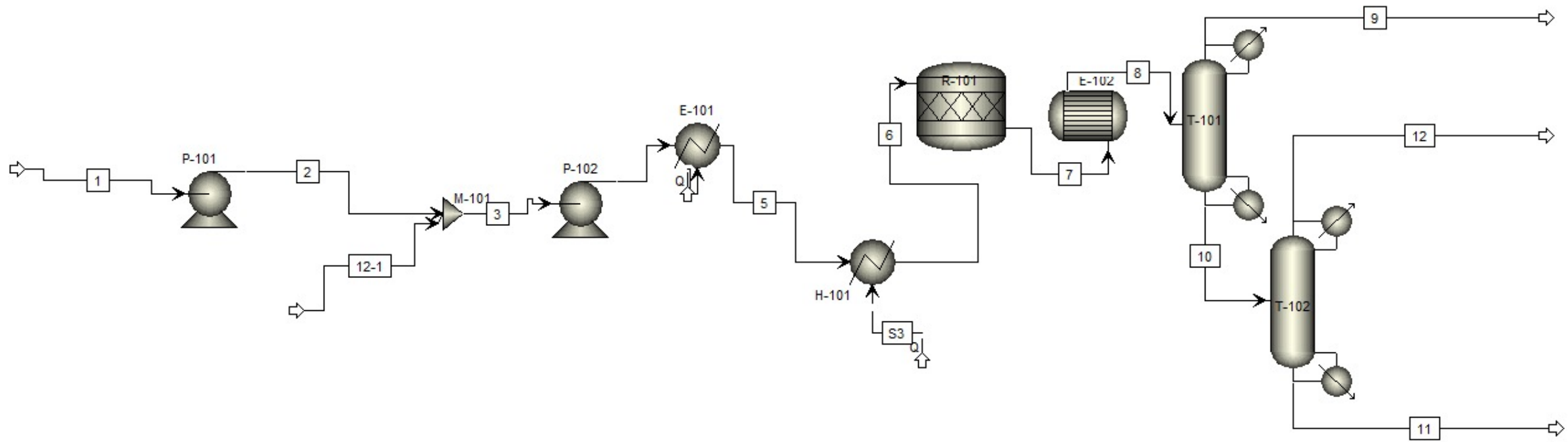
Design Data	
Number of actual trays	15
Total tower height (ft)	65.6
Column diameter (ft)	3.81
Maximum Pressure rating (psig)	218
Reflux ratio	4.5
Tray Spacing (ft)	2.62

Materials Handled	Feed	Liquid Distillate	Liquid Bottoms
Mass Flow (lb/hr)	8710	3120	5480
Mole flow (lbmol/hr)	400	98	302
Component Flow lbmol/hr			
Dimethyl Ether	3.99	0.00	0.00
Methanol	100	97	3.02
Water	29	0.970	299
Temperature (°F)	114	158	194
Pressure (psig)	162	106	107
Vapor Fraction	0.0	1.0	0.0

Associated Components					
Condenser (E-105)	CW = 649000 lb/hr	A = 74.45ft ²	Q = 1.18x10 ⁷ Btu/hr	- Fixed Head - Carbon Steel	Max Pressure = 102 psig
Reboiler (E-106)	mps = 100 lb/hr	A = 272 ft ²	Q = 1.14x10 ⁷ Btu/hr	- Floating Head - Carbon Steel	Max Pressure = 160 psig
Reflux Drum (V-102)	L = 8.30 ft	D = 12.3 ft	Carbon Steel	Max Pressure = 2160 psig	
Reflux Pump (P-103 A/B)	Power = 1.0 kW	Efficiency = 40 %	ΔP = 55.5 psig	Centrifugal/Carbon Steel	

ASPEN SIMULATION

SIMULATION

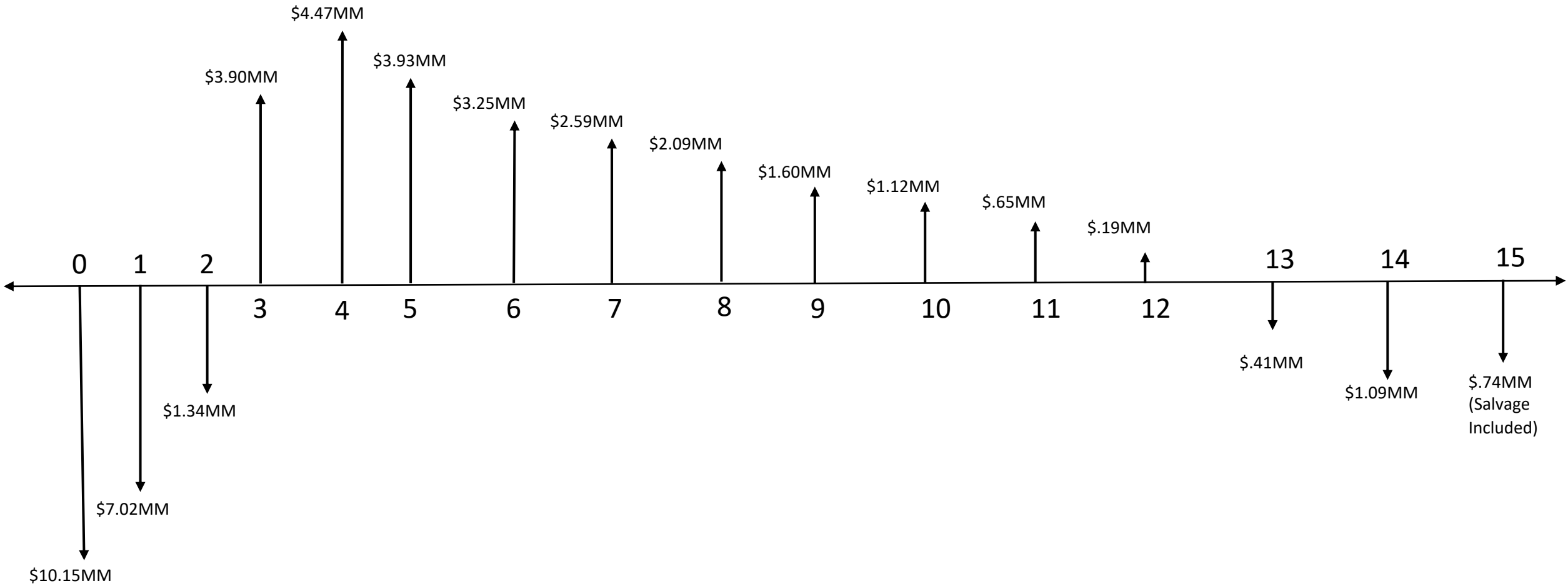


ECONOMICS

Economic Analysis

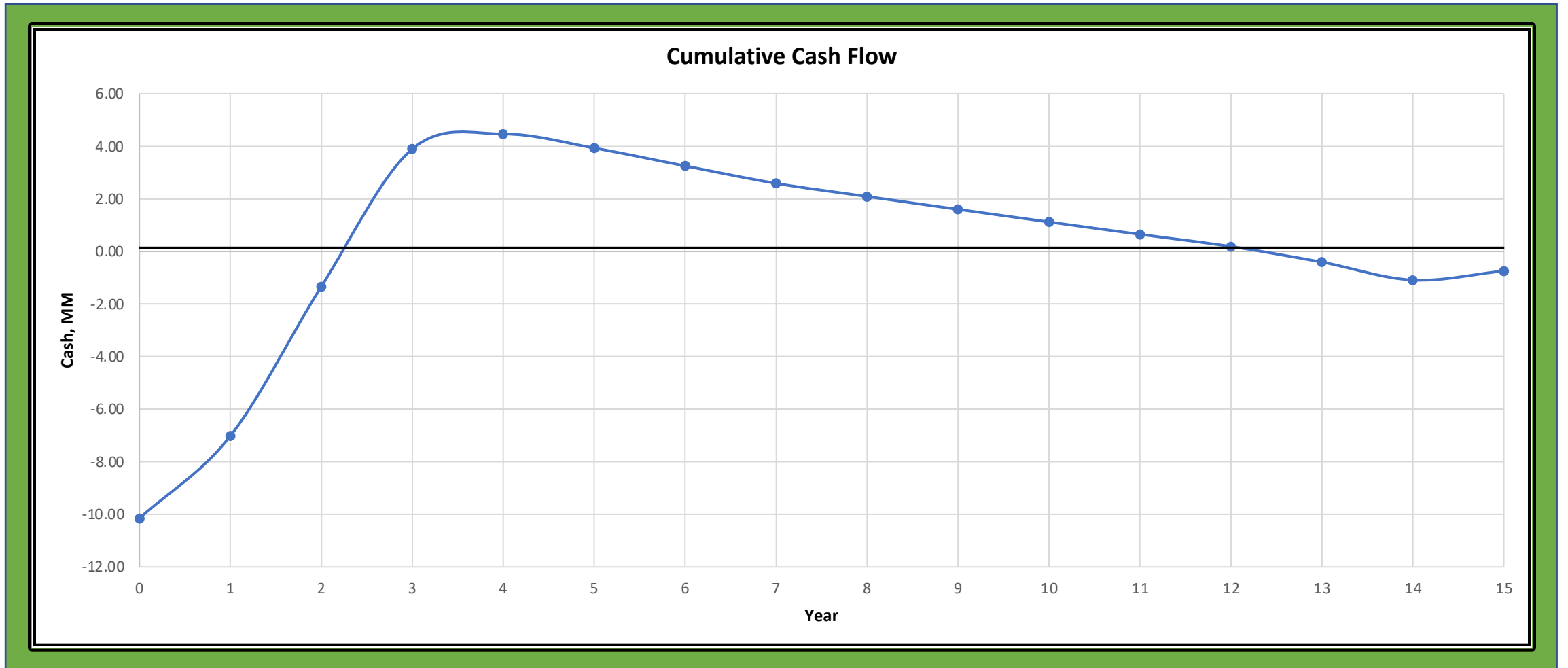
Economic Evaluation	
Total Capital Investment, 10^6	\$10.2
Annual Total Production Costs, 10^6	\$34
Annual Sales, 10^6	\$37
Payback Period, yrs	4.2
Return on Investment, %/year	22
Discounted Cash Flow Rate of Return, %/yr	13
Net Present Value, 10^6	\$8
Salvage Value, 10^6	\$1
Cumulative profit, 10^6	\$23

TCI Cash Flow Diagram



*Assume 2% TPC Inflation Rate + Depreciation

Cash Flow



SAFETY

PROCESS SAFETY HOLDING & HANDLING

HOLDING

Dimethyl Ether

- Keep away from heat
- Equipment must be grounded
- Store in a cool, well-ventilated area
- Keep away compressed oxygen or strong oxidizers
- Stored between 7-14 bar & up to 52°C

Methanol

- Methanol maximum exposure of 200 ppm (OSHA & EPA)
- Tightly closed container
- Well –ventilated area.
- Equipment must be grounded and bonded.

HANDLING

- Use of ventilators and breathing protection or local exhaust.
- The use of cold-insulating gloves.
- Oversee the use of Personal Protective Equipment (PPE).



SAFETY CONSIDERATIONS

Factor	Consideration
Markings and Labelling	Clear indications of toxicity and flammability reports on equipment at the plant. Toxicity (Exposure limits) - 1900 mg/m ³ , 1000 ppm. ("Dimethyl ether", 2021) NFPA Flammability no. - 4
Waste disposal	Determination of toxicity and physical properties to determine the proper waste classification and disposal methods.
Container disposal	Draining the containers thoroughly and venting in a safe place away from fire and sparks. Critical temperature – 126.9°C ("Dimethyl ether", 2021) Auto-ignition temperature - 350°C
Local Legislation	Waste disposal in accordance with local, regional and national laws and regulations

Safety Guidelines in Accordance with Rules and Regulations of Plaquemine, Louisiana

Pre-Line Opening Job Preparations

- The shutting down and energy isolation of all process systems prior to any line opening involving process piping, equipment or vessels (4.1.1).
- The draining and/or depressurization of all process piping, equipment or vessels to ensure clearance of hazardous materials (4.1.2).
- Ensuring temperatures for the process piping, equipment or vessels have sufficiently cooled to allow for safe work (4.1.3).

Line Opening Job Planning

- The barricading of affected areas with a minimum of 10 ft radius as a precautionary area (4.2.1.1)
- The issuance of permits strictly by authorized personnel (4.2.2.1)



HAZARD ANALYSIS T-102 FEED LINE

No.	Parameter	Guideword	Deviation	What if?	Possible Causes	Consequence	Safeguards	Action
1	Pressure	More	Pressure increase in the feed line	There is pressure build up in the feed line leading into the tower	-Blockage in the system	- Failure of feed line tube - Risk of expansion of column and bursting	Installation of quick-pressure relief valves at strategic locations before and after the column.	- Installation of a secondary pressure relief device. - Checking maintenance schedule and procedures
		Less	Pressure decreases in feed line	There are sudden pressure losses in the streams leading to the column	- Leakages in the system	- Insufficient reactant material entering the column	Pressure alarms at the feed, distillate and bottom streams	- Installation of pressure gauge - Checking maintenance schedule and procedures
2	Flow	Reverse	Backflow from T-102	The contents of the tower flow back to the feed line	- Clogging and blockages within the tower	- Pressure and temperature increase in the column	- Check valve to prevent backflow	- determining the best utilization of energy from recycle stream while preventing backflow - Following the stipulated maintenance schedule and procedures
3	Temperature	More	Increase in feed temperature	There is sudden increase in temperature at the feed of T-102	- Clogging of inlet into tower	Subsequent increase in pressure, risk of explosion and ineffectiveness of the tower	- Temperature alarms at feed entry point. - Panel alarms to warn of high pressure or temperature	-Installation of a temp gauge - Checking maintenance schedule and procedures

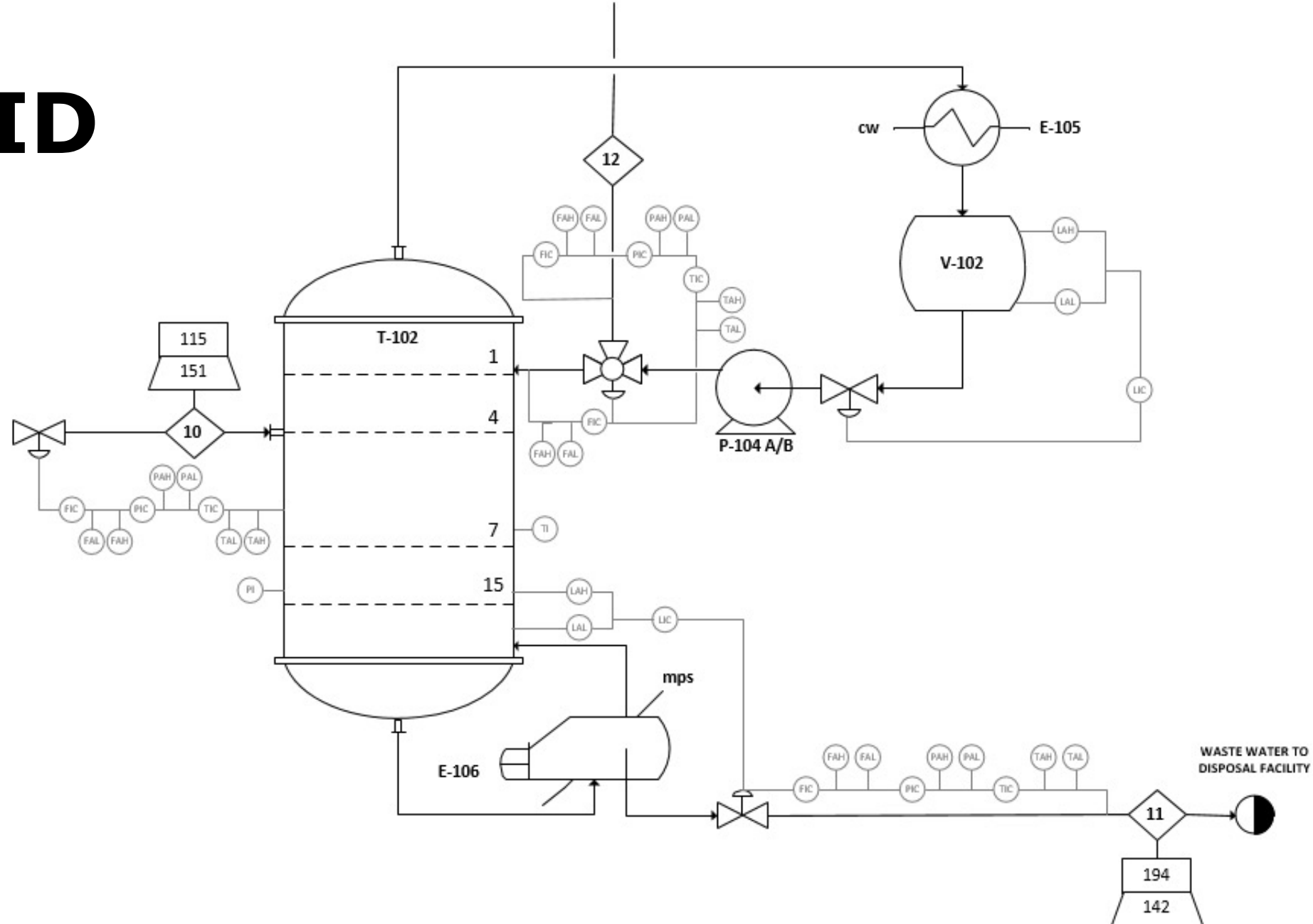
HAZARD ANALYSIS T-102 DISTILLATE LINE

No.	Parameter	Guideword	Deviation	What if ?	Possible Causes	Consequence	Safeguards	Action
1	Pressure	More	Pressure increase in the distillate line	There is pressure build up in the distillate line transporting recycled methanol to the mixer	-Blockage in the mixer or further up the distillation line	- Failure of distillate line tube - Risk of expansion of mixer and bursting. - Failure of mixer	Installation of quick-pressure relief valves at strategic locations before the mixer.	- Installation of a secondary pressure relief device. - Checking maintenance schedule and procedures
		Less	Pressure decreases in feed line	There are sudden pressure losses in the stream leading to the mixer	- Leakages in the distillate line	- Inefficiencies within the tower leading to less methanol distillate	Pressure alarms at the exit of the column where the distillate line begins.	- Installation of pressure gauge - Checking maintenance schedule and procedures
2	Flow	Reverse	Backflow to T-102	The contents of the distillate line flow back to the tower	- Clogging and blockages within the line	- Pressure and temperature increase in the column	- Check valve to prevent backflow	- determining the best utilization of energy from recycle stream while preventing backflow- Following the stipulated maintenance schedule and procedures
3	Temperature	More	Increase in distillate line temperature	There is sudden increase in temperature at distillate line transporting recycled methanol	- Clogging of inlet into the mixer	Subsequent increase in pressure, risk of explosion and ineffectiveness of the tower	- Temperature alarms at mixer entry point. - Panel alarms to warn of high pressure or temperature	-Installation of a temp gauge - Checking maintenance schedule and procedures

HAZARD ANALYSIS T-102 BOTTOM LINE

No.	Parameter	Guideword	Deviation	What if?	Possible Causes	Consequence	Safeguards	Action
1	Pressure	More	Pressure increase in the bottom line	There is pressure build up in the bottom-line transporting wastewater to treatment plant	-Blockages within bottom line	- Failure of bottom-line tube - Risk of expansion and bursting of the line.	Installation of quick-pressure relief valves at strategic locations within the line.	- Installation of a secondary pressure relief device. - Checking maintenance schedule and procedures
		Less	Pressure decreases in bottom line	There are sudden pressure losses in the stream within the bottom line leading away from the tower	- Leakages in the bottom line	- Inefficiencies within the tower causing decreased flow of wastewater from the tower	Pressure alarms at the exit point from the tower joining the bottom line	- Installation of pressure gauge - Checking maintenance schedule and procedures
2	Flow	Reverse	Backflow to T-102	The contents of the bottom-line flow back to the tower	- Clogging and blockages within the line	- Pressure and temperature increase in the column	- Check valve to prevent backflow	- determining the best utilization of energy from recycle stream while preventing backflow - Following the stipulated maintenance schedule and procedures
3	Temperature	More	Increase in bottom line temperature	There is sudden increase in temperature at bottom line transporting wastewater to the treatment plant	- Clogging of the line at various points	Subsequent increase in pressure, risk of explosion and ineffectiveness of the tower	- Temperature alarms at exit point of the tower to the bottom line. - Panel alarms to warn of high pressure or temperature	-Installation of a temp gauge - Checking maintenance schedule and procedures

P&ID



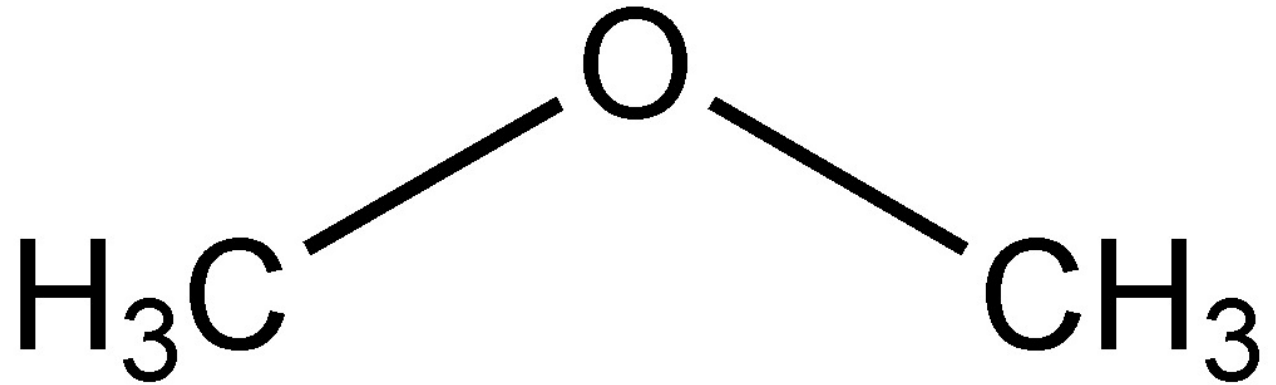


WASTEWATER TREATMENT

- Reduce Pollutants in Water
 - Negative health effects on life species
- Useful for all aspects of life
 - Irrigation or Recreational Use
- Send Wastewater to SNF Holding Company
 - Plaquemine Facility

CONCLUSION

- Methanol Dehydration To Form DME
- 99.9% Purity DME
- 90% Plant Utilization (329 Days)
- Collect Salvage After Year 12
- \$23MM Profit, 22% ROI
- Recommend Pursuing Design



ACKNOWLEDGEMENTS

Dr. Emmanuel Dada

Dr. Lealon Martin

Industrial Advisory Counsel

Roy G. Perry College of Engineering Faculty & Staff

Thank you!

QUESTIONS?

APPENDIX

REFERENCES

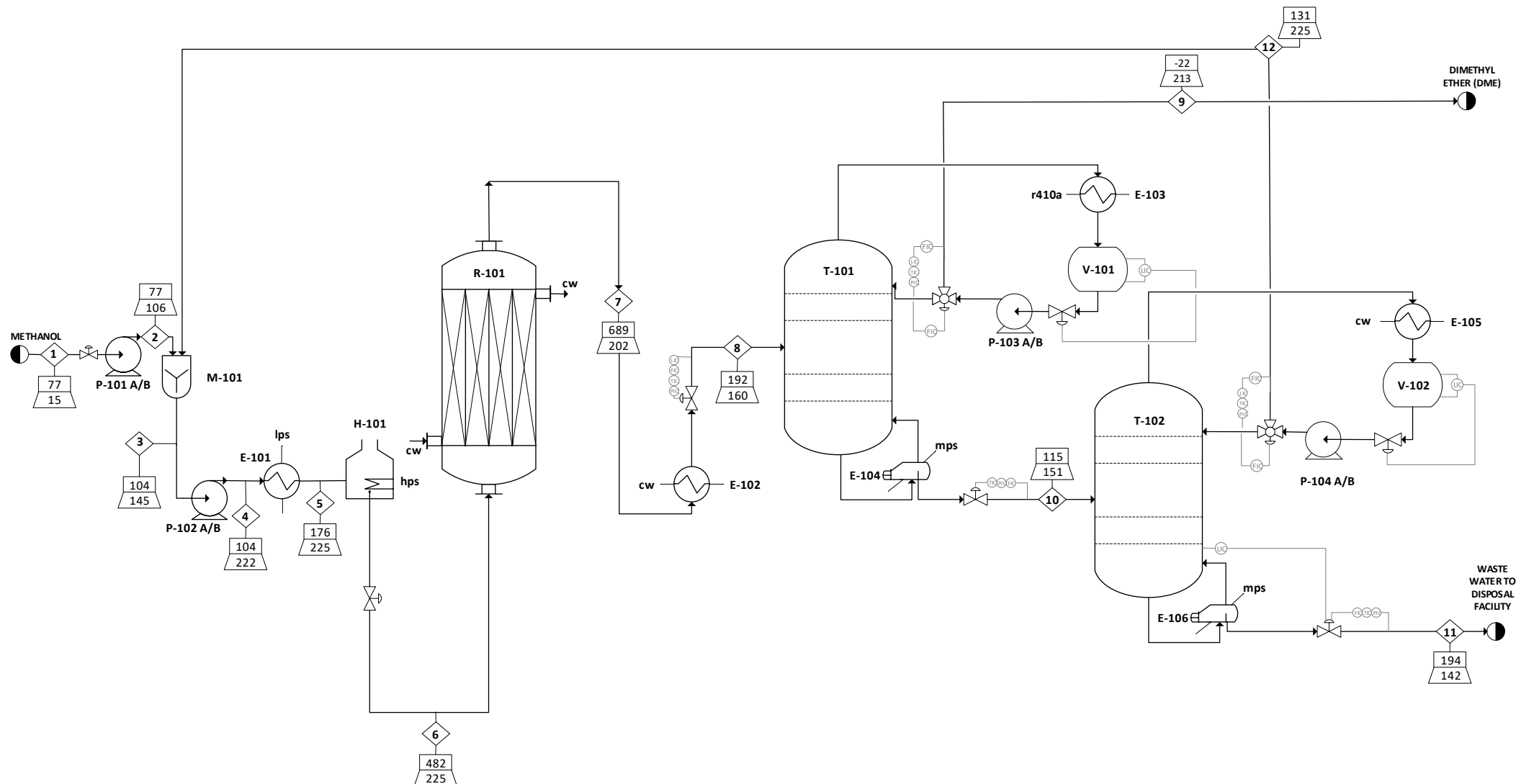
- Bakhtyari, A., & Rahimpour, M. (2018). *Methanol: Science and engineering*. Elsevier.
- Fortin, C., Gianfolcaro, N., Gonzalez, R., Lohest, J., Lonneux, A., Mordant, P., ... & Schmitz, C. (2020). Dimethyl ether, A review of production processes and a modeling of the indirect route.
- “Dimethylether China Domestic Price.” *Provide Better Products and Services* - Echemi.com, 10 Nov. 1970, www.echemi.com/pcp/dimethylether-pid_Seven1867.html
- *Dimethyl ether*. Pubchem.ncbi.nlm.nih.gov. (2021). Retrieved 19 November 2021, from <https://pubchem.ncbi.nlm.nih.gov/compound/Dimethyl-ether>.
- Giuliano, A., Catizzone, E., & Freda, C. (2021). Process Simulation and Environmental Aspects of Dimethyl Ether Production from Digestate-Derived Syngas. *International Journal of Environmental Research and Public Health*, 18(2), 807.
- “Methanol Price: *Methanol Institute*: www.methanol.org.” METHANOL INSTITUTE, 8 Nov. 2021, www.methanol.org/methanol-price-supply-demand/
- NFPA. (2021). NFPA 704: Standard System for the Identification of the Hazards of Materials for Emergency Response. Nfpa.org. Retrieved 22 September 2021, from <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=704>
- Turton, R., Bailie, R. C., Whiting, W. B., & Shaeiwitz, J. A. (2008). *Analysis, synthesis and design of chemical processes*. Pearson Education.
- Safety Data Sheet -DME. Mesagas.com. (2018). Retrieved 22 September 2021, from <https://mesagas.com/content/pdfs/Dimethyl%20Ether%20SDS.pdf>.
- Hankin, A., & Shah, N. (2017). Process exploration and assessment for the production of methanol and dimethyl ether from carbon dioxide and water. *Sustainable Energy & Fuels*, 1(7), 1541-1556.
- [Dimethylether Price Market Analysis - Echemi](#)
- Ayres, B. (2016). *HEALTH AND SAFETY PROGRAM 304 – COMPRESSED AIR AND GASES, WESTLAKE CHEMICAL* [Ebook]. Westlake Chemicals. Retrieved 5 April 2022, from https://www.westlake.com/safety_guidelines/PLQ_Safety_Guidelines/Safety/HSP%20304.pdf.
- EPA. (2000). *Methanol | Hazard Summary*. Epa.gov. Retrieved 20 April 2022, from <https://www.epa.gov/sites/default/files/2016-09/documents/methanol.pdf>.
- OSHA. (2021). *OSHA Occupational Safety Database | Methyl Alcohol (Methanol)*. osha.gov. Retrieved 20 April 2022, from <https://www.osha.gov/chemicaldata/474>.
- EPA. (2022). *System of Registries | US EPA*. Sor.epa.gov. Retrieved 20 April 2022, from https://sor.epa.gov/sor_internet/registry/substreg/searchandretrieve/advancedsearch/externalSearch.do?p_type=CASNO&p_value=115-10-6#.

STOICHIOMETRY



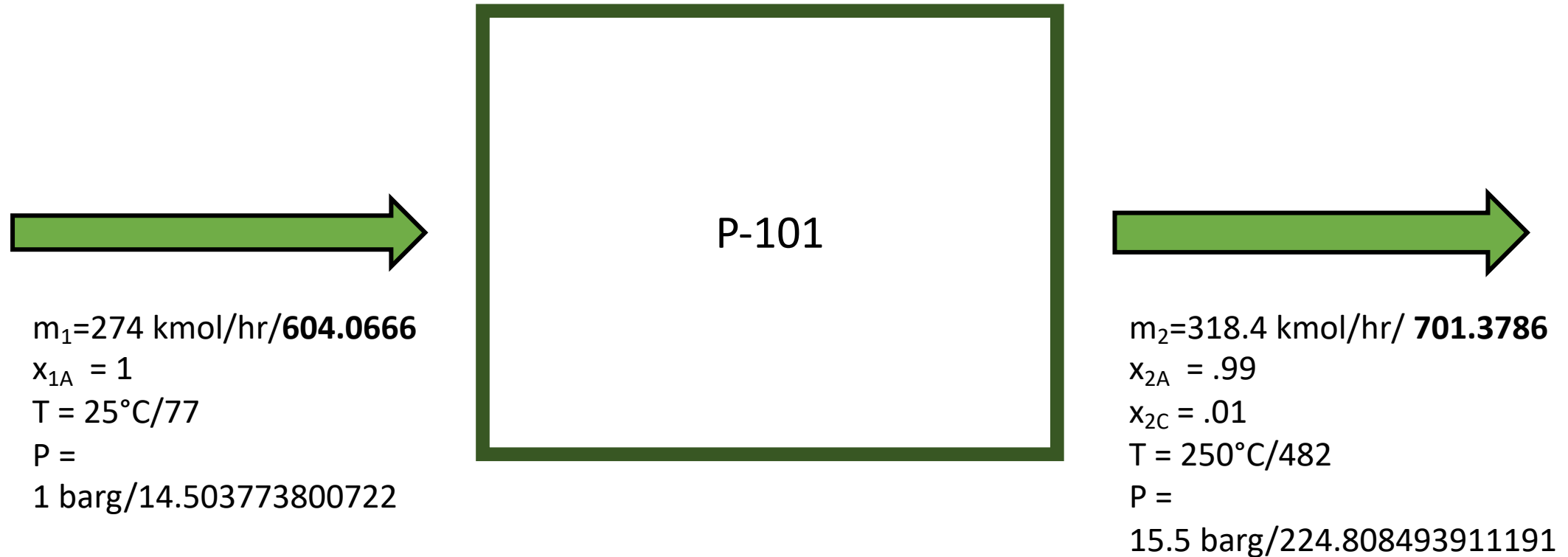
	A (Methanol)	B (Dimethyl Ether)	C (Water)
lb-mol	2	1	1
Molecular Weight lb/lbmol	32.04	46.07	18

P-101 A/B Feed Pump	M-101 Fresh & Recycled Methanol Mixer	P-102 A/B Combined Feed Pump	E-101 Methanol Vaporizer	H-101 Fired Heater	R-101 Methanol Catalytic Packed Bed Reactor	E-102 DME Cooler	T-101 DME Distillation Tower	E-103 T-101 Condenser	E-104 T-101 Reboiler	V-101 T-101 Reflux Drum	P-103 A/B T-101 Reflux Pump	T-102 Methanol Distillation Tower	E-105 T-102 Condenser	E-106 T- 102 Reboiler	V-102 Methanol Reflux Drum	P-104 A/B T-102 Reflux Pump
---------------------------	---	---------------------------------------	--------------------------------	--------------------------	---	------------------------	---------------------------------------	-----------------------------	----------------------------	----------------------------------	--------------------------------------	--	-----------------------------	-----------------------------	-------------------------------------	--------------------------------------

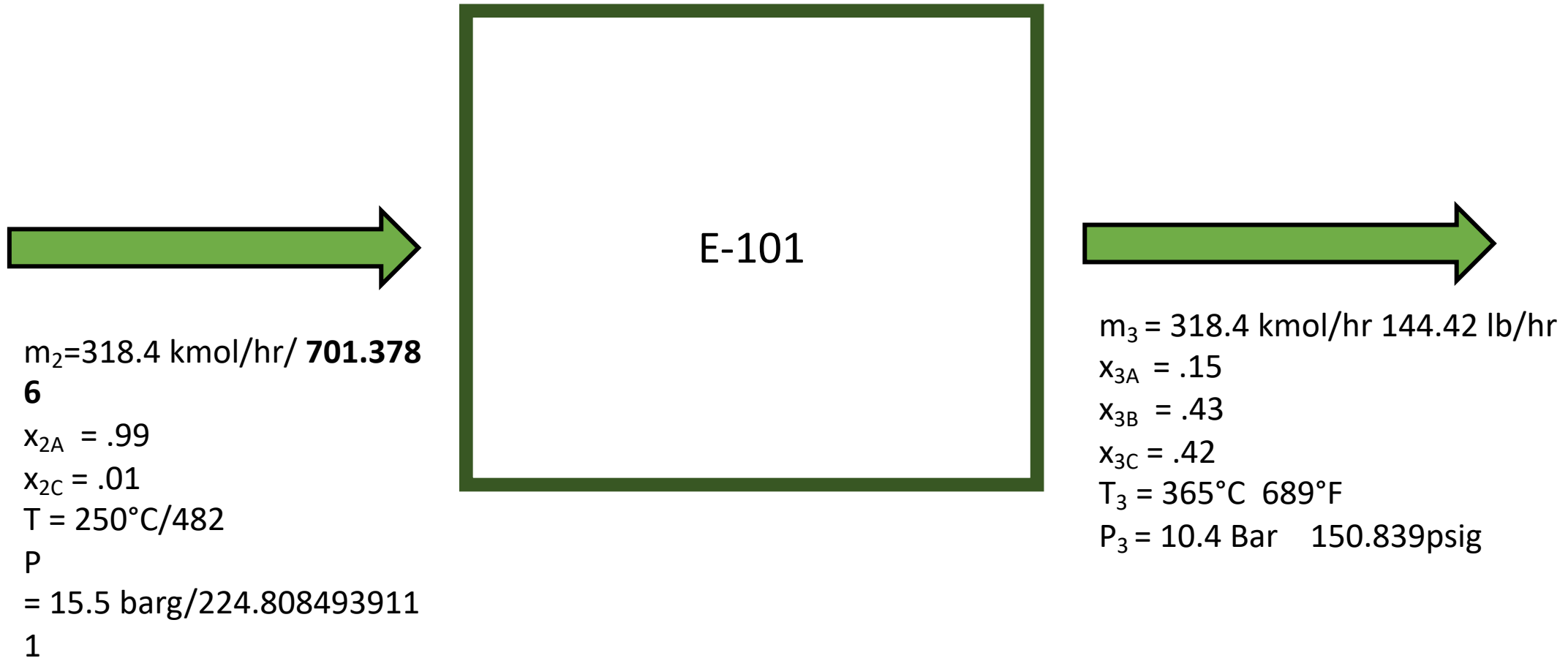


 Temperature, °F
 Pressure, psig

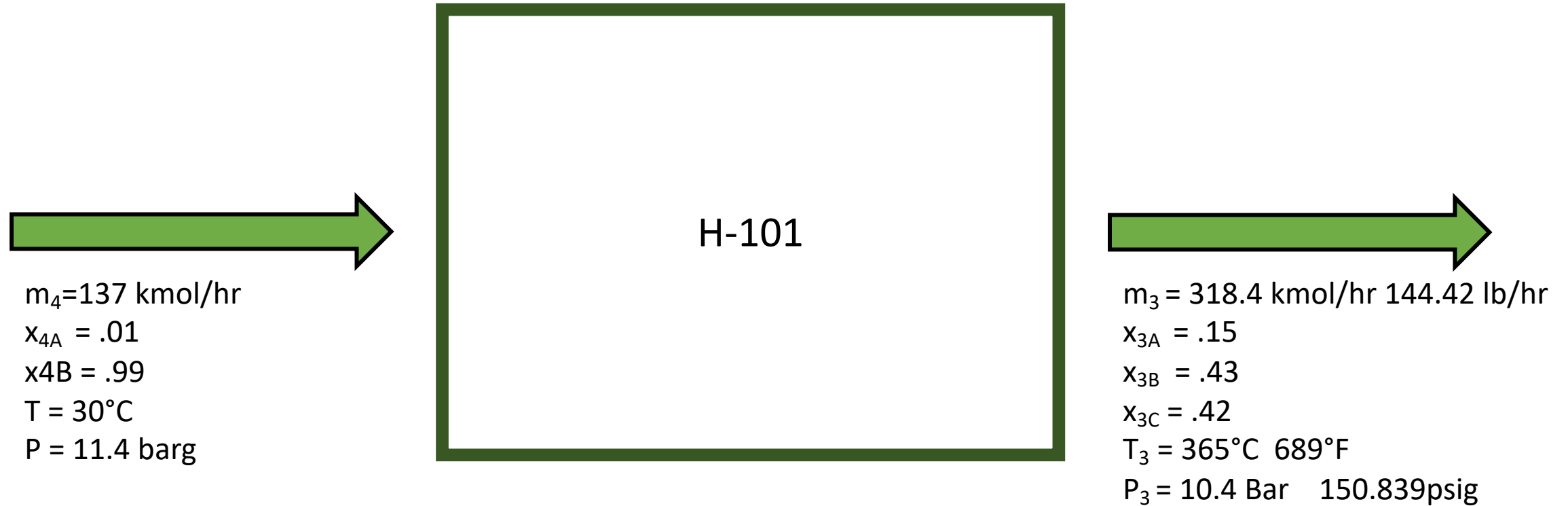
Pump Material Balance



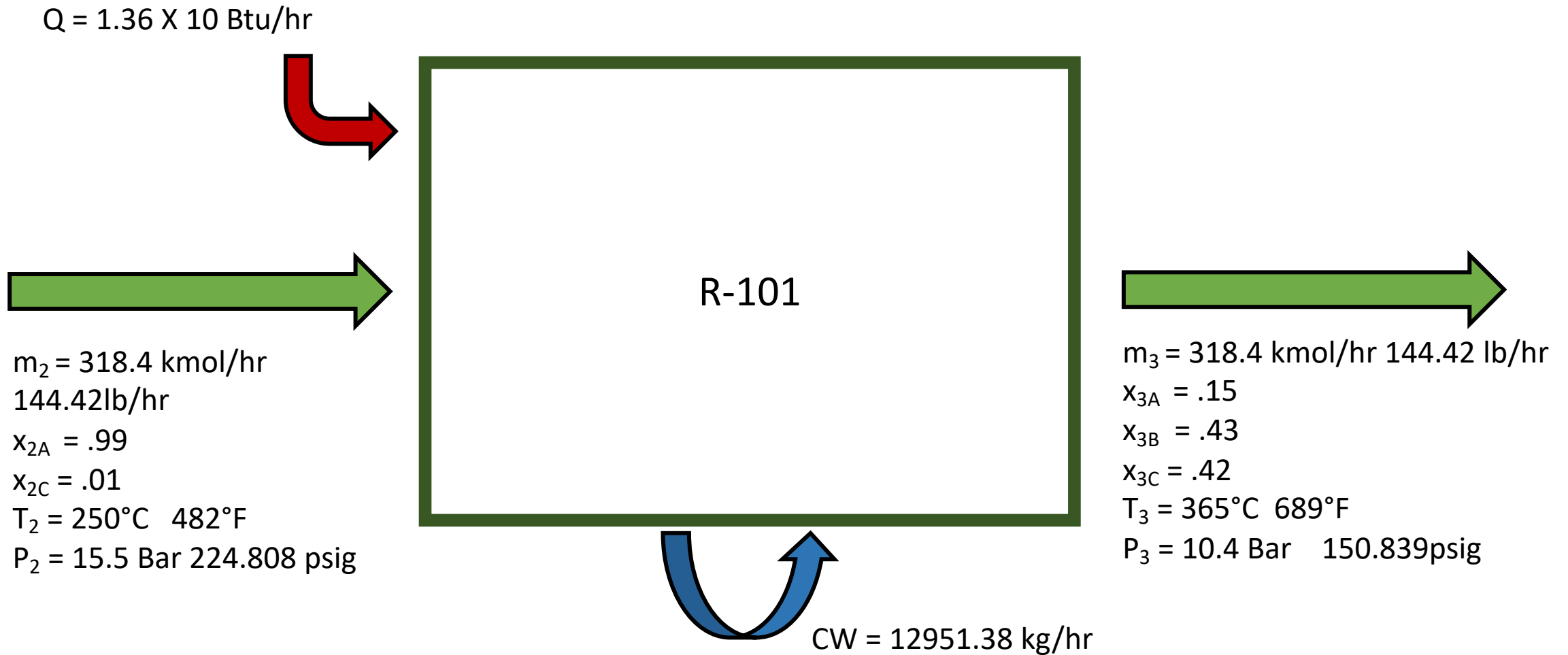
Vaporizer Material Balance



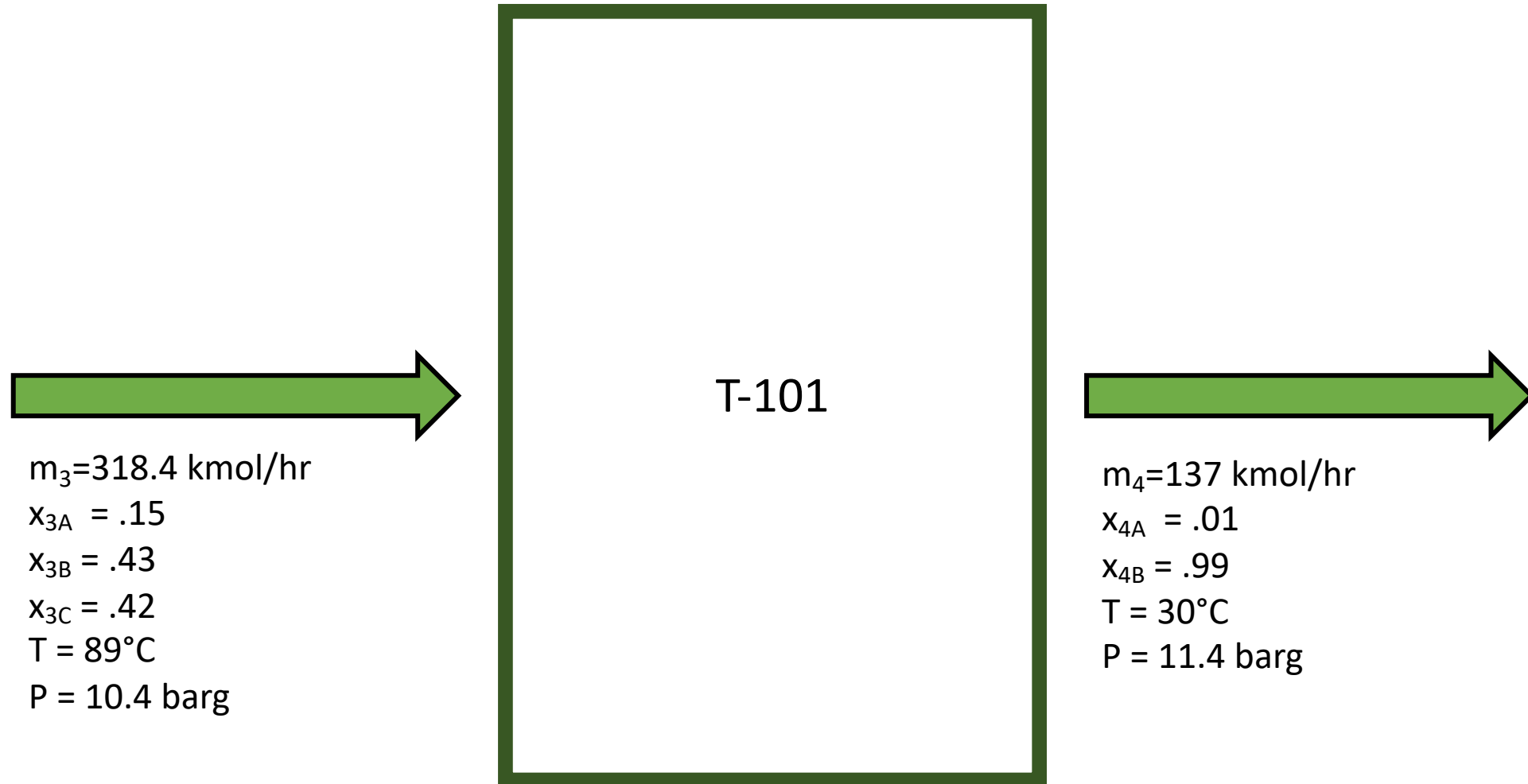
Furnance Material Balance



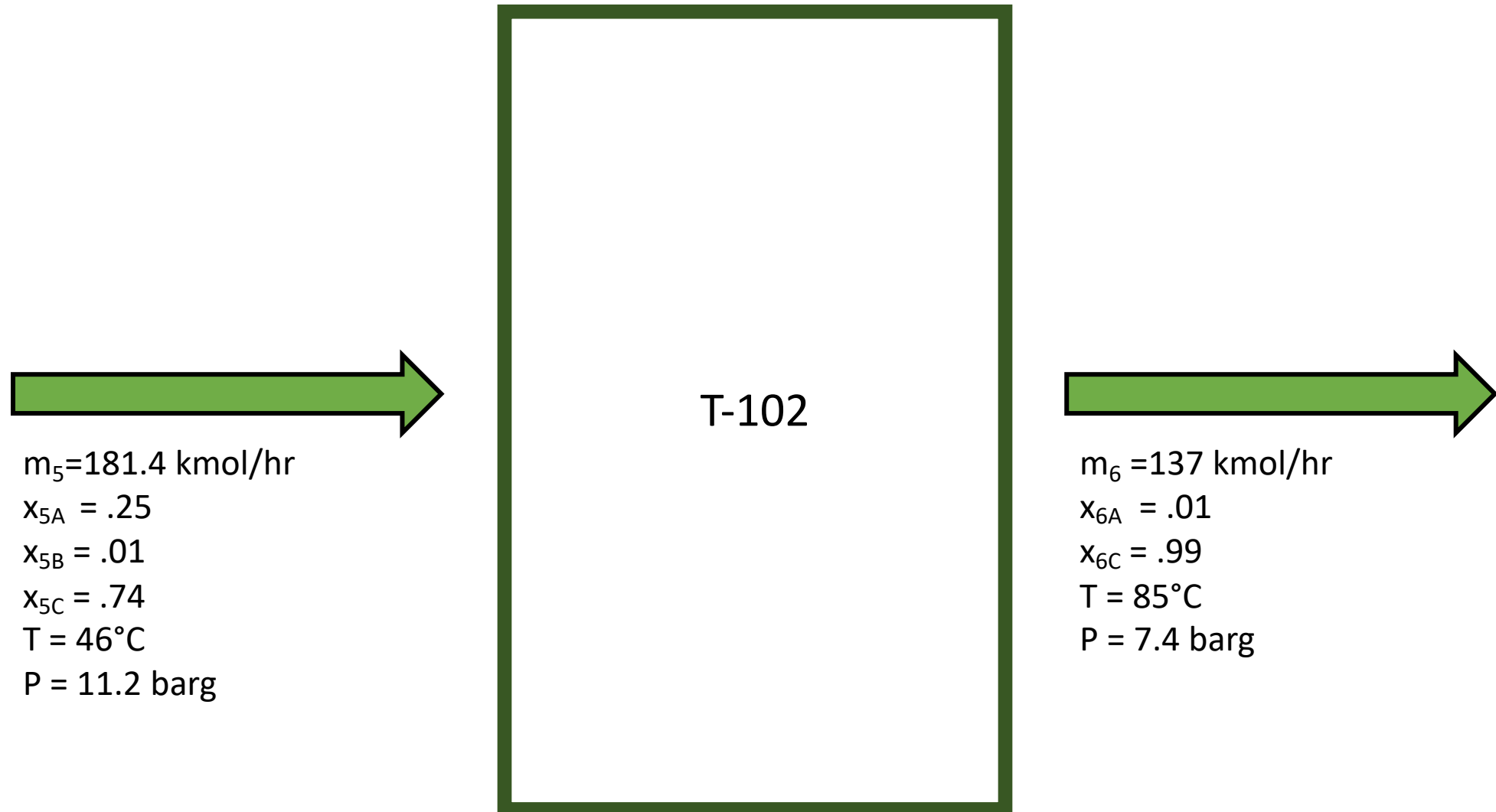
Dehydration Reactor Material Balance



1st Distillation Column Material Balance

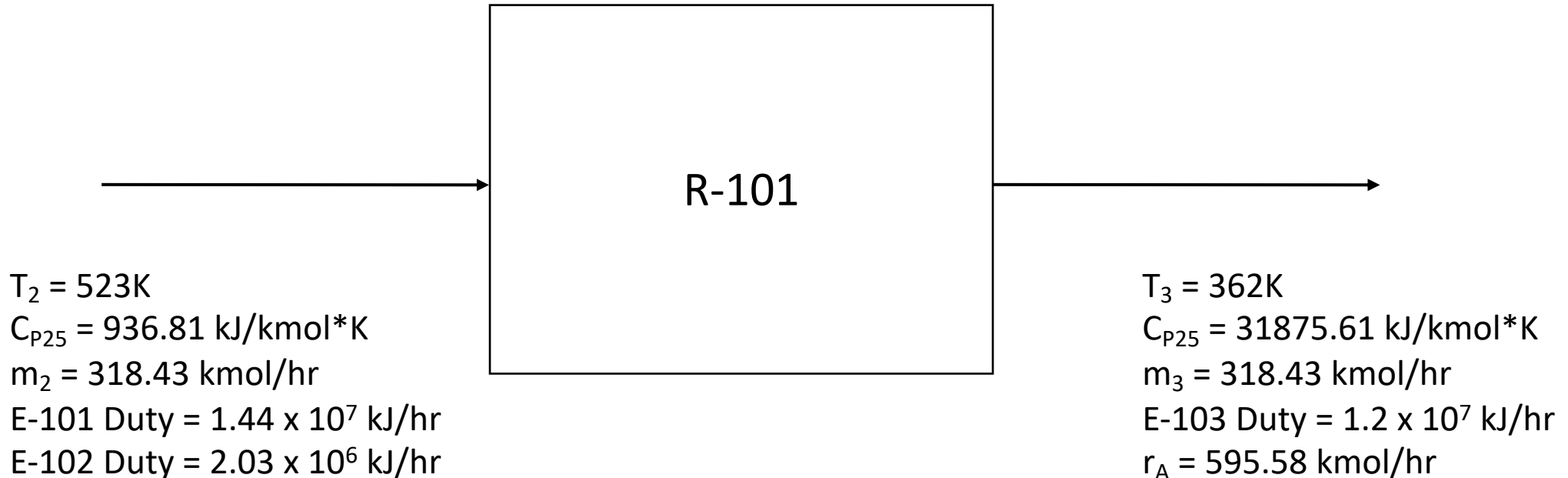


2nd Distillation Column Material Balance



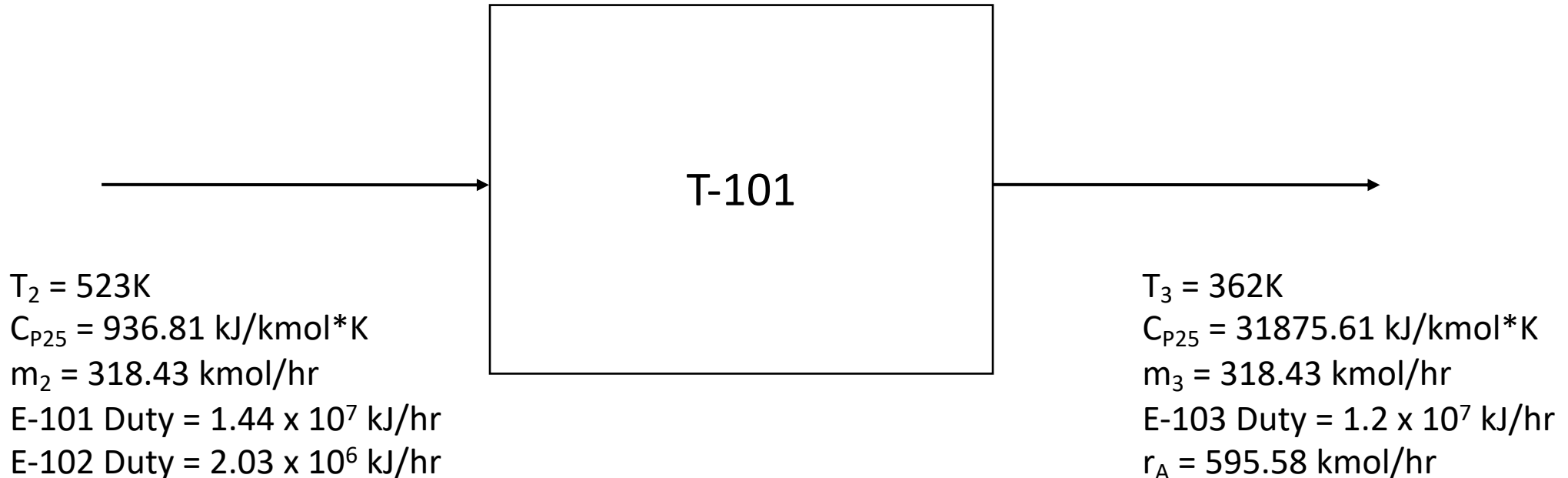
ENERGY BALANCE

$$\Delta H_{\text{RXN } 280} = -5.9 \times 10^6 \text{ kJ/kmol}$$



ENERGY BALANCE

$$\Delta H_{\text{RXN } 138} = -5.9 \times 10^6 \text{ kJ/kmol}$$



ENERGY BALANCE

Stream	1	2	3	4	5	6	7	8	9	10	11
Molar Enthalpy (kJ/kmol)	-238400	-238305	-201079	-200560	-164896	-198934	-234554	-179812	-239321	-280413	-233583
Mass Enthalpy (kJ/kg)	-7440.2	-7437.2	-6275.5	-6263.1	-3579.3	-6212.3	-7324.6	-3915.0	-12513.8	-15445	-7321.9
Molar Entropy (kJ/kmol*K)	-240.2	-239.9	-150.1	-148.6	-211.9	-120.2	-206.5	-244.2	-162.9	-148.7	-213.1
Mass Entropy (kJ/kg*K)	-7.5	-7.5	-4.7	-4.6	-4.6	-3.8	-6.4	-5.3	-7.6	-8.2	-6.7

R-101 Design Equations

$$\textcircled{1} \text{ Mole Balance: } F_{A0} \frac{dx}{dw} = -r'_A = \frac{\text{kg mol}}{\text{kg cat} \cdot \text{hr}}$$

$$\textcircled{2} \text{ Rate Law: } -r'_A = k C_A^2 = \frac{\text{kg mol}}{\text{kg cat} \cdot \text{hr}}$$

$$\textcircled{3} \text{ Stoichiometry: } C_A = \frac{C_{A0}(1-x)}{1+\epsilon x} \frac{P}{P_0} \frac{T_0}{T}, \quad \frac{P}{P_0} = p \quad (\text{pg. 169})$$

$$\begin{aligned} \frac{dp}{dw} &= -\frac{\alpha}{2p} (1+\epsilon x) \frac{T_0}{T} \\ \frac{T_0^2 p}{T} \frac{dp}{dw} &= -\alpha \\ \frac{T_0^2 p^2}{T} \frac{dp}{dw} &= -\alpha \quad (\text{pg. 174}) \end{aligned}$$

$$\textcircled{4} \text{ Combine: } \frac{dx}{dw} = \frac{k C_{A0}^2 (1-x)^2}{F_{A0} (1+\epsilon x)^2} \left(\frac{P}{P_0} \right)^2 \left(\frac{T_0}{T} \right)^2 = \text{kg cat}^{-1}$$

R-101 Design Equations

$$Q = UA\Delta T_{lm} f_r$$

$$Q = \dot{m} C_p \Delta T$$

$$T_{HIN} = 250^\circ\text{C}$$

$$T_{HOUT} = 305^\circ\text{C}$$

$$T_{CIN} = 30^\circ\text{C}$$

$$T_{COUT} = 45^\circ\text{C}$$

$$\dot{m} = 318.43 \text{ kmol/hr}$$

$$\dot{m} = 318430 \text{ mol/hr}$$

$$C_p = 110 \text{ J/mol K}$$

$$\Delta T = 305 - 250 = 115 + 273$$

$$= 388 \text{ K}$$

$$Q = \dot{m} C_p \Delta T$$

$$= 318430 \frac{\text{mol}}{\text{hr}} (110 \frac{\text{J}}{\text{mol K}}) (388 \text{ K})$$

$$Q = 1.433 \times 10^{10} \text{ J/hr}$$

$$U = 500 \text{ BTU/hr-ft}^2\text{ }^\circ\text{F}$$

$$\Delta T_{lm} = 204.7^\circ\text{C} \rightarrow 508.46^\circ\text{F}$$

$$f_r = 1.0$$

$$Q = 1.433 \times 10^{10} \text{ J/hr}$$

$$Q = 13582219.3 \text{ BTU/hr}$$

$$Q = UA\Delta T_{lm} f_r$$

$$A = \frac{Q}{U\Delta T_{lm} f_r}$$

$$= \frac{13582219.3 \text{ BTU/hr}}{(500 \frac{\text{BTU}}{\text{hr-ft}^2\text{ }^\circ\text{F}}) (508.46^\circ\text{F}) (1.0)}$$

$$A = 53.425 \text{ ft}^2$$

$$A = 4.963 \text{ m}^2$$

$$\text{Tubes: } A_T = \pi D L, n = A/A_T$$

$$D = 1.060 \text{ in} = 0.02667 \text{ m}$$

$$L = 14.477 \text{ ft} = 4.479 \text{ m}$$

$$A_T = (3.14) (0.02667 \text{ m}) (4.479 \text{ m})$$

$$A_T = 0.375 \text{ m}^2$$

$$n = \frac{A}{A_T} = \frac{4.963 \text{ m}^2}{0.375 \text{ m}^2}$$

$$n = 13.2 \approx 14 \text{ Tubes}$$

$$W = 24923 \text{ Kg cat}$$

$$1790.214 \text{ Kg cat per Tube}$$

$$\frac{Q}{A\Delta T_{lm} f_r} = U$$

$$\frac{13582219.3 \text{ BTU/hr}}{(107.039 \text{ ft})(508.46^\circ\text{F})(1)}$$

$$U = 249.167 \frac{\text{BTU}}{\text{hr-ft}^2\text{ }^\circ\text{F}}$$

$$U = 200 \frac{\text{BTU}}{\text{hr-ft}^2\text{ }^\circ\text{F}} \left(\begin{array}{l} \text{within} \\ \text{range} \end{array} \right)$$

$$A = \frac{13582219.3 \text{ BTU/hr}}{(200 \frac{\text{BTU}}{\text{hr-ft}^2\text{ }^\circ\text{F}}) (508.46^\circ\text{F}) (1.0)}$$

$$A = 133.56 \text{ ft}^2$$

$$A = 12.408 \text{ m}^2$$

T-101 Design Equations

Water: 100°C

$$N_{min} = \frac{\ln \left[\left(\frac{x_{1k}}{x_{2k}} \right)_D \left(\frac{x_{1k}}{x_{2k}} \right)_B \right]}{\ln \alpha_{1k}}; \alpha_{1k} \approx 9 \text{ (research)}$$

$$= \frac{\ln \left[\left(\frac{.99}{.01} \right) \left(\frac{.25}{.01} \right) \right]}{\ln(9)} = 3.5 \approx 4$$

R_{min} : $q = 0.0$ for saturated vapor (perry's 13-36)

$$1 - q = \sum_j \frac{\alpha_{1k} x_{1k,F}}{\alpha_{1k} - \phi} \quad \leftarrow \text{Underwood equation}$$

$$\alpha_{1k} - \phi = \alpha_{1k} x_{1k,F}$$

$$\phi = \alpha_{1k} - \alpha_{1k} x_{1k,F} = \alpha_{1k} (1 - x_{1k,F}) = 5.13 \quad \checkmark$$

Underwood constant
 $1 < \phi < \alpha_{1k}$

$$R_{min} = \sum_j \frac{\alpha_j x_{j,D}}{\alpha_j - \phi} - 1$$

$$= \frac{9 \cdot .99}{9 - 5.13} - 1 = 1.3$$

$$R/R_{min} = 1.2 - 1.3 \text{ (pg 235 in short cut design book)}$$

$$\therefore R = (R_{min})(1.3) = 1.7$$

$\leftarrow$ Gilliland correlation

Number of theoretical trays (pg 236 short cut book)

$$\frac{R - R_{min}}{R + 1} = \frac{1.7 - 1.3}{1.7 + 1} = .15 \quad \therefore \text{use chart on left}$$

$$@ .15, \quad \frac{N - N_{min}}{N + 1} = .45$$

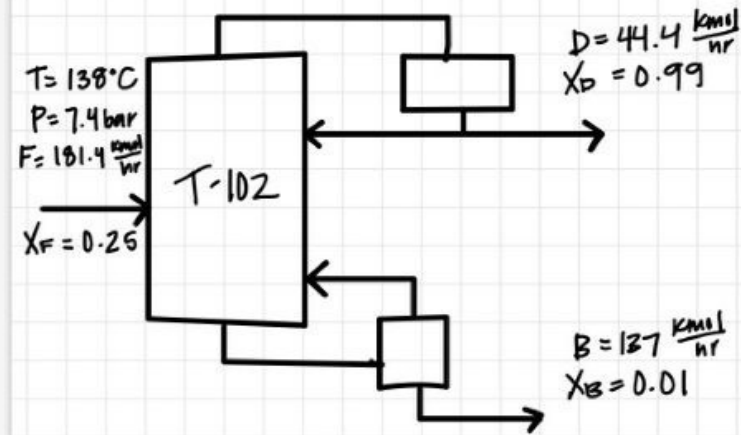
$$.45N + .45 = N - N_{min}$$

$$N_{min} + .45 = .55N$$

$$N = \frac{N_{min} + .45}{.55} = \frac{4.45}{.55} = 8.09 \approx 9$$

$$N/N_{min} = 1.8 - 2.5 = 8/4 = 2.25 \quad \checkmark$$

T-102 Design Equations



Rectifying

$$y_{N+1} = \frac{R}{R+1} X_N + \frac{X_D}{R+1}$$

$$y_{N+1} = \frac{4.472}{4.472+1} X_N + \frac{0.99}{4.472+1}$$

$$y_{N+1} = 0.817 X_N + 0.181$$

↳ rectifying operating line

Stripping

Feed: $X_F = 0.25$

$T = 411 \text{ K}$

$P = 7.4 \text{ bar}$

$$y = \frac{q}{q-1} X - \frac{X_F}{q-1} ; q = \frac{H_V - H_F}{H_V - H_L}$$

$$u = \frac{0.05}{0.05-1} X - \frac{0.25}{0.05-1} \rightarrow y = -0.05 X + 0.24$$

↳ stripping operating line

q-line

$$q = \frac{H_V - H_F}{H_V - H_L} = \frac{2704.24 - 2053.42}{2704.24 - 700.885}$$

$q = 0.05$

Interpolate

$$\begin{aligned} H_L &= 703.241 & y_1 &= 703.241 & y_2 &= 709.301 \\ X_1 &= 725 \text{ KPa} & X_2 &= 750 \text{ KPa} \end{aligned}$$

$$y = 703.241 + (740 - 725) \left(\frac{709.301 - 703.241}{750 - 725} \right)$$

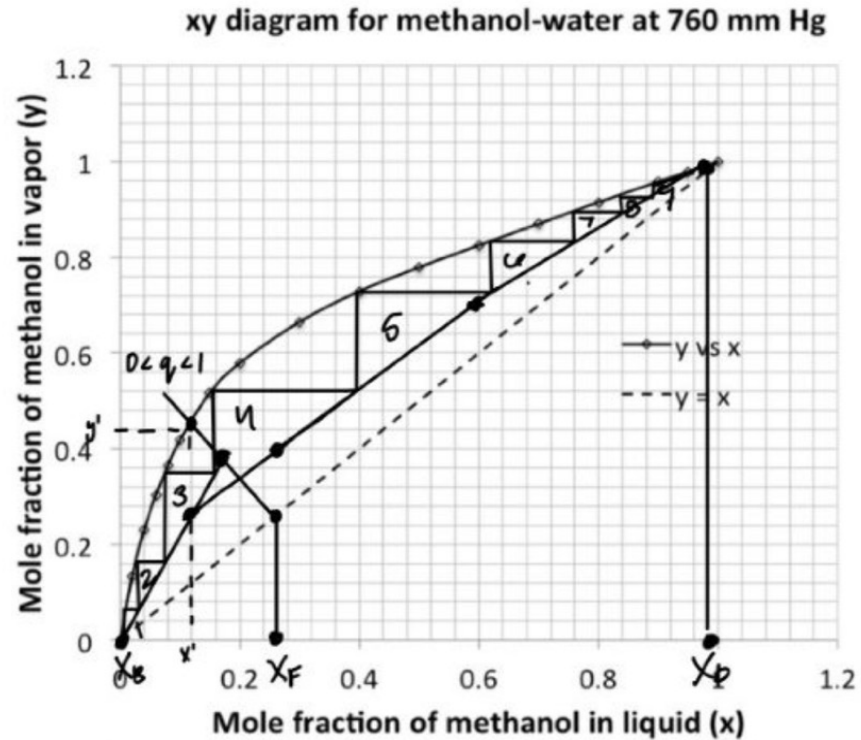
$$H_L = 700.885 \text{ kJ/kg}$$

$$\begin{aligned} H_V &= 2703.4 & y_1 &= 2703.4 & y_2 &= 2704.8 \\ X_1 &= 725 \text{ KPa} & X_2 &= 750 \text{ KPa} \end{aligned}$$

$$H_V = 2704.24 \text{ kJ/kg}$$

$$H_F = 2053.42 \text{ kJ/kg}$$

T-102 Design Equations



$$x' = 0.1$$

$$y' = 0.3$$

$$\text{SDL: } y = -0.05x + 0.26$$

$$\text{ROL: } y_{n+1} = 0.917x_n + 0.191$$

$$9 + 1 = \underline{10 \text{ stages}}$$

Minimum Reflux Ratio

$$\frac{R_m}{R_m + 1} = \frac{x_D - y'}{x_D - x'} \xrightarrow{\text{pinch point}} \frac{0.99 - 0.3}{0.99 - 0.1} = 0.775$$

$$\frac{R_m}{R_m + 1} = 0.775 \rightarrow R_m = 0.775R_m + 0.776 \rightarrow 0.225R_m = 0.775 \rightarrow \underline{R_m = 3.44}$$

Reflux Ratio

$$1.3 = \frac{R}{R_{\min}}$$

$$\underline{R = 4.472}$$

EPA & OSHA Regulations

OSHA (Methanol)

- The sampling group
- The sampling time at 60 min.
- The sampling volume at 3 L or 5L when humidity is greater than 50%

EPA (Methanol)

- Occupational exposure through inhalation.
- Exposure through the ambient air from its evaporation during solvent uses.
- Acute effects by inhalation and/or ingestion resulting in blurry vision and disorientation.
- Chronic effects including insomnia, elevated levels of liver enzymes and decreased brain weight.

EPA (DME)

- Tolerance exemptions that are associated with Dimethyl Ether (DME)
- Regulations of the emission standards associated with DME



Total Capital Investment

Direct Costs	
Purchased equipment, E'	1.496
Delivery, fraction of E'	0.150
Subtotal: delivered equipment	1.646
Purchased equipment installation	0.773
Instrumentation&Controls(installed)	0.592
Piping (installed)	1.119
Electrical systems (installed)	0.181
Buildings (including services)	0.296
Yard improvements	0.165
Service facilities (installed)	1.152
Total direct costs	5.924
Indirect Costs	
Engineering and supervision	0.543
Construction expenses	0.675
Legal expenses	0.066
Contractor's fee	0.362
Contingency	0.724
Total indirect costs	2.370
Fixed capital investment (FCI)	8.294
Working capital (WC)	1.465
Total capital investment (TCI)	9.758

Utilities

Steam		
LPS	MPS	HPS
\$1.16MM	\$.355MM	\$.392MM
TOTAL		\$1.91MM/yr

Cooling Water	
Amount Required, ft ³ /yr	9.92 x 10 ⁶
TOTAL	\$14,000/yr

Electricity	
Amount Required, kWh/yr	1.06 x 10 ⁵
TOTAL	\$5,000/yr

Wastewater Disposal	
Amount Required, ft ³ /yr	7.03 x 10 ⁵
TOTAL	\$11,000/yr

Refrigerant, r140a	
Amount Required, BTU/yr	4.10 x 10 ⁸
TOTAL	\$5,000/yr

Materials & Labor

Raw Materials		
Name of Material	Price, \$/lb	Annual Amount MM kg/year
Methanol	.16	~71
TOTAL		\$25.28MM/yr

Labor		
Number of Operators per Shift	Shifts Per Day	Operator Rate, \$/hr
3	3	34
TOTAL		~\$1MM/yr

Product		
Name of Material	Price, \$/lb	Annual Amount MM kg/year
DME	.41	50
TOTAL		\$45MM/yr

EMISSIONS

- The use of DME reduces carbon emissions by an average of 25%.
- DME synthesis from methanol is a low carbon footprint process.
- The total final emissions are negative at an estimate of **-39 ktCO₂eq per year**

Process stream	Units	Value
Methanol	KgCO _{2eq} /t	-1643
Wastewater	KgCO _{2eq} /t	500

ASPEN STREAM TABLES

Stream	Methanol	Recycle*	DME + Methanol + Water	Methanol + Water	DME	Recycle	Water
Mole Flows kmol/hr	274	44.4	318.4	177.13	141.27	34.72	142.01
Mass Flows kg/hr	8779.55	1416.44	10196	3687.81	6508.18	1117.85	2569.96

