

BINDER FOR OUTCOME "7"

"An ability to acquire and apply new knowledge as needed, using appropriate learning strategies"

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

**BINDER CONTAINING REPRESENTATIVE
ASSIGNMENTS FROM ALL COURSES USED TO
ASSESS OUTCOME "7"**

Last 4 Academic Years

09/15/2022 Revision

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 - CHEG 3023 Unit Operations**
 - CHEG 4472 Senior Design and Professionalism-I**

2. Description of Outcome "7" and its Performance Criteria

Outcome 7:

An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Sub-Outcomes and Performance Criteria

- 7.1: Acquire new knowledge using the appropriate learning strategies
- 7.2: Apply new knowledge to solve problems

3. List of Courses Used to Assess the Outcome

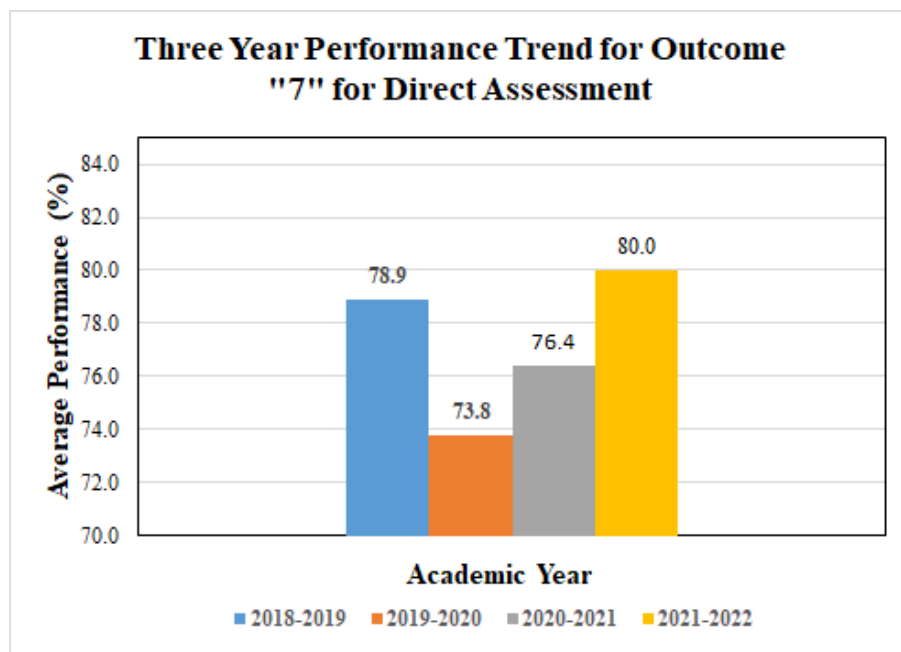
Outcome 7 is assessed in the following courses:

CHEG 3023 Unit Operations

CHEG 4472 Senior Design and Professionalism-I

4. Summary Assessment Results and Continuous Improvements for Outcome "7" over the Assessment Years.

The average performance for all students in the 2 courses used to assess outcome 7 for the past four academic years are shown below



Problems identified and recommended actions to be taken to address problems

1. At the course level

Problems Identified in the Various Courses	Recommended Actions to be Taken	Basis for Action
1. Students faced trouble to conceptualize, identify the appropriate laws, in order to analyze a problem. 2. They have problems extending their knowledge from examples that they have seen before to new problems. 3. Students knowledge did not have the required breadth in some subjects.	1. Tutor and grader help are suggested. 2. More hands on/laboratory projects related to junior-level courses can help them better understand non-intuitive engineering concepts. 3. Graded homework assignments should be given early in the semester, with an emphasis on the societal and engineering impacts of a process so that the students can think beyond what they are given in an engineering textbook.	The students' performance average for Outcome 7 in the last academic cycle (2019-2020) and aggregate percentage of students meeting the expected average in the last three academic cycles were below the set targets

2. At Department Level

(1) Faculty members in the program met periodically to review data from the Program Outcome Assessment Reports. The weak areas of outcomes performance were identified. Perceived problems were discussed in this forum. Faculty were provided with the data collected from student exit surveys for their review, as well as input from the Industrial Advisory Council (IAC).

(2) An additional program-level action that resulted from faculty consideration of exit survey findings to address teaching quality is the introduction of teaching observation of an instructor by fellow department colleagues

Basis of Action:

The aggregate percentage of students meeting the expected average in the last three academic cycles were below the set targets.

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

CHEG 3023 Unit Operations

CHEG 4472 Senior Design and Professionalism-I

**OUTCOME “7” SPECIFIC ASSIGNMENTS
USED TO ASSESS THE OUTCOME IN**

**UNIT OPERATIONS
FALL 2019**

**CHEMICAL ENGINEERING
OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET
CHEG 3023 UNIT OPERATIONS
FALL 2020**

Instructor: Dr. Keisha Antoine

Title of Assignment

T2-Understanding Bernoulli Principle 11/19/2020

Outcome Measured Using this Assignment

Outcome 7

An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Check the outcome characteristics related to this assignment

Ability to Acquire new knowledge using the appropriate learning strategies Requires students to:	
x	Be knowledgeable of and use different learning strategies (<i>Instructor may provide information on different learning strategies</i>)
x	Identify and take advantage of learning opportunities available in the library, online resources, seminars, webinars, conferences, workshops and tutorials.
x	Be aware of the need for and are able to independently acquire additional knowledge and data needed for solving problem using appropriate learning strategies and tools.
Ability to apply new knowledge to solve problems Requires students to:	
x	Demonstrate appropriate use of the new knowledge to solve problems.

Brief justification of why this assignment is suitable for this outcome

This assignment allows the students to gain fundamental understanding of the Bernoulli Principle across pipes, fittings and a centrifugal pump by deriving final equation forms.

CHEG 3023 Y02 T2-Understanding Bernoulli Principle-11/19/2020

Instructions

Groups will be assigned. Max of 5 students per group. Turn in group assignment on November 16, 2020.

Objective

In this assignment, students will study the principle of mechanical energy conservation (Bernoulli Principle) using Edibon PBCC Centrifugal Pump and the Venturi meter located on the Edibon AFT-B Fluid Friction in Pipes Equipment.

Edibon PBCC Centrifugal Pump

The program measures pump speed in rpm, pressure at the suction, $P_{suction}$ (bar), pressure at the discharge, $P_{discharge}$ (bar), torque, M (N.m), flow rate, Q (L/min), total head, H_t (m), mechanical energy of the pump, W_p . Disregard the values for pressures that the program records in carrying out these exercises.



Resources

- UOCE, 7th Ed., Chapter 4, Mechanical Energy Equation (pp 86 – 94), Ex. 4.6, Prob. 4.4; Chapter 8, Centrifugal Pumps (pp 208 – 209), Ideal Pump (pp 210), Actual pump performance (211 – 212), Ex. 8.1
- Chapter 4c class notes (available on eCourses)

Instructions

- Data have been provided for you for your use in completing the exercises. Please see data packet.
- You will first determine the pressure drop developed by the pump for various volumetric flow rates. This step is required to answer question 3 of the Exercises.
 - The experiment was run using the Edibon PBCC in Gilchrist Room 127.
 - The experiment was conducted for various openings of the discharge valve (a minimum of 4 readings of the volumetric flow rate, Q). The data was recorded for use in Exercise 3.

Exercises

- Using Bernoulli's principle,
 - Estimate the velocity of discharge of the tank. [25 points]
 - Estimate the time to completely empty the tank. Diameter of discharge tube from tank is equal to the diameter of the pipe feeding to the tank. [25 points]

State your assumptions.

- Use Bernoulli's principle to derive total head, H_t in meters. [20 points]

- Assuming the value of H_t measured by the software is correct and using a to represent the suction point and b to represent the discharge point, calculate the pressure developed by the pump, ΔP . State your assumptions. [50 points]

Venturi meter in Edibon AFT-B Fluid Friction in Pipes

$D_{pipe} = 26.5$ mm

Resources

- UOCE, 7th Ed., Chapter 4, Mechanical Energy Equation (pp 86 – 94); Chapter 8, Venturi Meter (pp 225 – 227)
- Chapter 4c class notes (available on eCourses)

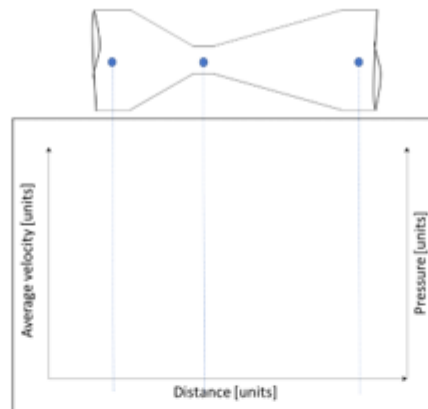
Instructions

- Data have been provided for you for your use in completing the exercises. Please see data packet.
- The pressures for the entrance, throat and downstream tap were measured for 4 readings of volumetric flow rate (replicates were taken of each data point)
 - Calculate the pressure drops (see data packet for AFT-B Venturi tab) [20 points]

Flow rate, Q [units?]	$P_{entrance}$ [units?]	P_{throat} [units?]	ΔP (entrance→throat) [units?]	P_{exit} [units?]	ΔP (entrance→exit) [units?]

Exercises

- How does the pressure vary with distance in the venturi meter as the flow moves from the large diameter to the small diameter? From the small diameter to the large diameter? Show the variation of pressure vs. distance in the flow direction on a graph. [20 points]
- How does the velocity vary with distance in the venturi meter as the flow moves from the large diameter to the small diameter? From the small diameter to the large diameter? Show the variation of average velocity vs. distance in the flow direction on a graph. [20 points]



3. Use the Bernoulli equation to explain the graphs of pressure and velocity vs. distance in going from:
 - a. Entrance to throat [10 points]
 - b. Throat to exit [10 points]Assume no frictional losses.
4. The pressure loss between the two ends of the venturi meter should be far less than the pressure drop between the entrance and throat of the venturi. Explain why this is the case. [10 points]
5. Find the diameter of the throat. [25 points]
6. Describe how venturi meters are used in industry [10 points]

Sample of student's graded solution

236/245



Course Name: CHEG 3023 - Unit Operations

Group Members

Anh Nguyen

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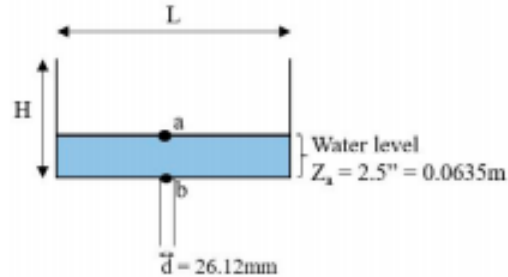
Instructor: Dr. K. Antoine

Test 2 - Understanding Bernoulli Principle

Edibon PBCC Centrifugal Pump

1. Assumptions:

- Datum level is at the point of discharge, $Z_b = 0$.
- Both pressures at point a and b are at atmospheric pressure (1.01325×10^5 Pa).
- Surface area of the tank is a lot larger than the area of the discharge pipe; therefore the velocity of point a u_a is negligible, $u_a \approx 0$.
- Density of water $\rho = 1000 \text{ kg/m}^3$; nearly incompressible.



- a, The elevation of water is point a, $Z = 2.5'' = 0.0635\text{m}$.
Discharge velocity $u_b = 1.12 \text{ m/s}$.

- b. Tank is full, which has the height: $H_0 = 11.75'' = 0.29845\text{m}$.
Time required to empty the tank is $t = 1.88 \text{ min}$

Bernoulli with Wp and hf 8/10
Sketch 10/10
Choice of a and b 5/5
Simplifying assumptions 5/5
Appropriate final equation to solve 6/6, 6/6
Correct values for variables 3/3, 2/3
Correct ans 1/1, 1/1

2. $H_t = \eta W_p = \frac{P_a - P_b}{\rho g} \text{ (m)}$

3. Assumptions:

- Point a: suction point, point b: discharge point.
- Friction loss (h_f) is negligible because we are at two points across the pump, so any friction loss is taken care of by the efficiency of the pump.
- Contribution of kinetic energy is small compared to pressure term.
- Elevation between point a and b is negligible.
- Density of water $\rho = 1000 \text{ kg/m}^3$; nearly incompressible

Result: Pressure developed ΔP

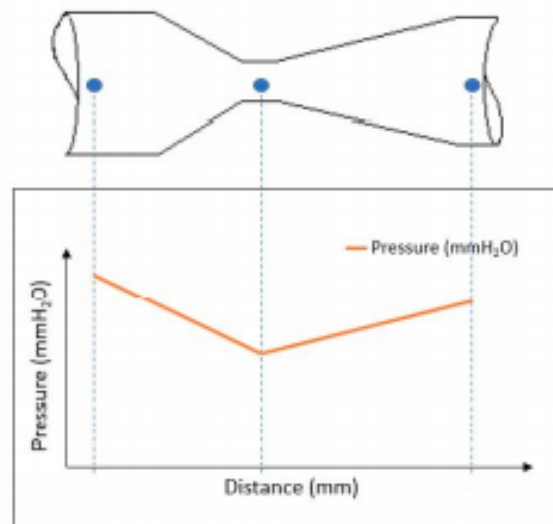
- Fully open: $91 \text{ kPa} = 0.91 \text{ bar}$
- 25% closed: $97.4 \text{ kPa} = 0.974 \text{ bar}$
- 50% closed: $111.4 \text{ kPa} = 1.114 \text{ bar}$
- 75% closed: $131.2 \text{ kPa} = 1.312 \text{ bar}$
- Fully closed: $209.2 \text{ kPa} = 2.092 \text{ bar}$

Venturi meter in Edibon AFT-B Fluid Friction in Pipes

Table:

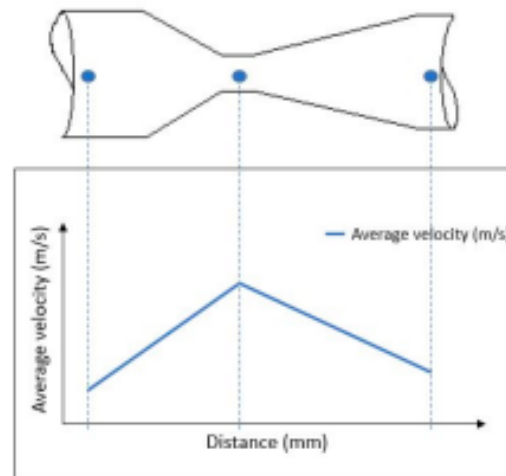
Flow rate Q (L/h)	P_{entrance} (mmH ₂ O)	P_{throat} (mmH ₂ O)	$\Delta P_{\text{entrance-throat}}$ (mmH ₂ O)	P_{exit} (mmH ₂ O)	$\Delta P_{\text{entrance-exit}}$ (mmH ₂ O)
1800	180	98	82 ¹⁰	175	5 ¹⁰
2000	218	130	88	205	13
2600	305	170	135	280	25
3000	368	198	170	330	38

1. Pressure vs. Distance: As the flow moves from the large diameter to the small diameter, the pressure drops. As the flow moves from the small diameter to the larger one, the pressure increases.



20/20

2. Average velocity vs. Distance: As the flow moves from the large diameter to the small diameter, the average velocity increases. As the flow moves from the small diameter to the larger one, the average velocity decreases.



20/20

3. Equations:

Bernoulli equation expresses the relation between the rate of flow velocity and the pressure and the greater the fluid flow speed within the lower pressure.

$$\frac{P_1}{\rho g} + h_1 + \frac{v_1^2}{2g} = \frac{P_2}{\rho g} + h_2 + \frac{v_2^2}{2g}$$

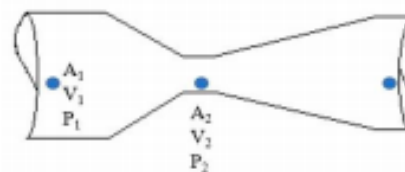
$$\text{In venturi meter specifically, } h_1 = h_2 \Rightarrow \frac{P_1}{\rho g} + \frac{v_1^2}{2g} = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} \Rightarrow v_2^2 - v_1^2 = \frac{2(P_1 - P_2)}{\rho g} \quad (1)$$

$$\text{Flow rate: } Q = v_1 A_1 = v_2 A_2$$

a: From entrance to throat: Flow rate is constant from the entrance to the throat, and the area of the throat, A_2 , is smaller than the area of the entrance, A_1 ($A_2 < A_1$). Therefore, the velocity at throat v_2 is larger than the velocity at entrance v_1 ($v_2 > v_1$). Through Bernoulli's equation, we see that $v_2 > v_1$ (left side of equation 1 is positive), so $P_1 > P_2$, which means pressure at the throat is smaller than pressure at the entrance. Thus, as it's flowing from the entrance to the throat, the pressure is decreasing while the average velocity is increasing.

8/10

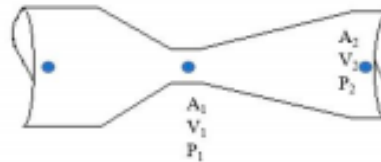
yes, but need to mention explicitly that this behavior shows conservation of total energy



$$b: A_2 < A_1 \Rightarrow v_1 > v_2 \Rightarrow P_1 < P_2$$

From throat to exit: The upstream area (A_1) is smaller therefore the downstream area (A_2) is bigger ($A_1 < A_2$), so velocity at the throat v_1 is greater than velocity at the exit v_2 . Using Bernoulli's equation, we see that $v_1 > v_2$ (left side of equation 1 is negative), so $P_1 < P_2$, which means pressure at the throat is smaller than the pressure at the exit. Thus, as it's flowing from the throat to the exit, the pressure is increasing while the average velocity is decreasing.

8/10



4. The pressure drop between the entrance and the exit will be much smaller than the pressure drop between the entrance and the throat because the average velocities of the entrance and the exit are closer than the average velocities of the entrance and the throat, which would make the pressure difference between the entrance and the exit much smaller than the pressure difference between the entrance and the throat. Shortly, using Bernoulli equation, the change in velocity between the entrance and exit is small, so the pressure drop is small while the change in velocity between the entrance and throat is large making the pressure drop large. Also, the pressure drop between entrance and exit is small because the venturi meter is designed to recover as much energy as possible of the fluid.

8/10

5. Throat diameter: $d = 20.745\text{mm}$

6. Venturi meters are flow measuring instruments which are able to use a converging section of a pipe to increase and measure the flow in velocity of a corresponding pressure drop, from which flow rates can be deduced. The most common use of venturi meters can be found in processing units and the water supply, oil, and paper and pulp industry. For example, in the water supply industry, venturi meters are used to reduce the pressure drop during transportation and to save cost. When using a venturi meter during transportation, the velocity of water is increased and pressure is decreased at the throat. Then pressure is mostly recovered from its initial pressure to consumers. Fuel injectors and jet pumps also play a role with the venturi effect. As the fluid with the high speed enters the smaller cross-section, it begins to create a vacuum and gives momentum to the other fluids.

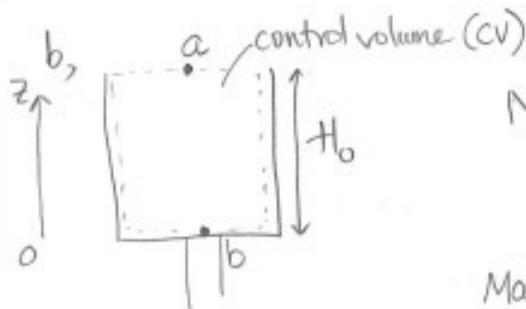
10/10

Pump

1. $a, \frac{p_a}{\rho} + gz_a + \frac{u_a^2}{2} = \frac{p_b}{\rho} + gz_b + \frac{u_b^2}{2}$ missing eff. Wp, hf

$$\Rightarrow u_b = \sqrt{2gz_a} = \sqrt{2(9.8 \text{ m/s}^2) \left(2.5 \text{ in} \times \frac{1 \text{ m}}{39.37 \text{ in}} \right)}$$

$$= 1.1156 \text{ m/s} \approx \boxed{1.12 \text{ m/s}}$$



No mass enters the control volume, $\dot{m}_{in} = 0$

$$\dot{m}_{in} - \dot{m}_{out} = \frac{dm_{cv}}{dt}$$

Mass leaving the tank through a pipe,

$$\dot{m}_{out} = \rho u_b A_{pipe} \text{ with } u_b = \sqrt{2gz_a}$$

$$A_{pipe} = \frac{\pi d^2}{4}$$

$$\Rightarrow \dot{m}_{out} = \rho \frac{\pi d^2}{4} \sqrt{2gz_a}$$

Mass of water in the tank at any time

$$m_{cv} = \rho V = \rho W L z_a \text{ with } W \text{ is width, } L \text{ is length}$$

As amount of water leaving the tank, only z_a is changing

$$\Rightarrow \frac{dm_{cv}}{dt} = \frac{d(\rho W L z_a)}{dt} = \rho W L \frac{dz_a}{dt}$$

$$-\dot{m}_{out} = \frac{dm_{cv}}{dt}$$

$$\Rightarrow -\rho \frac{\pi d^2}{4} \sqrt{2g z_a} = \rho W L \frac{dz_a}{dt}$$

$$\Rightarrow dt = \left(\frac{-4WL}{\pi d^2 \sqrt{2g}} \cdot \frac{1}{\sqrt{z_a}} \right) dz_a$$

Boundary Condition : $t=0, z_a=H_0$
 $t=t, z_a=0$

$$\text{Integration } t = -\frac{4WL}{\pi d^2 \sqrt{2g}} \int_{H_0}^0 z_a^{-1/2} dz_a$$

$$= -\frac{8WL\sqrt{z_a}}{\pi d^2 \sqrt{2g}} \Big|_{H_0}^0$$

$$= \frac{8WL\sqrt{H_0}}{\pi d^2 \sqrt{2g}}$$

$H=2.5 \text{ in}$

$$\left\{ \begin{array}{l} W = 15.5 \text{ in} \times \frac{1 \text{ m}}{39.37 \text{ in}} = 0.3937 \text{ m} \\ H = 11.75 \text{ in} \times \frac{1 \text{ m}}{39.37 \text{ in}} = 0.29845 \text{ m} \\ L = 24.5 \text{ in} \times \frac{1 \text{ m}}{39.37 \text{ in}} = 0.6223 \text{ m} \end{array} \right.$$

$$= \frac{8(0.3937 \text{ m})(0.6223 \text{ m})\sqrt{0.29845 \text{ m}}}{\pi (0.02612 \text{ m})^2 \sqrt{2(9.8 \text{ m/s}^2)}}$$

$$= 112.84 \text{ s} = \boxed{1.88 \text{ min}}$$

2.

- Bernoulli's Principle is applied to the passage of fluid within a control volume. Relates to the pressure, velocity, and height in fluid flow given at two points.

- Work performed on the fluid by centrifugal pump with discharge and suction point



Bernoulli with W_p and h_f 10/10
Simplifying assumptions 5/5
Appropriate final equation to solve 5/5

Mechanical energy balance equation

$$\frac{P_a}{\rho g} + \frac{v_a^2}{2g} + z_a + \eta W_p = \frac{P_b}{\rho g} + \frac{v_b^2}{2g} + z_b + h_f$$

$$\Rightarrow \eta W_p = \left(\frac{P_b}{\rho g} + \frac{v_b^2}{2g} + z_b \right) - \left(\frac{P_a}{\rho g} + \frac{v_a^2}{2g} + z_a \right) + h_f$$

$$\text{Head at suction: } H_{\text{suction}} = \frac{P_a}{\rho g} + \frac{v_a^2}{2g} + z_a$$

$$\text{Head at discharge: } H_{\text{discharge}} = \frac{P_b}{\rho g} + \frac{v_b^2}{2g} + z_b$$

$$\begin{aligned} \text{Total head: } H_t &= H_{\text{discharge}} - H_{\text{suction}} + h_f \\ &= \left(\frac{P_b}{\rho g} + \frac{v_b^2}{2g} + z_b \right) - \left(\frac{P_a}{\rho g} + \frac{v_a^2}{2g} + z_a \right) + h_f \end{aligned}$$

$$\Rightarrow \eta W_p = H_t$$

In case choosing a and b in the diagram:

$$+ z_a \approx z_b \Rightarrow z_a - z_b = 0$$

+ friction loss is taken care of by the pump efficiency, $h_f = 0$

+ kinetic energy term is small compared to pressure term

$$\Rightarrow H_t = \eta W_p = \frac{P_b - P_a}{\rho g} [=] \text{ m}$$

3. $\Delta P = \rho g H_t$

* Fully open: $H_{t, \text{avg}} = \frac{4.181557 + 9.361162 + 9.292306 + 9.317305}{4}$

Sketch 10/10

Choice of a and b 5/5

Simplifying assumptions 10/10

Head calculation 25/25

$$= 9.288 \text{ m}$$

$$\Delta P = \rho g H_t = (1000 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(9.288 \text{ m})$$

$$= 91,022 \text{ kg/m.s}^2$$

$$= \boxed{91 \text{ kPa}}$$

Similarly, 25% closed: $H_{t, \text{avg}} = 9.942 \text{ m}$

$$\Delta P = (1000 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(9.942 \text{ m}) = 97,432 \text{ kg/m.s}^2 = \boxed{97.4 \text{ kPa}}$$

50% closed: $H_{t, \text{avg}} = 11.3676 \text{ m}$

$$\Delta P = (1000 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(11.3676 \text{ m}) = 111,402 \text{ kg/m.s}^2 = \boxed{111.4 \text{ kPa}}$$

75% closed: $H_{t, \text{avg}} = 13.3855 \text{ m}$

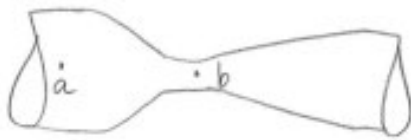
$$\Delta P = (1000 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(13.3855 \text{ m}) = 131,178 \text{ kg/m.s}^2 = \boxed{131.2 \text{ kPa}}$$

Fully closed: $H_{t, \text{avg}} = 21.3466 \text{ m}$

$$\Delta P = (1000 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(21.3466 \text{ m}) = 209,197 \text{ kg/m.s}^2 = \boxed{209.2 \text{ kPa}}$$

Venturi Meter:

5.



$$d_a = 26.5 \text{ mm} = 0.0265 \text{ m}$$

$$\alpha_a = \alpha_b = 1 \text{ : turbulent flow}$$

$$\rho_{\text{H}_2\text{O}} = 1000 \text{ kg/m}^3$$

$$\alpha_b \bar{V}_b^2 - \alpha_a \bar{V}_a^2 = \frac{2(P_a - P_b)}{\rho} \quad (8.22) \rightarrow \bar{V}_b^2 - \bar{V}_a^2 = \frac{2(P_a - P_b)}{\rho}$$

$$\bar{V}_a = \left(\frac{d_b}{d_a} \right)^2 \bar{V}_b \quad (8.23)$$

$$Q = \bar{V}_a A_a = \bar{V}_b A_b \text{ (continuity equation)}$$

Choosing to take the average of given data : flow rate (Q),

Pressure at entrance (P_a), Pressure at throat (P_b)

$$Q = \frac{1800 + 2000 + 2600 + 3000}{4} = 2350 \text{ L/h} \times \frac{1 \text{ m}^3}{10^3 \text{ L}} \times \frac{1 \text{ h}}{3600 \text{ s}}$$

$$= 6.5278 \times 10^{-4} \text{ m}^3/\text{s}$$

$$P_a = \frac{180 + 218 + 305 + 368}{4} = 267.75 \text{ mm H}_2\text{O} \times \frac{1.01325 \times 10^5 \text{ Pa}}{10.333 \text{ mm H}_2\text{O}} \times \frac{1 \text{ m H}_2\text{O}}{10^3 \text{ mm H}_2\text{O}}$$

$$= 2625.55 \text{ Pa}$$

$$P_b = \frac{98 + 130 + 170 + 198}{4} = 149 \text{ mm H}_2\text{O} \times \frac{1.01325 \times 10^5 \text{ Pa}}{10.333 \text{ mm H}_2\text{O}} \times \frac{1 \text{ m H}_2\text{O}}{10^3 \text{ mm H}_2\text{O}}$$

$$= 1461.089 \text{ Pa}$$

Velocity at entrance :

$$\bar{V}_a = \frac{Q}{A_a} = \frac{6.5278 \times 10^{-4} \text{ m}^3/\text{s}}{\frac{\pi (0.0265)^2}{4} \text{ m}^2} = 1.1835 \text{ m/s}$$

Velocity at throat

$$\begin{aligned}\bar{v}_b^2 &= \frac{2(P_a - P_b)}{\rho} + \bar{v}_a^2 \\ &= \frac{2(2625.55 - 1461.089) \frac{\text{kg m/s}^2}{\text{m}^2}}{1000 \frac{\text{kg}}{\text{m}^3}} + (1.1835 \text{ m/s})^2 \\ &= 3.7296 \text{ m}^2/\text{s}^2\end{aligned}$$

$$\Rightarrow \bar{v}_b = \sqrt{3.7296 \text{ m}^2/\text{s}^2} = 1.9312 \text{ m/s}$$

Diameter at throat

$$A_b = \frac{Q}{\bar{v}_b} = \frac{6.5278 \times 10^{-4} \text{ m}^3/\text{s}}{1.9312 \text{ m/s}} = 3.38 \times 10^{-4} \text{ m}^2$$

$$d_b = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4(3.38 \times 10^{-4}) \text{ m}^2}{\pi}} \times \frac{10^3 \text{ mm}}{1 \text{ m}} = \boxed{20.745 \text{ mm}}$$

1. Find v_b 10/10
2. use continuity equation to find D_{throat} 10/10
3. Correct answer 5/5

CHEMICAL ENGINEERING DEPARTMENT

OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET

UNIT OPERATIONS

FALL 2019

Instructor: Dr. Nabila Shamim

Title of Assignment

PROJECT REPORT

Outcome Measured Using this Assignment

Outcome 7

An ability to acquire and apply new knowledge as needed, using appropriate learning strategies. (Written Communication)

Check the complex engineering 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,
	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 student's ability to apply new knowledge as needed, using appropriate learning strategies.

AND REQUIREMENTS

Unit Operations CHEG 3023

Instructor: Dr. Nabila Shamim

Assistant Processor, Department of Chemical Engineering, Prairie View A & M University

ABET OUTCOME 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Specific Aim:

Being curious and constantly looking for inspiration are critical parts of learning. To be successful as an engineer, education must be broad, and you must think out of the box. The project requirement aims to encourage a habit of lifelong learning about innovation, creative thinking, team work and many other aspects of the engineering world. The goal of this requirement is to help inspire the habits of being open to new ideas or problems and solve it as a successful, innovative engineer.

Assignment: An open-ended problem regarding unit operations in chemical engineering

For Example: Hydraulic Folding Boom Sprayer Development and Fabrication

Guideline for the project:

- (i) Inquisitive studies on the problem and acquire knowledge and data for solving the problem.
- (ii) Gather information on relevant fundamentals, theory / concept (demonstrate technical competence) and relate them to the assignment/project.
- (iii) Effectively use the library and online resources for research, read magazines, journals, and other print or online materials so as to be aware of current developments in the discipline; and provide and properly site the sources in a list of references in the literature review section and other relevant sections of the report.

How to Write the Report:

Grading Rubric for Unit Operation CHEG 3023 Project

10 Title

Cover page
Table of Content
List of Table
List of Figures

5 Abstract

Conveys a sense of the full report concisely and effectively

10 Introduction/Theory

20 Material Selection, Availability Cost of Raw materials.

- o List of materials required for the system
 - o Pipe size and types
 - o Location of the pump
 - o Length of pipe for all parts of the system
 - o Valves and fittings
- Specification of a pump

25 Proposed design: Set up a model for calculations, key results and figures.

- o Piping layout
- o Presents visuals clearly and accurately
- o Presents verbal findings clearly and with sufficient support
- o **Results**

10 Discussion

10 Conclusion

Convincingly describes what has been learned in the project

5 References

5 Minutes of Meeting Weekly Assessment

90

Prairie View A&M University
College of Engineering
Department of Chemical Engineering



Fall 2019
Unit Operations of Chemical Engineering
(CHEG 3023- P01)
Final Project on Mechanism of fluid flow in a Gravity Toilet.

By: Navier Stokes Group

Members: Dorinda Yeboah Ntim

Ozem Onye-Franklin

Abeshai Bernard

Caleb Myers

Xavier Williamson

To: Dr. Nabila Shamim

ACKNOWLEDGEMENT

It is often said that no one person can undertake and complete a major project by himself. It for this reason that we feel indebted to some people, without whom we couldn't have completed this project. First of all, we give thanks to the almighty God for the strength He granted us throughout this project, and without Him, we are nothing.

Secondly, we would like to thank Dr. Shamim for her immeasurable support throughout this project. Also, our sincerest gratitude goes to the unit operations tutors for their help throughout our project. Our immense appreciation goes to all the staff of the Roy Perry College of Engineering, specifically the Chemical engineering department, for introducing this initiative.

Lastly, our greatest thanks go to all and sundry for help rendered in one way or the other in the undertaking and completion of this project.

ABSTRACT

In this project we studied the mechanism of a toilet as water is transferred from an underground water table to the bowl. Within this process, we also took the types and effects of several engineering units into consideration. Our map-out of this design from beginning to end included a gate valve, centrifugal pump, check valve, and another gate valve. The basis of our calculations was our use of the mechanical energy balance equation. We made it a goal to calculate the shaft work in the pump, which we set equal to the total head (the sum of pressure, velocity, static, and friction heads) of the system. By doing this, we would be able to utilize the performance curve, which plotted total head vs. volumetric flow rate at a constant rpm and derive the pump's power. Most importantly was the fact that our volumetric flow rate from the water table to the tank was maintained at a constant value. It was important to note that because we are assuming steady-state conditions, mass in = mass out. Since mass is a function of volume and constant density (incompressible fluid), it can be said that volumetric flow rate in = volumetric flowrate out when measuring across a certain time interval. We were able to prove that constructing a process of transferring available water to the bowl of a toilet would cost \$2187.82 and efficiently accomplish the goal.

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1. Introduction

1.1. Objectives

- 1.1.1. Analyze the properties and amounts of materials needed for the process design and obtain an estimate for the total cost of the design.
- 1.1.2. Successfully outline the path water traverses from the water table to the toilet.
- 1.1.3. Calculate the total head of the system by equating it to the pump's shaft work.
- 1.1.4. Yield a value for our centrifugal pump's power outlet using the performance curve and ensure that it is less than the maximum value that was provided in the manufacturer's specifications.
- 1.1.5. Calculate the NPSHA for the pump and ensure that it is significantly greater than the NPSHR provided by the manufacturer.

1.2. Background

A toilet can be divided into two main parts:

- Tank: The tank is the upper part of the toilet and is comprised of many components that each have their own functions. Inside the tank is the fill valve, flush valve seat, flapper, float ball, lever, refill tube, and overflow tube.
- Bowl: The bowl is the bottom half of the toilet and is responsible for releasing water and waste to the manhole. Typical bowls receive around 1.6 gallons of water per flush.

Being that the fluid in this project was water, there are certain properties that we kept in mind. Water has a density of 1000 kg/m^3 and a viscosity of 1 cP (or $10^{-3} \text{ Pa}\cdot\text{s}$). For the sake of simplicity, we chose to use SI units for most of the calculations in order to omit the conversion factor g_c . Figures 1 and 2 below show more in-depth diagrams of a toilet and the parts that make it up.

The centrifugal pump we included had a maximum suction lift of 25 ft, so we decided to choose a lift of 20 ft for simpler calculations and a smaller frictional head. The frictional contributions came from the roughness of the copper pipe, the contraction from the water table to the pipe, our three valves, and our two elbows.

use same unit

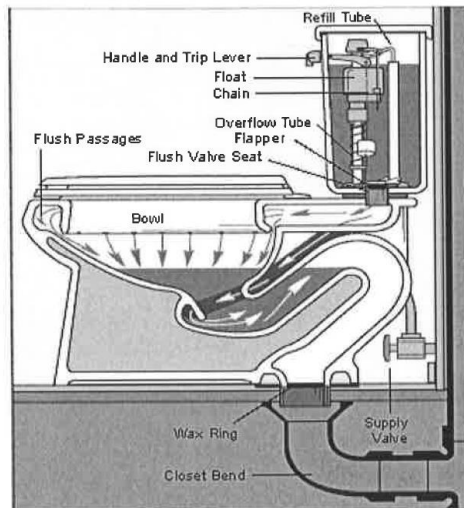


Figure 1: Mechanism of a regular lavatory design's fluid flow

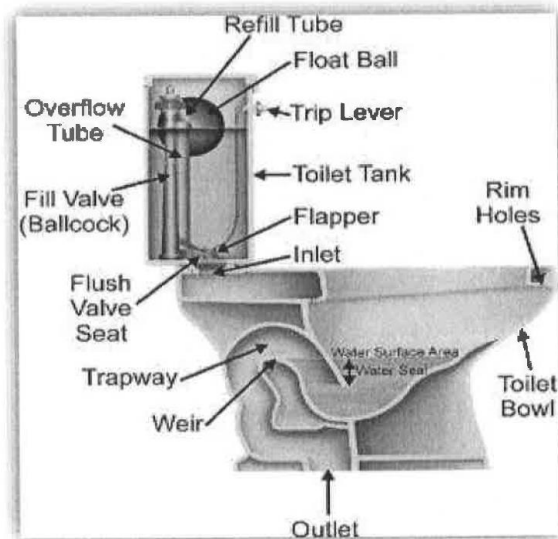
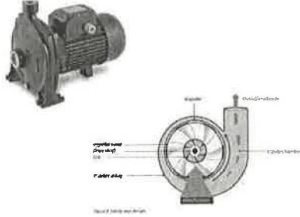
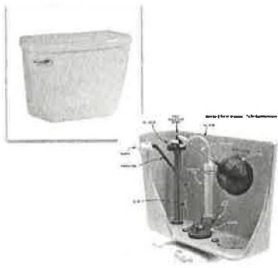


Figure 2: Parts of a complete Water Closet

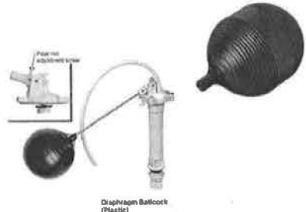
2. Construction

2.1. Material Selection, Availability, & Cost

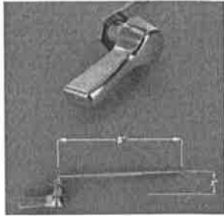
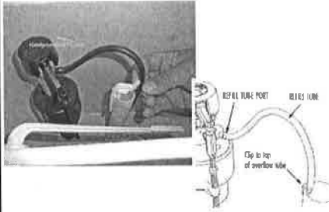
Table 1: Summary of Materials list

List of Materials	Quantity	Material & Location	Cost	Pictures
Underground Water Reservoir Stores wastewater, rainwater, and potable water. The source of where the toilet receives the needed water.	1	- Fiber Glass or Polyethylene - Located underground, directly beneath the pump.	<u>\$738.99</u> <i>Cost for which one?</i>	
Centrifugal Pump Mechanical device designed to move a fluid by means of the transfer of rotational energy from one or more driven rotors, called impellers.	1	Located	\$898.60	
Toilet Tank The tank is the upper-part of the toilet that holds about 2 gallons of water in reserve, which are transferred to the bowl at a rapid rate when the toilet is flushed	1	- Porcelain - Located above toilet bowl. Porcelain material allows our toilet to be waterproof, stainproof, & provides exterior sturdiness.	\$46.27	

MECHANISM OF FLUID FLOW

Fill Valve Controls the water that flows after flushing, to refill the tank; Has a float that corresponds with the water level the tank of the toilet.	1	- Porcelain - Located on the water supply pipe	\$9.98	
Flush Valve Seat Valve seat upon which the Flapper sits.	1	- Rubber - Located at the very bottom of the tank against the grain hole to the bowl.	\$3.26	
Flapper Resides in the tank & provides a protected seal that inhibits water from leaking from the tank to the bowl.	1	- Rubber - Rests against the flush valve seal until it's time to flush.	\$3.99	
Float Ball Attached to a ballcock by a thin metal rod & allows water to flow back into the tank after the toilet is flushed.	1	- Plastic - Floats on top of the water level opposite the side of the handle or lever	\$4.59	

MECHANISM OF FLUID FLOW

Lever Flushes the toilet; When the lever is pushed the flapper, lifts allowing water from the tank to flow down the flush valve into the bowl, washing the waste away.	1	- Brass - Located the top left corner of the front of the tank.	\$8.11	
Refill Tube Allows for the transfer of water from the fill valve to the overflow tube.	1	- Porcelain - Located above the overflow tube.	\$2.98	
Overflow Tube Allows the passage of water from the refill tube to the bowl & provides a response to a safety-related risk	1	- Plastic - Located below the refill tube and connected to the flush valve.	\$11.83	
Toilet Bowl Holds water and waste; Connected to a drain for disposal of waste; Includes the rim which is designed to prevent splashes and overflowing. Rim jets, openings through which water from the toilet tank flows into the bowl to	1	- Porcelain - Bottom part of the overall toilet, below the toilet.	\$65.07	

initiate the flush cycle				
Piping	12m 1-1/2inch schedule 40 pipe	▪ Copper pipe ▪ PVC for minor connections in the home	\$71.50/10ft	

2.2. Material Specifications

2.2.1. Pipes



Figure 3: Piping (United States Plastic Corp.)

In daily living, transferring fluid from one point to another, may sometimes seem like a herculean task. This is due to this reason that pipes and tubes exist in order to aid the transfer of such matter from one point to another. A pipe is a type of duct with constant cross-sectional area. For the benefit of this project, piping is a very essential part of the set up or layout. Pipes will be connected from the reservoir (water storage/source), right to the toilet tank, and even to the end point of the waste material (manhole).

Type: For the general piping, Polyvinyl Chloride Pipes (PVC) and copper pipes are used for the lavatory design. PVC pipes are generally used as main water supply for transporting high pressure water but is controversial because of its inability to carry hot water. This is the reason why Chlorinated Polyvinyl Chloride Pipes (CPVC) are used in areas prone to high temperature changes or hot water supply due to the fact that it can withstand heat. Since the proposed lavatory design neither requires hot water supply nor use in extremely high temperature zones, PVC will be used. For general home water supply, copper pipe is used to supply water to toilets, faucets, showers and any other appliance requiring water. Type M Straight Copper Water Tubing is thin-walled and ideal for use in homes, behind walls. Its rated internal working pressure is up to 569psi for 100°F temperature range: 32° to 400°F.

Location: The pipes would be connected for the transport of water from the reservoir to the pump then from the pump into the lavatory room then through a smaller pipe to the toilet tank and to the toilet bowl. The water solid waste mixture will also be transported to the manhole with a bigger pipe to prevent any issues of clogging.

Specifications: Different parts of the whole layout requires different types of piping. The various piping types are discussed below.

- Water Supply

The supply line to the toilet is standard 1/2-inch copper pipe. This standard 1/2-inch pipe connects to the home's 3/4-inch water pipes. The water supply line does not run directly to the toilet. However, a supply tube connects the supply pipe to the tank.

- Closet Bend

The closet bend is the elbow joint underneath the toilet that connects the vertical toilet drain pipe to the sloping drain pipe leading to the home's main drain stack. The closet bend has two diameters because it connects a 3-inch drain pipe to a 4-inch drain line. The top of the closet bend is 3-inch diameter pipe, while the other end is 4-inch. This pipe fitting is set under the toilet in the floor joists or ground (in toilets on concrete slabs).

- Drain Pipe

The drain pipe in the toilet carries waste away into the main drain line. The standard size for a toilet drain pipe is 3 inches in diameter but drains up to 4 inches in diameter are often used. The drain pipe connects to the flange, which mounts the toilet itself, and this flange is usually built to connect to 3-inch, schedule 40 toilet drain pipe. In most homes, PVC drain pipe is used instead of metal pipe.

- Drain Line

The drain line leading from the closet bend to the drain stack then into the manhole is 4 inches in diameter. This is a standard size pipe for toilet drains in most homes, and all main drain stacks usually consist of 4-inch-diameter pipe. However, some homes may have a smaller drain pipe diameter. In this case, a reducing connection attaches the closet bend to the main drain line.

Cost: The cost of pipes usually varies with the type and diameter per foot. Below is a table showing some pipe types, sizes and diameter with their respective cost per feet as obtained from United States Plastic Corp. (USP).

Table 2: Table showing pipe types and sizes with their cost as obtained from USP

Stock	Description	Catalog Pg.	Price
26306	1-1/2" Gray PVC Schedule 40 Pipe	P-380	\$1.89/Foot
26506	1-1/2" White PVC Schedule 40 Pipe	P-380	\$1.82/Foot
3ZA98	1-1/2" Copper Schedule 40 Pipe	N/A	\$71.50/10Feet

2.2.2. Valves & Fittings

Table 3: Table of Specifications of Valves & Fittings

List of Valves & Fittings	Location	Cost	Pictures
1 Check Valve	Located on the on the pump discharge line & is required to avoid backflow when the pump is stopped.	\$65.28	

2 Gate Valve	1. The first gate valve is located at the main water supply to the house. It is located right before the pump.	\$35.00	
	2. The second gate valve or "shut off" valve is located directly behind the toilet as shown in figure 1, under the tank's inlet.	\$7.87	
2 90 ° Elbows	The first elbow is located on surface lever close to the centrifugal pump. The second elbow is directly behind the toilet under the tank's inlet, right after the valve.	N/A- Accounted for in entire piping cost	

2.2.3. Pump

- Power: 10.163 Horsepower or 5.59 kW (As calculated in Methodology). The performance curve used in the calculation can be seen in the discussion.

3. THEORETICAL BASIS

3.1. Assumptions

1. The fluid being used in this flow mechanism is water, which is an incompressible fluid (Newtonian fluid). Hence, its density and other properties almost remains constant with varying conditions such as temperature and pressure.
2. Every analysis on the water closet occurs under steady state conditions.
3. Since the toilet tank is an open tank (open to the atmosphere) but has a removable cover, which does not establish the tank as a pressurized system, therefore it can be assumed that the pressure of the tank (P_1) is atmospheric pressure (1 atm, 14.7psi, 1.01325 bar or 101325Pa).
4. The pressure required by the cistern outlet (P_2) to flush solid waste is 20-80 psi. This assumption is made for the average human solid waste.
5. The underground water source has a gauge pressure.

3.2 Governing Equations & Parameters

1. Material and Energy Balance Equation

The law of conservation of matter states that, matter can neither be created nor destroyed. This in turn leads to the concept of mass, and results in the form that mass of a material taking part in

any process is constant. Conservation of this mass requires that materials entering each process either accumulate or leave the process. The equation is as follows:

$$(\text{Rate of mass flow in}) = (\text{Rate of mass flow out}) + (\text{Rate of mass accumulation})$$

1. Continuity Equation

The continuity equation is applied when a process is at steady state thus, there is no accumulation. As stated in the assumptions, this whole process is assumed to be a steady state process hence. As a result, from the material balance equation, the mass flow rate in the whole process is conserved. Mass flow rate in this system is the rate at which a specific mass of the fluid flows with time. The continuity equation can be therefore be represented by:

$$\dot{m}_1 = \dot{m}_2 \quad (\text{where } \dot{m} \text{ is the mass flowrate})$$

Equation 1

Since

$$\rho = \frac{\dot{m}}{Q}; \quad \text{where } Q \text{ is the volumetric flowrate}$$

Equation 2

The equation becomes,

$$\rho Q_1 = \rho Q_2$$

And,

$$Q = \text{velocity}(v) * \text{Cross sectional area}(A)$$

Therefore;

$$Q = vA$$

Equation 3

Now,

$$\rho v_1 A_1 = \rho v_2 A_2$$

$$v_1 A_1 = v_2 A_2$$

2. Mechanical Energy Balance Equation

This equation describes the energy interconversions that occur in a flowing fluid. The general equation states that the rate of increase of kinetic energy per unit mass (J/kg) equals the net rate of input of kinetic energy by convection. Including the rate of work done by the pressure of the surroundings, rate of reversible and irreversible conversion to internal energy, rate of work done by viscous forces, rate of work done by gravity, and mechanical energy as added to the fluid by a pump or a blower. This equation is restricted to one directional flow of incompressible fluids (constant density). For a flow analysis from point 1 to 2;

$$\frac{P_2 - P_1}{\rho} + \frac{1}{2} \alpha (v_2^2 - v_1^2) + g(z_2 - z_1) = W_s - h_f$$

Equation 4

3. Work due to Friction (h_f)

For fluid flow in pipes, there will always be an opposition to the flow motion of the fluid. This affects the energy that conversion and as a result, that head loss due to friction must be accounted for. This friction head loss is due to the length of the pipe in itself, the velocity of the moving fluid in the pipe, pipe diameter changes (contraction and expansion), as well as fitting (elbows, valves, Tees, etc.). Accounting for each friction loss:

Friction loss due to fluid flow in the length of a pipe:

$$h_{f(\text{main})} = \frac{2fLv}{D} = \frac{2fLv}{D}$$

Equation 5

1. Where f is the fanning friction factor which is a function of Reynolds number and relative roughness [$f=f(\text{Re}, \frac{k}{D})$]. The Fanning friction factor is the ratio of the wall shear stress to the product of the density and velocity head. This is calculated differently for different types of flow. For turbulent flow, the use of the Moody chart is employed. For laminar flow on the other hand, the friction factor can be calculated straight away using the relation $16/\text{Re}$. Reynold's number is dimensionless parameter used to identify types of fluid flow. Reynolds number is a function of density of the fluid, velocity at which it moves, diameter of the pipe it flows through, and the viscosity of that fluid.

$$\text{Re} = \frac{\rho v D}{\mu}$$

Equation 6

a. Friction loss due to fittings (K_f):

This is calculated by adding up the total number of fittings' K_f . These fittings include all elbows and tees in pipes, and valves. The various K_f values for each fitting can be found in any table containing loss coefficients for standard pipe fittings.

b. Friction loss due to expansions K_e :

This type of friction loss is calculated by adding the total number of pipe contractions in the whole pipe. The equation is as follows:

$$K_e = \left(1 - \frac{S_a}{S_b}\right)^2$$

Equation 7

Where S_a is the area of the pipe the fluid was flow through initially before the expansion into S_b , the bigger pipe.

c. **Friction loss due to contractions K_c :**

This type of friction loss is calculated by adding the total number of pipe contractions in the whole pipe. The equation is as follows:

$$K_e = 0.4 \left(1 - \frac{S_b}{S_a}\right)$$

Equation 8

Here, S_b is the area of the bigger pipe the fluid flows through initially before it contracts into S_a , the smaller pipe.

The general formula for calculating total friction head loss (h_f) therefore becomes:

$$h_f = \left(\frac{4fL}{D} + K_c + K_e + K_f\right) \frac{v^2}{2}$$

Equation 9

Net Positive Suction Head (NPSH)

To avoid cavitation, the pressure at the pump must exceed the vapor pressure by a certain value, known as the net positive suction head (NPSH). The required NPSH for a small centrifugal pump is usually 2-3 m (5-10 ft); but it increases with pump capacity, impeller speed, and discharge pressure as values up to 15 m (50 ft) are recommended for very large pumps. In order for a pump to fit for a particular installation, the available NPSH calculated must exceed the minimum required NPSHR specified by the pump manufacturer. NPSH calculation is as follows:

$$NPSHA = \frac{1}{g} \left[\frac{P'_a - P_v}{\rho} - H_{fs} \right] - z_a$$

Equation 10

3.3 Practical Relation to Theory

3.3.1 Results (Calculations)

To begin our calculations and to ensure water is safely pumped throughout the house the mechanical energy equation must be used to determine the power of the pump required to be able

to pump water from the underground well through the piping and eventually to the toilet's tank.

The mechanical energy equation states that:

$$\frac{P_2 - P_1}{\rho} + \frac{1}{2} \alpha (v_2^2 - v_1^2) + g(z_2 - z_1) = nW_s - h_f$$

Being that the chosen water source as an underground water well, the ideal height of the pipe was chosen based on the maximum suction lift of the chosen centrifugal pump; that is 20 ft underground. Therefore, to calculate the initial pressure at point 1, the well, we applied the equation:

$$P_{1g} = \rho g h_1$$

Plugging in the known values, we achieve

$$P_{1g} = \left(1000 \frac{\text{kg}}{\text{m}^3}\right) \left(9.81 \frac{\text{m}}{\text{s}^2}\right) (-20 \text{ ft}) \left(\frac{1 \text{ m}}{3.28 \text{ ft}}\right)$$

Our final value for P_1 is -59.817 kPa. Our P_2 was assumed to be atmospheric pressure, 101.325 kPa, because the tank of a toilet is generally not sealed.

The average volumetric flow rate was found through a literature review (Tutorial on centrifugal pumps by Chaurette, Jacques) to be 120 gal/min. Converting to SI units, we achieve $Q_1 = 0.082 \text{ m}^3/\text{s}$

$$Q_1 = \left(120 \frac{\text{gal}}{\text{min}}\right) \left(\frac{1.0 \text{ ft}^3}{7.48 \text{ gal}}\right) \left(\frac{1.0 \text{ m}^3}{3.28^3 \text{ ft}^3}\right) \left(\frac{1 \text{ min}}{60 \text{ s}}\right)$$

After careful selection of our piping, the piping we chose had a diameter preselected of 0.041 m; through this diameter we were able to calculate our velocity at point 2 (V_2) using the continuity equation shown later. Velocity at point one (V_1) can be assumed to be zero because it is coming from a very big tank.

All known parameters from either literature review or assumptions drawn previously:

$$D_{\text{inside}} = (1 \frac{1}{2} \text{ Sch. 40 pipe}) = 1.61 \text{ in} = 0.041 \text{ m}$$

$$P_1 = -59.817 \text{ kPa}$$

$$P_2 = P_{\text{atm}} = 101.325 \text{ kPa}$$

$$P_v = 23.8 \text{ torr} = 3173.1 \text{ Pa}$$

$$\Delta z = 21 \text{ ft} = 6.402 \text{ m}$$

$$Q = 0.082 \text{ m}^3/\text{s}$$

$$L = 40 \text{ ft} = 12.2 \text{ m}$$

$$\rho = 1000 \text{ kg/s}$$

$$\mu = 1 \text{ cp} = 10^{-3} \text{ Pa} \cdot \text{s}$$

$$g = 9.81 \text{ m/s}^2$$

Table 4: Known parameters that are being used for calculations

After inclusion of all assumptions, the mechanical energy balance reduces to:

$$\frac{P_2 - P_1}{\rho} + \frac{1}{2} V_2^2 + g \Delta z = n W_p - h_f$$

Plugging in the known values and rearranging for the head of the pump, (H_p), we achieve

$$H_p = \frac{P_2 - P_1}{\rho g} + \Delta z + \frac{1}{2} V_2^2 + h_f$$

First, we calculate the velocity of the fluid flowing through the pipe using the continuity equation for a fluid of constant density.

$$v = \frac{Q}{A} = \frac{0.082 \text{ m}^3/\text{s}}{\frac{\pi}{4} (0.041)^2}; v = 2.546 \frac{\text{m}}{\text{s}}$$

Reynold's number of the fluid is then calculated to classify the flow type of the water through the pipes.

Since the Reynold's Number is more than 2100, water flow through the pipe is turbulent.

To calculate the total friction through the tube, according to (Citation) we achieve our K_c value to be equal to 0.4. According to (same citation), K_f of elbows is 0.75 and valves is 0.17. In our system there were 2 elbows and 3 valves.

Plugging in values into the friction equation we get:

$$H_f = \left(\frac{4f(12.2 \text{ m})}{0.041 \text{ m}} + 2 * 0.75 + 3 * 0.17 + 0.4 \right) * \frac{(2.546 \frac{\text{m}}{\text{s}})^2}{2 * (\frac{9.81 \text{ m}}{\text{s}^2})}$$

Fanning Friction Factor is a function of both Reynold's number and relative roughness.

- The Reynold's number is given by

$$Re = \frac{(1000 \frac{\text{kg}}{\text{m}^3})(2.546 \frac{\text{m}}{\text{s}})(0.041 \text{ m})}{10^{-3} \text{ Pa} \cdot \text{s}} = 104386 = 1.0 \times 10^5$$

since this number is more than 2100 the flow is turbulent.

We utilized copper piping, from the water well, point 1, to right before it enters the house. Our roughness is $k_{cu} = 0.0014 \text{ mm}$. Hence, relative roughness becomes;

$$\frac{k}{d} = \frac{0.0014 * 10^{-3} \text{ m}}{0.041 \text{ m}} = 3.415 * 10^{-5}$$

Our fanning friction factor from the moody chart therefore is $f = 0.00465$

The final value for our total friction is $h_f = 2.625 \text{ m}$

Plugging in all known values to solve for W_p ,

$$H_p = \frac{101.325 \text{ kPa} - -59.817 \text{ kPa}}{\left(1000 \frac{\text{kg}}{\text{m}^3}\right) \left(9.81 \frac{\text{m}}{\text{s}^2}\right)} + 6.402 \text{ m} + \frac{\left(\frac{2.546 \text{ m}}{\text{s}}\right)^2}{2 \left(9.81 \frac{\text{m}}{\text{s}^2}\right)} + 2.625 \text{ m}$$

$$H_p = nW_p = 25.784 \text{ m}$$

Equation 11

From the performance curve chart, fig. 1.1 and fig. 1.2, of the centrifugal pump we will be using, a head of approximately 26 m gives a power of 5.59 kW with an impeller speed of 3450 rpm. The conversion is as follows:

$$P = (5.59 \text{ kW}) * \left(\frac{1 \text{ hp}}{0.74624 \text{ kW}}\right) = 7.5 \text{ hp}$$

Based on this obtained power value and the known safe volumetric flow rate, we can ensure that our values seem feasible and accurate.

Calculating NPSHA

Our second objective was to calculate NPSHA and compare it to the NPSHR given in the pump specifications. From the performance curve chart given by the manufacturer for pump D, the NPSHR for the given flowrate of 120gal/min was 2 m. To find NPSHA, the following equation (Equation 10) was utilized:

$$NPSHA = \frac{1}{g} \left[\frac{P'_a - P_v}{\rho} - H_{fs} \right] - z_a$$

In this equation, P'_a is the absolute pressure at the surface of the underground reservoir, which is equivalent to $P_{\text{gauge}} + P_{\text{atm}}$ from our calculation of total head. The vapor pressure P_v is also known at 25°C, which we will assume as the temperature. The friction along the suction line is represented by h_{fs} , which is different from our original h_f because it only includes frictional

contributions up to the pump's inlet and nothing within the discharge line. To find it, however, we will utilize the same formula and only consider the contraction, first elbow, and the first gate valve.

$$H_{fs} = \left(\frac{4fL}{D} + K_c + K_f + K_f \right) \frac{v^2}{2}$$

As before, $K_c = 0.4$, $K_{f_{\text{valve}}} = 0.17$, and $K_{f_{\text{elbow}}} = 0.75$. Taking the length of suction line to be equal to the elevation, z_a , our calculations yield a friction value as follows:

$$H_{fs} = \left(\frac{4(0.00465)(6.098\text{m})}{.0401} + 0.4 + 0.17 + 0.75 \right) \frac{(2.546)^2}{2} = 13.45 \text{ J/kg}$$

Plugging everything in, we get:

$$\text{NPSHA} = \frac{1}{9.81 \frac{\text{m}}{\text{s}^2}} \left(\frac{41508 \text{ Pa} - 3173.1 \text{ Pa}}{1000 \frac{\text{kg}}{\text{m}^3}} - 13.45 \frac{\text{m}^2}{\text{s}^2} \right) + 6.098 \text{ m} = 8.635 \text{ m} > \text{NPSHR} = 4 \text{ m}$$

Henceforth, our NPSHA is 8.635 m and because it is much greater than NPSHR, we can conclude that a pump of this design is feasible.

*Suction dia
should be bigger
than
discharge*

4. PROPOSED LAVATORY DESIGN

4.1. Piping Layout

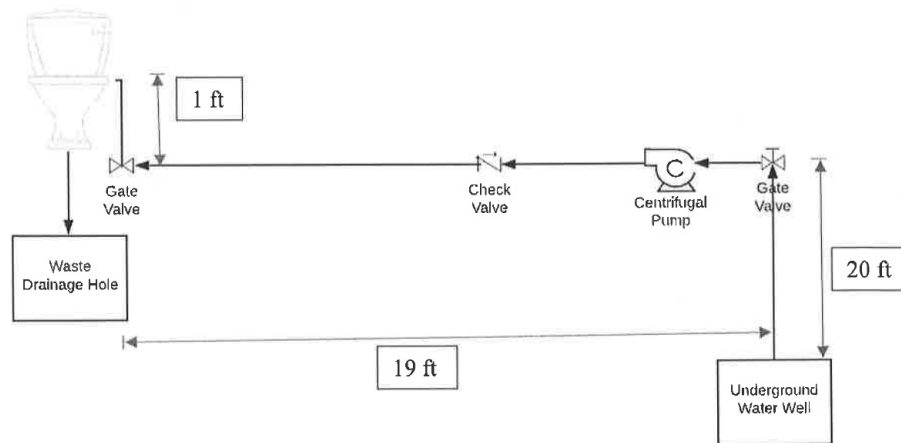


Figure 3: Lavatory Layout Piping layout designed with COCO Chemsep Application

4.2.Process Flow Diagram

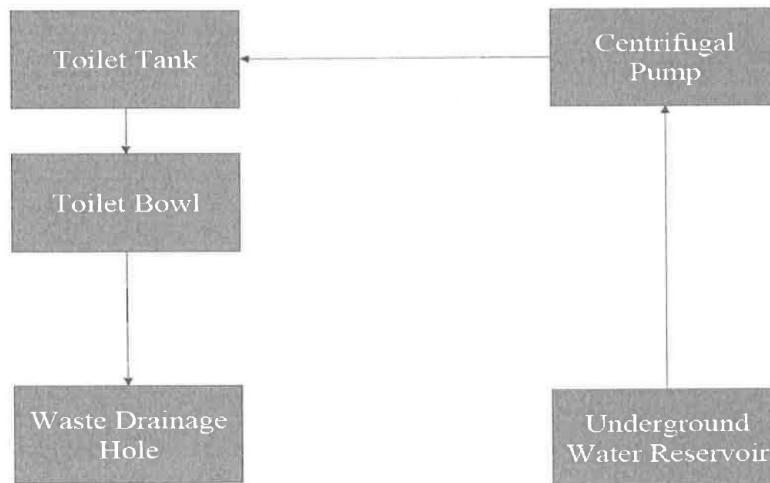


Figure 4: Process flow diagram

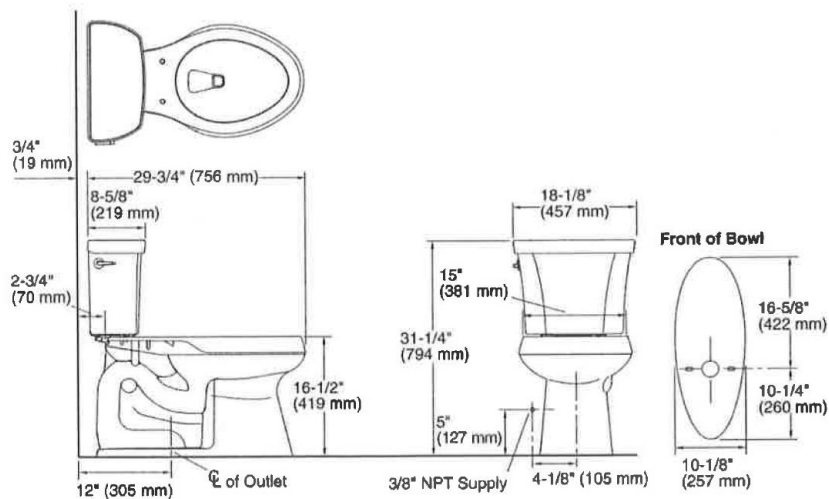
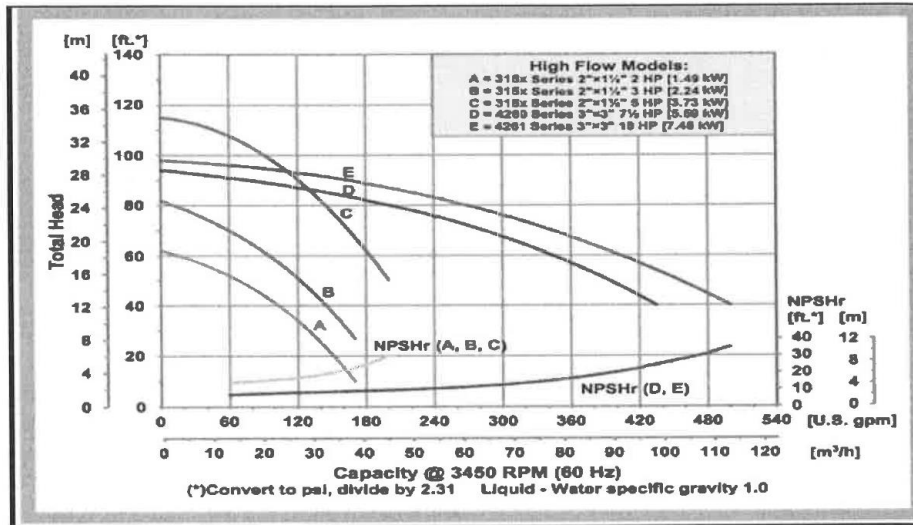


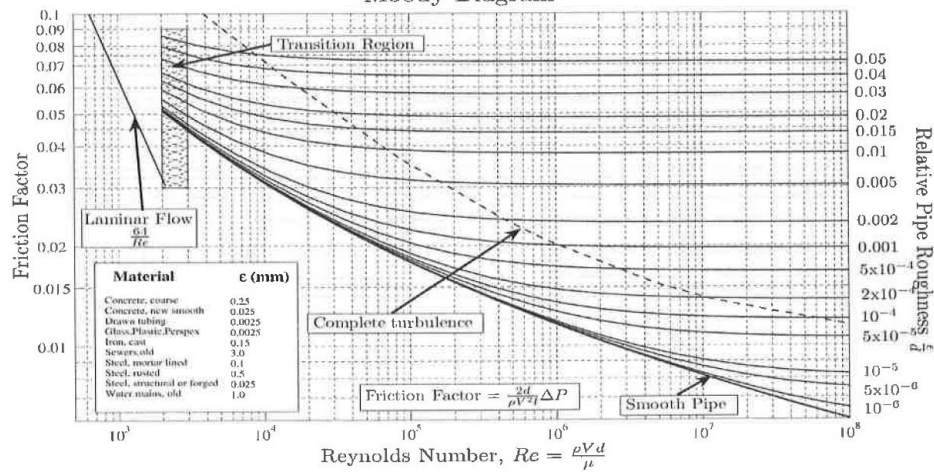
Figure 5: Overall Water Closet Dimensions

5. DISCUSSION

5.1. Results



Moody Diagram



5.2. Limitations

For the purpose of calculations, a few assumptions that were made brought about certain limitations. In the early stages of the development of our project, the assumption of a sump pump being an ideal pump for the system increased the necessity of more materials which would increase the cost of the overall system and had the potential to decrease the flow rate due to increase of elevation. A centrifugal pump was then agreed on due to its efficiency, and performance rate without extra costs. The flow of water would start from the water table and continue throughout the house, overall ending at the toilet the entrance of the toilet tank. Another limitation was the idea that a pump could be decided on and the placement of the pump could be anywhere as long as it increased the pressure of the water flow, further increasing flow rate. However, during preliminary research, and textbook reading, the approach taken was finding the flowrate first, finding length of the pipe and the diameter of the pipe.

5.3. Significance

Toilets are one of many appliances that allow a home to function. However, toilets add more value to the health of the individuals of the home more than the home itself. Toilets are crucial for the health development of humanity. Aiding in providing a safe disposal of human waste, it further prevents the contamination of others. An important mechanism of a toilet is the flow rate. Imagine trying to flush your waste and the time it took for your water to get from the water supply to the house, to the tank of the toilet and flushed down was 5 minutes. The whole house would stink not to mention it would cause frustration. An ideal flow rate is determined by the size of the pipe, the length of pipe and most importantly the location of the pump used by the house. The purpose of a pump is to increase the pressure of an incompressible fluid flowing through the pipe. The increase in pressure equals the increase in flow rate.

5.4. Feasibility

This process is 100% feasible. The total cost for this project was \$2000 which is very economical for a toilet that normally has a life span of five to ten years. The most common problem that's associated with toilets is clogging. The solution for this ever so frequent problem is unclogging it using a plunger that can be bought at a local grocery store or a chemical liquid that can be found at same location. The total amount for both of these items is less than \$40. In many cases, once you buy it once, you won't have to buy another for a year or two. On average, it costs about \$45-\$197 to fix a toilet by yourself and \$130-\$310 to hire a professional. If an issue arises with a toilet, service can be available to you and be completed the same day. Many items that are necessary for this process can be found at any home improvement store such as, Home depot, Lowes, and also on Amazon where it can be shipped at your convenience using Amazon prime. The only downside to this project is if an individual is not familiar to the technical meaning behind materials. For example, if one does not have the knowledge that a

smaller diameter pipe can increase flow rate and does not seek professional help, cost can increase due to trial and error.

Economic Analysis

5.4.1.1. Governing Equations & Parameters

Single payment compound amount is the future worth value calculated when we were provided with the present worth value, interest rate, and the time period.

$$F = P * (F/P, i\%, n);$$

Equation 12

Equation 5.1 Single Payment Compound Amount

5.4.1.2. Definitions

F= Future Worth Value

P= Present Worth Value

i%= Interest Rate

n= time period

5.4.1.3. Calculations

To calculate how much our whole system would be worth in the future we used the Single payment compound amount equation. The average life span for a toilet is 50 years and we used an interest rate of 3% percent. (F/P, i%, n) is a factor used to help calculate the future worth. which the parameters consist of the interest rate and the years. When using the table from the Engineering Economic Analysis 11th edition we found that the factor is 4.384. The future worth of our toilet system comes out to be. Throughout the years it is known that homeowners pay an average of \$221 to fix a toilet. We are stating that every 10 years these repairs will be needed.

$$F = 2187.82(4.384) - 221(3.262) - 221(2.427) - 221(1.806) - 221 = \$7710.41$$

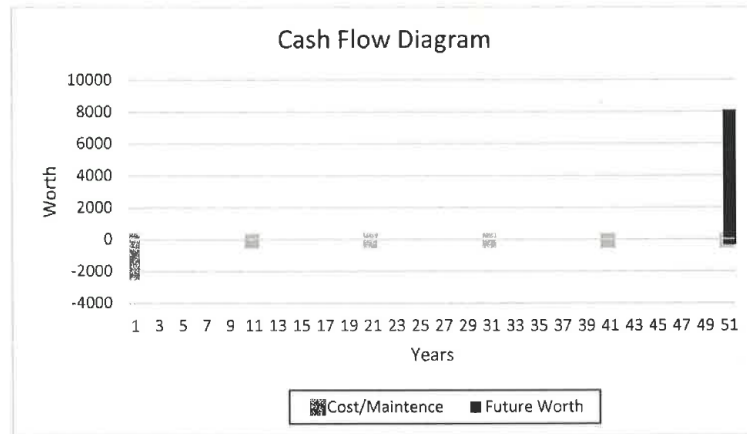


Figure 5.1: Cash Flow Diagram

5.5. Engineering Challenges

Accounting for the size of the impeller can be a bit tedious due to the fact that, the bigger your impeller, the more expensive your pump. However, it produces a greater flow rate. If the depth of water table is lower than what is expected, change in pipe length and friction will have to be considered as well as loss of friction head will have to be considered. In reality, there will be more bends and with more bends there is increase of friction.

6. CONCLUSION AND RECOMMENDATIONS

This project provided real life application to the terms and concepts acquired from our Unit Operations course. The goal of our process was to pump water coming from our underground water reservoir to the tank of the toilet ultimately reaching our volumetric flow value of 120 gallons per minute. The technicality of this project led us to choose a centrifugal pump with a maximum volumetric flow rate output of 170 gallons per minute and horsepower of 3 as well as a copper pipe for the overall system. We chose to do the toilet process based on the ability to apply valuable conceptual theories acquired from course. For calculations we used the mechanical energy balance and eliminated variables not necessary. With this equation, we solved for total head, used the performance curve to compare total head acquired with flow rate calculated and received power. In calculating for total head, we had to account for friction loss coming from two 90° elbows and 3 valves; check and 2 gates. The value received for flow rate allowed us to determine the appropriate pump need for toilet flow. Although a few assumptions led to limitations, a majority of them led to great answers.

Ref. 3

**CHEMICAL ENGINEERING DEPARTMENT
OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET
UNIT OPERATIONS**

FALL 2019

Instructor: Dr. Nabila Shamim

Title of Assignment

Oral Presentation

Outcome Measured Using this Assignment

Outcome 7

**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

Project presentation Slides for Oral communication

The slides and performance criteria based rubric for grading the oral presentation is provided to demonstrate student performance in oral presentation.

Instructor: Dr. Nabila Shamim

Assistant Processor, Department of Chemical Engineering, Prairie View A & M University

ABET OUTCOME 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Specific Aim:

Being curious and constantly looking for inspiration are critical parts of learning. To be successful as an engineer, education must be broad, and you must think out of the box. The project requirement aims to encourage a habit of lifelong learning about innovation, creative thinking, team work and many other aspects of the engineering world. The goal of this requirement is to help inspire the habits of being open to new ideas or problems and solve it as a successful, innovative engineer.

Assignment: An open-ended problem regarding unit operations in chemical engineering

For Example: Hydraulic Folding Boom Sprayer Development and Fabrication

Guideline for the project:

- (i) Inquisitive studies on the problem and acquire knowledge and data for solving the problem.
- (ii) Gather information on relevant fundamentals, theory / concept (demonstrate technical competence) and relate them to the assignment/project.
- (iii) Effectively use the library and online resources for research, read magazines, journals, and other print or online materials so as to be aware of current developments in the discipline; and provide and properly site the sources in a list of references in the literature review section and other relevant sections of the report.

CHEG 3023 Project Evaluation _____

Section Points	Points	
5	5	Title Describes Title concisely, adequately, appropriately
5	5	Abstract Conveys a sense of the full report concisely and effectively
15	2 5 8	Introduction/Theory Successfully establishes the concept Effectively presents the objectives and purpose governing equations
15	15	Material Selection, Availability Cost of Raw materials. o List of materials required for the system o Pipe size and types o Location of the pump o Length of pipe for all parts of the system o Valves and fittings Specification of a pump
20	5 5 5 5	Proposed design: Set up a model for simulation, calculations, key results and figures. o Piping layout o Presents visuals clearly and accurately o Presents verbal findings clearly and with sufficient support Successfully integrates verbal and visual representations
15	5 5 5	Results Friction Pump Power NPSHA
10	2 2	Discussion Opens with effective statement of support of hypothesis Backs up statement with reference to appropriate findings

- 3 Provides sufficient and logical explanation for the statement
- 3 Sufficiently addresses other issues pertinent to lab

5

Conclusion

- 5 Convincingly describes what has been learned in the lab

5

Presentation

- 2 Citations and references adhere to proper format
- 1 Format of tables and figures is correct
- 1 Report is written in scientific style: clear and to the point
- 1 Grammar and spelling are correct

5

Students presence and participation in the lab



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Safety Shower and Eyewash Station

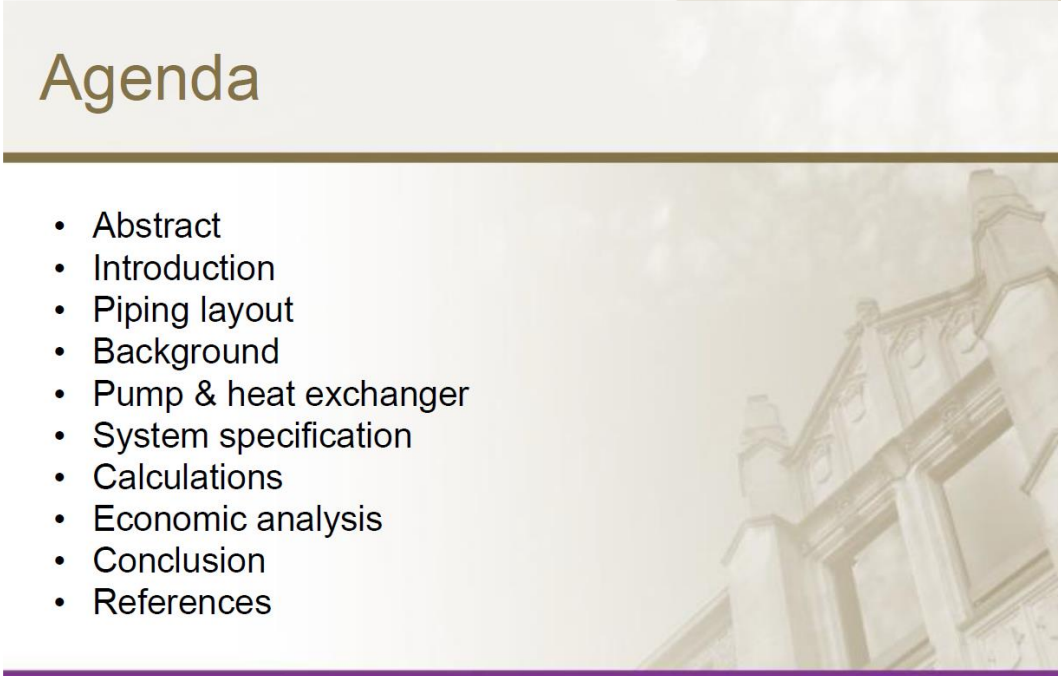
Presented by :

Paul Danjuma
Brandon Houston
Indira Ribeiro
Danria Taylor
Lilia Yang



Agenda

- Abstract
- Introduction
- Piping layout
- Background
- Pump & heat exchanger
- System specification
- Calculations
- Economic analysis
- Conclusion
- References



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Abstract

- Demonstration of fluid dynamics concepts.
- Recreate an emergency shower and eyewash station that meets Occupational Safety and Health Administration (OSHA) and American National Standards Institute (ANSI) standards.
 - 29 CFR 1910.151 (c)
 - Z358.1-2014

PRAIRIE VIEW A&M UNIVERSITY ₃

Abstract (2)

- Our safety shower and eyewash station will operate on the first floor of the New Science Building at Prairie View A&M University, as a closed system.
- Our goal was to find the best material, and system design that would result in the smallest amount of total friction without violating any physical laws.



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Introduction

Our project will consist of two main parts:

- “Before the process” : Will remain constant.
 - Water storage tank.
 - Heat exchanger.
 - Suction line.

- “The process”: Will vary.
 - Discharge line from the pump.
 - Complete emergency shower and eyewash station.

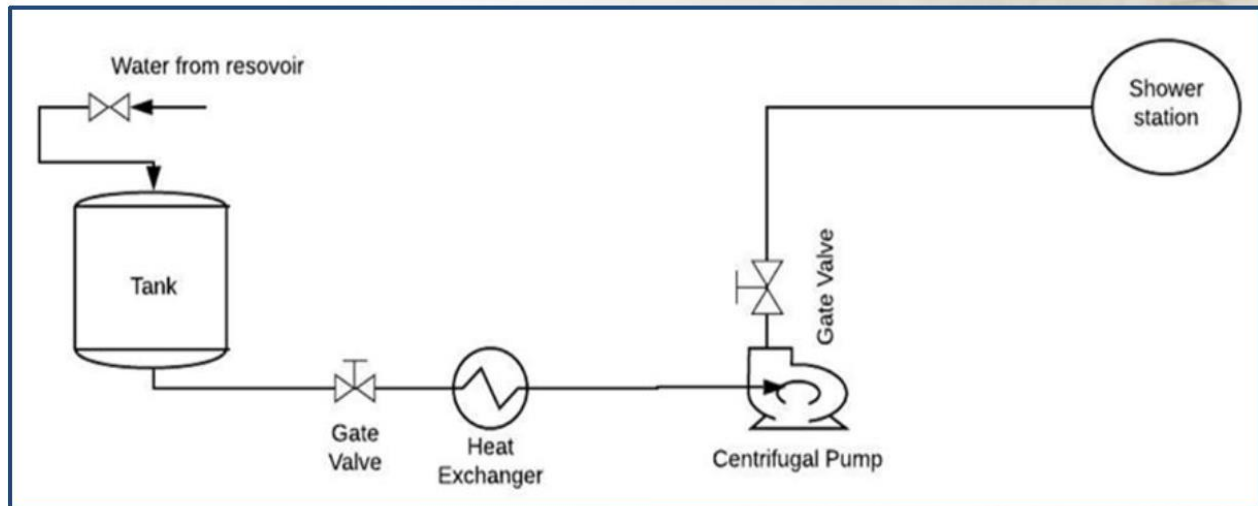
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Introduction (2): In “The Process”

- Variation of the pipe diameters from 0.0833 feet to 0.1458 feet, by half inch increments.
- Variation of the height of the water source until the system would fail or be physically impossible.
- We were constrained by OSHA and ANSI standards.

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Piping Total Layout



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Background

- Safety showers and eyewash stations act as first aid sites for emergency usage in case of exposure to harmful and corrosive substances.
- Access to such equipment gives a chance to rinse away the hazardous materials, greatly diminishing the damage or damages this exposure could cause.
- Laboratories and other facilities exposed to corrosive substances are required to have a safety shower available in strategic sites in which employees will be able to reach it no longer than ten seconds after being exposed to dangerous substances.

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Background (2)

The facilities that require safety showers and eyewash stations include:

- Oil and petroleum refineries.
- Dangerous chemical storing sites.
- Battery charging facilities.
- University and high-school laboratories.
- Hazardous waste disposal areas.

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Background (3): Our Goals

- **Meet OSHA & ANSI Standards**
 - OSHA and ANSI standards, 29 CFR 1910.151 and Z358.
 - Require a pressure of 4320 lbf/ft².
 - Shower head require 20 gallons/min.
 - Eyewash require 0.4 gallons/min.

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Pump

- We decided to use this pump top facilitate the transfer of water to the shower and eyewash station.
- As per OSHA standards, a pressure of 30 psi is required to run an emergency safety shower.

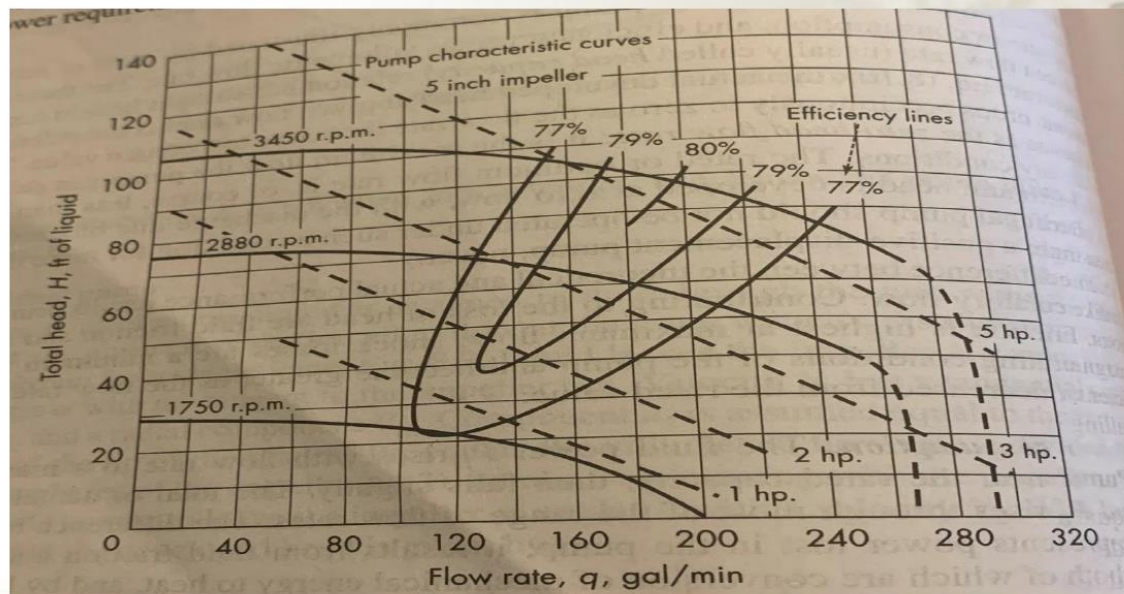
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Pump (2)



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Pump characteristic curve



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Pump specifications

Max Pressure	42 psi
Hz	60
Motor RPM	3450
Impeller type	Closed
Duty	Continuous
Best efficiency GPM @ head	33 @ 54 ft.

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Heat exchanger

- The main purpose of a heat exchanger in our system is to maintain a specific temperature.
- ANSI specifies water temperature requirements. Water supply has to be in tepid range from 60 to 100°F (16 to 38°C).
- We selected the RBI commercial gas fired water heater.
- Compact and suitable for light commercial uses.

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Heat exchanger (2)



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Heat Exchanger (3)

Fuel	Natural Gas
Ignition type	Electronic spark
Design pressure drop	12 psi
Net Btu	144,000
Net BtuH	199,000
Cabinet material	18g. steel
Vent type	Gravity
Pipe supply	1.5 in.
Pipe return	1.5 in.
AFUE	82%

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System Specifications

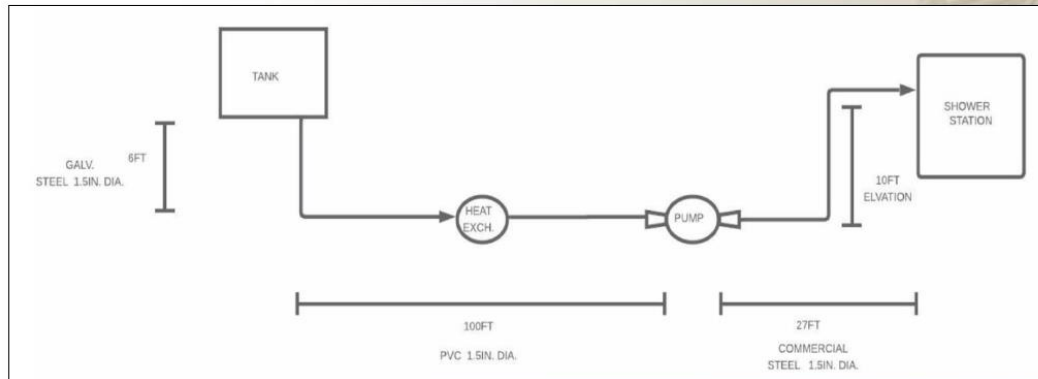
Properties	
Viscosity [lbm/ft*s]	0.000672
Density [lb/ft^3]	62
Gravity [ft/s^2]	32.174
Gravity Constant [lbm*ft/lbf*s^2]	32.174
Vapor Pressure [lbf/ft^2]	86.87

Friction Coefficients	
Fittings	K [f]
T-Joint	4.00E-01
T-Joint (90 Degree)	1.00E+00
90 Degree Elbow	7.50E-01
Ball Valve	6.00E+00
Gate Valve	1.70E-01

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System Specifications (2)

Pipe Material				
	Galvanized Iron	Commerical Steel	PVC	Smooth Tubing
Roughness [ft]	5.00E-04	1.50E-04	1.25E-05	5.00E-06



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System Specifications (3)

	Water Tower	Line to Heat EX	Suction Line
Relative Roughnes	4.00E-03	1.00E-04	1.00E-04
Re #	4.27E+04	4.27E+04	4.27E+04
Velocity [ft/s]	3.71E+00	3.71E+00	3.71E+00
Diameter [ft]	1.25E-01	1.25E-01	1.25E-01
Length [ft]	6.00E+00	1.00E+02	2.71E+01
Height [ft]	1.00E+01	0.00E+00	0.00E+00
Frictions	1.15E+00	1.17E+00	1.22E-01
Fanning factor	3.70E-03	3.10E-03	3.10E-03
Total hf [ft ² /s ²]	3.97E-01	2.37E+00	6.00E-01
Pressure In [lbf/ft ²]	8.47E+03	7.82E+03	5.95E+03
Pressure Out [lbf/ft ²]	7.82E+03	7.68E+03	5.90E+03
P (in) < P (out)	FALSE	FALSE	FALSE
Delta P	6.45E+02	1.47E+02	4.38E+01

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Calculation: Iterations

Galvanized Iron: 0.0833 feet ID

Discharge Line	Shower Head		Eye Wash			Sum
	Vertical	Horizontal	Vertical [1]	Horizontal	Vertical [2]	
6.00E-03	6.00E-03	6.00E-03	6.00E-03	6.00E-05	1.50E-04	
6.41E+04	6.41E+04	6.41E+04	6.41E+04	6.41E+04	6.41E+04	
8.34E+00	8.34E+00	8.34E+00	8.34E+00	8.34E+00	8.34E+00	
8.33E-02	8.33E-02	8.33E-02	8.33E-02	8.33E-02	8.33E-02	
2.00E+01	3.70E+00	2.30E+00	7.00E-01	5.80E-01	2.50E+00	
1.00E+01	3.70E+00	0.00E+00	-7.00E-01	0.00E+00	2.50E+00	
1.32E+00	1.40E+00	6.75E+00	1.15E+00	7.50E+00	1.50E+00	
8.00E-03	8.00E-03	8.00E-03	8.00E-03	2.60E-03	3.20E-03	
9.72E+00	3.05E+00	8.25E+00	1.53E+00	8.18E+00	2.04E+00	2.43E+00
6.05E+03	4.83E+03	4.41E+03	4.83E+03	4.77E+03	4.27E+03	
4.83E+03	4.41E+03	4.32E+03	4.77E+03	4.27E+03	4.32E+03	
FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	
1.22E+03	4.18E+02	8.67E+01	5.16E+01	5.07E+02	-5.38E+01	

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Calculation: Iterations (2)

PVC: 0.0833 feet ID

Discharge Line	Shower Head		Eye Wash			Sum
	Vertical	Horizontal	Vertical [1]	Horizontal	Vertical [2]	
1.50E-04	1.50E-04	1.50E-04	1.50E-04	6.00E-05	1.50E-04	
6.41E+04	6.41E+04	6.41E+04	6.41E+04	6.41E+04	6.41E+04	
8.34E+00	8.34E+00	8.34E+00	8.34E+00	8.34E+00	8.34E+00	
8.33E-02	8.33E-02	8.33E-02	8.33E-02	8.33E-02	8.33E-02	
2.00E+01	3.70E+00	2.30E+00	7.00E-01	5.80E-01	2.50E+00	
1.00E+01	3.70E+00	0.00E+00	-7.00E-01	0.00E+00	2.50E+00	
1.32E+00	1.40E+00	6.75E+00	1.15E+00	7.50E+00	1.50E+00	
3.40E-03	3.40E-03	3.40E-03	3.40E-03	2.60E-03	3.40E-03	
4.95E+00	2.17E+00	7.70E+00	1.37E+00	8.18E+00	2.06E+00	2.46E+00
6.05E+03	5.12E+03	4.76E+03	5.12E+03	5.08E+03	4.57E+03	
5.12E+03	4.76E+03	4.32E+03	5.08E+03	4.57E+03	4.32E+03	
FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	
9.27E+02	3.64E+02	4.37E+02	4.13E+01	5.07E+02	2.52E+02	

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Calculation: Iterations (3)

Commercial Steel: 0.0833 feet ID

Discharge Line	Shower Head		Eye Wash			Sum
	Vertical	Horizontal	Vertical [1]	Horizontal	Vertical [2]	
1.80E-03	1.80E-03	1.80E-03	1.80E-03	6.00E-05	1.50E-04	
6.41E+04	6.41E+04	6.41E+04	6.41E+04	6.41E+04	6.41E+04	
8.34E+00	8.34E+00	8.34E+00	8.34E+00	8.34E+00	8.34E+00	
8.33E-02	8.33E-02	8.33E-02	8.33E-02	8.33E-02	8.33E-02	
2.00E+01	3.70E+00	2.30E+00	7.00E-01	5.80E-01	2.50E+00	
1.00E+01	3.70E+00	0.00E+00	-7.00E-01	0.00E+00	2.50E+00	
1.32E+00	1.40E+00	6.75E+00	1.15E+00	7.50E+00	1.50E+00	
5.80E-03	5.80E-03	5.80E-03	5.80E-03	2.60E-03	3.20E-03	
7.44E+00	2.63E+00	7.98E+00	1.45E+00	8.18E+00	2.04E+00	2.43E+00
6.05E+03	4.97E+03	4.57E+03	4.97E+03	4.92E+03	4.41E+03	
4.97E+03	4.57E+03	4.32E+03	4.92E+03	4.41E+03	4.32E+03	
FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	
1.08E+03	3.92E+02	2.54E+02	4.67E+01	5.07E+02	9.26E+01	

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Calculation: Iterations (4)

Galvanized Iron: 0.125 feet ID

Discharge Line	Shower Head		Eye Wash			Sum
	Vertical	Horizontal	Vertical [1]	Horizontal	Vertical [2]	
4.00E-03	4.00E-03	4.00E-03	4.00E-03	4.00E-05	1.00E-04	
4.27E+04	4.27E+04	4.27E+04	4.27E+04	4.27E+04	4.27E+04	
3.71E+00	3.71E+00	3.71E+00	3.71E+00	3.71E+00	3.71E+00	
1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01	
2.00E+01	3.70E+00	2.30E+00	7.00E-01	5.80E-01	2.50E+00	
1.00E+01	3.70E+00	0.00E+00	-7.00E-01	0.00E+00	2.50E+00	
1.32E+00	1.40E+00	6.75E+00	1.15E+00	7.50E+00	1.50E+00	
7.10E-03	7.10E-03	7.10E-03	7.10E-03	3.70E-03	3.20E-03	
1.25E+00	4.78E-01	1.55E+00	2.79E-01	1.62E+00	3.75E-01	7.72E-01
6.05E+03	5.35E+03	5.09E+03	5.35E+03	5.38E+03	5.28E+03	
5.35E+03	5.09E+03	4.32E+03	5.38E+03	5.28E+03	4.32E+03	
FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	
6.98E+02	2.59E+02	7.71E+02	-2.61E+01	1.00E+02	9.56E+02	

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Calculation: Iterations (5)

PVC: 0.125 feet ID

Discharge Line	Shower Head		Eye Wash			Sum
	Vertical	Horizontal	Vertical [1]	Horizontal	Vertical [2]	
1.00E-04	1.00E-04	1.00E-04	1.00E-04	4.00E-05	1.00E-04	
4.27E+04	4.27E+04	4.27E+04	4.27E+04	4.27E+04	4.27E+04	
3.71E+00	3.71E+00	3.71E+00	3.71E+00	3.71E+00	3.71E+00	
1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01	
2.00E+01	3.70E+00	2.30E+00	7.00E-01	5.80E-01	2.50E+00	
1.00E+01	3.70E+00	0.00E+00	-7.00E-01	0.00E+00	2.50E+00	
1.32E+00	1.40E+00	6.75E+00	1.15E+00	7.50E+00	1.50E+00	
3.00E-03	3.00E-03	3.00E-03	3.00E-03	2.40E-03	3.00E-03	
6.91E-01	3.75E-01	1.49E+00	2.60E-01	1.61E+00	3.71E-01	7.18E-01
6.05E+03	5.39E+03	5.13E+03	5.39E+03	5.41E+03	5.31E+03	
5.39E+03	5.13E+03	4.32E+03	5.41E+03	5.31E+03	4.32E+03	
FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	
6.63E+02	2.53E+02	8.13E+02	-2.73E+01	9.98E+01	9.93E+02	

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Calculation: Iterations (6)

Commercial Steel: 0.125 feet ID

Discharge Line	Shower Head		Eye Wash			Sum
	Vertical	Horizontal	Vertical [1]	Horizontal	Vertical [2]	
1.20E-03	1.20E-03	1.20E-03	1.20E-03	4.00E-05	1.00E-04	
4.27E+04	4.27E+04	4.27E+04	4.27E+04	4.27E+04	4.27E+04	
3.71E+00	3.71E+00	3.71E+00	3.71E+00	3.71E+00	3.71E+00	
1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01	
2.00E+01	4.20E+00	2.30E+00	2.00E-01	5.80E-01	2.50E+00	
1.00E+01	4.20E+00	0.00E+00	-2.00E-01	0.00E+00	2.50E+00	
1.32E+00	1.40E+00	6.75E+00	1.15E+00	7.50E+00	1.50E+00	
5.10E-03	5.10E-03	5.10E-03	5.10E-03	2.50E-03	3.00E-03	
9.78E-01	4.45E-01	1.52E+00	2.52E-01	1.61E+00	3.71E-01	7.68E-01
6.05E+03	5.37E+03	5.08E+03	5.37E+03	5.36E+03	5.26E+03	
5.37E+03	5.08E+03	4.32E+03	5.36E+03	5.26E+03	4.32E+03	
FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	
6.81E+02	2.88E+02	7.59E+02	3.25E+00	9.99E+01	9.44E+02	

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Calculation: Iterations (7)

Commercial Steel: 0.104 feet ID

Discharge Line	Shower Head		Eye Wash			Sum
	Vertical	Horizontal	Vertical [1]	Horizontal	Vertical [2]	
1.44E-03	1.44E-03	1.44E-03	1.44E-03	4.80E-05	1.20E-04	
5.13E+04	5.13E+04	5.13E+04	5.13E+04	5.13E+04	5.13E+04	
5.34E+00	5.34E+00	5.34E+00	5.34E+00	5.34E+00	5.34E+00	
1.04E-01	1.04E-01	1.04E-01	1.04E-01	1.04E-01	1.04E-01	
2.00E+01	4.20E+00	2.30E+00	2.00E-01	5.80E-01	2.50E+00	
1.00E+01	4.20E+00	0.00E+00	-2.00E-01	0.00E+00	2.50E+00	
1.32E+00	1.40E+00	6.75E+00	1.15E+00	7.50E+00	1.50E+00	
5.30E-03	5.30E-03	5.30E-03	5.30E-03	2.40E-03	3.10E-03	
2.39E+00	9.98E-01	3.19E+00	5.27E-01	3.34E+00	7.96E-01	1.19E+00
6.05E+03	5.28E+03	4.96E+03	5.28E+03	5.26E+03	5.05E+03	
5.28E+03	4.96E+03	4.32E+03	5.26E+03	5.05E+03	4.32E+03	
FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	
7.68E+02	3.22E+02	6.38E+02	2.03E+01	2.07E+02	7.33E+02	

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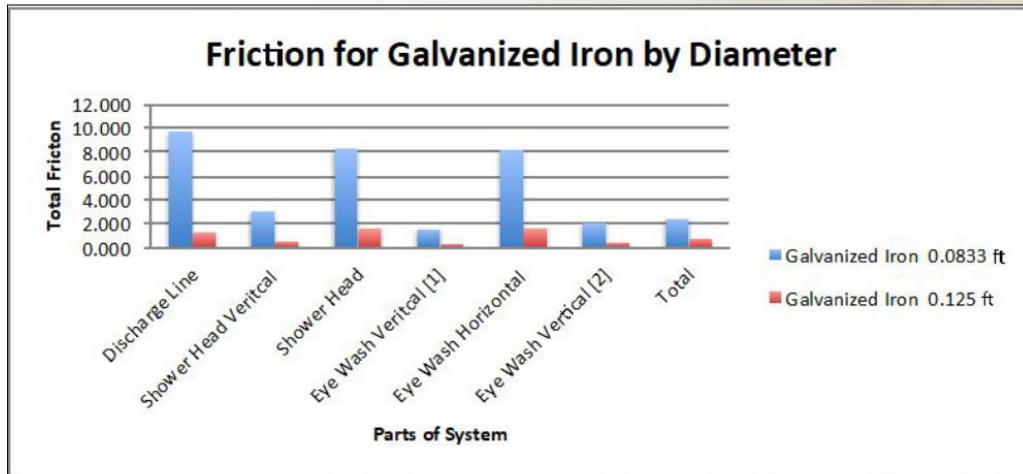
Calculation: Iterations (8)

Commercial Steel: 0.146 feet ID

Discharge Line	Shower Head		Eye Wash			Sum
	Vertical	Horizontal	Vertical [1]	Horizontal	Vertical [2]	
1.03E-03	1.03E-03	1.03E-03	1.03E-03	3.43E-05	8.57E-05	
3.66E+04	3.66E+04	3.66E+04	3.66E+04	3.66E+04	3.66E+04	
2.72E+00	2.72E+00	2.72E+00	2.72E+00	2.72E+00	2.72E+00	
1.46E-01	1.46E-01	1.46E-01	1.46E-01	1.46E-01	1.46E-01	
2.00E+01	4.20E+00	2.30E+00	2.00E-01	5.80E-01	2.50E+00	
1.00E+01	4.20E+00	0.00E+00	-2.00E-01	0.00E+00	2.50E+00	
1.32E+00	1.40E+00	6.75E+00	1.15E+00	7.50E+00	1.50E+00	
5.10E-03	5.00E-03	5.00E-03	5.00E-03	2.20E-03	2.90E-03	
4.74E-01	2.28E-01	8.14E-01	1.36E-01	8.68E-01	1.96E-01	5.35E+03
6.05E+03	5.40E+03	5.12E+03	5.40E+03	5.40E+03	5.35E+03	
5.40E+03	5.12E+03	4.32E+03	5.40E+03	5.35E+03	4.32E+03	
FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	
6.49E+02	2.75E+02	8.04E+02	-3.99E+00	5.38E+01	1.03E+03	

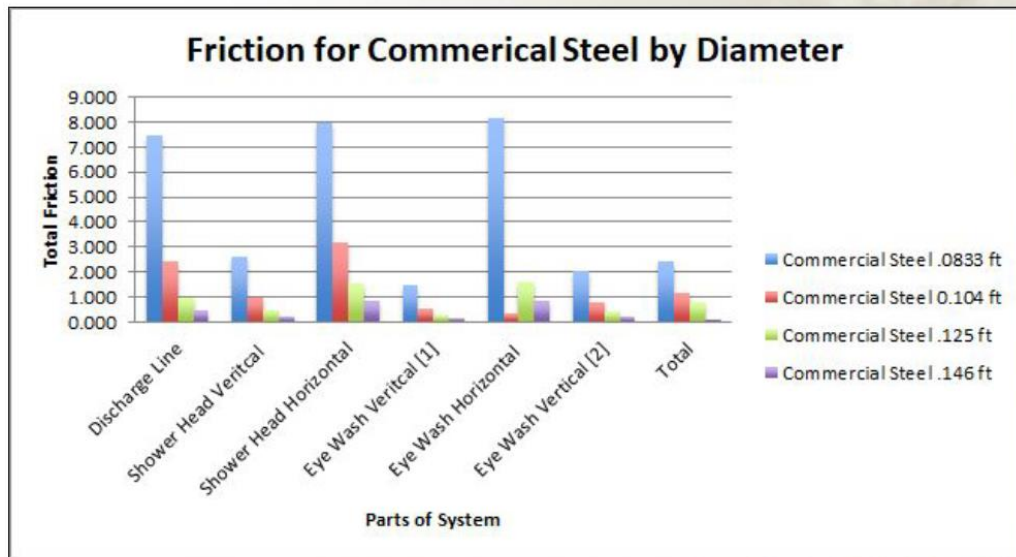
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Total Friction Comparison



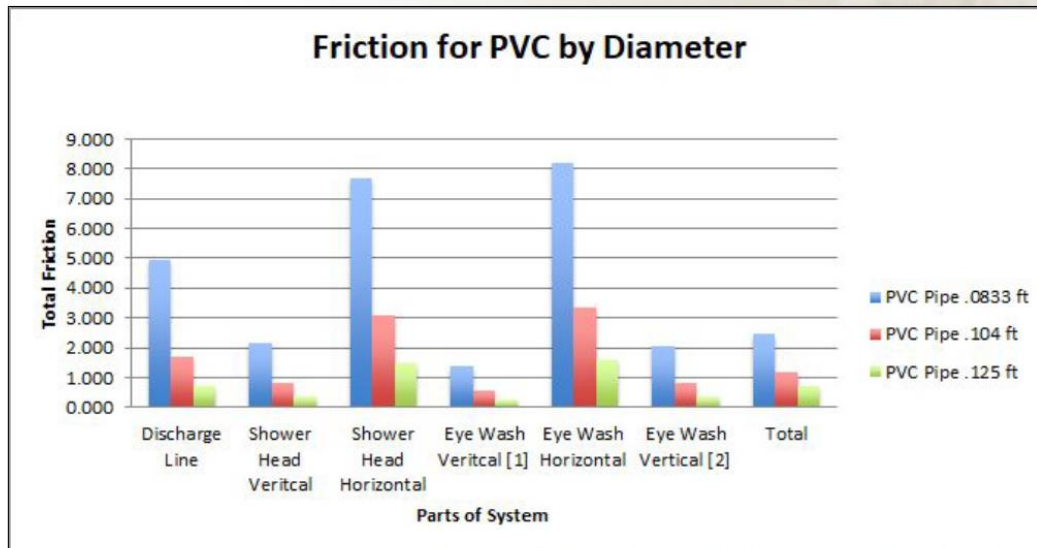
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Total Friction Comparison (2)



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Total Friction Comparison (3)



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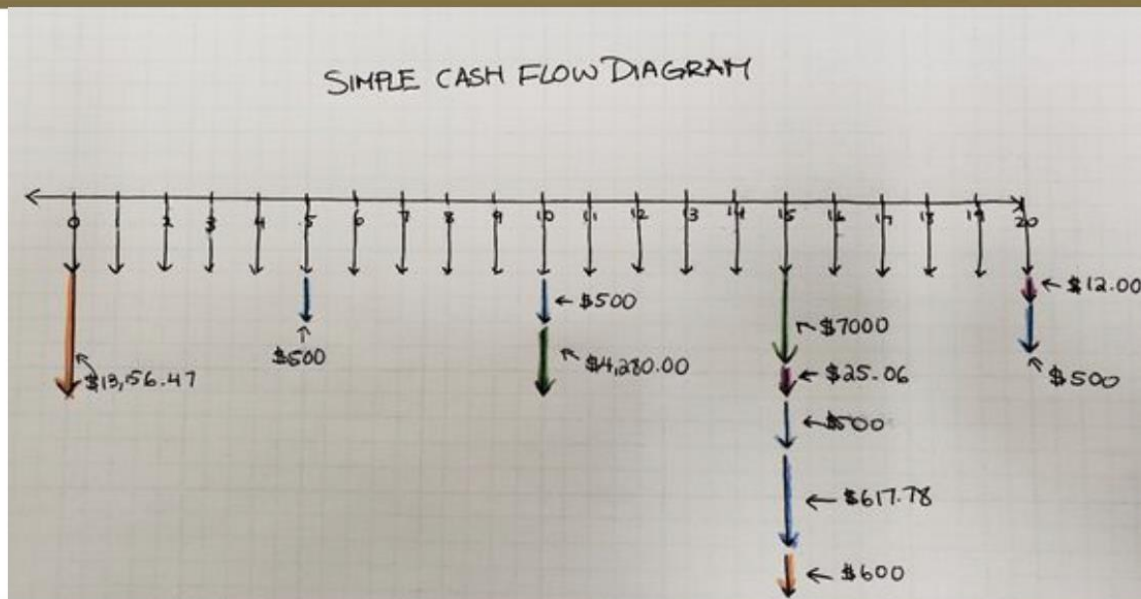
Economic Analysis

<u>Materials</u>	<u>Quantity</u>	<u>Cost</u>	<u>(Quantity* Cost)</u>	<u>Type</u>	<u>Sizing</u>	<u>Sustainability</u>
Tank	1	\$7,000	\$7,000	Plastic	20,000 gal.	15-20 years
Gate valves	2	\$250.00	\$500.00	Cast iron	1.5 in. dia.	5 years (review)
Elbows	2	\$25.00	\$50.00	Stainless steel	1.5in. dia.	15-25 years
Piping (1)	1 (10ft/each)	\$12.00	\$12.00	Galvanized iron	1.5in. dia.	20-50 years
Piping (2)	13 (10ft/each)	\$5.51	\$71.63	PVC	1.5in. dia.	30-50 years
Piping (3)	2 (12ft/each)	\$12.53	\$25.06	Commercial Steel	1.5in. dia.	15-25 years
Pump	1	\$617.78	\$617.78	Cast iron	N/A	15 years
Heater	1	\$4,280.00	\$4,280.00	18 ga. steel	N/A	10-15 years
Shower & eyewash unit	1	\$600	\$600.00	Commercial Steel	N/A	15-25 years

Total Cost : \$13,156.47

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Economic Analysis (2)



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Economic Analysis (3)

$(F/P, 4\%, 20) = 2.1911$	$(P/F, 4\%, 5) = 0.8219$	$(P/F, 4\%, 10) = 0.6756$	$(P/F, 4\%, 15) = 0.5553$
---------------------------	--------------------------	---------------------------	---------------------------

$$\begin{aligned} FW = & -[13,156.47(F/P, 4\%, 20) + 1,500(F/A, 4\%, 20) + \\ & 500(P/F, 4\%, 5)(F/P, 4\%, 20) + (4280 + 500)(P/F, 4\%, 10)(F/P, 4\%, 20) + \\ & (7000 + 25.06 + 500 + 617.78 + 600)(P/F, 4\%, 15)(F/P, 4\%, 20) + 12 + 500 + 1500] \end{aligned}$$

Future Worth: **-\$52,739.66**

OSHA Penalty Cost:

Serious violations: \$12,675-\$13,260

Repeat violations: \$126,749-\$132,598

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Conclusion: What We Learned

- The importance of having a fail safe in Excel, because it can not tell you when there are physical limitations.
- Networking and external resources were vital to determining specification on piping and equipment.
- Using economic analysis on a real application to determine cost and future worth.
- The financial impact of companies.

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Conclusion

1. Limitation

- a. Heat exchanger
- b. Centrifugal pump
- c. Construction sites
 - i. Water tower

2. Economic & Engineering Challenges

- a. Physical design
- b. Material limitations
 - i. Sustainability (material) vs. Cost

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Conclusion: Feasibility

- Safety showers and eyewash stations are very popular in various industries, thus making this project feasible.
- Ideally, one process won't be made to supply just one station.
- Although the project is feasible, it is not economically practical.

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**OUTCOME “7” SPECIFIC ASSIGNMENTS
USED TO ASSESS THE OUTCOME IN**

**CHEG 4472 - SENIOR DESIGN AND
PROFESSIONALISM I**

CHEMICAL ENGINEERING DEPARTMENT
OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET
CHEG 4472-P02 SENIOR DESIGN &
PROFESSIONALISM I
FALL 2019
Instructor: DR. LEALON L. MARTIN

Title of Assignment

HOMEWORK 4

Outcome Measured Using this Assignment

Outcome 7

An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Check the outcome appropriate characteristics related to this assignment

Ability to Acquire new knowledge using the appropriate learning strategies	
Requires students to:	
X	Be knowledgeable of and use different learning strategies <i>(Instructor may provide information on different learning strategies)</i>
X	Identify and take advantage of learning opportunities available in the library, online resources, seminars, webinars, conferences, workshops and tutorials.
X	Be aware of the need for and are able to independently acquire additional knowledge and data needed for solving problem using appropriate learning strategies and tools.
Ability to apply new knowledge to solve problems	
Requires students to:	
X	Demonstrate appropriate use of the new knowledge to solve problems.

Brief justification of the suitability of assignment for the outcome

The assignments test competency in the areas that include problems that test student's ability to identify, retrieve, and organize information needed for a particular new task even if the task is outside of their area of expertise.

CHEG 4472: SENIOR DESIGN & PROFESSIONALISM I

FALL 2019 ASSIGNMENT STATEMENT/QUESTIONS

Senior Design & Professionalism I (Fall 2019): Home Work 4

You will be graded based on your ability to engage in life-long learning. Start each question on a new page. Clarity of presentation is essential if you are to avoid losing points.

Present a comprehensive literature review/survey of your project, citing all sources. Include (a) an introduction, (b) review of literature on production of your product including process/production routes, physical and chemical properties, handling and storage, uses and product specification, (c) process selection (using process sorting), (d) process description, stating the main steps involved in the production, and providing details of the steps involved.

Note: Make sure to use effective and well-placed subheadings, so that the sections and subheadings follow the logical sequence of the report outline.

Limiting your sources to only the internet or merely copying what you find in the literature without a brief discussion highlighting the relevance or otherwise of the information will be considered inadequate.

DEPARTMENT OF CHEMICAL ENGINEERING
SENIOR DESIGN & PROFESSIONALISM I CHEG 4472
COURSE ASSESSMENT GRADING SCHEME & OUTCOME

ABET Outcome 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Assignments that test competency in this area will include problems that test a student's ability to identify, retrieve, and organize information needed for a particular new task even if the task is outside of their area of expertise.

Name: _____

Title of Assignment: _____ Due Date _____

Competency Area		
7. Ability to engage in in life-long learning <i>Effectively use library and online resources for research and are abreast with current developments relating to the project</i>	Max for this Assignment	Your Score
(i) Identify the types of information needed for a complete understanding of all aspects of the project (Based on task described in the project planning).	25	
(ii) Gather information on relevant fundamentals, theory / concept (demonstrate technical competence) and relate them to the design.	50	
(iii) Provide the sources in a list of references properly cited in the literature review section and relevant sections of the report.	25	
TOTAL	100	

DEPARTMENT OF CHEMICAL ENGINEERING
SENIOR DESIGN & PROFESSIONALISM I CHEG 4472
COURSE ASSESSMENT GRADING SCHEME & OUTCOME

ABET Outcome 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Assignments that test competency in this area will include problems that test a student's ability to identify, retrieve, and organize information needed for a particular new task even if the task is outside of their area of expertise.

Name: Bio-Design Group #2

Title of Assignment: H.W. #3 Due Date: _____

Competency Area		
7. Ability to engage in in life-long learning	Max for this Assignment	Your Score
<i>Effectively use library and online resources for research and are abreast with current developments relating to the project</i>		
(i) Identify the types of information needed for a complete understanding of all aspects of the project (Based on task described in the project planning).	25	20
(ii) Gather information on relevant fundamentals, theory / concept (demonstrate technical competence) and relate them to the design.	50	50
(iii) Provide the sources in a list of references properly cited in the literature review section and relevant sections of the report.	25	15
TOTAL	100	85

CHEG 4472: SENIOR DESIGN & PROFESSIONALISM I
FALL 2019

ASSIGNMENT STATEMENT/QUESTIONS

Senior Design & Professionalism I (Fall 2019): Home Work 3
Due October 17, 2019

You will be graded based on your ability to engage in life-long learning. Start each question on a new page. Clarity of presentation is essential if you are to avoid losing points.

Present a comprehensive literature review/survey of your project, citing all sources. Include (a) an introduction, (b) review of literature on production of your product including process/production routes, physical and chemical properties, handling and storage, uses and product specification, (c) process selection (using process sorting), (d) process description, stating the main steps involved in the production, and providing details of the steps involved.

Note: Make sure to use effective and well-placed subheadings, so that the sections and subheadings follow the logical sequence of the report outline.

Limiting your sources to only the internet or merely copying what you find in the literature without a brief discussion highlighting the relevance or otherwise of the information will be considered inadequate.

Where is your pdf?

I. Introduction

The goal ^{of} for this project is to design a chemical plant that produces glucose-fructose syrup that will match the current global supply and demand for the product. The plant designing process involves many steps such as economic analysis, process specification, safety and handling of product, mass and energy balances of the systems, etc. High Fructose Syrup (HFS) or glucose-fructose syrup is a high valued liquid sweetener for the food and beverage industries containing positive attributes such as high sweetness, non-crystalline nature, ability to enhance flavor in food products and keeps products fresh by maintaining moisture content [1]. Since globally sugar consumption is continually increasing within these industries, there ^{is} will be a need to look for alternate ^{lines} sugar substitutes from sugar cane due to increase in expense [1]. Syrup sweeteners provide a relatively cheap alternative for food and beverage industries than [?] graduated sugar [2]. HFS is traditionally produced using three cost-intensive enzyme reactors such as liquefaction, saccharification, and isomerization with a raw material containing starch [3]. Since the conversion of the raw materials to starch is a very expensive process, the inversion of sucrose into inverted sugar will provide an economic advantage by producing two products for the food and beverage industry (Inverted sugar & HFS) [4]. This literature review studies the production details and properties of glucose-fructose syrup that is cost-effective and efficient for food and beverage industries.

II. Production of Fructose Syrup

a. Process Route

The Drafting of our system's process for Fructose-Glucose Syrup (HFS) production was accomplished in part by the use of numerous resources and forms of literature to support and give a better insight of both process design and process routes. There are numerous process routes for the production of HFS, many of which include processing raw materials that yield starch. This starch is reacted to form glucose, which will be further processed to HFS. For these starch-based raw materials, corn, cassava, and potato are commonly used, regarding usage in HFS production. Between these starch-based routes deviation in the process lies in the method of isolating starch. Each starch-based process has focused on maximizing starch removal techniques. For example, corn utilizes steeping which involves soaking corn kernels in a water solution with added sulfur dioxide to loosen up starch in relation to gluten and fiber, and for potatoes rasping (a process of grinding up potatoes and disrupting the cell wall to free up starch within amyloplast). But the chemistry of these processes follows the same three steps to yield HFS: liquefaction, saccharification, and isomerization. Liquefaction describes the process of partial hydrolysis and saccharification completion of hydrolysis resulting in starch conversion to glucose [3]. Isomerization will take care of glucose conversion to fructose through use enzyme of glucose isomerase.

In retrospect to starch-based production for our process design sugar beets could be used as raw material to form sucrose which could be reached through hydrolysis to yield inverted sugar. This alternative process is common in the production of sucrose and can produce viable coproducts of molasses and animal feed (from beet pulp removed in sugar

why? why not just use corn or potatoes??

beet extraction) [14]. That ^{be}invert sugar can split into two streams to produce both glucose and fructose syrup which is refined for deashing and removal of impurities.

b. Physical Properties [15]

- For HFS 42 density 1333.67 kg/m³, solid 946.63
- For HFS 55 1373.21 kg/m³, solid 1056.87
- Viscosity HFS42(@27C): 0.16 Pa*s
- Viscosity HFS 55(@27C): 0.76 Pa*s,
- Colorless, odorless

c. Chemical Properties [16]

- Freezing/Melting Point: 103-105 deg C (dec)
- Decomposition Temperature: 103-105 deg C
- Solubility: Freely Soluble
- Molecular Formula: C₆H₁₂O₆
- Molecular Weight: 180.16
- Chemical Stability: stable under normal conditions
- Incompatible materials: strong acid and bases, oxidizing agents

d. Handling and Storage

- HFS should be handled with care while properly observing proper industrial hygiene. Appropriate protective equipment should be worn and contact with the eye should be avoided [5].
- HFS should be stored at room temperature in a cool and dry place with proper ventilation. The container should be sealed tightly, and the product should be kept away from incompatible materials [5].

e. Uses

Glucose Fructose Syrup is also commonly known as High Fructose Syrup (HFS) because of the higher composition of fructose present in the syrup mixture. HFS is usually named based on the composition of fructose present in the syrup. The three common forms produced industrially are HFS-42, HFS-55, and HFS-90. HFS-90 is the major product obtained and is further processed to yield HFS-42 and HFS-55 which are used in the food and beverage industries as sweeteners. HFS-55 is widely used in the production of carbonated soft drinks while HFS-42 which is not as sweet is generally used in the production of baked goods, noncarbonated beverages and many processed foods [6]. When compared to sucrose, HFS possesses qualities that are beneficial in the food industry. Firstly, it is relatively cheaper than sucrose. Secondly, it has preservative properties because of its high acidity. Thirdly, it is more soluble and does not crystallize in solutions [3]. In addition to this, it helps to lower the freezing point to retain moisture in certain processed foods such as cereals and breakfast bars [6].

f. Product Specification

Three types that can be produced are HFS-42, HFS-55, and HFS-90

III. Process Selection

a. Market Analysis

Our target market is the U.S. food and beverage industry. In the U.S., there are over 30,000 processing plants owned by over 26,000 companies. Products include meats, dairy, beverages, animal food, sugar, baked goods, grains, dairy, fruit, and

vegetables. Out of a \$354 billion industry 17 percent is beverage, 18 percent for meats, and 11 percent for baked goods [13].

b. Process Screening

Our process will incorporate sugar beets as our raw materials. The average national price of sugar beets is \$41.20 per short ton. The price of our main products glucose-fructose 42% is 35.21 cents per pound and 41.23 cents per pound for glucose-fructose 55% [13]. The general process is the same no matter the raw materials. The glucose is converted to a glucose-fructose mixture of the desired concentration. The cost of starch conversion to glucose is higher than converting sucrose to glucose. Correspondingly, the process of converting starch is more complex than sucrose. The sucrose is inverted and forms equal amounts of glucose and fructose in cation resins. The Ca^{++} form of the same resin separate glucose from fructose using a column chromatography [4]. Allowing for simple mixing form the product concentration (Inverted sugar & HFS) [4]. So, instead of using a starch such as cassava, potatoes, or corn we choose sugar beets. Sugar beets are chosen over sugarcane due to it being the cheaper raw material.

what about other starch sources?
what is this in cents per pound?

why? justification

reference??
what about corn??
where will you get sugar beets?

IV. Process Description

Two different process description routes:

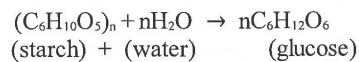
1. Starch Hydrolysis

Starch hydrolysis is the breakdown of bonds in the starch molecule using water. This process can be facilitated by the use of acids or enzymes (amylases). Acidic hydrolysis gives a lower yield and increased undesired by-products. [11] therefore, enzymatic hydrolysis is more favorable in industrial use. First, starch extracted from the raw material undergoes

first

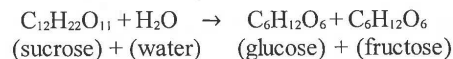
gelatinization where the starch is broken down with the addition of heat and water and a slurry is formed. Liquefaction occurs next and the starch slurry is partially hydrolyzed to give oligosaccharides like maltose and thermostable α -amylase enzyme is used to speed up the reaction. This slurry then undergoes saccharification which is the hydrolysis of carbohydrates such as starch, with water [7]. In saccharification, glycosidic bonds of the starch molecule are broken down into simple sugars using glucoamylase enzyme as the catalyst. This process converts the starch slurry to glucose syrup. To obtain the desired concentration of fructose, glucose isomerase enzyme is added to the glucose syrup in an enrichment column and some glucose is isomerized to fructose [10]. Suggested bioreactor temperature is 60 – 65°C [8].

The overall reaction for the conversion of starch to glucose is shown below where n is from 50 to thousands:



2. Sucrose Inversion

Sucrose inversion is the hydrolysis of sucrose to an equimolar mixture of glucose and fructose (50:50). This equimolar mixture is also known as invert sugar which is sent to an enrichment column where the fructose concentration is increased. Any remaining glucose syrup can be subject to isomerization until the desired fructose concentration is achieved. The overall reaction for sucrose inversion to invert sugar is represented by the equation below:



Invertase is the commercial enzyme used for sucrose inversion which is usually carried out in a fixed bed reactor with a strong cation resin [4]. Research showed into the use of immobilized invertase shows successful sucrose hydrolysis [9] and suggested operational temperature for the enzyme in the reactor is 55 – 60°C.

please be consistent
in presenting your references!!

References

- [1] Johnson, Regy, et al. "Production of High Fructose Syrup from Cassava and Sweet Potato Flours and Their Blends with Cereal Flours." *Food Science and Technology International*, vol. 16, no. 3, June 2010, pp. 251–58, doi:10.1177/1082013210366770.
- [2] Kay Parker, Michelle Salas and Veronica C. Nwosu. "High Fructose Corn Syrup: Production, Uses and Public Health Concerns." *Biotechnology and Molecular Biology Reviews*, vol. 5, no. 5, 2010, pp. 71–78, <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.967.775&rep=rep1&type=pdf>.
- [3] Johnson, Regy, G. Padmaja, and S.N. Moorthy. "Comparative Production of Glucose and High Fructose Syrup from Cassava and Sweet Potato Roots by Direct Conversion Techniques." *Innovative Food Science & Emerging Technologies* 10.4 (2009): 616-20. Print.
- [4] Gehlawat, J. K. "New technology for invert sugar and high fructose syrups from sugarcane." *Indian Journal of Chemical Technology*, vol. 8, 1998.
- [5] Newseeu. "High Fructose Corn Syrup MSDS, High Fructose Corn Syrup Materials Safety Data Sheet." *Food Additives & Ingredients Supplier - Newseed Chemical Co., Limited*. N.p., 03 Jan. 2018. Web. 17 Oct. 2019.
- [6] Jacqueline, Marcus. "High Fructose Corn Syrup." *High Fructose Corn Syrup – an Overview* | ScienceDirect Topics. N.p. 2019. Web.

- [7] Azmi, A, et al. "A Review on Acid and Enzymatic Hydrolyses of Sago Starch." *International Food Research Journal*, 2017, pp. 265– 273, www.ifrj.upm.edu.my/vv.
- [8] Converti, A, et al. "Simulation of a Reactor for Glucose Isomerization to Fructose by Immobilized Glucose Isomerase with Continuous Enzyme Renewal." *Biotechnology Techniques*, vol. 11, no. 2, 1997, pp. 99–103.
- [9] Kilara, Arun, et al. "The Use of Immobilized Enzymes in the Food Industry: A Review.." *C R C Critical Reviews in Food Science and Nutrition*, vol. 12, no. 2, 1979, pp. 161–198., doi:10.1080/10408397909527276.
- [10] Lima, Danyo, et al. "Fructose Syrup: A Biotechnology Asset." *Food Technology and Biotechnology*, 2011, pp. 424–434.
- [11] Ramprakash, Balasubramani, and Karuppan Muthukumar. "Comparative Study on the Production of Biohydrogen from Rice Mill Wastewater." *International Journal of Hydrogen Energy*, vol. 39, no. 27, 2014, pp. 14613–14621. *ScienceDirect*, doi:10.1016/j.ijhydene.2014.06.029.
- [12] Schenck, Fred. "Glucose and Glucose-Containing Syrups." *Ullmann's Food and Feed*, by Barbara Elvers and Fritz Ullmann, Wiley-VCH Verlag GmbH & Co. KGaA, 2017.
- [13] "Background of Sugar Beets." *USDA ERS - Background*. N.p. n.d. Web. 17 Oct. 2019.
- [14] Singh, R.. (2014). *Membrane Technology and Engineering for Water Purification: Application, Systems Design and Operation: Second Edition*.
Membrane Technology and Engineering for Water Purification: Application, Systems Design and Operation: Second Edition. 1-435.

- [15] Hanover, L M, and J S White. "Manufacturing, Composition, and Applications of Fructose." *The American Journal of Clinical Nutrition*, vol. 58, no. 5, Jan. 1993, doi:10.1093/ajcn/58.5.724s.
- [16] "D-Fructose SDS." 24 Oct. 2014.

CHEG 4472-P01: SENIOR DESIGN & PROFESSIONALISM I

FALL 2019

ASSIGNMENT STATEMENT/QUESTIONS

Senior Design & Professionalism I (Fall 2019): Home Work 4 Due: November 7, 2019

You will be graded based on your understanding of professional and ethical responsibilities as they relate to your project. Clarity of presentation is essential if you are to avoid losing points.

- 1. Write a 2-page synopsis comparing the National Council of Examiners for Engineering and Surveying (NCEES) code of professional conduct with the American Institute of Chemical Engineers (AIChE) and National Society of Professional Engineers (NSPE) code of ethics.**
- 2. Using the NSPE Code of Ethics, analyze the following case study. For the case study, justify your opinions by quoting relevant sections of the NSPE Code of Ethics that supports the opinion you make and why the opposite opinion may not be right.**

Case Study

Fact pattern:

Engineer A is a principal in a medium-sized engineering firm with expertise in mechanical and electrical engineering. Engineer A's firm is retained on a speculative basis by Engineer B, a local civil engineer, to assist City X in applying for a federal grant for certain wastewater treatment equipment upgrades for the city's wastewater treatment facility. The application is successful, City X obtains the grant, and Engineer B is retained to design the waste water equipment upgrades. In recognition of Engineer A's work in securing the grant, Engineer C, the chief city engineer, verbally promises to select Engineer A's firm on a future engineering project for City X.

Question: Was it ethical for Engineer C to offer to select Engineer A's firm on a future engineering project for City X?

CHEMICAL ENGINEERING DEPARTMENT

SENIOR DESIGN & PROFESSIONALISM I CHEG 4472

GRADING SCHEME AND OUTCOME ASSESSMENT SHEET FOR FALL 2019

ABET OUTCOME 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts

Assignments that test competency in this area will include problems that test the student knowledge in the Professional Code of Ethics, ability to apply relevant aspects of the professional code of ethics when considering alternative decisions or solutions, ability to ethically evaluate the short and long term impact of engineering solutions on community and environment.

Names:

Adeyemi, Tope

Aliado, Michael A.

Anderson, Javon J.

Guillory, Cayla

Brooks Jr, Nigel P.

Title of Assignment: Engineering Ethics

Competency Area	Max for this Assignment	Your Score
4.1 An understanding of professional and ethical responsibility <i>This assignment tests the student knowledge in the Professional Code of Ethics, and ability to apply relevant aspects of the professional code of ethics when considering alternative decisions or solutions.</i>	100	85
TOTAL	100	85

857

Senior Design & Professionalism I
Homework # 4

Submitted by

Tope Saheed Ade
Michael Aliado
Nigel Brooks Jr.
Javon Anderson
Cayla Guillory

To
~~Dr. Leon Martin~~

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

November 7, 2019

Comparison of the three codes of ethics

Having a strong understanding and appreciation for a code of ethics is critical to the success and longevity of an engineer's career. A devotion to such a code of ethics allows an engineer to ultimately shape and execute difficult decisions which affect the safety and wellbeing of those around him/her. Under stressful situations, economics can drive an engineer to take shortcuts and risks to ensure the completion of a project. Despite the concern for profitability and efficiency, an engineer's code of ethics must always have the safety of the general public at the forefront of each decision. Many professional engineering organizations stringently maintain and uphold their own ethics for each discipline of engineering that exists, and it is well understood that each engineer should meticulously adhere to these codes.

In this report, the codes of conduct and ethics from three engineering organizations will be compared. The three organizations in question are the National Council of Examiners for Engineering and Surveying (NCEES), the National Society of Professional Engineers (NSPE), and the American Institute of Chemical Engineers (AIChE). Upon examining the codes of conduct for all three organizations, they heavily emphasize that engineers have a direct responsibility for the health and safety of the public. For example, in the case that an engineer's judgement is overruled in circumstances that endanger life or property, it is the engineer's responsibility to notify their client, employer, or another authority of the risks that come with such a decision. [1] If an engineer does not voice valid concerns or deliberately approves something that is not properly regulated and may endanger the public welfare, severe consequences will be dealt notwithstanding the potential loss of life and property. Remaining silent on any decision-making process is an unacceptable behavior, as ordained by all three codes of ethics.

Another consideration found in all three organizational code of ethics is that it is unethical for an engineer to perform professional services outside of their area of competence. [2] Professional engineers must be properly trained and tested from an accredited institution for them to work. It is a commonly shared sentiment that no one would want an unlicensed doctor to perform a surgery on them, and it is the same for any professional. Engineers must be able to demonstrate that they are able to competently execute technical tasks before beginning work on a project. Similarly, engineers must demonstrate that they are able to maintain a high level of integrity regarding confidentiality. Unless required by law, engineers should not breach confidentiality with their clients/employers by revealing facts, data, or information obtained in a professional capacity without the prior consent of the client/employer. [3] Selling a client's trade secrets to a competitor for personal monetary profit is unethical and shows that such an individual is untrustworthy for future endeavors.

Comparatively, while the three organizations all have common facets found in their code of ethics, the main differences between them are that they are tailored to a specific audience. The NSPE code of ethics is targeted at engineers who have attained their professional engineer license (PE). A PE is the only engineer who can prepare, sign and seal, and submit engineering plans or drawings to a public authority for approval, or seal engineering work for other clients. [1] As a result, the NSPE code of ethics contains sections that are specific to that type of work. The NCEES code of professional conduct is similar to the NSPE code of ethics, though it also includes provisions specific to surveyors. The AIChE code of ethics is primarily tailored to chemical engineers and those who work in the chemical processing industry. While each organization's code of ethics and professional conduct address different audiences, all three maintain that engineers of all disciplines should conduct business and perform their work at the highest accordance to their respective ethical code.

PART B: Using the NSPE Code of Ethics, analyze the following case study. For the case study, justify your opinions by quoting relevant sections of the NSPE Code of Ethics that supports the opinion you make and why the opposite opinion may not be right.

In reviewing this case study, all conduct was ethical until engineer C. Being the chief city engineer, promised engineer A's firm a future engineering project. The promise of this offer is a violation of multiple codes of ethics laid out in the NSPE code of ethics handbook. The following are potential areas of unethical behavior and or actions.

Section 4c. states that, "Engineers shall not solicit or accept financial or other valuable consideration, directly or indirectly, from outside agents in connection with the work for which they are responsible." Engineer A's firm accepting an indirect offer for a future project in City X. Based on their connection in successfully receiving a grant for City X, it is a clear violation of NSPE rules.

No. How did A violate this rule? No offer or solicitation.

Under section 4e "Engineers shall not solicit or accept a contract from a governmental body on which a principal or officer of their organization serves as a member." [1] Engineer A accepting such an offer in this circumstance from the city engineer, while being retained by Engineer C violates NSPE rules of practice.

No. C has no employment or financial interest in A

Section 5b "Engineers shall not offer, give, solicit, or receive, either directly or indirectly, any contribution to influence the award of a contract by public authority, or which may be reasonably construed by the public as having the effect or intent of influencing the awarding of a contract. They shall not offer any gift or other valuable consideration in order to secure work." [1] The city engineer, a public official, is promising "to select Engineer A's firm on a future engineering project for City X" based on his work in securing a grant for City X. Should an offer be accepted by Engineer A's firm, such actions could be reasonably construed by the public as being biased, and is in violation of NSPE rules.

No. That's a stretch.

The real issue is whether A is ^{shown} competent to work on just any future project. This is determined through the bidding/proposal process, which C is attempting to circumvent

References

- [1] "Code of Ethics." Code of Ethics | National Society of Professional Engineers. July 2007.
Accessed November 2, 2019. <https://www.nspe.org/resources/ethics/code-ethics>.
- [2] "Rules of Professional Conduct." NCEES Model Rules of Professional Conduct. Accessed
November 2, 2019. <http://sites.bsye.wsu.edu/pitts/be120/handouts/codes/ncees.htm>
- [3] "Code of Ethics." AIChE. November 2, 2019. Accessed November 2, 2019.
<https://www.aiche.org/about/code-ethics>.

CHEG 4472-P01: SENIOR DESIGN & PROFESSIONALISM I

FALL 2019

ASSIGNMENT STATEMENT/QUESTIONS

Senior Design & Professionalism I (Fall 2019): Home Work 4 Due: November 7, 2019

You will be graded based on your understanding of professional and ethical responsibilities as they relate to your project. Clarity of presentation is essential if you are to avoid losing points.

- 1. Write a 2-page synopsis comparing the National Council of Examiners for Engineering and Surveying (NCEES) code of professional conduct with the American Institute of Chemical Engineers (AIChE) and National Society of Professional Engineers (NSPE) code of ethics.**
- 2. Using the NSPE Code of Ethics, analyze the following case study. For the case study, justify your opinions by quoting relevant sections of the NSPE Code of Ethics that supports the opinion you make and why the opposite opinion may not be right.**

Case Study

Fact pattern:

Engineer A is a principal in a medium-sized engineering firm with expertise in mechanical and electrical engineering. Engineer A's firm is retained on a speculative basis by Engineer B, a local civil engineer, to assist City X in applying for a federal grant for certain wastewater treatment equipment upgrades for the city's wastewater treatment facility. The application is successful, City X obtains the grant, and Engineer B is retained to design the waste water equipment upgrades. In recognition of Engineer A's work in securing the grant, Engineer C, the chief city engineer, verbally promises to select Engineer A's firm on a future engineering project for City X.

Question: Was it ethical for Engineer C to offer to select Engineer A's firm on a future engineering project for City X?

CHEMICAL ENGINEERING DEPARTMENT
SENIOR DESIGN & PROFESSIONALISM I CHEG 4472
GRADING SCHEME AND OUTCOME ASSESSMENT SHEET FOR FALL 2019

ABET OUTCOME 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts

Assignments that test competency in this area will include problems that test the student knowledge in the Professional Code of Ethics, ability to apply relevant aspects of the professional code of ethics when considering alternative decisions or solutions, ability to ethically evaluate the short and long term impact of engineering solutions on community and environment.

Names:

Bustos Escudero, Hector

Epperson, Angela

Clark, Randall L.

Drey, Michael J.

Duruzor, Chris

Title of Assignment: Engineering Ethics

Competency Area	Max for this Assignment	Your Score
4.1 An understanding of professional and ethical responsibility <i>This assignment tests the student knowledge in the Professional Code of Ethics, and ability to apply relevant aspects of the professional code of ethics when considering alternative decisions or solutions.</i>	100	85
TOTAL	100	85

85

**CHEG 4472-P02 SENIOR DESIGN AND PROFESSIONALISM I
FALL 2019
PROJECT ASSIGNMENT COVER SHEET**

GROUP NUMBER 2

ASSIGNMENT # 4

Assignment Title Ethics Assignment Due Date: November 7, 2019

No	Group Member Name Group Member Signature	Brief Description of Work Assigned to Member	% Completed by Member*	Your Score
1	Heather Pustus Escondido <i>HP</i>	Complete a portion of question 1	100%	
2	Aracelis Ipperson <i>Aracelis Ipperson</i>	Critique report and add to question 2.	100%	
3	Ronald Clark <i>Ronald Clark</i>	Complete a portion of question 2	100%	
4	Michael Drey <i>Michael Drey</i>	Complete a portion of question 1	100%	
5	Chris Dreyer <i>Chris Dreyer</i>	Complete a portion of question 2	100%	

*100% means the member completed his/her assigned work.

By signing this assignment cover sheet, I agree that the percentages stated in the % completed column reflect the contribution made by me and other members of the group.

CHEG 4472-P02 SENIOR DESIGN AND PROFESSIONALISM I FALL 2019

MINUTES OF GROUP MEETINGS

Meeting Date: 11/5/2019 Meeting Time: 10:00am
Meeting Location: C.L. Wilson

Members Present: Hector Bustos Escudero, Angela Epperson, Randall Clark, Michael Drey, Chris Duruzor

Agenda for Meeting (List all items to be discussed or discussed at the meeting)

- Complete and revise power-point to meet all requirements
- Review Gantt chart and update team members
- Start Material and Energy Balance for block flow diagram
- Schedule meeting with Dr. Martin to receive graded work back

Detailed Minutes: (should include name of speaker and summary of what he/she suggested)

- Angela Epperson
 - 30 Minutes
 - Suggested working on the final report and making corrections from the graded report.
- Randall Clark
 - 30 Minutes
 - Suggested finding a plant within the Galveston Bay area to visit to gain a better understanding of ethylbenzene and how an industrial process works.
- Michael Drey
 - 30 Minutes
 - Suggested completing the material and energy balance in addition to breaking each component down into smaller segments.
- Hector Bustos Escudero and Chris Duruzor:
 - 30 Minutes
 - Suggested starting the Aspen process before next week

**CHEG 4472-P02 SENIOR DESIGN AND PROFESSIONALISM I
FALL 2019**

TASK ASSIGNMENT & DELIVERABLES AT MEETINGS

Use this table to document task assigned and deliverables completed/submitted by each group member at each meeting. If deliverables are not completed, indicate the actions taken by the group on this individual

Meeting Date: 11/5/2019 Meeting Time: 10:00am
Meeting Location: C.L Wilson

Name	Task Assigned	Deliverables Completed & Submitted
Hector Bustos Escudero	Question 1	- Completed a portion of question one - Searched for differences within the organizations - Introduction
Angela Epperson	Question 2 & Critique	- Critique the entire report for any grammar mistakes - Add to question 2 if needed
Randall Clark	Question 2	Research the scenario and determine which codes were abused
Michael Drey	Question 1	- Completed a portion of question one - Searched for similarities within the organizations - Conclusion
Chris Duruzor	Question 2	Research the scenario and determine which codes were abused

Ethics Assignment

Ethics is a very important theme in the career of an engineer. One of the key concepts in ethics is that it helps guide an engineer on the topic of safety as well as quality. Engineers face challenges on a daily basis and sometimes those challenges involve making major decisions that can impact the safety of all those involved. However, the code of ethics is the guiding principle that makes sure no shortcuts are taken where safety is concerned. Many organizations have ethical codes for different types of engineering disciplines. It is of great importance that every engineer, whether being a student or working professional, to maintain a good understanding of these codes for the safety of everyone at the workplace. In this short paper, a synopsis will be made comparing the code of conduct from three of the most highly credited engineering organizations in the industry.

What is not "public well-being" or "safety" or "competence"

Even though the three organizations have differences, there are still similar traits that the organizations share. One main characteristic/trait is their strong emphasis on engineers' top responsibility to provide the safest decisions for the public. For instance, the National Society of Professional Engineers (NSPE) code of ethics states that "if engineers' judgment is overruled under circumstances that endanger life or property, they shall notify their employer or client and such other authority as may be appropriate." [1] This is a very important code that these organizations have in common. However, it is very unethical and unacceptable for an engineer to remain silent if they are aware of a potentially harmful situation or circumstance. In addition to the expectation for the safest decisions, another common trait between these organizations is engineers' acceptance of responsibility for wrongful actions. For example, according to the American Institute for Chemical Engineers (AIChE) code of ethics, an engineer should "accept responsibility for their actions, seek and heed critical review of their work and offer objective criticism of the work of others." [2] In addition to learning from previous mistakes, taking responsibility in any given situation ensures that proper procedures are followed. Additionally, no one wants to risk termination as a result of someone else's incorrect actions. Another common characteristic is the promotion of competing fairly while offering a diversified opportunity. For example, the National Council of Examiners for Engineering and Surveying (NCEES) code of professional conduct states that an engineer's "professional reputation shall be built on the merit of their services, and they shall not compete unfairly with others." [3] It is never fair to treat anyone unequally, based on a person's sex, religion, race, color, creed, disability, age or

reference.

relationship when competing with others. There are clearly more traits that these organizations have in common. These are just three that play a significant role within the industry.

This section of the report discusses the differences in the ethical codes of the three organizations. The main difference in these codes is the targeted audience. The NSPE Code of Ethics targets engineers who have obtained the Professional Engineer (PE) license from the PE licensure exams. A licensed PE is the only engineer allowed to prepare, sign, and submit engineering plans and drawings to a public authority for approval, or to seal engineering work for public or private clients. [1] As a result, this code of ethics is designed mainly for that purpose. The NCEES Code of Professional Conduct is intended for both PEs and surveyors. This code of conduct is very similar to the NSPE Code of Ethics but adds provisions for the surveyors. Lastly, the AIChE Code of Ethics is specifically for chemical engineers no matter the expertise. This code of ethics can aid any engineer in their work environment. Despite the difference in audiences, all the ethics codes have the same objective of requiring engineers to be ethical in every aspect of their job.

Ethics is important not only for engineers but for society as well. Without ethics, a person has the freedom to lie, cheat, and take advantage of any given situation. Engineers are trusted by society to create brilliant and safe products within their profession while advancing and obtaining knowledge. It is an engineer's responsibility to abide by the ethical codes that are provided by the NCEES, AIChE, and NSPE code of ethics.

Part B: Ethical Case Study

Engineers are held to a higher standard than most professions. As a member of this profession, they are expected to demonstrate the utmost integrity, adhering to the highest principles of ethical conduct. For the case study in question, my group and I believe it did not reflect good ethics for Engineer C to make such an offer to Engineer A. By doing so Engineer C has violated more than one rule set down in the NSPE Code of Ethics. We will be providing the exact codes of ethics in question to justify and support our opinion.

Engineer C is in ethical violation of the NSPE Code of Ethics by selecting Engineer A's Engineering Firm for a future City X engineering project. Engineer C is in clear violation of the Professional Obligations section bullet-point four stating, "Engineers shall not disclose, without consent, confidential information concerning the business affairs or technical processes of any present or former client or employer, or public body on which they serve." [1] In further detail, he/she is violating subpoint b of bullet point four that also states, "Engineers shall not, without consent of all interested parties, promote or arrange for new employment or practice in connection with a specific project for which the engineer has gained particular and specialized knowledge." [1] Engineer C is in violation of these codes because he/she hasn't contacted all parties before notifying Engineer A of his intentions to employ Engineer A's Firm. Engineer C is also putting City X in danger, as Engineer A's Firm has expertise in Mechanical & Electrical engineering, not civil engineering. If Engineer A accepted the offer, the firm would be in infringement of section II.2.A of the NSPE Code of Ethics, "Engineers shall undertake assignments only when qualified by education or experience in the specific technical fields involved." [1] Engineer A could speculate for Engineer B to receive the grant because he/she was protected by section II.2.C of the NSPE Code of Ethics. "Engineers may accept an assignment and assume responsibility for coordination of an entire project and sign and seal the engineering documents for the entire project, provided that each technical segment is signed and sealed only by the qualified engineers who prepared the segment." [1] This clarifies that Engineer A may be permitted to do speculation jobs under Engineer B's supervision or cooperation. Some state statutes and policies governing the awarding of government contracts may also find Engineer C in violation of nepotism laws/policies and may take corrective action against Engineer C. Engineer C should notify his entire crew before attempting to hire Engineer A's firm and do the necessary research to determine if they are qualified for his projects.

How is this violated?

is there a specific project involved?

this is a weak connection

Yes!

yes!!

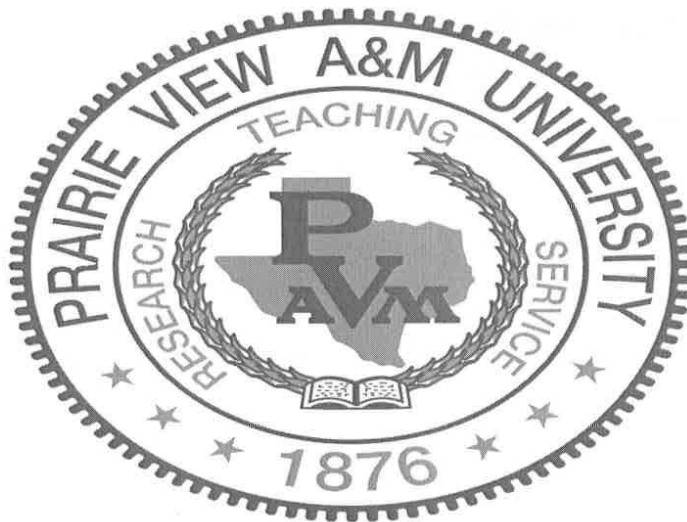
ok.

no mention of parties being related.

Works Cited

1. Code of Ethics. (2019, July). Retrieved from <https://www.nspe.org/resources/ethics/code-ethics>.
2. Code of Ethics. (2019, January 14). Retrieved from <https://www.aiche.org/about/code-ethics>.
3. NCEES Model Rules of Professional Conduct. (1990, July). Retrieved from <http://sites.bsyse.wsu.edu/pitts/be120/Handouts/codes/ncees.htm>.

Prairie View A&M University
Senior Design and Professionalism I
CHEG 4472



Literature Survey on Nitric Acid Production
Homework Assignment 3

Professor: Dr. Lealon Martin

Group 3- ChemRG

Fearon, James
Francisco, Guty K.
Hooks, Ryan R.
Hunter, Maya M.
Jackson II, Robert

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CHEG 4472: SENIOR DESIGN & PROFESSIONALISM I

FALL 2019

ASSIGNMENT STATEMENT/QUESTIONS

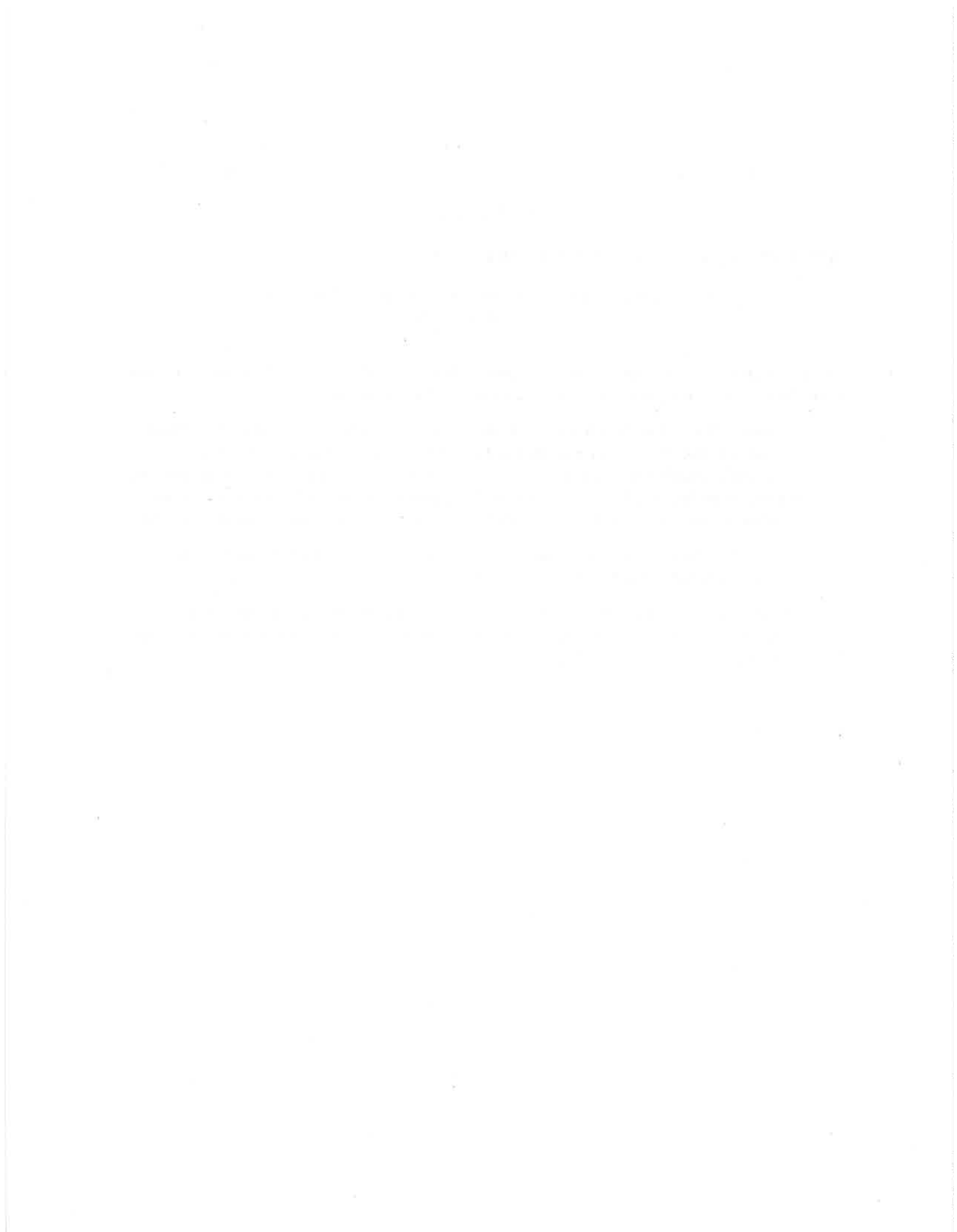
**Senior Design & Professionalism I (Fall 2019): Home Work 3
Due October 17, 2019**

You will be graded based on your ability to engage in life-long learning. Start each question on a new page. Clarity of presentation is essential if you are to avoid losing points.

Present a comprehensive literature review/survey of your project, citing all sources. Include (a) an introduction, (b) review of literature on production of your product including process/production routes, physical and chemical properties, handling and storage, uses and product specification, (c) process selection (using process sorting), (d) process description, stating the main steps involved in the production, and providing details of the steps involved.

Note: Make sure to use effective and well-placed subheadings, so that the sections and subheadings follow the logical sequence of the report outline.

Limiting your sources to only the internet or merely copying what you find in the literature without a brief discussion highlighting the relevance or otherwise of the information will be considered inadequate.



DEPARTMENT OF CHEMICAL ENGINEERING
SENIOR DESIGN & PROFESSIONALISM I CHEG 4472
COURSE ASSESSMENT GRADING SCHEME & OUTCOME

ABET Outcome 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Assignments that test competency in this area will include problems that test a student's ability to identify, retrieve, and organize information needed for a particular new task even if the task is outside of their area of expertise.

Name: Gray 3

Title of Assignment: H.W #3 Due Date 10/17/2019

Competency Area		
7. Ability to engage in in life-long learning	Max for this Assignment	Your Score
<i>Effectively use library and online resources for research and are abreast with current developments relating to the project</i>		
(i) Identify the types of information needed for a complete understanding of all aspects of the project (Based on task described in the project planning).	25	20
(ii) Gather information on relevant fundamentals, theory / concept (demonstrate technical competence) and relate them to the design.	50	40
(iii) Provide the sources in a list of references properly cited in the literature review section and relevant sections of the report.	25	12.5
TOTAL	100	72.5



Goal??

Introduction

Nitric acid (HNO_3) is a highly corrosive strong mineral acid that is can be used as an oxidizing agent for rocket fuels and explosives, while also possessing chemical properties that are conducive to the production of fertilizers. Nitric acid is typically known to be produced using the Ostwald process that was developed and patented in the early 20th century (1902) by Wilhelm Ostwald. Though this process is currently the most widely used route to producing nitric acid this production route was of effect after the development of the Haber process that would enable the mass production of ammonia (NH_3) that would be needed in the initial stages of the oxidation process. On the other hand, there are also other production routes by which nitric acid is produced. Using the Nitrate Process or Chile Saltpeter that was developed in the 17th century and also the Birkeland/ Eyde or Arc process that was developed almost simultaneously with the Ostwald process in 1903. Even though there were multiple processes that were developed to produce nitric acid over time, the Ostwald process stands out as the most extensively used production route currently to produce the chemical.

In regards to producing the product there are two sub processes under the Ostwald process that are taken into consideration one being a single pressure and the other a dual pressure process. The sub processes also offers flexibility in regards to the client's needs. [Dependent on the desired strength and purity of the acid a manufacturer will choose either the single or dual pressure processes to get the specified outcome.] In light of these factors it was in the best interest to select a single pressure process, having considered several factors one of which is efficient energy management and a lower number of equipment. The main units of this process selected are the reactor, oxidation chamber and two separation columns.

what are they?

this is not a separator

?

??

why?

The plant capacity is set to produce 400,000 tons of nitric acid during 8,000 working hours per year. In order to effectively operate the nitric acid plant safety and storage handling of the product was put into consideration as well as the environmental and societal impact was not left out due to the acids corrosive and toxic nature.

The nitric acid production process is one gaining vital recognition and is studied to minimize production cost and to meet the demand of this highly used chemical especially in the fertilizer industry. The raw materials used for the production of nitric acid are ammonia and air and the product will be 68% wt. In the fertilizer industry for nitric acid is for the production of ammonium nitrate for the fertilizer and explosives industries, which accounts for approximately 85% of the world production of nitric acid. Nitric acid is mostly used as an intermediate product for fertilizers and explosives.

why?
what's the
other
52%??

Why are you detailing each of these methods? Provide an overview of the advantages/disadvantages only

Process/ Production Routes

Literature Review

Physical and Chemical Properties

Compound IUPAC Name	Nitric Acid
Chemical Formula	HNO ₃
Molecular Weight (g/mol)	63.012
Boiling Point (°F)	181
Melting Point (°F)	-44
Energy of Vaporisation (BTU/lb)	16.81
Vapor Pressure (psia)	0.89
Critical Pressure (psia)	1,4493.77
Critical Temperature (°F)	476.33
Critical Density (lb/ft ³)	0.12-0.19
Specific Gravity	1.502
Solubility in Water	Completely miscible
Acidity (pKa)	-1.4
Standard Enthalpy of Formation ($\Delta_f H^\ominus_{298}$)	-207 kJ·mol ⁻¹
Standard Molar Entropy ($S^\ominus_{298}$)	146 J·mol ⁻¹ ·K ⁻¹
Odor	acid, suffocating
Appearance	Colorless, yellow or red fuming liquid

Ostwald

Process

Raw

materials

used to

produce

nitric acid

include ammonia, and air that is taken from the atmosphere. The plant will produce 68% by weight of nitric acid and 32 % water. High quality steam (150 psi and 970°F) is generated in the process and will be sold as by product of our process to generate additional income. The single pressure process was selected as the most advantageous process, having considered several factors one of which is efficient energy management and required lesser number of equipment. [ref]

The main units of this process selected are reactor, oxidation chamber and two separation columns. The process begins with the vaporization of ammonia at 145 Psi and 95°F using process heat. Steam is then used to superheat the ammonia up to about 176°F. Filtered air is compressed in an axial compressor to a discharge pressure of about 107.3 Psi and temperature of 311°F. Part of the air is diverted for acid stripping. This preheated air and the ammonia vapor are then mixed and passed through the platinum/rhodium catalyst gauze in a converter for oxidation.

The reaction gas flows through a series of heat exchangers for recovery of energy as either high-pressure superheated steam, or as shaft horsepower from the expansion of hot tail gas in the turbine. The other process which is known dual-pressure process employs a conversion stage operating in the range 14.5-51 psia, and a reactor temperature of about 1589 °F which has Low-pressure ammonia oxidation and high- pressure absorption for acid production. In addition to the higher conversion, the lower catalyst gauze temperature (associated with the low-pressure ammonia oxidation) results in a much lower rate of platinum deterioration. [ref]

The Birkeland/ Eyde or Arc process

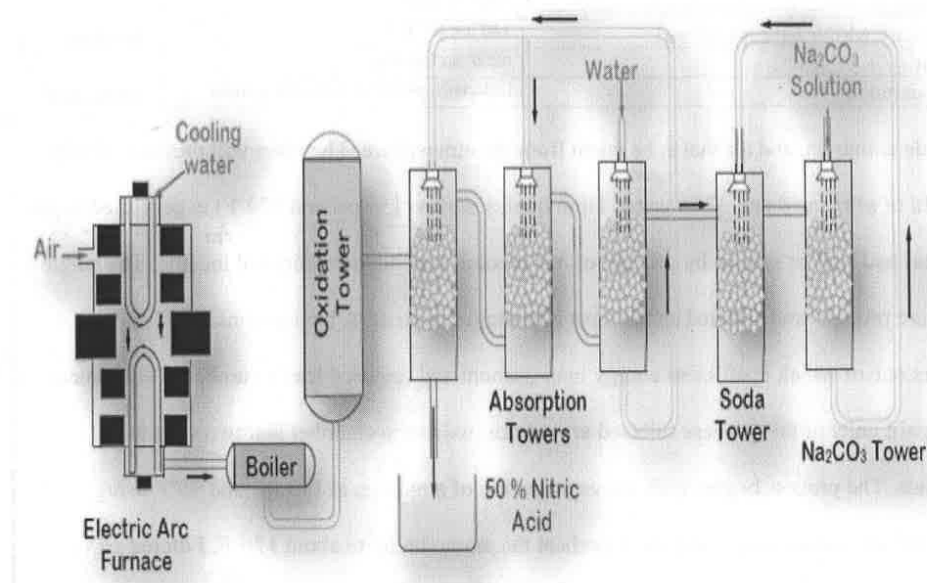
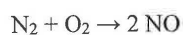
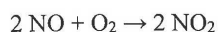


Figure 1: Diagram showing production of Nitric acid from arc/ Birkeland-Eyde process.

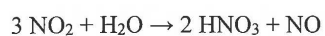
The Birkeland–Eyde process was one of the competing industrial processes in the establishment of nitrogen based fertilizer production. An electrical arc formed between two coaxial electrodes, and through the use of a strong magnetic field, is spread out into a thin disc. The plasma temperature in the disc is at approximately 3000 °C. Air is then blown through this arc, causing some of the nitrogen to react with oxygen forming nitric oxide. Controlling the energy of the arc and the velocity of the air stream, yields of up to approximately 4-5% nitric oxide at 3000 °C and less at lower temperatures. The process is extremely energy intensive. The reaction is carried out using natural source from lightning which converts atmospheric nitrogen to soluble nitrates.



The hot nitric oxide is cooled and combines with atmospheric oxygen to produce nitrogen dioxide.



This nitrogen dioxide is then dissolved in water to give rise to nitric acid, which is then purified by fractional distillation.



Nitrate Process or Chile Saltpeter

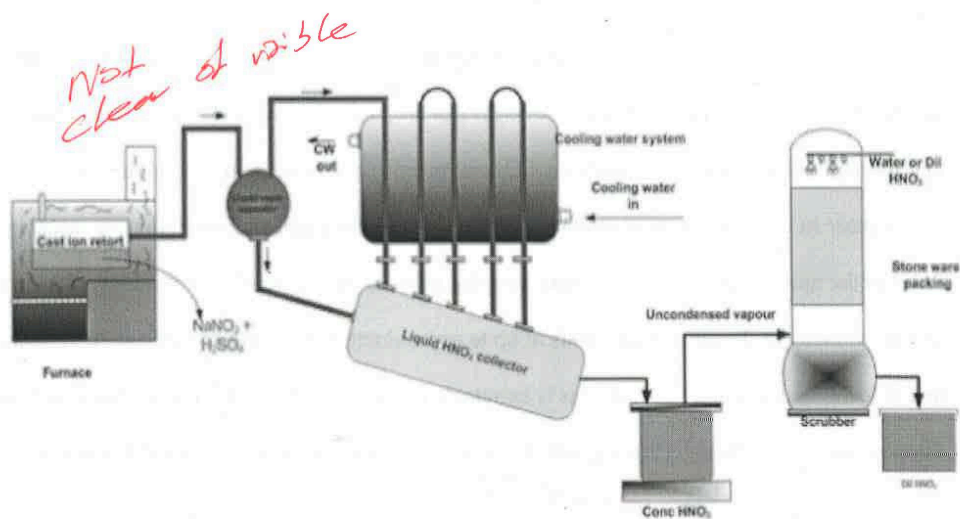
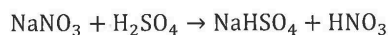
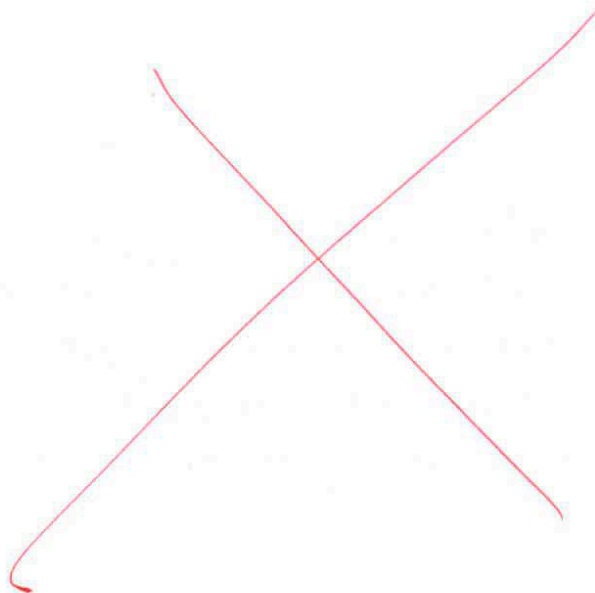


Figure 2: Diagram showing production of Nitric acid from nitrate process. [ref]



This process is the oldest known process to produce nitric acid as it was developed in the 17th century. In this production route potassium nitrate is used to produce 35-50% sodium nitrate and remainder salt. Sodium nitrate and sulfuric acid is heated in a cast iron retort where the nitric acid is produced as a liquid and further cooled to form concentrated nitric acid. The uncondensed nitric acid vapor is further sent to be scrubbed by water and diluted nitric acid collected in receiver. This process however is not used since it takes higher energy and new production processes have received higher recognition due to them being more economically feasible. For example the advent of Ostwald process replaced this process due to less energy consumption. [ref]



HANDLING, STORAGE, AND SAFETY FOR HNO₃

what??

The production of nitric acid from the ChemRG company is considered hazardous by the 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200). As a strong oxidizing agent, nitric acid can be very corrosive depending on its concentration and temperature. Therefore, materials selected for the manufacture of its storage and handling equipment have to be readily available, easy to fabricate and most importantly corrosion resistant to HNO₃ at a specific range of concentrations and temperatures. The main industrial use of nitric acid for the ChemRG company is the production of fertilizers. Nitric acid is neutralized with ammonia to give ammonium nitrate. This application consumes 75–80% of the 26 million tons produced annually

(1987). The other main applications are for the production of explosives, nylon precursors, and specialty organic compounds

Handling

Nitric acid decomposes on heating producing nitrogen oxides. It reacts violently with combustible and reducing materials (e.g., turpentine, charcoal, alcohol). Nitric acid should never be mixed with acetic, chromic, or hydrocyanic acids, aniline, carbon, hydrogen sulfide, flammable liquids or gases, or other substances which are readily nitrated. While handling nitric acid wear neoprene or rubber gloves, apron and other protective clothing suitable to the risk of exposure.

Storage

Nitric acid should be stored in tightly closed containers, in a well-ventilated area away from organic substances, corrosive materials, and flammable materials. Nitric acid is such a powerful oxidizing agent that it dissolves many metals except for gold and platinum.

Disposal

What does this mean?

Material is disposed of as hazardous waste. Contact the Waste Management Group for specific disposal requirements and procedures. Containers and other materials that are contaminated with nitric acid must also be treated as hazardous waste.

Uses of nitric acid

Nitric acid has diverse applications in the chemical industry. It has commercial uses as a nitrating agent, oxidizing agent, solvent, activating agent, catalyst and hydrolyzing agent. The most

important use is in the production of ammonium nitrate for the fertilizer and explosives industries, which accounts for approximately 65% of the world production of nitric acid. Nitric acid has a number of other industrial applications. It is used for pickling stainless steels, steel refining, and in the manufacture of dyes, plastics and synthetic fibers. Most of the methods used for the recovery of uranium, such as ion exchange and solvent extraction use nitric acid. The commercial manufacture of ammonium nitrate uses nitric acid below its azeotropic point in the range 50-60% (wt.).

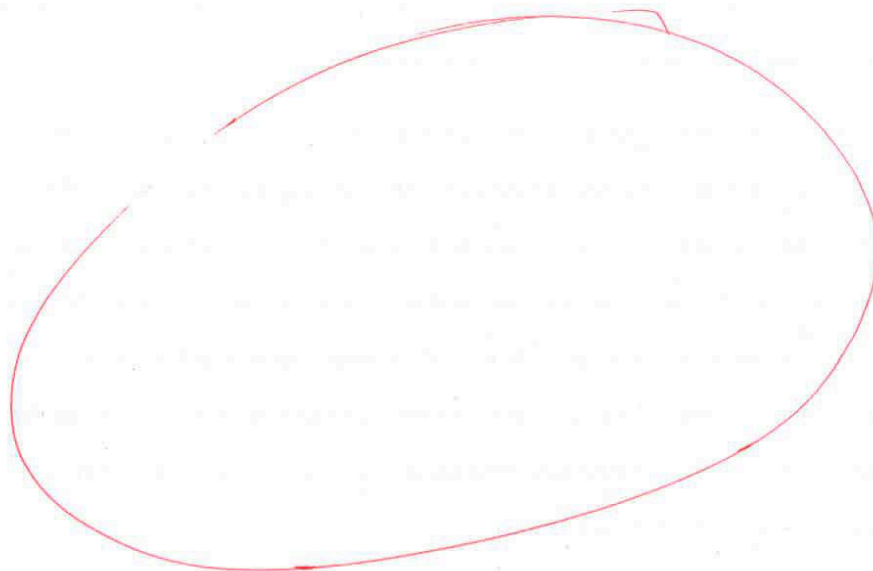
what about the other 35%

finally!!

Product Specification	
NITRIC ACID HNO ₃	
PRODUCT CODE	169215
SYNONYMS	Aqua Fortis
CASR NO.	7697-37-2
ATOMIC OR MOLECULAR FORMULA	HNO ₃
ATOMIC OR MOLECULAR WEIGHT	63.013g/mol
PROPERTIES Hygroscopic,	strong oxidizing agent.
HNO ₃	

PARAMETER	LIMIT
Description	A clear liquid with a corrosive vapour.
Solubility	Miscible with water.
Assay	69.0 - 72.0%
Wt. per ml at 20°C	1.41 - 1.42 g
MAXIMUM LIMIT OF IMPURITIES	
Nonvolatile matter	0.01%
Hydrochloric acid (HCl)	0.005%
Sulphuric acid (H ₂ SO ₄)	0.01%
Arsenic (As)	0.0001%
Iron (Fe)	0.005%
Lead (Pb)	0.0005%
Standards and Regulations • OSHA. PEL: 29 CFR 1910.1000 Table Z-1; Respiratory Protection: 29 CFR 1910.134 • EPA. Release: 40 CFR 355.40; Waste: 40 CFR 261.21-261.24 • California Fire Code, Chapters 27 through 41 (24 CCR Part 9)	
Hazard Pictogram(s):	
 Oxidising liquids Corrosive to metals Acute toxicity	

Figure 1.1 Product Specifications Details *Eret*



Process Selection - Process Sorting

The goal of this company is to manufacture a chemical plant that will produce nitric acid with a concentration of 68%. Through the chosen method, the Ostwald process will be used to help produce a weak nitric acid with a concentration of about 68%. This process is a highly used process for nitric acid and has been used at numerous plants for many years. The Ostwald process is a combination of oxidation, condensation, and absorption with a system that uses pressure that ranges from 14.7 to 203 psia. Nitric acid at the proposed concentration will be considered as weak.

The Ostwald Process has three main steps: Primary Oxidation, Second Oxidation and Absorption. The primary oxidation step is where the ammonia and oxygen being mixed and then

going onto the second oxidation step which is when the newly converted nitric oxide is involved with the secondary oxidation process. Lastly, there is the absorption step.

This selected process for the absorption portion of the process will be the single-stage pressure process. This process is not used as much as the dual-stage pressure process which includes a compressor that is inserted between the ammonia oxidizer and the condenser. Instead of using a process that will produce ammonia, the decision was made to utilize the single-stage pressure process, use an outside source to bring in the ammonia supply which will be needed. The process flow diagram which was constructed utilizes a waste heat boiler to ensure that the ammonia is as pure as needed for the process to function properly. The description of this process can be found in the following section.

Process Description

The process starts with two raw materials. They are Ammonia and Oxygen. The source of the oxygen is the air and it goes through a separator to become pure oxygen. We buy ammonia that is not pure and mixed with water. The two streams of ammonia and oxygen are fed into a converter where it is thoroughly mixed. This is where it will become a mixture of a certain amount of each compound. To get the mixture to the proper operating temperature, it is fed into a heater. This will be calculated by knowing the proper temperature required for the reaction to occur. To remove the water that was mixed with the ammonia, everything is fed into a boiler to remove the waste. This causes the water to exit as steam. To ensure that there are no impurities left in the process, a filter is used. The mixture turns into nitric oxide. To get the reaction to the proper temperature for absorption, a cooling tower is used. Where water is pumped into the

this is not a sentence,

tower from the Mississippi River. The water is evenly spread throughout the tower in its own closed system. As the nitric oxide flows around the water where it is cooled. The water exits as steam and the nitric oxide exits cooled. The nitric acid is then fed into the top of an absorption tower. Oxygen from the separator is fed into the bottom. We will have Nitric Acid exiting from the bottom and other compounds exiting from the top. Throughout the entire process, we will have other parts such as pumps and more in-depth absorbers.

too vague!

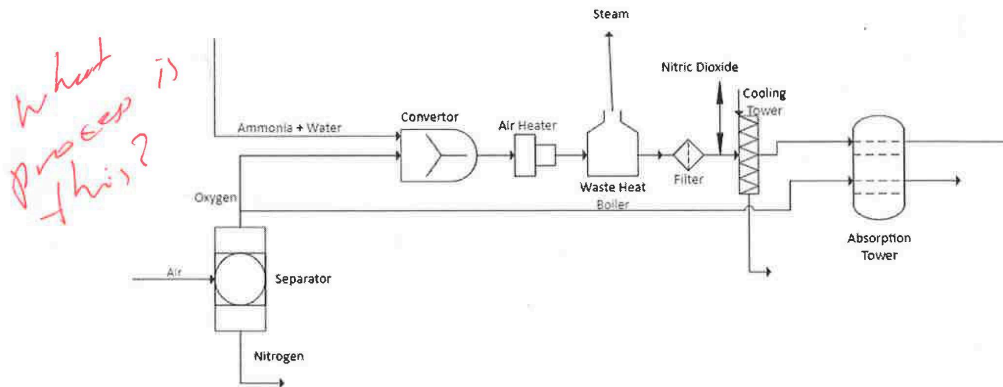


Figure 1.2 - Process Flow Diagram

[ref]

Citations

OSHA. "Safety and Health Topics: Ammonia." Accessed September 25, 2015.

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*I do not follow your
reference/citation style.*

References

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R. L. Peer, et al., Characterization Of Nitrous Oxide Emission Sources, U. S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC, pp. 2-15, 1995

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**CHEG 4472-P02 SENIOR DESIGN AND PROFESSIONALISM I
FALL 2019**

MINUTES OF GROUP MEETINGS

Meeting Date: 10/08/19 Meeting Time: 1:00 P.M. Meeting Location: CL
Wilson Success Center

Members Present: Natalie Russell, Chloe Sanders, Leah McClellan Francis Saneii, and Ariel
Taylor

Agenda for Meeting (List all items to be discussed or discussed at the meeting)

Homework #3

- What do we have?
- What do we need?

Detailed Minutes: (should include name of speaker and summary of what he/she suggested)

- Chloe Sanders: Walked through assignment deliverables; Discussed what do we have and what do we need to complete homework assignment #3

CHEG 4472: SENIOR DESIGN & PROFESSIONALISM I

FALL 2019

ASSIGNMENT STATEMENT/QUESTIONS

**Senior Design & Professionalism I (Fall 2019): Home Work 3
Due October 17, 2019**

You will be graded based on your ability to engage in life-long learning. Start each question on a new page. Clarity of presentation is essential if you are to avoid losing points.

Present a comprehensive literature review/survey of your project, citing all sources. Include (a) an introduction, (b) review of literature on production of your product including process/production routes, physical and chemical properties, handling and storage, uses and product specification, (c) process selection (using process sorting), (d) process description, stating the main steps involved in the production, and providing details of the steps involved.

Note: Make sure to use effective and well-placed subheadings, so that the sections and subheadings follow the logical sequence of the report outline.

Limiting your sources to only the internet or merely copying what you find in the literature without a brief discussion highlighting the relevance or otherwise of the information will be considered inadequate.

DEPARTMENT OF CHEMICAL ENGINEERING
SENIOR DESIGN & PROFESSIONALISM I CHEG 4472
COURSE ASSESSMENT GRADING SCHEME & OUTCOME

ABET Outcome 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Assignments that test competency in this area will include problems that test a student's ability to identify, retrieve, and organize information needed for a particular new task even if the task is outside of their area of expertise.

Name: Natalie Russell, Chloe Sanders, Leah McClellan Francis Saneii, and Ariel Taylor

Title of Assignment: Homework 3 Due Date 10/17/19

Competency Area		
7. Ability to engage in in life-long learning	Max for this Assignment	Your Score
<i>Effectively use library and online resources for research and are abreast with current developments relating to the project</i>		
(i) Identify the types of information needed for a complete understanding of all aspects of the project (Based on task described in the project planning).	25	20
(ii) Gather information on relevant fundamentals, theory / concept (demonstrate technical competence) and relate them to the design.	50	40
(iii) Provide the sources in a list of references properly cited in the literature review section and relevant sections of the report.	25	25
		

TOTAL	100	85
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I. Introduction

The scope of this project is to design a grassroots ethylene oxide plant that operates safely and economically. This report will provide an analysis of the production routes, physical and chemical properties, proper handling and storage, and uses of ethylene oxide. Furthermore, an analysis of process selection and a description of the selected method for the project will also be discussed.

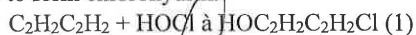
II. Ethylene Oxide

a. Production Routes

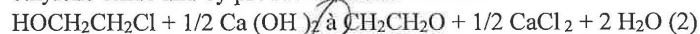
i. Chlorohydrin Process

Although the chlorohydrin process is no longer used for production of ethylene oxide, the process was considered for production routes. The chlorohydrin process is a multi-step process that can be divided into two phases.

During the first phase of production, ethylene is reacted with hypochlorous acid to form chlorohydrin.



The second phase of production is the dehydrochlorination step, which involves the reaction of the chlorohydrin with a base to give ethylene oxide and by product calcium chloride.



The problem with the chlorohydrin process is that it was not very economic. A large portion of the chlorine, which was introduced in the first step as hypochlorous ended up as calcium chloride (Burdick, Leffler, & Dodd, 2000):

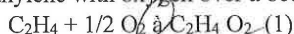
ii. Direct Catalytic Oxidation

The direct oxidation process has replaced the chlorohydrin process and involves the direct oxidation of ethylene in the presence of a silver catalyst. The process is highly exothermic and heat control is considered a major design constraint for the process. If the process temperature exceeds the appropriate conditions, it can lead to catalyst deterioration and reduce the yield of ethylene oxide (Sami Hatch & Lewis, 2001).

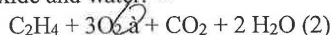
The process can be performed using two routes. The routes are classified by considering the source of the oxidizing agent, which are air and oxygen. Although the routes of production are similar, there are a few differences. One of the primary differences between them is that air-based direct oxidation produces a large amount of nitrogen, which ends up concentrated in the recycle gas stream. The recycle stream must be vented to prevent the nitrogen concentration from getting too high (Rebsdat & Mayer, 2017).

Currently, the oxygen-based direct oxidation is the main production route used for the commercial production of ethylene oxide (Rebsdats & Mayer, 2017).

The main reaction involved in the direct oxidation process is the reaction of ethylene with oxygen over a bed of silver catalyst.



A side reaction occurs and results in the formation of byproducts carbon dioxide and water.



The side reaction is limited based on catalyst selectivity. An optimized design of the direct oxidation process will produce high amounts of ethylene oxide over a catalyst cycle and reduces the amount of ethylene consumed during production (Rebsdats & Mayer, 2017).

b. Physical & Chemical Properties

i. Physical Properties

Ethylene oxide (also known as Oxirane, Epoxyethane, and more)

Molecular formula: $\text{C}_2\text{H}_4\text{O}_2$

Molecular weight: 44.05 g/mol

Ethylene Oxide is a colorless and toxic gas that is used as a chemical intermediate, a sterilant in the medical fields, and more. It has a sweet odor that resembles the soft smell of overly ripe apples. It is possible to smell in water if the volume is at, or above, 140 mg per liter and can also be detected in air, if it is present at, or above, 430ppm.

ii. Chemical Properties

Table 1: Chemical Properties of Ethylene Oxide

Property	SI (AES) Units
Boiling Point	11°C (51°F)
Freezing point	-112°C(-169°F)
Flash Point	-29°C through -30°C (-20° F through -22°F)
Specific Gravity	0.88
Density	.822 at 50°F (.882 at 10°C/10°C)
Vapor Density	1.49 relative to air
Vapor Pressure	1068 mmHg at 68°F
Water Solubility	22.7 M
Melting point	-170.5 ° F (-111.7°C)
Exposure limits (highest)	800ppm
Exposure limits (lowest)	< .1ppm

Ethylene oxide at room temperature is extremely reactive and flammable. If heated, it has the potential to explode and will also explode

in the presence of ammonia, amines, alkali metal hydroxides. However, ethylene oxide is completely soluble in water and breaks down in water and/or destroyed by bacteria in a span of a few days. Ethylene Oxide levels decrease as it is broken down into other substances.

why?
is
this
hazard?

c. Handling & Storage

Safety is of the utmost importance when it comes to the handling and storage of ethylene oxide. When it comes to storage, the vessels considered here are above ground, mounded and buried vessels. Types, advantages and disadvantages will be discussed as well as the best materials of construction in order to mitigate ethylene oxide hazards and handle the product safely.

Above ground storage vessels offer three different types for storing ethylene oxide: Vertical or horizontal cylindrical tanks and spherical tanks. Vertical cylindrical tanks offer minimal contact between the product and flame sources, otherwise known as flame impingement. This type of vessel also allows for the inventory to be monitored easily as well as minimizing the potential for the product to accumulate polymer. Horizontal cylindrical tanks minimize the potential of impact from any flying debris. (American Chemistry Council's Ethylene Oxide/Ethylene Glycols Panel, 2007)

what's
one?

Mounded and buried vessels have the same advantages and disadvantages. The difference is mounded vessels are covered with sand or soil at ground level whereas buried vessels are below ground level. Their advantages are their ability to provide protection against fires and impact. Their disadvantages include the inability to detect leaks as well as the inability to survey the condition of the tank on the outside. These tanks require that personnel enter the inside in order to observe the tanks integrity. (American Chemistry Council's Ethylene Oxide/Ethylene Glycols Panel, 2007)

So
what
is
the
conclusion?

Handling ethylene oxide should be done in such a way that mitigates the hazards the product presents. In order to do so, it is best to keep in mind the materials that make up the process equipment as well as storage tanks. The equipment used to handle, and store ethylene oxide is usually made from austenitic stainless steel or mild carbon steel. Stainless steel minimizes the potential of the formation of rust which facilitates the polymerization of ethylene oxide. However, depending on the conditions of the environment, stainless steel has the potential to corrode on the outside but can be prevented by using a protective outer coating. Similarly, carbon steel can corrode on the outside which can also be prevented. However, carbon steel can accumulate rust internally and cause ethylene oxide to polymerize. Therefore, when it comes to choosing what materials to use for storage and handling, it is imperative to understand the process and ambient conditions in order to protect the equipment's integrity. (American Chemistry Council's Ethylene Oxide/Ethylene Glycols Panel, 2007)

b. Ethylene Oxide Scrubber

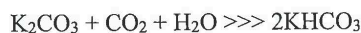
After the gas from the reactor has been cooled, ethylene oxide (1 – 2 %) must be removed by scrubbing with water. In the ethylene oxide scrubber, practically all the ethylene oxide and small amounts of constituents such as CO₂, N₂, CH₄, CH₂CH₂, and aldehydes within natural gas dissolve in water and separate from other gaseous products (Rebsdats & Mayer, 2017)).

c. Ethylene Oxide Desorber

The resulting aqueous ethylene oxide solution comes out from ethylene oxide scrubber, then passes to the ethylene oxide desorber. The ethylene oxide recovers as the head product. Ethylene oxide leaving the desorber is subsequently stripped of its low-boiling components (CO₂, N₂, CH₄, CH₂CH₂, and aldehydes) and finally distilled, thereby separating into water and ethylene oxide (Rebsdats & Mayer, 2017)).

d. CO₂ Scrubber and Desorber

The recycle gas from the ethylene oxide scrubber (5-10% CO₂) is compressed, and a side stream loses carbon dioxide by scrubbing with hot aqueous potassium carbonate solution. Removing the CO₂ is not only by physical dissolution but also by a reaction with potassium carbonate to create potassium formate.



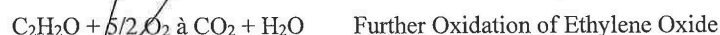
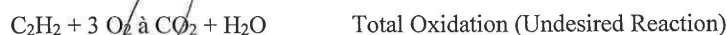
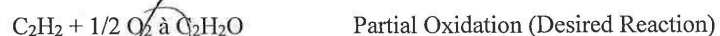
The potassium carbonate solution is sent to the CO₂ desorber. Carbon dioxide is stripped at atmospheric pressure and is either released into the atmosphere or fed to a CO₂ utilization plant, after optional catalytic treatment (Pd/Pt) to remove residual hydrocarbons.

The recycle gas, which is free from ethylene oxide and has a lower CO₂ content, is returned to their initial levels by separate addition of oxygen, ethylene, inhibitor (1, 2-dichloroethane, ethyl chloride or vinyl chloride), and if necessary, a diluent CH₄ (Rebsdats & Mayer, 2017)).

PFD ?

walk through

in the range of 15-25 atm pressure (Aryana, 2009). The raw materials consist of ethylene (purity > 99.5 % and free of sulfur), oxygen (purity > 99%), and recycle gas is heated and fed to the reactor. The oxidation reaction takes place inside the tubes in contact with a silver-based catalyst to form the products, including ethylene oxide and CO₂ and H₂O, along with unreacted ethylene and some other impurities (Rebsdats & Mayer, 2017). In general, three parallel reactions take place during the oxidation of ethylene inside the reactor, which shows as follows:



The reaction is highly exothermic and produces a large amount of heat. Because of the different enthalpies of the partial and total oxidation reactions, the total available heat depends on the selectivity, and the quantity of energy released increases rapidly as selectivity decreases. Therefore, the cooling system must be sufficiently adaptable to overcome growing heat release in the reactor at rising reaction temperatures during the aging process of the catalyst. The coolant temperature of the catalyst tubes is restricted by the maximum design pressure, which usually does not allow temperature to increase higher than 572 F (Rebsdats & Mayer, 2017). When the maximum temperature is reached the catalyst should be replaced. The hot outlet gas is cooled by using steam generation or will be used directly to heat the reactor inlet gases before going to the next stage of the process.

The catalyst, which has a significant role in the production of ethylene oxide, is packed in the reactor tubes in the form of spheres or rings with a diameter of 3 – 10 mm. The initial selectivity of new catalysts is 80 – 90%, depending on the type of catalysts used. No material can compete with silver in the catalysis of ethylene to ethylene oxide. The catalyst is a supported catalyst that means silver being deposited on a porous material in a concentration of 7-20 percent. Ultra-pure aluminum oxide (99%) fires at a high temperature to make a porous structure (pore diameter 0.5-50 μm) and low specific surface area (< 2 m²/g) is used as the catalyst support. Materials with a high specific surface area that have small pores will increase the time it takes to react and cause unwanted further oxidation. This decreases the selectivity of the catalyst. To significantly improve the catalyst performance and increase selectivity, a concentration (100-500 ppm) of promoters, including salts or other compounds of alkali and alkaline earth metals such as cesium, are added to the catalyst. During this time, we must focus on increasing the desired combustion reaction of ethylene in the reactor and increase the selectivity. Some materials that are called Inhibitors such as 1,2-dichloroethane or vinyl chloride are added to the feed in a low concentration (1-3 ppm) in order to prohibit the formation of the undesired reactions. With recent optimization of catalyst support, materials and new methods for uniformly distributing silver and using promoters and inhibitors will increase the selectivity of ethylene oxide production to 90 percent (Rebsdats & Mayer, 2017).

d. Uses

Ethylene oxide is used as an intermediate in the production of ethylene glycol and makes up the majority of ethylene oxide consumption. It can also be used in the production of ethoxylates which can be made into detergents, paint solvents and other textile industry applications. Moreover, another major application is the use of ethylene oxide to produce ethanolamine. (Burdick, Leffler, & Dodd, 2000)

e. Product Specifications

Ethylene oxide is produced with a purity of 99.5%. Because ethylene oxide's primary end-use is to make ethylene glycol, the purity needs to be high in order to appeal to ethylene glycol producers. High purity technical grade ethylene oxide is produced with a purity of 99.7%. (Burdick, Leffler, & Dodd, 2000)

III. Process Selection

A comparison of the two processes shows that the direct oxidation is favored from an economic standpoint. One of the disadvantages with the chlorohydrin process is the cost of operation, primarily the feedstock. The chlorohydrin process requires chlorine and is costly. Another disadvantage of the chlorohydrin process is accumulation of calcium chloride which causes issues with disposal and does not have any economic benefit. (Burdick, Leffler, & Dodd, 2000).

IV. Process Description

The reactor used for commercial production of ethylene oxide is a fixed-bed tubular reactor, which consists of a large bundle of several thousand tubes that are 6-13 meters long and have 20-50 mm internal diameter. The diameter of the tubes must not be excessive to ensure enough heat transfer to the heat transfer medium. A tube diameter of 20 - 40 mm is most commonly found. Since ethylene oxide is corrosive, the reactors and the sections of the plant that contain ethylene oxide are usually made of mild steel. Mild steel is a kind of steel with a low amount of carbon (0.05 to 0.25 by weight) which is typically more ductile, machinable and weldable than high carbon steel. However, to reduce the formation of acetaldehyde by isomerization of ethylene oxide on rust, stainless steel is increasingly being used for the reactors and the ensuing cycle gas lines, where temperatures are highest (Rebsdatt & Mayer, 2017).

The reactor tubes filled with the catalyst are surrounded by a coolant, which can be either water or a high-boiling hydrocarbon that removes the reaction heat and allows for temperature control. The temperature inside the reactor depends on the type of catalyst. The lower and higher selectivity catalyst range from 482-572 F respectively (Aryana, 2009). However, the initial temperature is about 392 F. The operational pressure inside the reactor varies depending on process characteristics, but it is generally

References

American Chemistry Council's Ethylene Oxide/Ethylene Glycols Panel. (2007). *Ethylene Oxide*.

Aryana, S., Ahmadi, M., Gomes, Vincent G., Romagnoli, Jose A and Ngian, K. (2009) *Modelling and Optimization of an Industrial Ethylene Oxide Reactor, Chemical Product and Process Modeling: Vol. 4: Iss. 1, Article 14. DOI: 10.2202/1934-2659.1231*

Berty, J. M. (1983). Ethylene oxide Synthesis. In *Applied Industrial Catalysis* (Vol. 1, pp. 207-238). New York, NY: Academic Press.

Burdick, D. L., Leffler, W. L., & Dodd, S. R. (2000). *Petrochemicals in Non-Technical Language (3rd Edition)*. Tulsa: PennWell.

(provides product specification for ethylene oxide product; see table here)

Perzon H. (2015). *A Simulation Model of a reactor for Ethylene Oxide production* (Unpublished master's thesis). Department of Chemical Engineering Lund University.

Rebsdat, S., & Mayer, D. (2017). Ethylene Oxide. *ULLMANN'S Encyclopedia of Technical Chemistry*, 13, 547-572

Sami Hatch M., & Lewis F. (2001). *Chemistry of Petrochemical Processes* (Vol. 2). Elsevier BV. doi:10.16/b978-088415315-3/50008-0

**OUTCOME “7” SPECIFIC ASSIGNMENTS
USED TO ASSESS THE OUTCOME IN**

**UNIT OPERATIONS
FALL 2019**

CHEMICAL ENGINEERING
OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET
CHEG 3023 UNIT OPERATIONS
FALL 2019
Instructor: Dr. Keisha Antoine

Title of Assignment

T2-Understanding Bernoulli Principle 10/11/2019

Outcome Measured Using this Assignment

Outcome 7

An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Check the outcome characteristics related to this assignment

Ability to Acquire new knowledge using the appropriate learning strategies Requires students to:	
x	Be knowledgeable of and use different learning strategies <i>(Instructor may provide information on different learning strategies)</i>
x	Identify and take advantage of learning opportunities available in the library, online resources, seminars, webinars, conferences, workshops and tutorials.
x	Be aware of the need for and are able to independently acquire additional knowledge and data needed for solving problem using appropriate learning strategies and tools.
Ability to apply new knowledge to solve problems Requires students to:	
x	Demonstrate appropriate use of the new knowledge to solve problems.

Brief justification of why this assignment is suitable for this outcome

This assignment allows the students to gain fundamental understanding of the Bernoulli Principle across pipes, fittings and a centrifugal pump by deriving final equation forms.

**UNIT OPERATIONS
FALL 2019**

**SAMPLE TEST QUESTIONS, SOLUTION,
AND GRADING SCHEME FOR
PROJECT-UNDERSTANDING
BERNOUILLI PRINCIPLE 10/11/2019**

Instructions

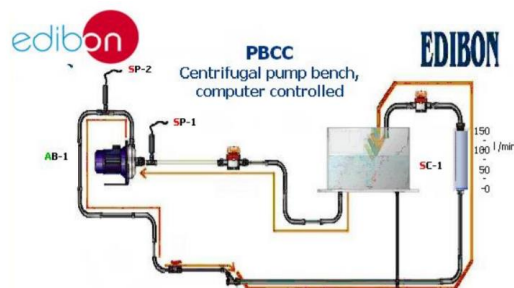
Groups will be assigned. Max of 5 students per group. Turn in group assignment on November 20, 2019.

Objective

In this assignment, students will study the principle of mechanical energy conservation (Bernoulli Principle) using Edibon PBCC Centrifugal Pump and the Venturi meter located on the Edibon AFT-B Fluid Friction in Pipes Equipment.

Edibon PBCC Centrifugal Pump

The program measures pump speed in rpm, p_{suction} (bar), $p_{\text{discharge}}$ (bar), torque (N.m), Q (L/min), H_t (m), W_p . Disregard the values for pressures that the program records in carrying out these exercises.



Resources

1. UOCE, 7th Ed., Chapter 4, Mechanical Energy Equation (pp 86 – 94); Chapter 8, Centrifugal Pumps (pp 208 – 209), Ideal Pump (pp 210), Actual pump performance (211 – 212)
2. Chapter 4c class notes (available on eCourses)

Instructions

1. Determine the pressure drop developed by the pump for various volumetric flow rates. This step is required to answer question 3 of the Exercises.
 - a. Turn on the pump and the Edibon computer program.
 - b. Run the experiment for various opening of the discharge valve (a minimum of 4 readings of the volumetric flow rate, Q). Record the data for use in Exercise 3.

NOTE: You can email the data to yourselves or save the data to a flash drive.

Exercises

1. Using Bernoulli's principle, estimate the velocity of discharge of the tank. [50 points]
 - a. Measure volume of water in tank.
 - b. Measure dimensions of discharge port or tube
 - c. Measure Z_a , Z_b
 - d. State your assumptions.
2. Use Bernoulli's principle to derive total head, H_t in meters. [20 points]
3. Assuming the value of H_t measured by the software is correct and using a to represent the suction point and b to represent the discharge point, calculate the values of p_{suction} and $p_{\text{discharge}}$. State your assumptions and the additional variables that you measured. [50 points]

Venturi meter in Edibon AFT-B Fluid Friction in Pipes

$D_{\text{inlet}} = 26.5 \text{ mm}$

Resources

1. UOCE, 7th Ed., Chapter 4, Mechanical Energy Equation (pp 86 – 94); Chapter 8, Venturi Meter (pp 225 – 227)
2. Chapter 4c class notes (available on eCourses)

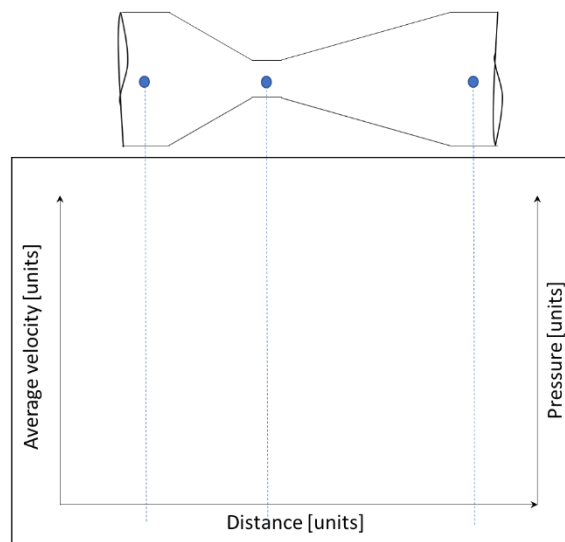
Instructions

1. For 4 readings of volumetric flow rate (take replicates of each data point) [20 points]
 - a. Measure the pressures for the entrance, throat and downstream tap.

Flow rate, Q [units?]	P_{entrance} [units?]	P_{throat} [units?]	$\Delta P(\text{entrance} \rightarrow \text{throat})$ [units?]	P_{exit} [units?]	$\Delta P(\text{entrance} \rightarrow \text{exit})$ [units?]

Exercises

1. How does the pressure vary with distance in the venturi meter as the flow moves from the large diameter to the small diameter? From the small diameter to the large diameter? Show the variation of pressure vs. distance in the flow direction on a graph. [20 points]
2. How does the velocity vary with distance in the venturi meter as the flow moves from the large diameter to the small diameter? From the small diameter to the large diameter? Show the variation of average velocity vs. distance in the flow direction on a graph. [20 points]



3. Use the Bernoulli equation to explain the graphs of pressure and velocity vs. distance in going from:
 - a. Entrance to throat [10 points]
 - b. Throat to exit [10 points]

Assume no frictional losses.

4. The pressure loss between the two ends of the venturi meter should be far less than the pressure drop between the entrance and throat of the venturi. Explain why this is the case. [10 points]
5. Find the diameter of the throat. [25 points]
6. Describe how venturi meters are used in industry? [10 points]

ABOVE AVERAGE

Above Average Student Original Graded Assignment

234
245

CHEG 3023 P02

Unit Operations Lab

Understanding the Bernoulli Principle

Group 2: Maha Khan, Chidinma Uhiara, Fred
Williams, Vance Allison, Jose Luis Ondo Mba Adjibi
11-22-2019

Unit Operations Lab Report

CHEG 3023 P02
Dr. Antoine

Understanding Bernoulli Principle
October 11, 2019

By: Maha Khan, Chidinma Uhiara, Fred Williams, Vance Allison, Jose Luis Ondo Mba Adjibi

BACKGROUND

Objective: In this assignment, students will study the principle of mechanical energy conservation (Bernoulli Principle) using Edibon PBCC Centrifugal Pump and the Venturi meter located on the Edibon AFT-B Fluid Friction in Pipes Equipment.

Equipment used: The Edibon PBCC Centrifugal Pump is a unit commonly used to transfer fluids from point a to point b. PBCC is a unit consisting of a computer controlled centrifugal pump, a water tank, regulation valves and circulation pipes. The centrifugal pump uses an impeller to induce fluid flow by using centrifugal force. This particular pump is generally used for fluids of low viscosity such as water.

The Edibon AFT-B fluid friction pipes unit is designed to determine friction coefficients in pipes, pipe diameters, and pressure differences in pipes. This unit is equipped with five various straight pipes with differences in diameter, material, and roughness. This unit allows us to calculate the fluid friction pressure losses which occur when a non-compressible fluid flows through pipes

Good Background

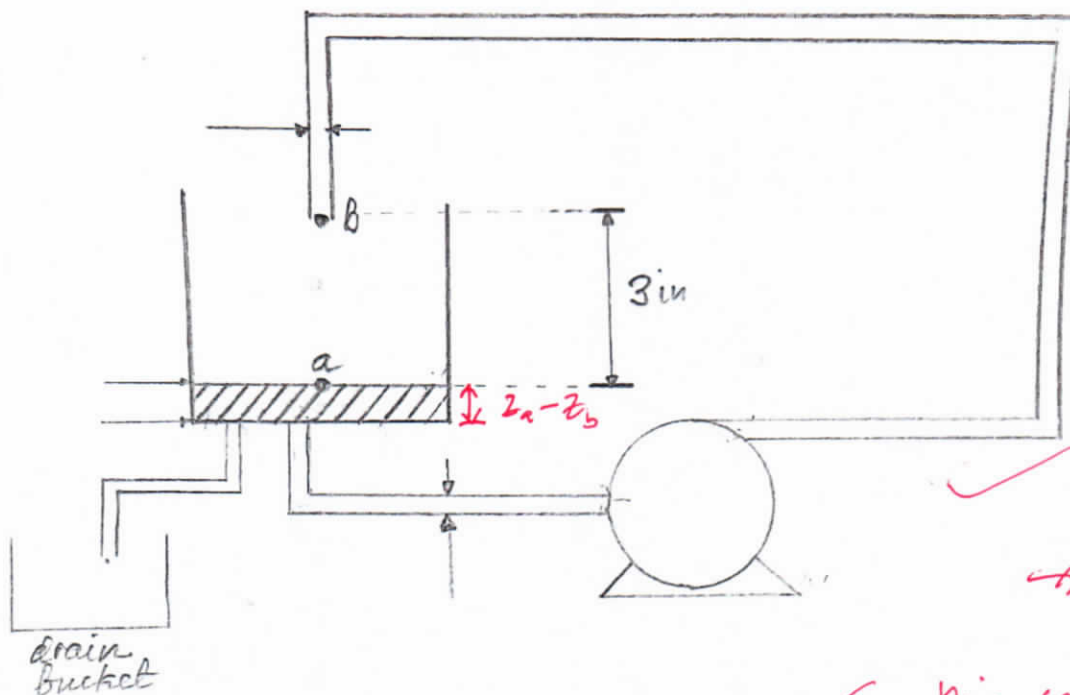
Edibon PBCC Centrifugal Pump

Data readings:

PART ONE

Data	RPM	Padm(bar)	Pdes(bar)	Torque	Q (l/min)	Ht(m)	Nh(W)	Nm(W)	Eff(%)
1	2400	-0.02	0.30	0.45	20.05	3.40	11.15	116.10	9.82
2	2400	-0.02	0.30	0.44	20.15	3.39	11.16	111.80	9.99
3	2400	-0.02	0.30	0.38	20.07	3.43	11.25	96.69	11.64
4	2400	-0.02	0.30	0.46	20.04	3.40	11.13	115.09	9.67
5	2400	0.01	0.38	0.45	12.50	3.89	7.95	112.97	7.04
6	2400	0.01	0.38	0.43	12.61	3.94	8.13	106.89	7.61
7	2400	0.01	0.38	0.43	12.65	3.90	8.07	107.89	7.48
8	2400	0.01	0.37	0.45	12.82	3.84	8.04	113.26	7.10
9	2400	0.03	0.43	0.42	4.50	4.24	3.11	105.36	2.96
10	2400	0.03	0.43	0.43	3.76	4.25	2.62	108.21	2.42
11	2400	0.03	0.43	0.43	4.21	4.24	2.92	107.70	2.71
12	2400	0.03	0.41	0.48	6.11	4.09	4.08	120.31	3.39
13	2400	0.02	0.39	0.50	9.87	3.91	6.30	125.90	5.00
14	2400	0.02	0.39	0.50	10.65	3.92	6.83	125.77	5.43
15	2400	0.02	0.39	0.50	10.37	3.93	6.66	124.74	5.34
16	2400	0.02	0.39	0.51	9.95	3.94	6.41	127.49	5.03

1. Using Bernoulli's principle estimate the velocity of discharge of the tank.



✓ \$5

In this case

$$\frac{P_a}{\rho} + gz_a + \frac{\alpha_a \bar{v}_a^2}{2} + \eta \omega_p = \frac{P_b}{\rho} + gz_b + \frac{\alpha_b \bar{v}_b^2}{2} + \eta \omega_p$$

$$gz_a = gz_b + \frac{\bar{v}_b^2}{2}$$

$$gz_a - gz_b = \frac{\bar{v}_b^2}{2} \Rightarrow \bar{v}_b^2 = \frac{g(z_a - z_b)}{2}$$

$$\bar{v}_b^2 = \frac{g(z_a - z_b)}{2} \quad \left\{ \begin{array}{l} \text{Incorrect a and b} \\ \text{Choice of a and b} \\ -5 \end{array} \right.$$

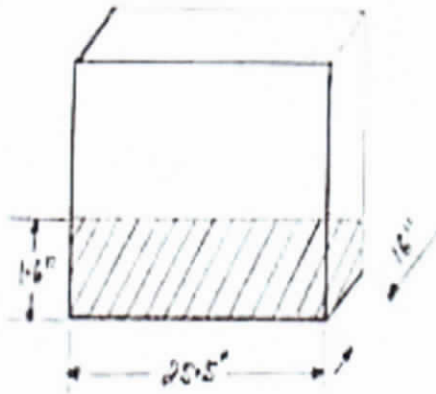
$$\bar{v}_b^2 = \frac{g(z_a - z_b)}{2} \quad \left\{ \begin{array}{l} \text{Incorrect ans} \\ -5 \end{array} \right.$$

$$\bar{v}_b^2 = \frac{9.8 \text{ m/s}^2 \times 0.0762 \text{ m}}{2} = 0.61 \text{ m/s}$$

40/50

A. Measure volume of water in tank:

25.5in (L) x 16in (W) x 1.6in (H) → 647.7mm (L) x 406.4mm (W) x 40.64mm (H)



$$V = L \cdot h \cdot W$$

$$= 1.6 \text{ in} \times 25.5 \text{ in} \times 16 \text{ in}$$

$$= 652.8 \text{ in}^3 \times \left(\frac{1 \text{ ft}}{12 \text{ in}}\right)^3 = 0.36 \text{ ft}^3$$

$$0.36 \text{ ft}^3 \times \left(\frac{0.3048 \text{ m}}{1 \text{ ft}}\right)^3 = 0.010 \text{ m}^3$$

B. Measure dimensions of discharge port or tube

(OD) - Outer Diameter: 19.59mm

(ID) - Inner Diameter: 17.24mm

b) dimensions of discharge tube: discharge tube or pump discharge, taken as point "b", see above drawing, was measured to be:

$$\text{OD (outside diameter)} = 19.59 \text{ mm} \times \frac{1 \text{ m}}{1000 \text{ mm}} = 0.01959 \text{ m}$$

$$\text{ID (inside diameter)} = 17.24 \text{ mm} \times \frac{1 \text{ m}}{1000 \text{ mm}} = 0.01724 \text{ m}$$

$$0.01959 \text{ m} \times \frac{3.28084 \text{ ft}}{1 \text{ m}} = 0.0643 \text{ ft}$$

$$0.01724 \text{ m} \times \frac{3.28084 \text{ ft}}{1 \text{ m}} = 0.0566 \text{ ft}$$

C. Measure Z_a and Z_b

Z_a - (Suction): 0in

Z_b - (Discharge): 3i

D. State your assumptions

- Frictionless
- Incompressible fluid
- Constant Flow (no air bubbles)
- Velocity at station "a" is negligible due to the size of the tank compared to the drain port.
- Turbulent flow is also assumed, so the kinetic energy factor can be taken as 1.0 with negligible error.

2. Use Bernoulli's principle to derive total head, H_t in meters

From Bernoulli's Equation:

$$\overbrace{\eta W_p + \frac{P_a}{\rho} + Z_a g + \frac{\alpha_a V_a^2}{2}}^{\text{Head}_{\text{Suction}}} = \overbrace{\frac{P_b}{\rho} + Z_b g + \frac{\alpha_b V_b^2}{2} + h_f}_{\text{Head}_{\text{Discharge}}}$$

- Assume frictionless for this pump, $h_f = 0$

$$\eta W_p = \frac{P_a - P_b}{\rho} + \frac{Z_b - Z_a}{g} + \frac{\alpha_b V_b^2 - \alpha_a V_a^2}{2}$$

- Assume the height is negligible, small difference, $(Z_b - Z_a) = 0$
- Assume velocity is negligible, small difference compared to pressures, $\frac{\alpha_b V_b^2 - \alpha_a V_a^2}{2} = 0$

$$\eta W_p = \frac{P_a - P_b}{\rho g}$$

- Here, ηW_p is equal to H_t

$$H_t = \frac{P_a - P_b}{\rho g}$$

3. Assuming the value of H_t measured by the software is correct and using "a" to represent the suction point and "b" to represent the discharge point, calculate the values of P_{suction} and $P_{\text{Discharge}}$. State your assumptions and the additional variables that you measured.

- Average H_t values were calculated from the data readings table; each head pressure was averaged using 4 trials, as highlighted on the table. The values are as follows:

$$H_t = \frac{3.4 + 3.39 + 3.43 + 3.40}{4} = 3.405 \text{ m}$$

$$H_t = \frac{3.89 + 3.94 + 3.9 + 3.84}{4} = 3.89 \text{ m}$$

$$H_t = \frac{4.24 + 4.25 + 4.24 + 4.09}{4} = 4.2 \text{ m}$$

$$H_t = \frac{3.91 + 3.92 + 3.93 + 3.94}{4} = 3.92 \text{ m}$$

- With the above information (averaged total heads), the pressure drop across the pump was found using each head pressure, and using the total head pressure equation derived above:

$$H_t = \frac{P_a - P_b}{\rho g} \Rightarrow P_a - P_b = H_t \rho g$$

50
50

$$\text{for } H_t = 3.405 \text{ m} \Rightarrow P_a - P_b = 3.405 \text{ m} \times 1000 \text{ kg/m}^3 \times 9.8 \text{ m/s}^2 = 33369 \text{ Pa}$$

$$H_t = 3.89 \text{ m} \Rightarrow P_a - P_b = 3.89 \times 1000 \times 9.8 = 38122 \text{ Pa}$$

$$H_t = 4.20 \text{ m} \Rightarrow P_a - P_b = 4.20 \times 1000 \times 9.8 = 41160 \text{ Pa}$$

$$H_t = 3.92 \text{ m} \Rightarrow P_a - P_b = 3.92 \times 1000 \times 9.8 = 38416 \text{ Pa}$$

- Converting above readings to bar:

Reading 1: 33369 Pa $\rightarrow$ 0.33369 Bar

Reading 2: 38122 Pa $\rightarrow$ 0.38122 Bar

Reading 3: 41160 Pa $\rightarrow$ 0.4116 Bar

Reading 4: 38416 Pa $\rightarrow$ 0.38216 Bar

- Assumptions made:

1. Frictionless system

2. Negligible velocities at points "a" and "b"

3. Change of height can also be neglected with minimum to no change in the pressure drop

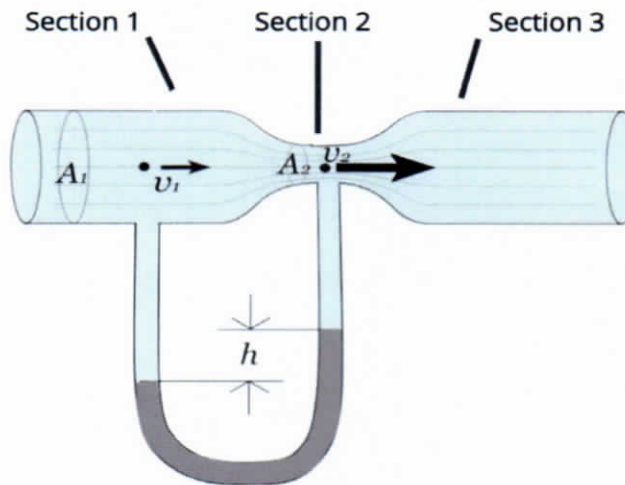
PART TWO

Venturi meter in Edibon AFT-B Fluid Friction in Pipes

$D_{\text{inlet}} = 26.5\text{mm}$

Data readings for 4 volumetric flow rates:

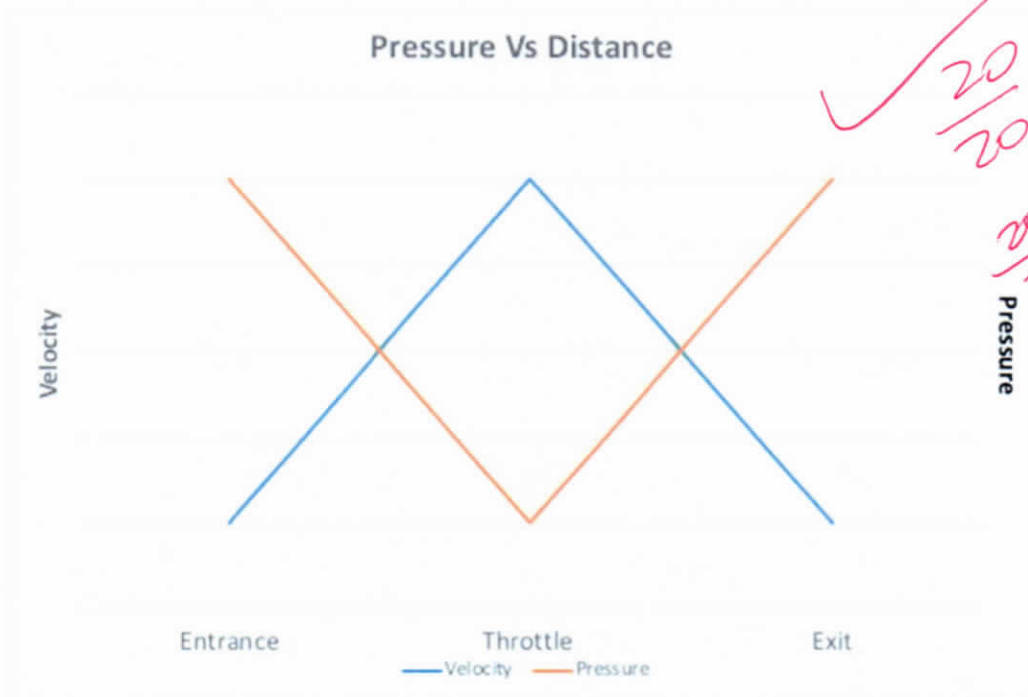
Flow rate, Q [L/Hr]	P _{entrance} [mmH ₂ O]	P _{throat} [mmH ₂ O]	ΔP (entrance throat) [mmH ₂ O]	P _{exit} [mmH ₂ O]	ΔP (entrance to exit) [mmH ₂ O]
3200	330			255	75
3200	465	105	360		
3200		135		422	
2800	270			215	55
2800	380	90	290		
2800		115		350	
2400	180			150	30
2400	260	60	200		
2400		90		225	
1600	195			190	5
1600	225	155	70		
1600		155		225	



Please refer to the figure above for questions 1, 2, and 3

1. How does the pressure vary with distance in the venturi meter as the flow moves from the large diameter to the small diameter? From the small diameter to a large diameter? Show the variation of pressure vs. distance in the flow direction on a graph.

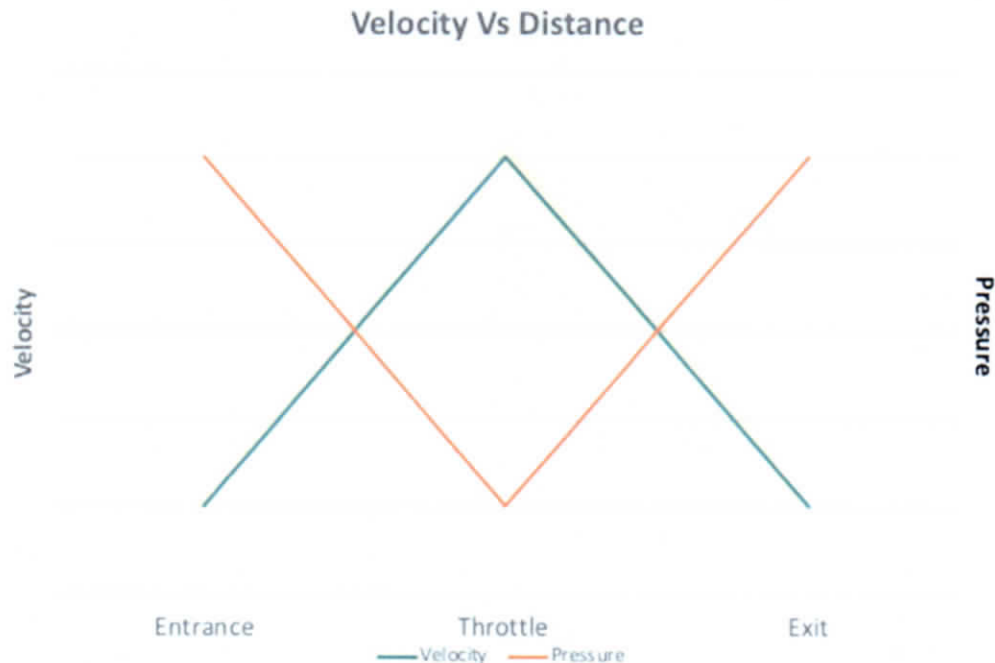
When the liquid flows from the large diameter (section 1) to the small diameter/throat (section 2), the pressure difference as associated with distance decreases dramatically, hence Bernoulli's equation. As the flow moves forward from the throat (section 2) to the large diameter (section 3), the pressure difference increases about 2.5x times that from its previous pressure at the throat.



✓ 20/20 Velocity
20/20 Pressure

2. How does the velocity vary with distance in the venturi meter as the flow moves from the large diameter to the small diameter? From the small diameter to the large diameter? Show the variation of average velocity vs. distance in the flow direction on a graph.

When the liquid flows from the large diameter (section 1) to the small diameter (section 2), or throat, the velocity increases to compensate for the loss of cross sectional area of the pipe. As the flow continues to flow forward through the pipe from the small diameter (section 2) to the large diameter once more (section 3), the velocity decreases as the cross-sectional area of the pipe increases.



3. Use the Bernoulli equation to explain the graphs of pressure and velocity vs distance in going from: (Assume no frictional losses)

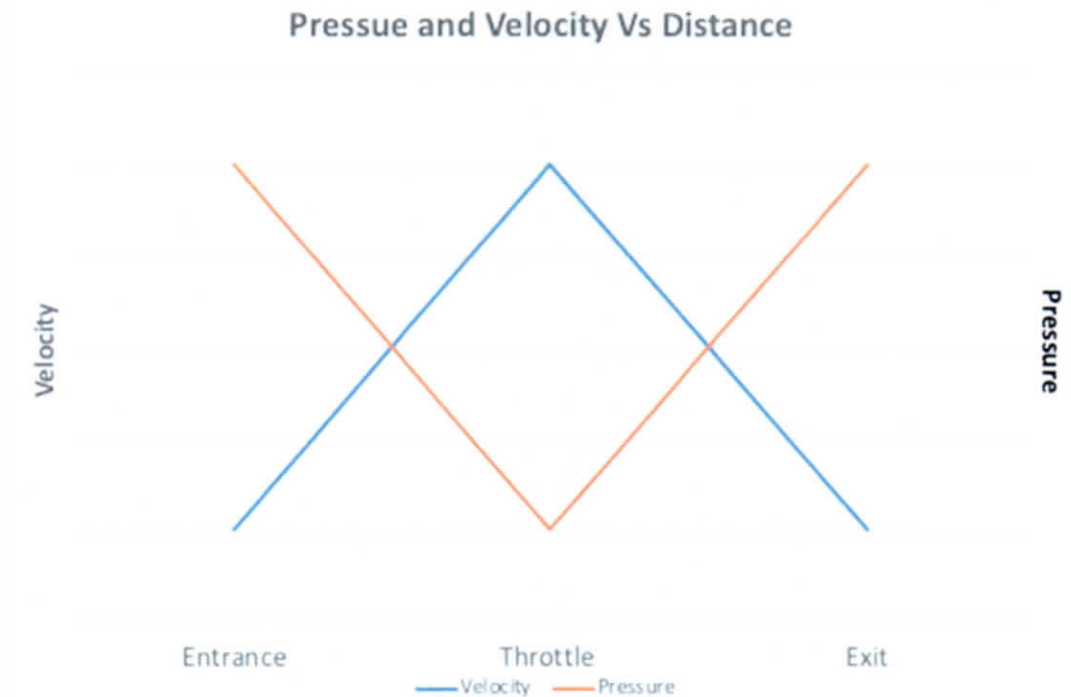
- a. Entrance to throat
- b. Throat to exit

Bernoulli's principle states that as the velocity of a fluid increases within a pipe, the pressure of the flow will decrease, therefore the conduction of this experiment validates Bernoulli's principle. We observed that as the fluid flows vertically from the entrance to the throat (section 1 through section 2) the fluid is moving through a large diameter into a smaller diameter, which restricts the fluid flow. Since the fluid is being constricted as it approaches the throat, the fluid is forced to flow at a faster rate in order to maintain continuous flow. As the fluid is transitioning from section one to section 2, the speed of the fluid increases and the pressure dramatically decreases (as shown by our graph below). The same principle applies as the fluid is flowing from the throat to

$$\frac{10}{10}$$

$$\frac{10}{10}$$

the exit. As the diameter expands, the fluid is no longer facing restriction, and this will cause the velocity to decrease as the pressure increases.



4. The pressure loss between the two ends of the venturi meter should be far less than the pressure drop between the entrance and throat of the venturi. Explain why this is the case.

9/10

The pressure loss between the two ends of the venturi meter is far less than the entrance to the throat because of how the fluid flows through the venturi. In the inlet tube, the fluid velocity is increased, and its pressure decreased because of the contracting cross-sectional area of the throat. The angle of discharge cone is made small to prevent boundary layer separation and to minimize friction which allows the original pressure from the entrance to be largely recovered. As it goes from the entrance to the throat the pressure drops significantly because it is constricted. This is known as the venturi effect. Thus, making the velocity increase which results in the pressure drop difference being a lot more. By the time the fluid reaches the exit the flow is no longer constricted. It will return to about the same initial pressure as when it first entered the venturi meter. Therefore, the difference is minimal as compared to when it first goes through the throat than the exit.

5. Find the diameter of the throat.

See next pages
(Total of 4 pages for the calculation of the throat diameter)

① Estimate reynolds number for flows to determine if turbulent/laminar/transitional ①

$$Re = \frac{\rho v D}{\mu} = \frac{v d}{\nu}$$

$Re < 2100 \rightarrow$ laminar

$2100 < Re < 4000 \rightarrow$ transitional

$Re > 4000 \rightarrow$ turbulent

- at 3200 L/hr

$$Q_A = 3200 \text{ L/hr} = 3.2 \text{ m}^3/\text{hr}$$

$$\text{Internal Diameter} = ID = 26.5 \text{ mm} = 0.0265 \text{ m}$$

assuming that H_2O at room temp

$$\text{is } 20^\circ\text{C}, \therefore \nu = 1.0034 \frac{\text{mm}^2}{\text{s}} = 0.00361224 \frac{\text{m}^2}{\text{hr}}$$

$$V_A = \frac{Q}{A} = \frac{3.2 \text{ m}^3/\text{hr}}{\frac{\pi}{4} (0.0265 \text{ m})^2} = 5801.87 \frac{\text{m}}{\text{hr}}$$

↓

$$Re = \frac{v d}{\nu} = \frac{(5801.87 \frac{\text{m}}{\text{hr}})(0.0265 \text{ m})}{(0.00361224 \frac{\text{m}^2}{\text{hr}})} = 42,563.5 \therefore [\text{turbulent}]$$

- at 2800 L/hr

$$Q_B = 2800 \text{ L/hr} = 2.8 \text{ m}^3/\text{hr}$$

$$V_B = \frac{Q_B}{A} = \frac{2.8 \text{ m}^3/\text{hr}}{\frac{\pi}{4} (0.0265 \text{ m})^2} = 5076.64 \frac{\text{m}}{\text{hr}} \rightarrow Re = \frac{v d}{\nu} = \frac{(5076.64 \frac{\text{m}}{\text{hr}})(0.0265 \text{ m})}{(0.00361224 \frac{\text{m}^2}{\text{hr}})}$$

$$= 37,243.08 \therefore [\text{turbulent}]$$

at 2400 L/hr

$$Q_C = 2400 \text{ L/hr} = 2.4 \text{ m}^3/\text{hr}$$

$$V_C = \frac{Q_C}{A} = \frac{2.4 \text{ m}^3/\text{hr}}{\frac{\pi}{4} (0.0265 \text{ m})^2} = 4351.41 \frac{\text{m}}{\text{hr}} \rightarrow Re = \frac{v d}{\nu} = \frac{(4351.41 \frac{\text{m}}{\text{hr}})(0.0265 \text{ m})}{(0.00361224 \frac{\text{m}^2}{\text{hr}})}$$

$$= 31,922.7 \therefore [\text{turbulent}]$$

- at 1600 L/hr

$$Q_D = 1600 \text{ L/hr} = 1.6 \text{ m}^3/\text{hr}$$

$$V_D = \frac{Q_D}{A} = \frac{1.6 \text{ m}^3/\text{hr}}{\frac{\pi}{4} (0.0265 \text{ m})^2} = 2900.94 \frac{\text{m}}{\text{hr}} \rightarrow Re = \frac{v d}{\nu} = \frac{(2900.94 \frac{\text{m}}{\text{hr}})(0.0265 \text{ m})}{(0.00361224 \frac{\text{m}^2}{\text{hr}})}$$

$$= 21281.78 \therefore [\text{turbulent}]$$

(2) From Bernoulli's equation, find diameter: (2)

- In a closed tube where fluids are passing, the total energy remains conserved. The following equation identifies the sum of all energies:

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

- Since the venturimeter is leveled, the tube's height becomes negligible: or $Z_1 = Z_2$. So the equation becomes

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} = \frac{P_2}{\rho g} + \frac{V_2^2}{2g}$$

- Rearranging the equation gives:

$$\underbrace{\frac{P_1 - P_2}{\rho g}} = \frac{V_2^2 - V_1^2}{2g} \quad \xrightarrow{\text{thus}} \quad h = \frac{V_2^2 - V_1^2}{2g} \dots (1)$$

is the difference P_{HEAD} in the meter and is equal to "h"

- From the continuity equation:

$$A_1 V_1 = A_2 V_2$$

$$V_2 = \frac{A_1 V_1}{A_2} \dots (2)$$

- Combining equation (1) and (2) we get:

$$h = \frac{\left(\frac{A_1 V_1}{A_2}\right)^2 - V_1^2}{2g}$$

, from here we solve for "A₂":

$$h = \frac{V_1^2}{2g} \left[\left(\frac{A_1}{A_2}\right)^2 - 1 \right] \quad \rightarrow \quad \sqrt{\frac{2gh}{V_1^2} + 1} = \frac{A_1}{A_2} \quad \therefore$$

$$\frac{2gh}{V_1^2} = \left(\frac{A_1}{A_2}\right)^2 - 1$$

$$\frac{2gh}{V_1^2} + 1 = \left(\frac{A_1}{A_2}\right)^2$$

$$\left[A_2 = \frac{A_1}{\sqrt{\frac{2gh}{V_1^2} + 1}} \right] \dots (3)$$

③ using equation ③ for the area of the throat & data readings we find diameter ③

• given:

$$A_1 = \frac{\pi}{4} (.0265\text{m})^2 = .000551546 = 5.52 \times 10^{-4} \text{ m}^2$$

$$g = 9.8 \text{ m/s}^2$$

$$h = \Delta P (\text{entrance to throat}) \text{ mm} \rightarrow \text{m}$$

• at 3200 L/hr

$$V_A = 5801.87 \text{ m} \left| \frac{1 \text{ hr}}{3600 \text{ s}} \right| = 1.611630556 \frac{\text{m}}{\text{s}}$$

$$h = 360 \text{ mm} \left| \frac{1 \text{ m}}{1000 \text{ mm}} \right| = .36 \text{ m}$$

$$A_2 = \frac{A_1}{\sqrt{\frac{2gh}{V_1^2} + 1}} = \frac{(5.52 \times 10^{-4} \text{ m}^2)}{\sqrt{\frac{2(9.8 \frac{\text{m}}{\text{s}^2})(.36 \text{ m})}{(1.611630556 \frac{\text{m}}{\text{s}})^2} + 1}} = .000286329 \text{ m}^2$$

$$A_2 = \frac{\pi}{4} (d)^2$$

$$D_A = \sqrt{\frac{A_2 \cdot 4}{\pi}} = \sqrt{\frac{(.000286329)(4)}{\pi}} = .01909 \text{ m} = \boxed{19.09 \text{ mm}}$$

• at 2800 L/hr

$$V_B = 5076.64 \text{ m} \left| \frac{1 \text{ hr}}{3600 \text{ s}} \right| = 1.410177778 \frac{\text{m}}{\text{s}}$$

$$h = 290 \text{ mm} \left| \frac{1 \text{ m}}{1000 \text{ mm}} \right| = .29 \text{ m}$$

$$A_2 = \frac{(5.52 \times 10^{-4} \text{ m}^2)}{\sqrt{\frac{2(9.8 \frac{\text{m}}{\text{s}^2})(.29 \text{ m})}{(1.410177778 \frac{\text{m}}{\text{s}})^2} + 1}} = .000281023$$

$$D_A = \sqrt{\frac{(.000281023)(4)}{\pi}} = .01892 \text{ m} = \boxed{18.92 \text{ mm}}$$

• at 2400 L/hr

$$V_c = 4351.41 \frac{\text{m}}{\text{hr}} \bigg| \frac{1 \text{ hr}}{3600 \text{ s}} = 1.208725 \frac{\text{m}}{\text{s}}$$

$$h = 200 \text{ mm} \bigg| \frac{1 \text{ m}}{1000 \text{ mm}} = .2 \text{ m}$$

$$A_2 = \frac{(5.52 \times 10^{-4} \text{ m}^2)}{\sqrt{\frac{2(9.8 \frac{\text{m}}{\text{s}^2})(.2 \text{ m})}{(1.208725 \frac{\text{m}}{\text{s}})^2} + 1}} = .00028763 \text{ m}^2$$

$$D_A = \sqrt{\frac{(.00028763 \text{ m}^2)(4)}{\pi}} = .01914 \text{ m} = \boxed{19.14 \text{ mm}}$$

• at 1600 L/hr

$$V_D = 2900 \frac{\text{m}}{\text{hr}} \bigg| \frac{1 \text{ hr}}{3600 \text{ s}} = .805555556 \frac{\text{m}}{\text{s}}$$

$$h = 70 \text{ mm} \bigg| \frac{1 \text{ m}}{1000 \text{ mm}} = .07 \text{ m}$$

$$A_2 = \frac{(5.52 \times 10^{-4} \text{ m}^2)}{\sqrt{\frac{2(9.8 \frac{\text{m}}{\text{s}^2})(.07 \text{ m})}{(.805555556 \frac{\text{m}}{\text{s}})^2} + 1}} = .000312795 \text{ m}^2$$

$$D_A = \sqrt{\frac{(.000312795 \text{ m}^2)(4)}{\pi}} = .01996 \text{ m} = \boxed{19.96 \text{ mm}}$$

- Summarized chart from findings:

Flow rate, Q [L/Hr]	Throat Diameter, D ₂ [mm]
3200	19.09
2800	18.92
2400	19.14
1600	19.96

Note: Although the throat diameters of the pipe may differ, they are roughly in the same marginal range. The difference in diameters from one flow to the next is due to human error. These errors could possibly be derived from incorrect readings of the meter, air bubbles in the system, or improper data collection of numbers. Taking the average diameter of the 4 readings gives:

$$\frac{19.09 + 18.92 + 19.14 + 19.96}{4} = 19.28 \text{ mm}$$

25
25

6. Describe how venturi meters are used in industry?

Venturi meters are used as a standard tool of accurate measurement for flow rate through a pipe for water and gases and especially for highly viscous liquids (slurries, suspended solids, dirty liquids). When a fluid passes through the inlet section of the meter to the throat, there is a drop-in pressure or a change of pressure. This drop of pressure is usually measured by an instrument which will then display the flowrate of the given fluid. Because of its application, a venturi meter is used to measure high flow rates and where high-pressure recovery is required in a system. These meters are used in a variety of areas within the industry such as oil pipelines, research centers, chemical plants, water treatment facilities, airplanes, and even carburetors.

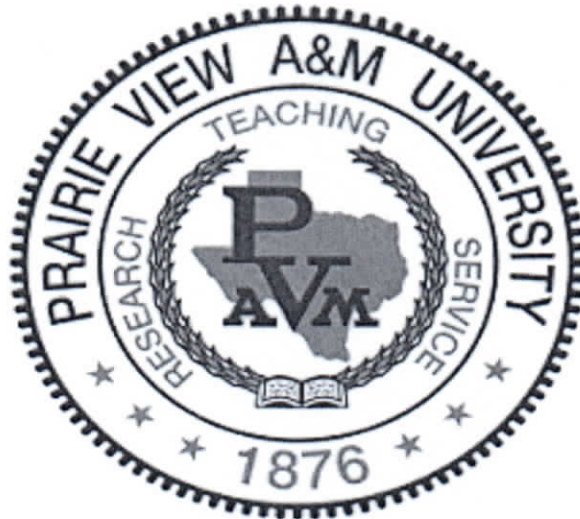
10
10

AVERAGE

Average Student Original Graded Assignment

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

186
245



Unit Operations
CHEG 3023 P02

Lab Assignment: Bernoulli's Principle

November 22, 2019

Khristen Liverman

Tysiannah Anderson

Iwinosa Omo-Ojo

Grant McTier

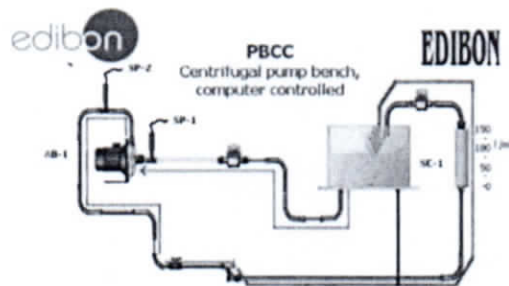
Ehimen Ekhuemelo

Dr. Keisha Antoine

Unit Operations Lab Assignment

In this assignment, the principles of mechanical energy conservation were studied using an Edibon PBCC Centrifugal Pump and the Venturi meter located on an Edibon AFT-B Fluid Friction in Pipes Equipment. Bernoulli's Principle was the focus of the study. The research was conducted on November 11, 2019 and November 13, 2019. Below are the findings after the data collection was analyzed.

Edibon PBCC Centrifugal Pump



- 1.
- a. In calculating the velocity of the discharge tank, Bernoulli's principle states

$$\frac{p_a}{\rho} + gZ_a + \frac{\overline{v_a^2}}{2} = \frac{p_b}{\rho} + gZ_b + \frac{\overline{v_b^2}}{2}$$

Some assumptions can be made.

1. Friction is disregarded
2. The pump is off, which means no pump work
3. Pressure change is negligible because both fluids are operating at atmospheric pressure
4. The velocity at suction point (p1) is disregarded due to the large area of the tank in regard to that of the pipe
5. Point 1 is our datum point, height is equal to 0 — not shown explicitly
6. The equation reduces to

$$-gZ_b = \frac{\overline{v_b^2}}{2}$$

$$-9.81 \frac{m}{s^2} (-0.0440 m) = \frac{\overline{v_b^2}}{2}$$

$$v_b^2 = 0.864 \frac{m^2}{s^2}$$

$$v_b = .930 \frac{m}{s}$$

- b. The volume in the tank is found by $l \times w \times h_{water}$

p1 isn't shown in a sketch. Therefore, its location is not well-defined. Or, if defined by the description it cannot be the suction pt.

45/50

Measured values for the tank are in the table below. The volume of the water is equal to 0.0119 m^3 .

Width (meter)	0.416
Length (meter)	0.648
Height (meter)	0.0440

c. Z_a is the datum point at 0. The measurement of Z_b is 0.0440 m; assuming the pump is off.

d. Assumptions:

- Steady flow system
- Density is constant
- No work done on or by the fluid
- No heat transferred to or from the fluid
- No change in internal energy

2. To find the head, Bernoulli's principle is divided by gravity giving the equation below

$$\frac{p_a}{\rho g} + Z_a + \frac{\overline{v_a^2}}{2g} = \frac{p_b}{\rho g} + Z_b + \frac{\overline{v_b^2}}{2g}$$

The head derivation is listed below.

$$\frac{p}{\rho g} = \frac{\frac{N}{m^2}}{\frac{kg \times m}{m^3 \times s^2}}$$

We know $N = \frac{kg \times m}{s^2}$

The units $\frac{kg \times m}{s^2 \times m^2} \times \frac{m^3 \times s^2}{kg \times m}$ reduce to m.

Z is already in meters.

$$\frac{\overline{v^2}}{2g} = \frac{m^2}{s^2} \times \frac{s^2}{m}$$

The units reduce to m. Add all parts of the head together to calculate the head.

3. The equation for H_t is given below

$$H_t = (Z_d - Z_s) + \frac{p_d - p_s}{\rho g} + \frac{Q^2}{g} \times \left(\frac{1}{A_d^2} - \frac{1}{A_s^2} \right)$$

20
20

Assumptions:

1. The difference in height is negligible, because it is so small
2. The diameter of the suction and discharge are the same, that term can be neglected

The equation reduces to

$$H_t = \frac{p_d - p_s}{\rho g}$$

From the software, four trials were conducted, review the results below. An average between four was completed. From the average the pressure difference was calculated.

Data	RPM	Padm(bar)	Pdes1(bar)	Torque(N*m)	Q(l/min)	Ht(m)	Nh(W)	Nrm(W)	Eff(%)
1.00	2400.00	-0.04	0.23	0.41	24.80	2.97	12.02	103.05	11.67
2.00	2400.00	-0.04	0.23	0.39	25.02	3.00	12.29	98.02	12.54
3.00	2400.00	-0.04	0.24	0.38	24.97	3.02	12.34	96.38	12.80
4.00	2400.00	-0.04	0.23	0.38	25.03	3.01	12.32	95.23	12.93
5.00	2400.00	-0.01	0.31	0.37	19.95	3.48	11.34	93.23	12.16
6.00	2400.00	-0.01	0.31	0.37	19.81	3.49	11.30	91.92	12.30
7.00	2400.00	-0.02	0.31	0.37	19.57	3.52	11.25	92.99	12.10
8.00	2400.00	-0.01	0.31	0.37	19.48	3.53	11.24	92.53	12.15
9.00	2400.00	0.02	0.43	0.32	7.31	4.25	5.08	80.74	6.30
10.00	2400.00	0.02	0.42	0.32	6.97	4.24	4.83	80.16	6.03
11.00	2400.00	0.02	0.43	0.33	8.55	4.29	5.99	82.01	7.31
12.00	2400.00	0.03	0.44	0.32	7.14	4.35	5.08	79.89	6.36
13.00	2400.00	0.02	0.41	0.32	9.86	4.19	6.76	81.21	8.32
14.00	2400.00	0.02	0.41	0.32	10.27	4.16	6.98	81.23	8.59
15.00	2400.00	0.02	0.41	0.32	10.68	4.17	7.29	79.78	9.13
16.00	2400.00	0.02	0.42	0.33	10.41	4.23	7.21	81.78	8.81

Trial	Average Head in Meters
1	3.00
2	3.505
3	4.1875
4	4.2825

Trial 1:

$$3.00 \text{ m} = \frac{p_d - p_s}{1000 \frac{\text{kg}}{\text{m}^3} \times 9.81 \frac{\text{m}}{\text{s}^2}}$$

$$p_d - p_s = 29430 \frac{\text{N}}{\text{m}^2}$$

Trial 2:

$$3.505 \text{ m} = \frac{p_d - p_s}{1000 \frac{\text{kg}}{\text{m}^3} \times 9.81 \frac{\text{m}}{\text{s}^2}}$$

$$p_d - p_s = 34384.1 \frac{\text{N}}{\text{m}^2}$$

Trial 3:

$$4.1875 \text{ m} = \frac{p_d - p_s}{1000 \frac{\text{kg}}{\text{m}^3} \times 9.81 \frac{\text{m}}{\text{s}^2}}$$

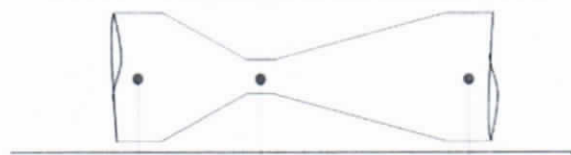
$$p_d - p_s = 41079.4 \frac{\text{N}}{\text{m}^2}$$

Trial 4:

$$4.2825 \text{ m} = \frac{p_d - p_s}{1000 \frac{\text{kg}}{\text{m}^3} \times 9.81 \frac{\text{m}}{\text{s}^2}}$$

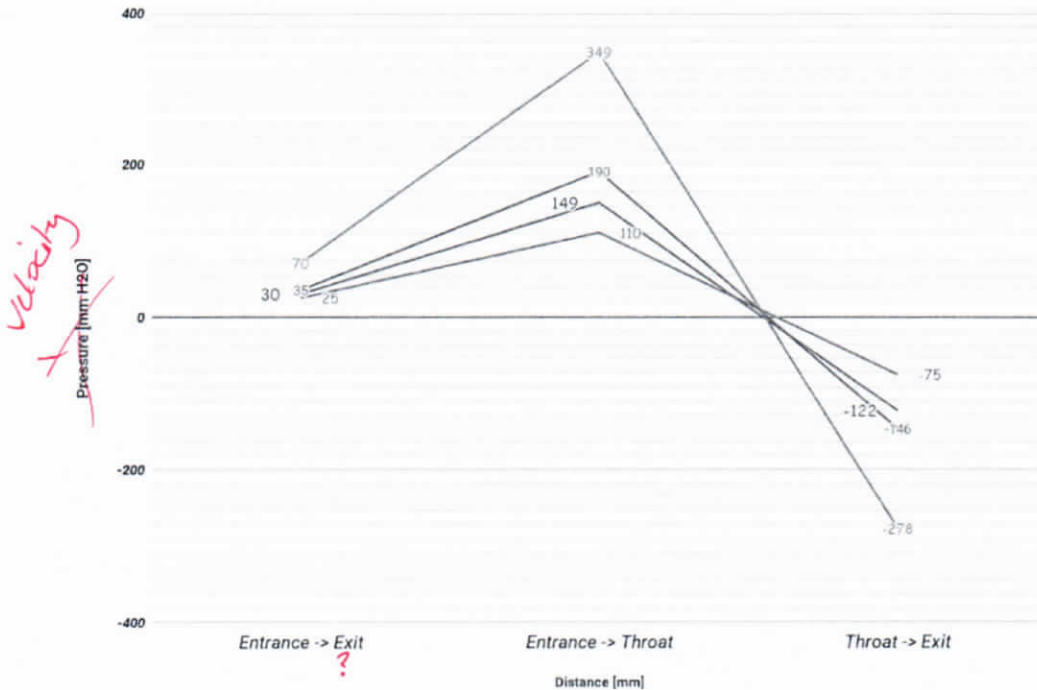
$$p_d - p_s = 42011.3 \frac{\text{N}}{\text{m}^2}$$

Venturi Meter in Edibon AFT-B Fluid Friction in Pipes



Below you will see a graph that demonstrates the pressure change vs. the distance throughout the venturi meter. This graph gives a visual representation of how area and pressure are inverse. As the area of the venturi meter increase the pressure will decrease and as the area decreases the pressure will increase.

Pressure vs. Distance



- Q = 1600 [L/Hr]
- Q = 2000 [L/Hr]
- Q = 2400 [L/Hr]
- Q = 3000 [L/Hr]

Can't tell which Q's correspond to which lines.

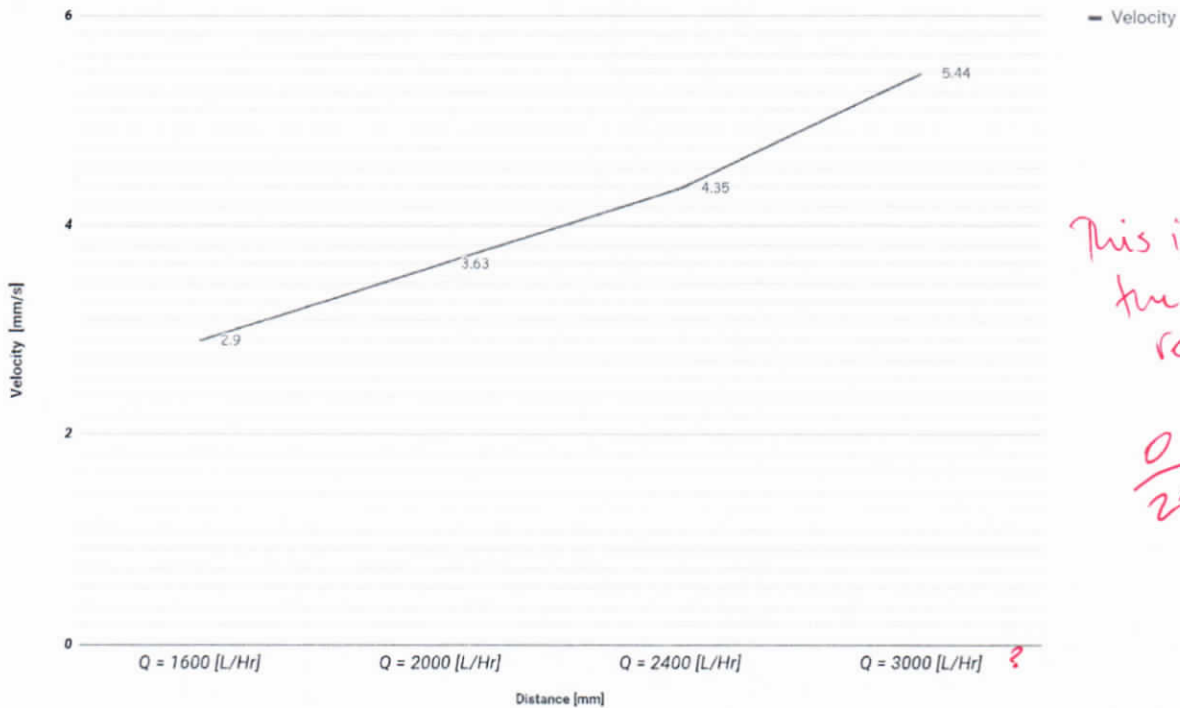
Why is exit pressure lower than entrance pressure?

$\frac{2P}{\rho}$ $\frac{1}{\rho}$

The Velocity vs. Distance graph below shows that as the flow rate (Q) increase the Velocity will increase as well. One can also conclude that as the area of the venturi meter increase the velocity will be low (decrease) and vice versa. When the diameter is larger on one side it will have less energy loss than of the smaller diameter of the pipe. Therefore the lowest velocity will have the most energy and the highest velocity will have the least amount of energy depending on if the diameter is smaller than the initial diameter (26.5mm).

? The point is that energy is conserved. Thus as velocity head increases, pressure head decreases correspondingly to conserve energy.

Velocity vs. Distance



This is not the graph requested.

0/20

3.) Bernoulli's equation application

$$\frac{p_a}{\rho g} + Z_a + \frac{\overline{v_a^2}}{2g} = \frac{p_b}{\rho g} + Z_b + \frac{\overline{v_b^2}}{2g}$$

(Assuming no friction loss and work)

i.) Entrance to throat: Due to the flow being horizontal, the effect of gravity can be neglected for this case. The difference in height will also be negligible. The final equation after simplification gives us: $v_b^2 - v_a^2 = 2\left(\frac{p_b - p_a}{\rho}\right)$. As seen in the graph, the velocity through the throat will

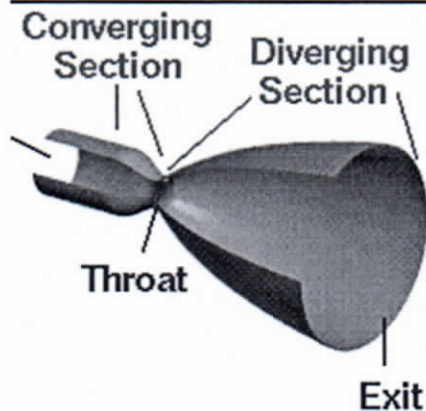
significantly increase from entrance velocity because it flows through a constriction. The pressure will be lower in the throat as compared to the entrance, to accommodate for this increase. Velocity is related to Diameter at certain points in the venturi meter. Proof of this is

with the continuity relation: $v_a = \left(\frac{D_b}{D_a}\right)^2 \times v_b$

ii.) Throat to exit: Due to the flow being horizontal, the effect of gravity can be neglected for this case. The difference in height will also be negligible. The final equation after simplification gives us: $v_b^2 - v_a^2 = 2\left(\frac{p_b - p_a}{\rho}\right)$. As seen in the graph, the velocity through the exit will significantly decrease from throat velocity. It will however be higher than entrance velocity. To accommodate for this, the outlet pressure from the exit is higher than our throat pressure.

4. Pressure Loss

The pressure loss between the two ends is far less than the pressure drop between the entrance and the throat due to the distance of the separation. *no*
 In the convergent section, flow velocity is accelerated and pressure decreases. In divergent section, flow velocity decreases and pressure increases. from Bernoulli equation.



5. Diameter of the throat

$$V = Q/A, D = 26.5\text{mm} = 0.0265\text{m}$$

$$Q_1 = 2400\text{l/hr} = 0.00067\text{m}^3/\text{sec}$$

$$V = (0.00067\text{m}^3/\text{sec})/(\pi(0.0265)^2/4) = 1.21\text{m/sec} \quad \checkmark$$

$$p_1/P + V_1^2/2 = p_2/P + V_2^2/2$$

$$V = \sqrt{(2(P_2 - P_1)/P + V_2^2)}$$

P_2 = entrance, P_1 = throat

$$V_1 = \sqrt{(2(525-335)/1000 + 1.21^2)} = 1.36\text{m/sec} \quad \times \quad 2.28\text{ m/s}$$

did not convert to pressure

$$Q_2 = 3000\text{l/hr} = 0.00083\text{m}^3/\text{sec}$$

$$V = (0.00083\text{m}^3/\text{sec})/(\pi(0.0265)^2/4) = 1.51\text{m/sec} \quad \checkmark \quad \times \quad 3.02\text{ m/s}$$

$$V_2 = \sqrt{(2(674-324)/1000 + 1.51^2)} = 1.73\text{m/sec} \quad \times \quad 3.02\text{ m/s}$$

$$Q_3 = 2000\text{l/hr} = 0.00056\text{m}^3/\text{sec}$$

$$V = (0.00056\text{m}^3/\text{sec})/(\pi(0.0265)^2/4) = 1.02\text{m/sec} \quad \checkmark$$

$$V_3 = \sqrt{(2(457-307)/1000 + 1.02^2)} = 1.16\text{m/sec} \quad \times \quad 1.99\text{ m/s}$$

$$Q_4 = 1600\text{l/hr} = 0.00044\text{m}^3/\text{sec}$$

$$V = (0.00044\text{m}^3/\text{sec})/(\pi(0.0265)^2/4) = 0.80\text{m/sec} \quad \checkmark$$

5/10

*20 for part 1
 ΔP vs Q*

15/25

5

$$V_1 = \sqrt{(2(365-255)/1000 + 0.80^2)} = 0.93 \text{ m/sec} \quad \times 1.68 \text{ m/s}$$

$$V = Q/A$$

$$V = Q/(\pi D^2/4)$$

$$D = \sqrt{4Q/V\pi} \quad + \sqrt{\frac{Q \cdot 4}{V \cdot \pi}} \quad -5$$

$$D_1 = 0.025 \text{ m} = 25 \text{ mm} \quad +$$

$$D_2 = 0.0247 \text{ m} = 24.7 \text{ mm} \quad +$$

$$D_3 = 0.0264 \text{ m} = 26.4 \text{ mm} \quad +$$

$$D_4 = 0.0245 \text{ m} = 24.5 \text{ mm} \quad +$$

$$D_{\text{average}} = 25.15 \text{ mm} \quad +$$

6. Venturi meters in industry

Venturi meters they can provide rate of flow control or measure sewage; they can be used reliably for billing or custody transfer; and they can be used for rectangular or circular metering. In addition, Venturi meters can be oriented in any plane and can measure accurately whether the line fluid is flowing upwards or downwards.

Here is a list of Advantages:

- Less chance of getting stuck with sediment
- Discharge coefficient is high
- HS behavior can be predicted perfectly
- Can be installed vertically, horizontally, inclined
- Precise can be used for a whole range of flows
- About 90% of the pressure drop can be recovered

Plumbing

- Used in pipelines at wastewater collection systems and treatment plants. Solids are passed through instead of collecting in front of it. Less build up in the pipes produces more accurate readings.

Carburetors

- Used to measure airflow in a car engine and to ensure that the correct amount of fuel is fed in the gas combustion engine when necessary.

Process Control

- Steam injection systems for the animal feeds industry.

Cost Allocation

- Allows energy cost to be allocated to a particular product department.

BELOW AVERAGE

Below Average Student Original Graded Assignment

There are zero BELOW AVERAGE student samples available.

CHEMICAL ENGINEERING
OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET
CHEG 3023 UNIT OPERATIONS
FALL 2019
Instructor: Dr. Keisha Antoine

Title of Assignment

T3-Centrifugal Pump Data Exercise 11/20/2019

Outcome Measured Using this Assignment

Outcome 7

An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Check the outcome characteristics related to this assignment

Ability to Acquire new knowledge using the appropriate learning strategies Requires students to:	
x	Be knowledgeable of and use different learning strategies <i>(Instructor may provide information on different learning strategies)</i>
x	Identify and take advantage of learning opportunities available in the library, online resources, seminars, webinars, conferences, workshops and tutorials.
x	Be aware of the need for and are able to independently acquire additional knowledge and data needed for solving problem using appropriate learning strategies and tools.
Ability to apply new knowledge to solve problems Requires students to:	
x	Demonstrate appropriate use of the new knowledge to solve problems.

Brief justification of why this assignment is suitable for this outcome

This assignment allows the students to gain fundamental understanding of the Bernoulli Principle with an emphasis on data analysis using EXCEL.

**UNIT OPERATIONS
FALL 2019**

**SAMPLE TEST QUESTIONS, SOLUTION,
AND GRADING SCHEME FOR T3-PBCC
Centrifugal**

Instructions

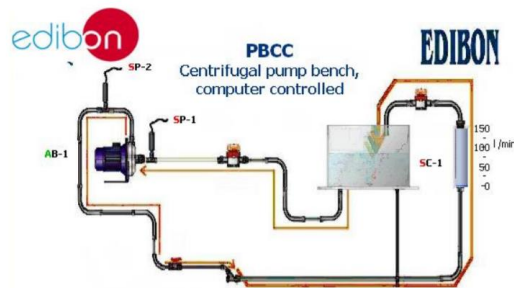
This assignment is to be done individually. Submit work on Taskstream and online by Tuesday 11/26.

Objective

In this assignment, students will study the characteristics of a centrifugal pump by using EXCEL to manipulate raw data obtained from Edibon PBCC Centrifugal Pump Equipment.

Edibon PBCC Centrifugal Pump

The program measures pump speed in rpm, p_{suction} (bar), $p_{\text{discharge}}$ (bar), torque (N.m), Q (L/min), H_t (m), W_p . Disregard the values for pressures that the program records in carrying out these exercises.



Resources

1. UOCE, 7th Ed., Chapter 4, Mechanical Energy Equation (pp 86 – 94); Chapter 8, Centrifugal Pumps (pp 208 – 209), Ideal Pump (pp 210), Actual pump performance (211 – 212)
2. Chapter 4c class notes (available on eCourses)
3. Pump Hydraulics (available on eCourses)
4. NPSH (available on eCourses)

Instructions

You have been provided with data file: 3000 rpm.txt.

Disregard values of pressure in the data.

Flow rates are under the SC-1 heading and have units of L/min.

Exercises

1. Plot total head, H_t in meters vs. flow rate, Q (L/min) for various pump speeds. [20 points]
2. On the same graph as 1., plot efficiency lines connecting points of equal efficiency across different pump speeds. (See Fig. 8.10 in UOCE 6th Ed.) [20 points]
3. At what speed(s), flow rate(s) and total head(s) does the pump have the highest efficiency, η ? State your answer and show on graph. [30 points]
4. For a pump speed of 3000 rpm, plot total head, H_t , hydraulic power, N_h and efficiency vs. flow rate, Q . [30 points]

EXTRA CREDIT [20 POINTS]

If you could add or remove any components or change the orientation of the equipment of this system, how would you increase the efficiency of pumping water with this pump system?

No.Data	RPM	SP-1	SP-2	Torque	SC-1	Ht	Nh	Nm	Eff(%)
1	3000	-0.15683	0.299079	0.557104	39.72524	4.868781	31.62311	175.0195	18.06834
2	3000	-0.15547	0.291677	0.562343	39.55092	4.779041	30.90403	176.6652	17.493
3	3000	-0.15443	0.293787	0.557165	39.94369	4.790967	31.28882	175.0387	17.87537
4	3000	-0.15521	0.294585	0.556816	39.39928	4.805555	30.95634	174.9288	17.69654
5	3000	-0.14756	0.339594	0.562472	37.88053	5.182598	32.09825	176.7058	18.16479
6	3000	-0.14728	0.322342	0.547966	38.06469	5.00438	31.14514	172.1487	18.092
7	3000	-0.14707	0.33813	0.55849	37.76236	5.162386	31.87333	175.455	18.1661
8	3000	-0.14413	0.333725	0.560895	37.67124	5.087315	31.33404	176.2103	17.78218
9	3000	-0.10523	0.408605	0.556644	34.66627	5.447019	30.87335	174.8748	17.65454
10	3000	-0.11341	0.413755	0.54395	34.55543	5.582649	31.54092	170.887	18.45718
11	3000	-0.11599	0.4122	0.555875	34.56322	5.59305	31.60681	174.6334	18.09895
12	3000	-0.11509	0.41178	0.544937	34.58925	5.579671	31.55495	171.1971	18.43194
13	3000	-0.04464	0.550532	0.485535	24.0606	6.255881	24.61006	152.5352	16.13402
14	3000	0.017021	0.1232	0.240775	6.720607	1.253819	1.377721	75.64174	1.821377
15	3000	0.020898	0.149013	0.290138	9.601018	1.478965	2.321629	91.14962	2.547053
16	3000	0.01068	0.156178	0.296582	9.126591	1.65587	2.470886	93.17394	2.651907
17	3000	-0.00046	0.4909	0.433554	16.71141	5.187904	14.17499	136.2051	10.40709
18	3000	-0.00231	0.476691	0.4311	16.42458	5.061551	13.59239	135.4341	10.03616
19	3000	0.008848	0.345058	0.391739	14.51656	3.604084	8.55414	123.0683	6.950725
20	3000	0.029859	0.166333	0.284042	6.73264	1.562642	1.720136	89.2343	1.927662
21	2000	0.031426	0.094924	0.172871	4.512974	0.817938	0.603533	36.20593	1.666946
22	2000	0.033045	0.097738	0.171001	4.198834	0.830041	0.569831	35.81441	1.591067
23	2000	0.030818	0.095002	0.175418	2.875743	0.824539	0.387685	36.73948	1.055227
24	2000	0.032936	0.096305	0.166703	4.224729	0.816546	0.564024	34.91427	1.615453
25	2000	0.026402	0.09586	0.170642	2.759578	0.878284	0.396274	35.73908	1.108797
26	2000	0.031008	0.091913	0.165254	3.077251	0.791153	0.398053	34.61076	1.150085
27	2000	0.033544	0.097271	0.172843	4.229656	0.820198	0.567207	36.2002	1.566862
28	2000	0.031491	0.094852	0.172423	2.244461	0.81605	0.299465	36.1122	0.829264
29	2000	0.031316	0.093523	0.168783	2.991337	0.804413	0.393425	35.3499	1.112946
30	2000	0.027866	0.098377	0.169069	4.991964	0.889586	0.726068	35.40976	2.050474
31	2000	0.032572	0.100239	0.171551	2.728349	0.860018	0.383641	35.92951	1.06776
32	2000	0.027807	0.094175	0.163702	4.718596	0.84726	0.653653	34.28561	1.906493
33	2000	0.025383	0.093585	0.17268	2.418867	0.86542	0.34226	36.16599	0.94636
34	2000	0.026028	0.094599	0.172281	5.027212	0.869814	0.714943	36.08252	1.981412
35	2000	0.027517	0.095113	0.172298	4.816417	0.859808	0.677085	36.08608	1.876306
36	2000	0.029121	0.093647	0.168313	0	0.82775	0	35.25136	0
37	1800	0.031401	0.093434	0.166482	4.604774	0.803031	0.604586	31.38104	1.926597
38	1800	0.031217	0.097043	0.16926	0	0.841014	0	31.90483	0
39	1800	0.031468	0.095736	0.165225	0	0.825122	0	31.14411	0
40	1800	0.029827	0.097807	0.171022	0	0.862968	0	32.23693	0
41	1800	0.032257	0.094693	0.169552	0	0.806453	0	31.95983	0
42	1800	0.029946	0.093512	0.16673	0	0.817964	0	31.42783	0
43	1800	0.030134	0.092193	0.16604	0	0.802609	0	31.29787	0
44	1800	0.03242	0.092602	0.166385	2.566645	0.783693	0.328874	31.36278	1.048612
45	1800	0.030317	0.090284	0.167648	0	0.781281	0	31.60095	0
46	1800	0.031101	0.093057	0.168966	3.887697	0.802047	0.509812	31.84937	1.600697

47	1800	0.02994	0.094636	0.170413	0	0.829483	0	32.12218	0
48	1800	0.031488	0.091257	0.167894	0	0.779259	0	31.64735	0
49	2200	0.028375	0.093081	0.181583	8.145089	0.831759	1.107672	41.83374	2.647796
50	2200	0.026304	0.097967	0.18075	7.708654	0.902449	1.137415	41.64172	2.731431
51	2200	0.026284	0.098206	0.18961	7.283942	0.904882	1.077646	43.68305	2.466967
52	2200	0.02518	0.099342	0.186368	8.135165	0.92814	1.234519	42.93621	2.875239
53	2200	0.024966	0.096139	0.186847	7.850887	0.897521	1.152076	43.0465	2.676352
54	2200	0.025631	0.10061	0.193088	8.346243	0.936579	1.278065	44.48432	2.873069
55	2200	0.027052	0.09939	0.192856	8.111689	0.909536	1.206282	44.43084	2.714966
56	2200	0.0234	0.094703	0.181265	7.916947	0.898876	1.163523	41.76053	2.78618
57	2200	0.025212	0.105738	0.197945	6.870529	0.992392	1.114786	45.60333	2.444527
58	2200	0.028498	0.102938	0.19835	6.553735	0.930216	0.99676	45.6965	2.18126
59	2200	0.027101	0.110097	0.204386	6.265246	1.017315	1.042105	47.0871	2.213143
60	2200	0.02697	0.103732	0.196188	6.296149	0.953777	0.981838	45.19845	2.172281
61	2200	0.031224	0.112809	0.19327	2.676916	1.001886	0.438501	44.52626	0.984815
62	2200	0.030367	0.111512	0.194169	0	0.997162	0	44.73322	0
63	2200	0.03286	0.113088	0.185625	0	0.987817	0	42.76487	0
64	2200	0.029882	0.112916	0.191582	0	1.016416	0	44.13734	0
65	2200	0.028442	0.10932	0.190429	4.517421	0.99511	0.734987	43.87176	1.675308
66	2200	0.0298	0.109475	0.195762	5.09015	0.983028	0.818114	45.10024	1.813991
67	2200	0.030748	0.10844	0.193662	3.822772	0.962445	0.60155	44.61657	1.348266
68	2200	0.030981	0.11003	0.193516	5.402586	0.976744	0.86278	44.58286	1.935228
69	2400	0.00164	0.088475	0.220011	15.65482	1.063147	2.721191	55.29482	4.921241
70	2400	-5.7E-05	0.08029	0.230356	14.82329	0.996189	2.414372	57.89478	4.170275
71	2400	0.008501	0.093084	0.224335	14.2855	1.038855	2.426434	56.38162	4.30359
72	2400	0.006012	0.091033	0.225666	15.20611	1.044205	2.596101	56.71617	4.577356
73	2400	-0.04124	0.14367	0.299612	25.00436	2.075214	8.483918	75.30065	11.26673
74	2400	-0.04897	0.149133	0.309151	26.15733	2.21163	9.458529	77.69802	12.17345
75	2400	-0.05547	0.154943	0.321084	26.98	2.338561	10.31593	80.69734	12.78349
76	2400	-0.05926	0.159032	0.3264	27.54565	2.419898	10.89853	82.03328	13.2855
77	2400	-0.05474	0.192471	0.336516	26.83645	2.713466	11.90603	84.57579	14.07735
78	2400	-0.05917	0.197594	0.347484	27.46687	2.811893	12.62775	87.3322	14.45944
79	2400	-0.05786	0.194288	0.351025	27.58017	2.765041	12.46856	88.22233	14.13311
80	2400	-0.05921	0.200427	0.347177	27.44626	2.841193	12.74975	87.25514	14.61203
81	2400	-0.03327	0.264658	0.344804	23.72782	3.225338	12.51269	86.65875	14.43904
82	2400	-0.03249	0.264012	0.339907	23.43357	3.210364	12.30015	85.42787	14.39829
83	2400	-0.03522	0.263632	0.338014	23.42029	3.234289	12.3848	84.95227	14.57853
84	2400	-0.0352	0.261101	0.339919	23.42557	3.208282	12.28798	85.43088	14.38353
85	2400	-0.00093	0.351322	0.32528	16.62086	3.769759	10.24436	81.7518	12.53105
86	2400	-0.00317	0.351956	0.330217	16.97668	3.799437	10.54605	82.99261	12.70722
87	2400	-0.0013	0.345079	0.323412	16.28855	3.709458	9.878946	81.28229	12.15387
88	2400	0.001279	0.352056	0.326131	16.67585	3.754767	10.23738	81.96561	12.48985
89	2400	0.018183	0.402068	0.314165	11.06139	4.08718	7.39182	78.95817	9.361691
90	2400	0.017881	0.406544	0.316358	10.35405	4.135395	7.000758	79.50956	8.804926
91	2400	0.018878	0.404053	0.316328	11.20775	4.100442	7.513922	79.50186	9.451252
92	2400	0.018236	0.405281	0.311795	10.55219	4.119033	7.106499	78.36262	9.068736
93	2400	0.030975	0.256437	0.274353	4.976015	2.469089	2.008798	68.95244	2.913309

94	2400	0.030075	0.268016	0.281666	3.945817	2.595995	1.674783	70.79039	2.365835
95	2400	0.030499	0.272931	0.278981	4.495601	2.641928	1.941898	70.11557	2.769568
96	2400	0.033972	0.274704	0.286001	3.601899	2.624366	1.545517	71.8799	2.150137
97	2400	0.029732	0.275008	0.286805	4.889669	2.671041	2.135392	72.08205	2.962447
98	2400	0.033142	0.329837	0.274996	0	3.194408	0	69.11401	0
99	2400	0.031517	0.326131	0.260972	0	3.173208	0	65.58943	0
100	2400	0.034165	0.329089	0.263768	0	3.176352	0	66.29218	0
101	2400	0.031378	0.330199	0.27397	0	3.216081	0	68.85622	0
102	2600	-0.09853	0.183208	0.411135	32.8461	3.077091	16.52502	111.9404	14.76234
103	2600	-0.09891	0.180122	0.402661	33.0977	3.050043	16.50523	109.6331	15.05497
104	2600	-0.09802	0.187354	0.409267	33.33182	3.115209	16.97712	111.4317	15.23545
105	2600	-0.0989	0.183666	0.415311	33.14203	3.086114	16.72279	113.0772	14.78883
106	2600	-0.10033	0.181645	0.402389	33.24461	3.080376	16.74336	109.5589	15.28252
107	2600	-0.09201	0.201247	0.410542	32.20462	3.193168	16.81349	111.7787	15.04176
108	2600	-0.09326	0.203655	0.405384	32.15096	3.23034	16.98087	110.3745	15.38478
109	2600	-0.09478	0.201722	0.401282	32.13057	3.225999	16.9473	109.2575	15.51134
110	2600	-0.09322	0.201925	0.40491	32.12601	3.212231	16.87257	110.2454	15.30457
111	2600	-0.08133	0.233351	0.408222	30.46006	3.407928	16.97223	111.1471	15.27007
112	2600	-0.07875	0.232042	0.4003	30.44192	3.368267	16.76472	108.9903	15.38184
113	2600	-0.0825	0.227741	0.39825	30.55582	3.362885	16.80055	108.4322	15.49407
114	2600	-0.0799	0.233319	0.402724	30.45592	3.393018	16.89568	109.6503	15.40869
115	2600	-0.05414	0.294865	0.386375	27.18597	3.751706	16.67598	105.1988	15.85187
116	2600	-0.05463	0.295897	0.397424	26.88513	3.76666	16.55718	108.2071	15.30138
117	2600	-0.05224	0.293853	0.382341	27.30041	3.722185	16.61441	104.1004	15.95999
118	2600	-0.05334	0.297257	0.400863	26.95989	3.767568	16.60722	109.1435	15.21595
119	2600	-0.00609	0.41237	0.34876	14.89345	4.442883	10.81877	94.95733	11.3933
120	2600	0.015904	0.197181	0.264888	9.495715	2.020816	3.137417	72.1213	4.350194
121	2600	0.028839	0.139008	0.223046	5.486168	1.294011	1.160713	60.72891	1.911302
122	2600	0.032158	0.138415	0.213601	4.216509	1.253731	0.864321	58.15752	1.486173
123	2600	0.015222	0.340526	0.319988	12.14686	3.490849	6.932868	87.12364	7.957506
124	2600	0.008568	0.341738	0.314819	12.36076	3.571207	7.217355	85.71625	8.420054
125	2600	0.009575	0.334107	0.322432	12.17717	3.483001	6.934542	87.78908	7.899094
126	2600	0.009939	0.295405	0.31341	10.82866	3.083768	5.459767	85.33249	6.398228
127	2600	0.03223	0.347097	0.282927	5.089514	3.380496	2.813031	77.03306	3.651719
128	2600	0.028198	0.349783	0.278575	4.881953	3.448912	2.752919	75.84791	3.629525
129	2600	0.031943	0.356101	0.280688	5.069093	3.47519	2.880227	76.42329	3.768781
130	2600	0.028896	0.363654	0.279395	5.181937	3.583282	3.035924	76.07136	3.99089
131	2600	0.031994	0.445783	0.266711	0	4.388034	0	72.61776	0
132	2600	0.03452	0.4492	0.269491	0	4.397118	0	73.37478	0
133	2600	0.031815	0.441521	0.279229	0	4.346407	0	76.02616	0
134	2600	0.033313	0.450517	0.279854	0	4.42285	0	76.19619	0
135	2800	-0.11513	0.284176	0.502406	34.73531	4.279641	24.30504	147.3132	16.49889
136	2800	-0.11691	0.292414	0.486402	34.77427	4.381869	24.91352	142.6206	17.4684
137	2800	-0.11635	0.289647	0.491499	34.9342	4.348378	24.83681	144.115	17.23403
138	2800	-0.11547	0.295654	0.499111	34.49427	4.39963	24.81309	146.347	16.95497
139	2800	-0.14731	0.19563	0.508212	38.39055	3.713849	23.31129	149.0155	15.64353
140	2800	-0.14455	0.190869	0.502156	38.17142	3.636639	22.69636	147.2398	15.41455

141	2800	-0.1541	0.207999	0.50807	38.39686	3.909102	24.5409	148.9738	16.4733
142	2800	-0.14569	0.201894	0.502558	38.40677	3.761171	23.6183	147.3577	16.02786
143	2800	-0.14341	0.207387	0.519153	37.89504	3.792639	23.49858	152.2235	15.43689
144	2800	-0.14028	0.207603	0.513438	37.84968	3.762881	23.2863	150.548	15.46769
145	2800	-0.06876	0.15059	0.431541	30.3519	2.435972	12.0886	126.5344	9.553603
146	2800	-0.13712	0.210803	0.499874	36.32181	3.759599	22.32681	146.5708	15.23279
147	2800	-0.14984	0.222349	0.515897	38.09607	4.011268	24.98502	151.2689	16.51696
148	2800	-0.14145	0.226947	0.524095	38.01002	3.972363	24.6868	153.6725	16.06455
149	2800	-0.14426	0.211665	0.512063	38.01677	3.845234	23.90098	150.1447	15.91864
150	2800	-0.14303	0.223188	0.530552	37.88054	3.949772	24.46279	155.566	15.72502
151	2800	-0.13547	0.227033	0.49593	37.22931	3.91038	23.80245	145.4142	16.36873
152	2800	-0.13495	0.231258	0.517386	37.32062	3.948346	24.0925	151.7054	15.88111
153	2800	-0.13457	0.236297	0.521612	37.1784	3.99549	24.28725	152.9448	15.87976
154	2800	-0.14337	0.236337	0.518232	37.22036	4.085686	24.86356	151.9534	16.36262
155	2800	-0.12146	0.262344	0.509367	35.93526	4.124455	24.23289	149.3543	16.2251
156	2800	-0.11961	0.260369	0.514109	35.97149	4.0855	24.02821	150.7447	15.93967
157	2800	-0.1301	0.26721	0.506802	35.95391	4.262122	25.05473	148.602	16.8603
158	2800	-0.12558	0.258578	0.513435	35.96541	4.128093	24.27461	150.547	16.12427
159	2800	-0.09994	0.308936	0.498099	33.09778	4.373591	23.66763	146.0502	16.20513
160	2800	-0.10404	0.325395	0.499739	33.31626	4.58363	24.96799	146.5311	17.03938
161	2800	-0.09913	0.319159	0.505369	33.10158	4.469587	24.18989	148.1819	16.32446
162	2800	-0.09706	0.329204	0.510055	33.04892	4.55079	24.59019	149.556	16.44212
163	2800	-0.05485	0.428942	0.476567	27.6171	5.12641	23.14777	139.7366	16.56529
164	2800	-0.05573	0.431376	0.478109	27.13839	5.15941	22.89296	140.189	16.33007
165	2800	-0.05386	0.434501	0.483051	27.14447	5.172198	22.95484	141.6381	16.20669
166	2800	-0.05266	0.436949	0.475551	26.97088	5.184622	22.86283	139.4388	16.39632
167	2800	-0.06032	0.432771	0.469688	26.74797	5.219747	22.82748	137.7196	16.57533
168	2800	-0.03025	0.498171	0.451012	23.26986	5.574165	21.20759	132.2435	16.03677
169	2800	-0.01686	0.411765	0.416227	20.57967	4.552996	15.31981	122.0443	12.55267
170	2800	-0.0152	0.375891	0.405015	20.10742	4.169854	13.70865	118.7566	11.54349
171	2800	-0.00951	0.346953	0.387819	18.23117	3.814506	11.37027	113.7146	9.998956
172	2800	0.001759	0.429941	0.396749	16.48929	4.543606	12.24956	116.3328	10.52975
173	2800	-0.0065	0.452384	0.402041	16.97174	4.857039	13.47769	117.8845	11.43297
174	2800	-0.00775	0.473245	0.405639	17.34218	5.082897	14.41228	118.9395	12.11732
175	2800	0.009735	0.432225	0.38767	14.98743	4.484046	10.98791	113.6707	9.666436
176	2800	0.02265	0.152907	0.256192	6.33536	1.499101	1.552816	75.11939	2.067131
177	2800	0.021392	0.165937	0.257154	6.39415	1.644783	1.719527	75.40152	2.280494
178	2800	0.027302	0.17473	0.255927	6.429843	1.674185	1.760035	75.04164	2.345412
179	2800	0.026111	0.160072	0.249993	6.328414	1.536869	1.590191	73.30169	2.169379
180	2800	0.025104	0.487982	0.343132	6.817747	4.889939	5.450823	100.6114	5.417697
181	2800	0.029557	0.511277	0.365539	7.713356	5.082432	6.409626	107.1816	5.980153
182	2800	0.028392	0.515422	0.361958	6.700687	5.136089	5.626906	106.1316	5.301817
183	2800	0.025823	0.544055	0.356598	6.679889	5.454141	5.956804	104.5601	5.697015
184	2800	0.034144	0.560498	0.333445	0	5.535479	0	97.77104	0
185	2800	0.02436	0.563826	0.337956	0	5.669142	0	99.09398	0
186	2800	0.031462	0.546241	0.335828	0	5.417497	0	98.46981	0
187	2800	0.027142	0.565027	0.33439	0	5.653032	0	98.04836	0

ABOVE AVERAGE

Above Average Student Original Graded Assignment



CHEG 3023 PO2

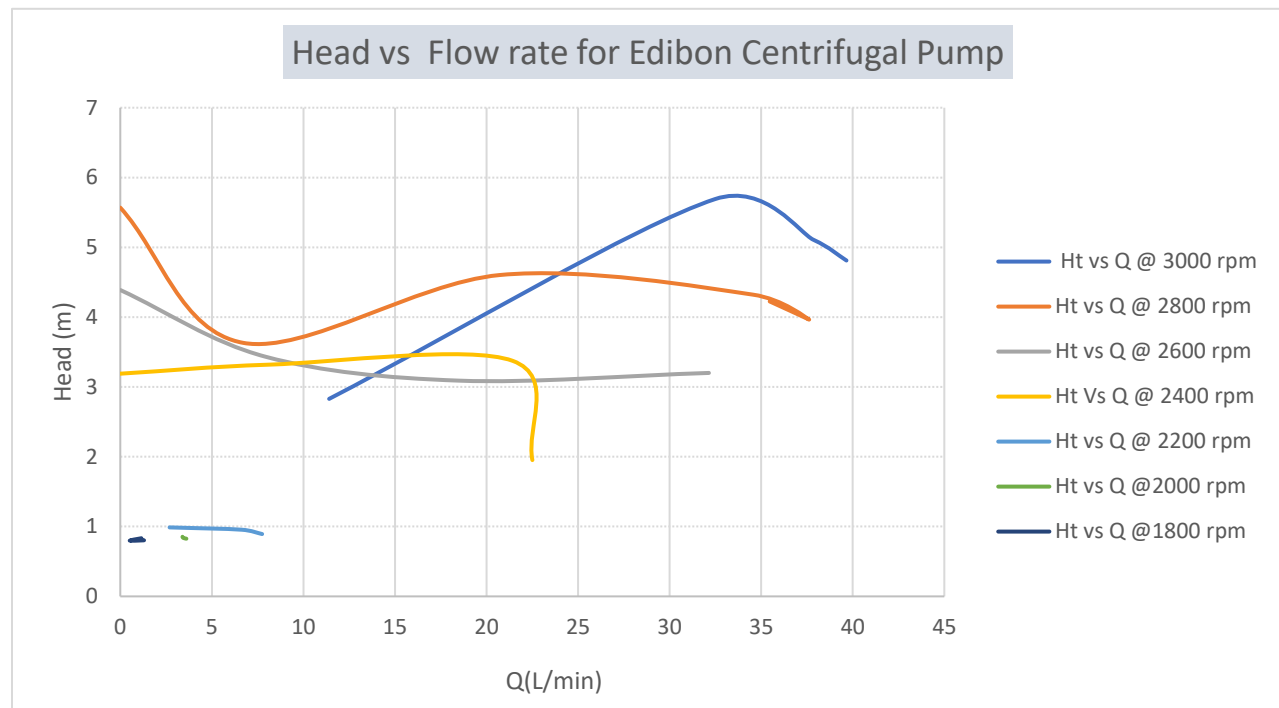
CHARACTERISTICS OF A CENTRIFUGAL PUMP, USING DATA FROM EDIBON PBCC
CENTRIFUGAL PUMP

CONSTANTINO NGUEMA MANSOGO

November 27, 2019

85/100 +25 extra credit

1. 20/20



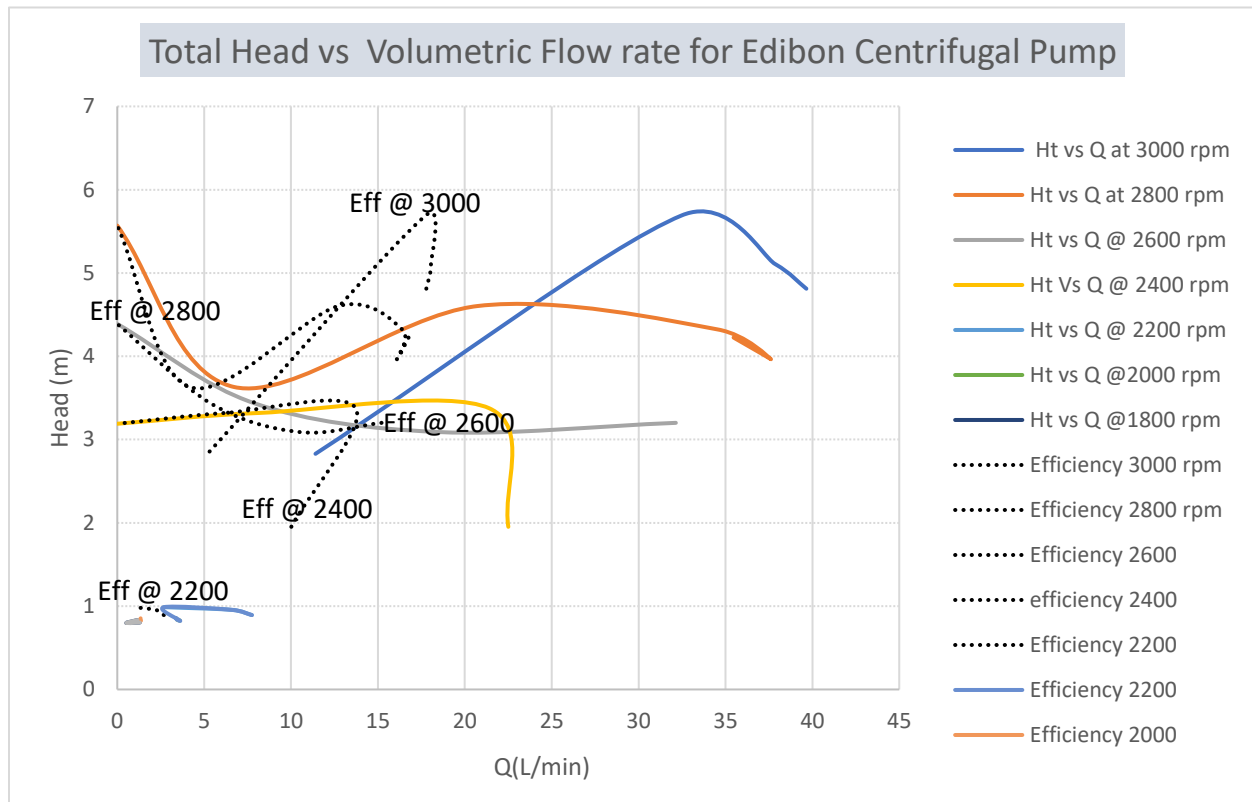
The graph shows the characteristics curves of the total head of the centrifugal pump versus their corresponding volumetric flow rates at different pump speeds.

The total head of each pump speed is situated on the Y axis of the graph, while the corresponding volumetric flow rate is on the x axis. The data was collected from various speeds at 3000, 2800, 2600, 2400, 2200, 2000 and 1800 RPM.

While the data might not be exactly accurate, the graph shows that the speed of the pump is increasing proportionally as the volumetric flow rate increases, from a minimum speed of 1800 rpm corresponding to a volumetric flow rate of 0.513 L/min, to a maximum speed of 3000 rpm corresponding to a volumetric flow rate of 39.654 L/min.

The pump head versus flow rate curve that results from a pump speed of 3000 RPM, illustrate a small conflicting pattern with the rest of the graph which in general show that the pump transits from zero flow at maximum head of 5.69 m to maximum flow of 39.654 L/min at minimum head of 0.798 m which is almost invisible due to the dimension of the graph.

2. 10/20

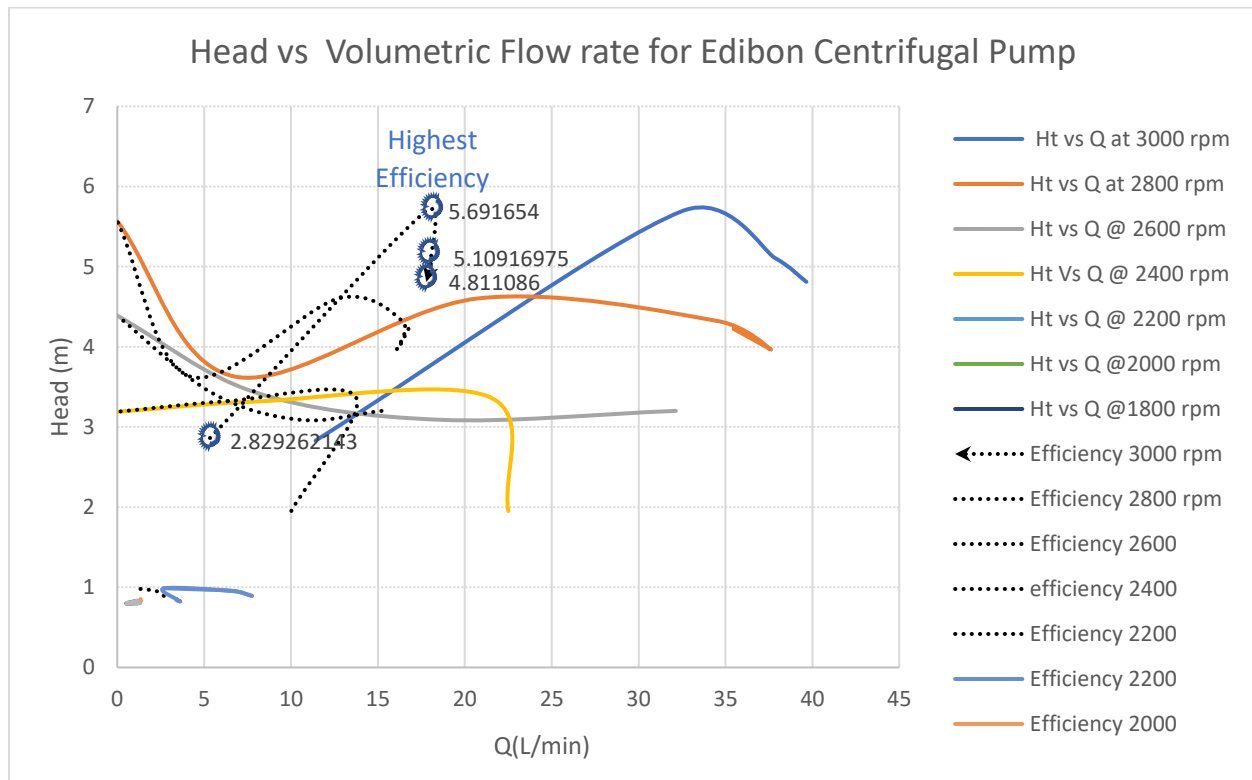


This graph illustrates the pattern of the efficiency lines, represented in dots lines with respect to the various speeds and subsequent head and flow rates.

Generally, the graphs show that efficiency increases initially as flow is being raised in the pump, you can also observe that the efficiency falls back, this happens because the volumetric flow rate approaches the zero head value. Flow increases total head reduces.

Because there is a small amount of information gathered in the speed range of 2000 to 1800 revolution per minute, it is hard to visualize the efficiency lines of these speeds, but the assumption will be that they follow the same pattern as the rest of the efficiency lines clearly identified in the graph, a proportional initial increase with respect to the volumetric flow rates, reaches its maximum point and falls back because as flow increases, the total head tend to decrease as observed in the first question.

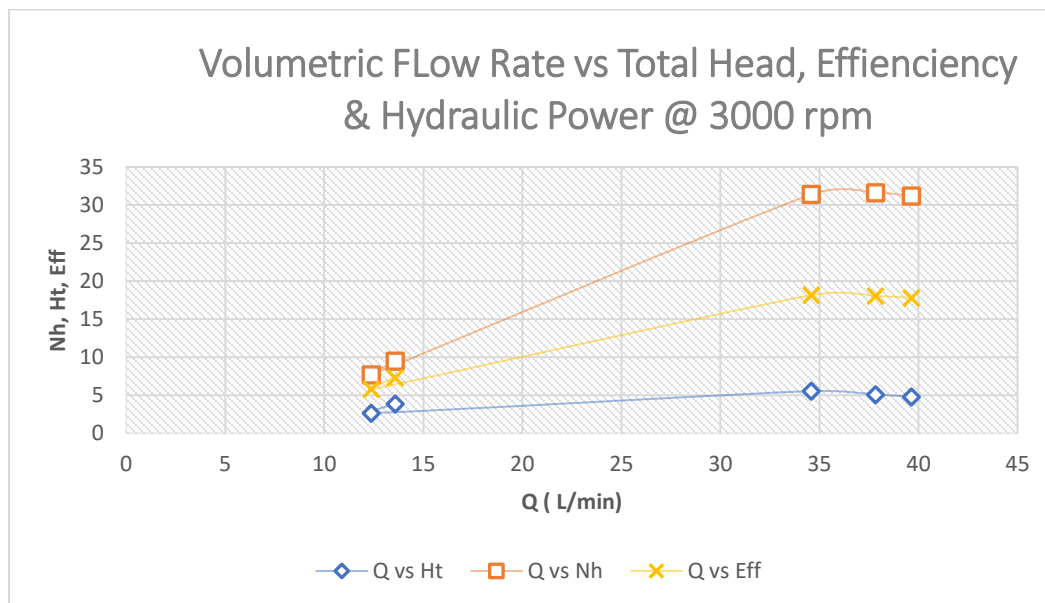
3.



As previously observed with respect to the rest of the efficiency lines, the pump efficiency increases initially as the volumetric flow rate increases, but, the maximum efficiency will be not exactly at the maximum flow but at moderate flow, take for example the volumetric flow rates of 39.65 L/Min, 37.84 L/Min, 32.48 L/Min, 11.40 L/Min at the speed of 3000 revolution per minute, you can observe from the graph that the maximum efficiency occurs not at the maximum speed of 39.65 L/Min but at the volumetric flow rate of 32.48 L/Min which corresponds to a head of 5.69 m.

This shows that the pump will have its highest efficiency at the speed of 3000 revolution per minute, at a head of 5.69 meters which correspond to a flow rate of 32.48 Liter per minute.

4. 30/30



The graph shows the relationship between the volumetric flow rate and the total head, hydraulic power and the efficiency. As the volumetric flow rate increases, the total head increases, until the pump develop a full flow then the total head fall down, total head being the difference between suction and discharge of the pump, when the pump develops flow, the pump builds pressure at the discharge therefore reducing the head difference with the suction, that explain why the total head falls down when the pump's flow goes to full operation. At the minimum head of 2.66 m the volumetric flow rate is 12.37 L/min but maximum flow of 39.65 has a head of 4.81 m.

The hydraulic power of the pumps follows the same pattern as the total head, the fluid power rises with flow rate to a maximum and later falls back. Hydraulic power is directly proportional to the pump efficiency, as the efficiency rises the pump hydraulic rises, and they both fall down in the hydraulic power is due to the pump overcoming friction, because of fluids going to the bearing seals, small amounts of leakages etc.

Efficiency and flow rate follow the same pattern rises with volume, reaches the maximum value, and the falls back, they were explained in question number two, but they produce the same behavior as the hydraulic power, total head with respect to the volumetric flow rate.

Extra Credit 25

The pump efficiency can be increased by changing the size of the impellers, or by increasing the amount of stages of the pump making the pump a multistage pump. We can also increase the speed of the pump, that will in return produce more flow and efficiency.

References:

1. McCabe, W. L., Smith, J. C., & Harriott, P. (2005). *Unit operations of chemical engineering*. Boston, MA: McGraw-Hill.

AVERAGE

Average Student Original Graded Assignment



Tysiannah Anderson

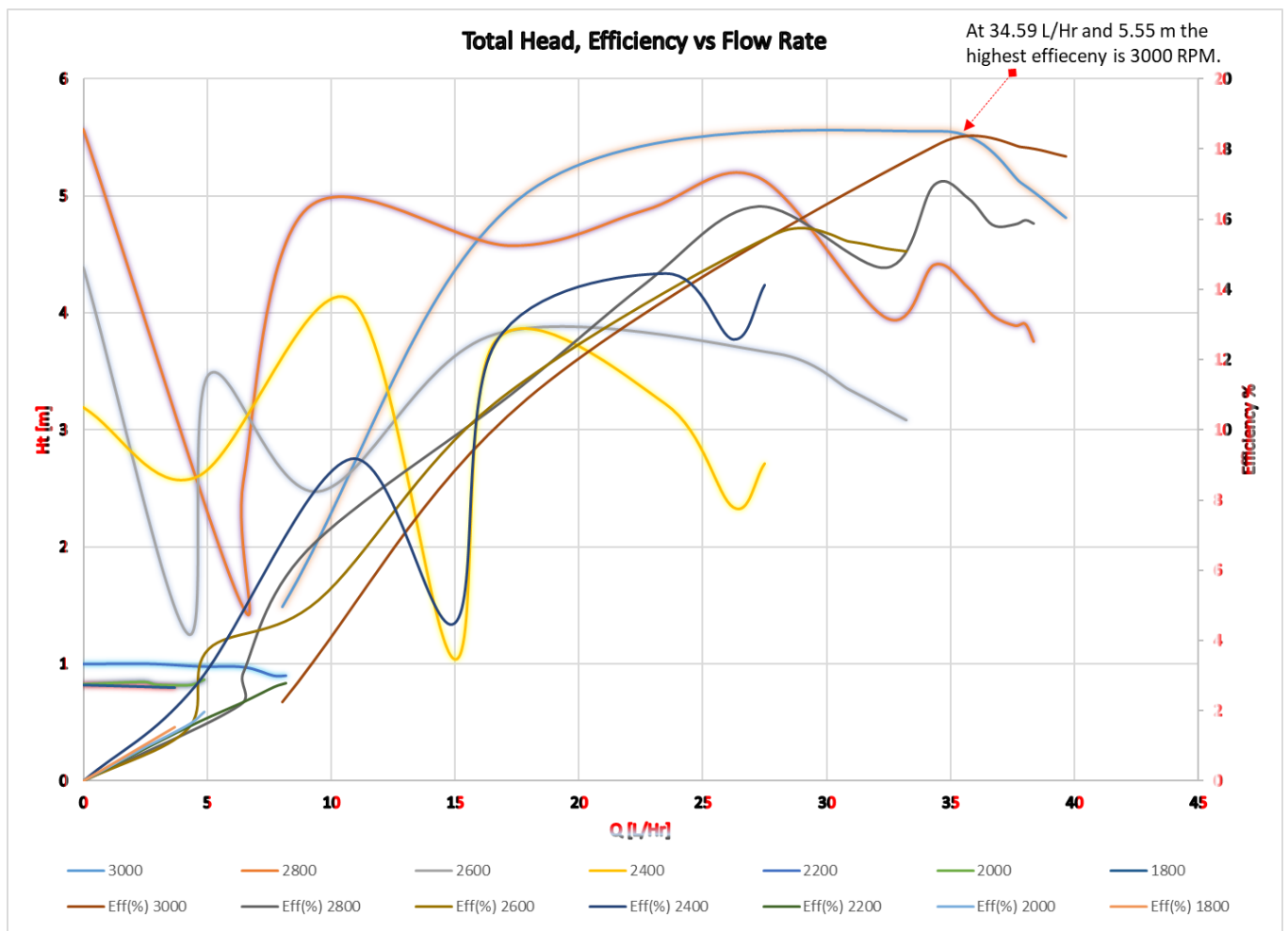
70/100 + 10 extra credit

10

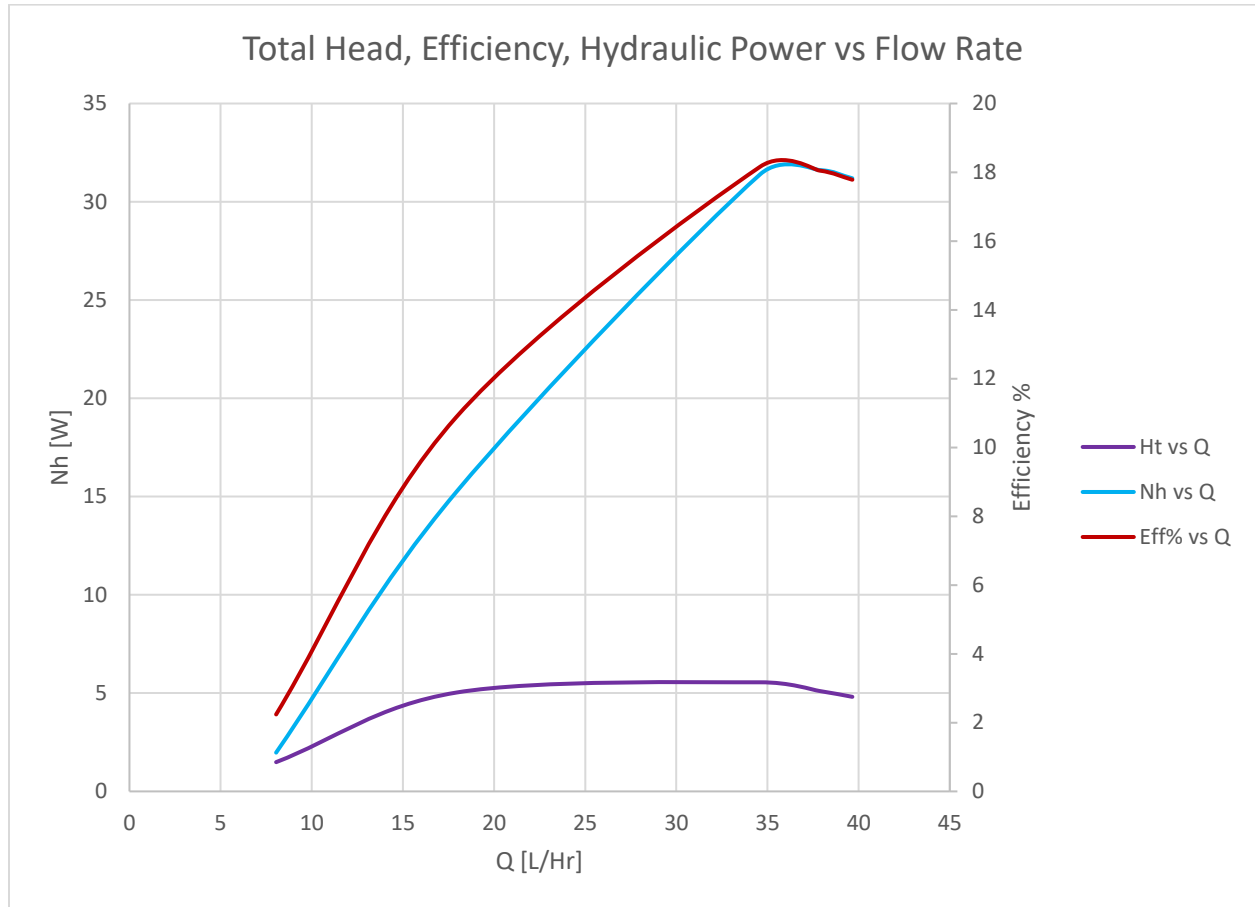
Extra Credit: To increase the Efficiency you could increase the Mechanical Power (Nm) of the pump, and Total Head (Ht).



1) 20/20, 10/20, 15/30



4) 25/30

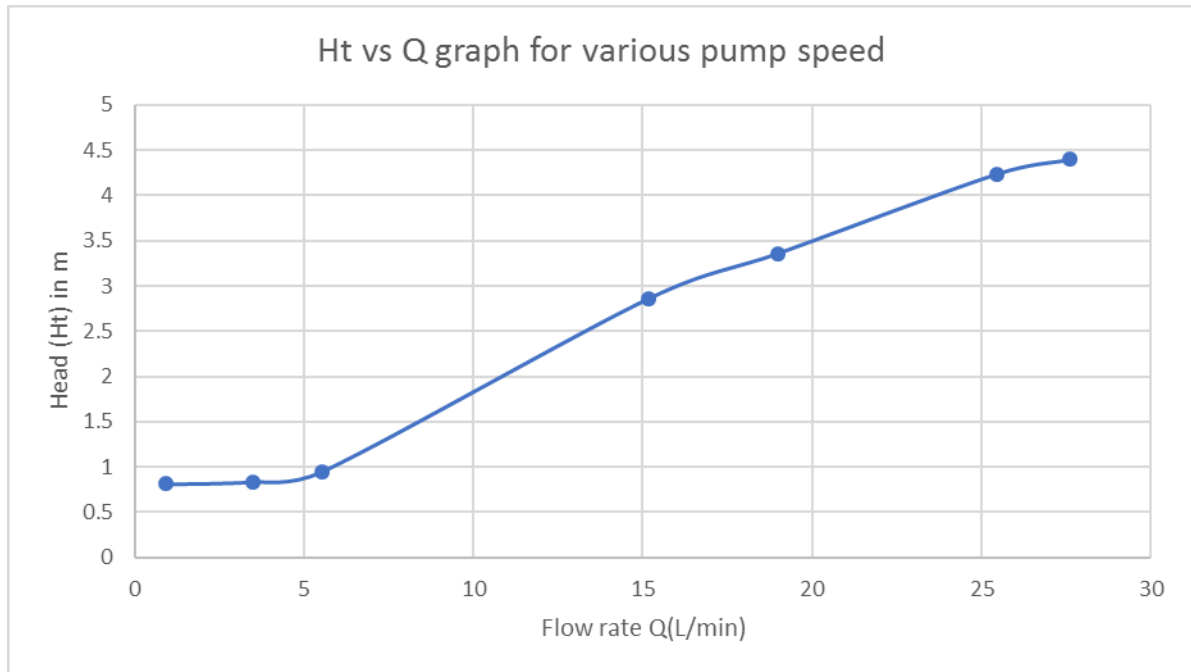


BELOW AVERAGE

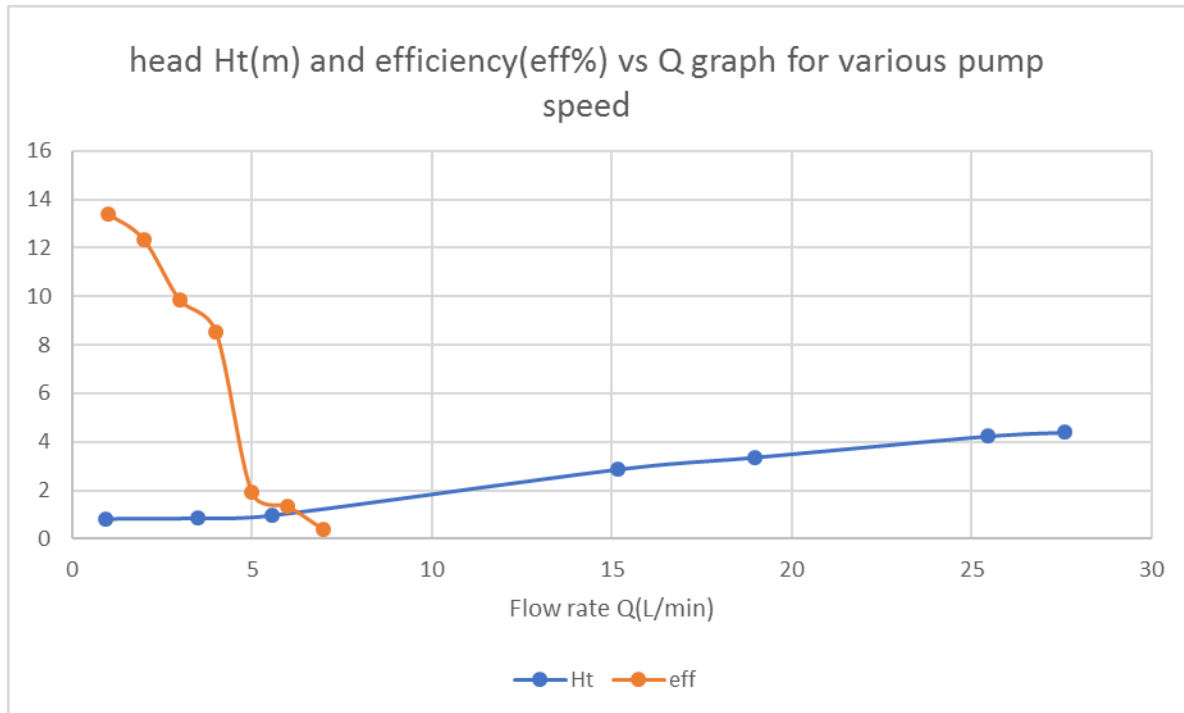
Below Average Student Original Graded Assignment

Centrifugal Pump Data Exercise

1. Plot total head, H_t in meters vs. flow rate, Q (L/min) for various pump speeds 10/20



2. On the same graph as 1., plot efficiency lines connecting points of equal efficiency across different pump speeds 10/20

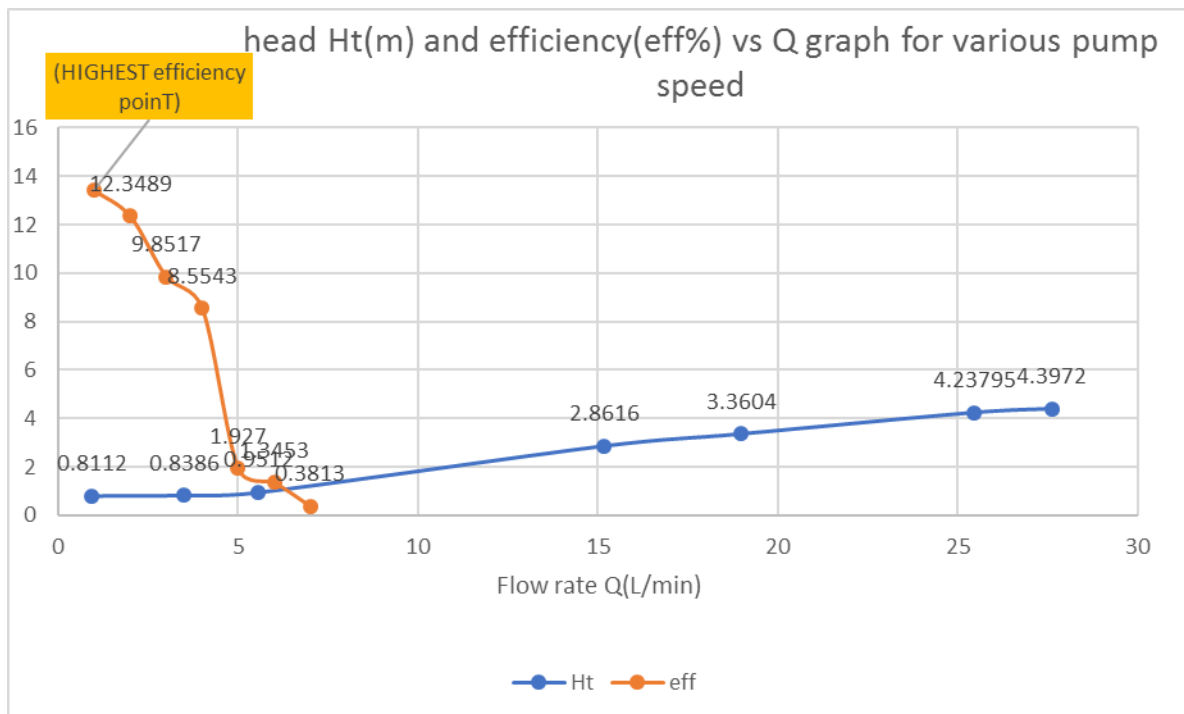


3. At what speed(s), flow rate(s) and total head(s) does the pump have the highest efficiency, %?

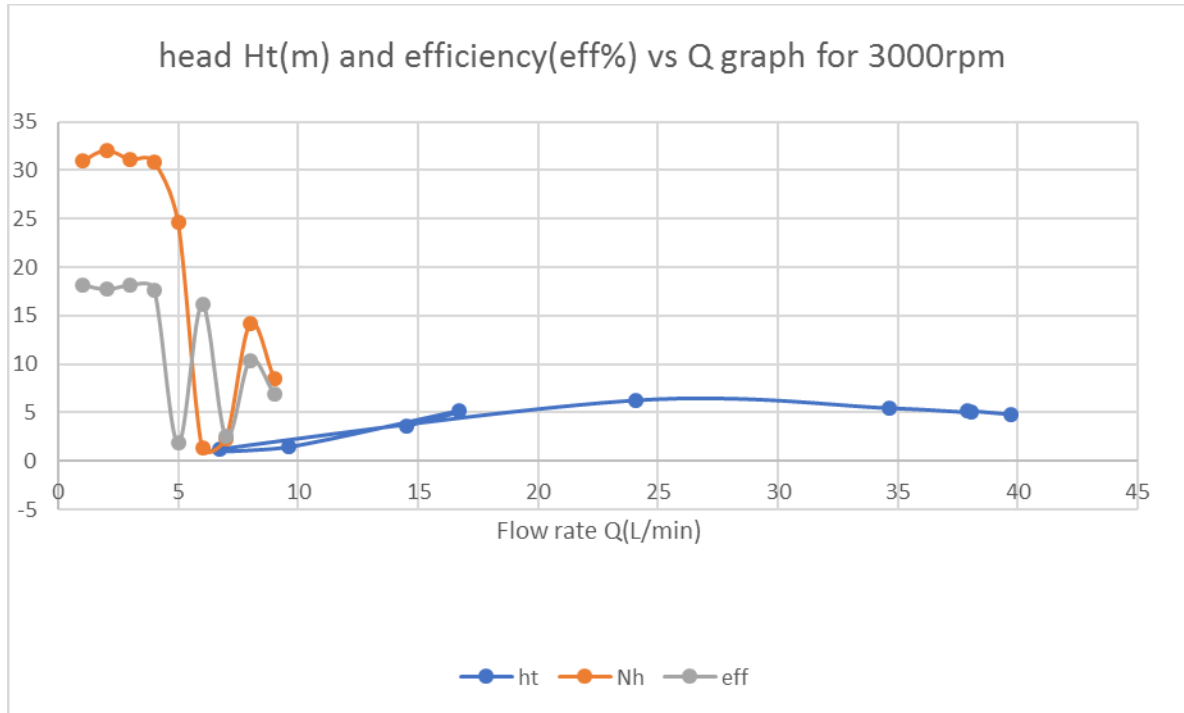
At the highest Efficiency these are the data that we have:

15/30

RPM	Q(sc-1)L/min	Ht(m)
3000	27.6133	4.3972



4. For a pump speed of 3000 rpm, plot total head, H_t , hydraulic power, N_h and efficiency vs. flow rate, Q 15/30



**SENIOR DESIGN AND PROFESSIONALISM I
FALL 2021**

Title of Assignment: HOMEWORK 3

TOPICS COVERED IN HOMEWORK 3

- 1. Literature review**
- 2. Process selection**
- 3. Production route analysis**
- 4. Process description**

**SENIOR DESIGN AND PROFESSIONALISM I
FALL 2019**

HOMEWORK #3 QUESTION

**CHEG 4472 Senior Design & Professionalism I (Fall 2019):
Assignment 3**

September 12, 2019

Due: September 26, 2019

You will be graded based on your ability to define and plan the project. Clarity of presentation is essential if you are to avoid losing points. Use the below cover page.

- (a) Create a list of major tasks and their respective duration to be accomplished to enable you achieve the goals and objectives for your project**
- (b) Organize the tasks into phases/module**
- (c) Identify sub-tasks and their respective duration**
- (d) Link major tasks and/or sub-tasks when required**
- (e) Identify milestones and deadlines to track an important event**
- (f) Prepare a Gantt Chart print out using Microsoft Project or Excel**

**DEPARTMENT OF CHEMICAL ENGINEERING
SENIOR DESIGN & PROFESSIONALISM I CHEG 4472
COURSE ASSESSMENT GRADING & OUTCOME
ASSESSMENT SHEET FOR FALL 2019 SEMESTER**

ABET Outcome 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factor.

Assignments that test competency in this area will include problems testing students' understanding of the design process, identification of a need, problem definition, project planning, project management, information gathering, idea generation and creativity, feasibility studies and evaluation of ideas to select the most feasible and suitable concept, appropriate of the process, performing design calculations and evaluating the design solution.

Name: _____

Title of Assignment: _____ Due Date _____

Competency Area	Max for this Assignment	Student's Score
ABET Outcome 2: An ability to design a system, a component, or process to meet desired needs within realistic constraints		
2.1. Ability to Plan the Project Students ability to (i) Define the design strategy and methodology, (ii) Identify and break down work into tasks and subtasks and identify the personnel and deliverables for each. .		
2.2. Ability to Plan the Project Students ability to (iii) Develop a Gantt chart and critical path analysis for managing the project (iv) Establish major milestones for tracking progress and define performance metrics to measure success		
TOTAL	100	

MAJOR TASKS

1. Project Conception and Definition
2. Flow sheet development
3. Reporting

PHASES

1. Phase 1 – Project conception and definition
2. Phase 2 – Flow sheet development
3. Phase 3 – Reporting

SUB-TASKS

- A. Project conception and definition
 - a. Client identification and recognition of need
 - i. Market analysis and trends: Define market- volume, quality, uses and cost of product
 - b. Process screening of alternatives
 - i. Process chemistry: Reactants, reactions (reaction stoichiometry) and products; catalysts, incomplete reactions and decomposition
 - ii. Screening processes using gross profit analysis
 - iii. Reaction kinetics and rate equations
 - iv. Handling, storage and safety: Physical and chemical properties; EPA, OSHA regulations and waste disposal
 - c. Defining process conditions and capacities
 - i. Plant capacity where product demand or raw material supply defines the feed rate
 - ii. Defining temperatures, pressures and other process variables; process description
- B. Flow Sheet Development
 - a. Process description
 - b. Preliminary Process Flow Diagram
 - i. Equipment symbols
 - ii. Process stream flow lines
 - iii. Equipment numbers and names
 - iv. Utility designations
 - v. Temperature and pressure designations on process lines
 - c. Materials and energy balances
 - i. Basis of calculations
 - ii. Material and Energy balances around each process unit: use of degree of freedom analysis, assumptions and use of heuristics

- d. Finalized Process Flow Diagram
 - i. Equipment symbols
 - ii. Process stream flow lines
 - iii. Equipment numbers and names
 - iv. Utility designations
 - v. Temperature and pressure designations on process lines
 - vi. Selected volumetric and molar flow rates
 - vii. Material balance table showing flow summary of process
- e. Computer (ASPEN/HYSYS) simulation of process
 - i. Fluid package selection
 - ii. Assumptions for modeling process units

C. Reporting

- a. Homework Assignments
- b. Midterm Report and Presentation
- c. Final End of Semester Presentation
- d. Final End of Semester Report

ABOVE AVERAGE

CHEG 4247: SENIOR DESIGN & PROFESSIONALISM I

FALL 2021

ASSIGNMENT STATEMENT/QUESTIONS

Senior Design & Professionalism I (Fall 2021): Home Work 3
Due October 26, 2021

You will be graded based on your ability to engage in life-long learning. Start each question on a new page. Clarity of presentation is essential if you are to avoid losing points.

Present a comprehensive literature review/survey of your project, citing all sources. Include (a) an introduction, (b) review of literature on production of your product including process/production routes, physical and chemical properties, handling and storage, uses and product specification, (c) process selection (using process sorting), (d) process description, stating the main steps involved in the production, and providing details of the steps involved.

Note: Make sure to use effective and well-placed subheadings, so that the sections and subheadings follow the logical sequence of the report outline.

Limiting your sources to only the internet or merely copying what you find in the literature without a brief discussion highlighting the relevance or otherwise of the information will be considered inadequate.

DEPARTMENT OF CHEMICAL ENGINEERING

SENIOR DESIGN & PROFESSIONALISM I CHEG 4247

COURSE ASSESSMENT GRADING SCHEME & OUTCOME

ABET Outcome 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Assignments that test competency in this area will include problems that test a student's ability to identify, retrieve, and organize information needed for a particular new task even if the task is outside of their area of expertise.

Name: Taylor Linton, Tyecia Franklin, Wasil Mahmood, Franck Nangomoko

Title of Assignment: Homework #3 Due Date: October 26, 2021

Competency Area		
7. Ability to engage in in life-long learning	Max for this Assignment	Your Score
<i>Effectively use library and online resources for research and are abreast with current developments relating to the project</i>		
(i) Identify the types of information needed for a complete understanding of all aspects of the project (Based on task described in the project planning).	25	20
(ii) Gather information on relevant fundamentals, theory / concept (demonstrate technical competence) and relate them to the design.	50	47
(iii) Provide the sources in a list of references properly cited in the literature review section and relevant sections of the report.	25	25
TOTAL	100	92

OK. But
could be organized
better

start with the
earliest chemical
production of
sulfuric
acid

A) introduction

The origin of sulfuric acid is unknown; however, it is estimated that the first appearance of the acid can date back to the 10th century. Moving to the 15th century, the burning of sulfur with saltpeter became the first documented process for creating the compound. The implementation of the lead chamber process (first sulfuric acid mass production process) by John Roebuck in 1746 opened usability pathways for sulfuric acid by other processes. The lead chamber process, however, was made obsolete early 85 years later by the process currently utilized by modern Sulfuric Acid production systems (Austin, 1984).

In 1831 Peregrine Phillips introduced the contact process. While being known as the modern-day industry standard, the contact process was not a commercial success for nearly 40 years post-introduction. Many aspects such as lack of demand, slow technological development, and confusion related to catalytic gas reactions were all determinants for the lack of commercial success. The process first gained momentum through a boom in the dye industry, for which sulfuric acid became a necessary compound in the production of organic coloring matter.

The process itself utilized the feeding of sulfur dioxide and air over a catalyst to form sulfur trioxide, followed by its absorption in sulfuric acid (98-99%). The contact process would be later refined in modern usage; however, the foundational reaction would remain the same (Austin, 1984).

(b) Review of literature on production of your product including process/production routes, physical and chemical properties, handling and storage, uses and product specification

Production routes

As explained previously, the production of sulfuric acid is conducted through the contact process in modern production setups. A refined version of the contact process (double absorption) was utilized within our production system. The process is derivative of the foundational contact process, as it utilizes two absorption towers instead of a single a tower, to yield a higher conversion of sulfur dioxide (produced through sulfur burning) to sulfur trioxide. Vanadium pentoxide was determined to be the catalyst utilized to facilitate the double absorption process (Austin, 1984).

Physical and chemical properties

As the name suggests, sulfuric acid is a strong dibasic acid which exists as both an oxidizing and dehydrating compound. Sulfuric acid is a clear colorless, oily liquid which has a tendency of turning yellowish-amber upon aging. Physical properties and special considerations that must be taken in the processing and storage of sulfuric acid can be found below (OSHA, n.d).

Property	Value
Formula	H ₂ SO ₄
Molecular Weight	98.08 g/mol
Melting Point	51 F
Boiling Point	554 F
Relative Density (Water = 1)	1.84 (93% H ₂ SO ₄)
Odor	Odorless when cold; acrid odor upon heating
Appearance	Clear, colorless, oily liquid
Heat Capacity	1.34 kJ/(kg K)

Handling

Sulfuric acid is an extremely corrosive chemical. Special consideration must be taken into account with storage, transport, and general safety associated with sulfuric acid plant operation.

What?

The most common system utilized for the transport of sulfuric acid is through trucking, hence adequate PPE (personal protective equipment) is essential for the safe operation and handling of sulfuric acid for both plant and transportation personnel. Further information on PPE and general safety guidelines is given below.

Due to the physical nature of sulfuric acid, an emphasis must be placed on the wellbeing of all personnel working with the compound. The NFPA hazard rating diagram for sulfuric acid is shown below.



The diagram shown outlines four key safety aspects that individuals must be weary of when working with sulfuric acid. The red diamond establishes a value of 0 for compound flammability (will not burn under normal fire conditions). The yellow diamond assigns a value of 2 for instability, as the compound undergoes violent chemical changes at elevated temperature and pressures. The white diamond displays a W, which indicates a violent reaction with water. The last and possibly most important section, the blue diamond assigns a value of 3 indicating that the compound can cause serious or permanent injury. (cameochemicals, n.d; Teck, 2015)

To mitigate the dangers involved with sulfuric acid interactions the table below shows 4 separate classes of PPE, depending on an individual's expected exposure. (Veolia, n.d)

Need to connect chemical safety to your process

Class D: for low risk of exposure	• Safety glasses with side shields • Steel-toe safety shoes with PVC, neoprene or composite soles • Pants and sleeved shirt, or coveralls, made of acid-resistant polyester, acrylic or wool • Hard hat
Class C: for moderate risk of exposure	• Coverall splash goggles (a face shield can be added over the goggles if desired, but is not a replacement for goggles) • Acid-resistant gauntlet gloves • Optional, acid-resistant jacket • Optional, face shield

Class B: for high risk of exposure	• Head Protection: splash hood and hard hat (limit duration of tasks to avoid oxygen deficiency in hood) • Eye Protection: chemical splash goggles • Respiratory: not required for non-fuming sulfuric acid • Hand Protection: acid-resistant gauntlet length gloves with sleeves over gloves • Body Protection: acid suit, 1 piece or 2 piece (fabric must pass ASTM testing for $\geq 93\%$ sulfuric acid) • Foot Protection: acid-resistant boots with pant legs over boots
Class A: or maximum risk of exposure, used during an emergency leak/spill situation	• hard hat • Eye Protection: full face mask • Respiratory: NIOSH approved respiratory protection • Body Protection: acid-resistant, fully-encapsulated suit (Fabric must pass a 45 min breakthrough ASTM F739 chemical permeation test for $\geq 93\%$ Sulfuric Acid) • Foot Protection: acid-resistant boots with pant legs over boots

Storage

As mentioned previously, sulfuric acid is an aggressive oxidizer. This physical property makes it difficult to process and store sulfuric acid, as corrosion becomes a major concern for any material which is utilized in the production and storage tanks for the acid. Another major cause for concern is the relative density of sulfuric acid (Relative Density (Water = 1): 1.84 (93% H_2SO_4)). Any material which is utilized must retain structural integrity (especially in the bottom third portion of the tank where static load is highest), as sulfuric acid is nearly twice the density of water. A handful of industry standard storage systems are listed in the table below.

Steel Tanks	• Ideal for 98% sulfuric acid • May require additional lining if utilized for other concentrations
FRP (Fiberglass Reinforced Plastic) Tanks	• Can be purchased with a variety of linings • Structural layer consisting of chopped fiber glass and resin
Polyethylene or Plastic Tanks	• Consist of linear or high-density cross-linked polyethylene • Specialized in chemical containment

Secondary containment measures are recommended to mitigate the risks and hazards associated with chemical spills and leaks (PolyProcessing, n.d).

(c) Process selection (using process sorting)

The production of sulfuric acid can be carried out in several different ways. In order to determine the most efficient and cost-effective process, necessary research was conducted.

Research shows that there are three different sets of raw materials that can be used to achieve the desired product of sulfuric acid.

The first set includes the use of elemental sulfur. In this process the elemental sulfur is burned in the presence of oxygen to form sulfur dioxide. This is the most common way of producing sulfur dioxide because it is the easiest to carry out and its main raw material is relatively inexpensive and easy to obtain. The second method for producing sulfur dioxide is the

metallurgical method. It involves the use of metal ores and smelter gas burning. The use of these raw materials accounts for 20% of world production. However, it requires use of large and expensive equipment. The third way of achieving sulfur dioxide to eventually produce sulfuric acid is by way of acid regeneration. This method involves the use of spent sulfuric acid and accounts for only 10% of world production, due to its high transportation cost and production of transportation emissions.

There are different process methods of creating sulfur acid. This includes the contact method and the lead chamber method. However, the lead chamber method is almost obsolete due to its costly equipment and low concentration yield. The contact process is carried out by passing sulfur dioxide and oxygen over the catalyst vanadium pentoxide. This process is more cost effective and produces higher concentration. Within this process there are 2 types of absorption, double and single. The single absorption method yields a lower sulfuric acid concentration and involves the use of only one absorption tower. Double absorption is the most used method due to its greater conversion of SO_2 to SO_3 and greater concentration yield.

Process Sorting for Sulfuric acid production, scored 1-3 with 3 being the highest

	Sulfur Burning	Metallurgical	Acid Regeneration
Cost Effectiveness	3	1	2
Operation/ Safety	3	2	1
Usage of process	3	2	1
	9	5	4

Based on our research we have concluded that our process will involve the burning of elemental sulfur to obtain sulfur dioxide. It will be carried out using the double contact absorption process and will contain the catalyst vanadium pentoxide.

(d) process description, stating the main steps involved in the production, and providing details of the steps involved.

There are four main reactions that place within our process to produce sulfuric acid. These reactions are as listed below:

- 1) $\text{S(l)} + \text{O}_{2\text{(g)}} = \text{SO}_{2\text{(g)}}$
 - 2) $\text{SO}_{2\text{(g)}} + \frac{1}{2} \text{O}_2 = \text{SO}_{3\text{(g)}}$
 - 3) $\text{SO}_{3\text{(g)}} + \text{H}_2\text{SO}_{4\text{(l)}} = \text{H}_2\text{S}_2\text{O}_7\text{(l)}$
 - 4) $\text{H}_2\text{S}_2\text{O}_7\text{(l)} + \text{H}_2\text{O(l)} = 2\text{H}_2\text{SO}_{4\text{(l)}}$
- 

A stream of air with a composition of 21% O₂ and 79% N₂ blows into an air separator at 122,427 lb/hr. After separating the air, the nitrogen is purged out and stored in for nitrogen consumers and the oxygen is compressed to a sulfur burning furnace. The sulfur burner includes a feed of molten sulfur being pumped at 294°F and 35 psi with a flowrate of 17,140 lb/hr and the oxygen being compressed inside. Once the sulfur is oxidized, SO₂ leaves the furnace and is cooled at 770°F it will lead into the 4-pass catalytic converter.

The 4-pass converter has a 99.7% conversion rate of sulfur trioxide. The first and second stage of the converter has a 92.4% conversion rate, therefore once SO₃ and SO₂ leaves the reactor at 908°F and 29.4 psi it is slightly cooled down to 302°F so gases will be able lead into the first absorbing tower. In the third and fourth stage of the converter the gases are cooled down even more. The gases will then be 810°F and cooled to 302°F, so it now has a 7.3% conversion and leads to the second absorbing tower.

Using the absorption process of SO_2 and SO_3 assists with producing the intermediate component oleum. After the absorption process in the first absorber, oleum will pump into the first dilution tank at 203°F and 14.7 psi and SO_2 is recycled directly back into the reactor at the same temperature and pressure. When the absorption is complete in the second absorber, oleum is pumped to the second dilution tank and SO_2 is recycled back to the stream that leaves the sulfur burner and enters the reactor.

Inside of the dilution tanks oleum and water will react to make sulfuric acid. The first dilution tank pumps sulfuric acid at 97,294 lb/hr, 89°F , and 14.7 psi for storage into the acid storage tank and the concentrated sulfuric acid splits from the stream and recycled to the first absorbing tower at 48,647 lb/hr. Last, from the second dilution tank, sulfuric acid is pumped at 7,685 lb/hr, 89°F , and 14.7 psi for storage in and having concentrated sulfuric acid split from the stream to be recycled to Stream 9 at 3,842 lb/hr to lead back into the reactor. This process will lead us to producing 52,491 pounds of sulfuric acid every hour.

good.
But how will
you use this information
to make your design?

References

- Austin, G. T. (2005). *Shreve's chemical process industries*. McGraw-Hill.
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AVERAGE

CHEG 4247: SENIOR DESIGN & PROFESSIONALISM I

FALL 2021

|ASSIGNMENT STATEMENT/QUESTIONS

**Senior Design & Professionalism I (Fall 2021): Home Work 3
Due October 26, 2021**

You will be graded based on your ability to engage in life-long learning. Start each question on a new page. Clarity of presentation is essential if you are to avoid losing points.

Present a comprehensive literature review/survey of your project, citing all sources. Include (a) an introduction, (b) review of literature on production of your product including process/production routes, physical and chemical properties, handling and storage, uses and product specification, (c) process selection (using process sorting), (d) process description, stating the main steps involved in the production, and providing details of the steps involved.

Note: Make sure to use effective and well-placed subheadings, so that the sections and subheadings follow the logical sequence of the report outline.

Limiting your sources to only the internet or merely copying what you find in the literature without a brief discussion highlighting the relevance or otherwise of the information will be considered inadequate.

DEPARTMENT OF CHEMICAL ENGINEERING
SENIOR DESIGN & PROFESSIONALISM I CHEG 4247
COURSE ASSESSMENT GRADING SCHEME & OUTCOME

ABET Outcome 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Assignments that test competency in this area will include problems that test a student's ability to identify, retrieve, and organize information needed for a particular new task even if the task is outside of their area of expertise.

Name: Caleb Myers, Chiebuka Ejimadu, Katelynn Inman, Tiarra Rodrigues

Title of Assignment: _____ Due Date: October 26, 2021

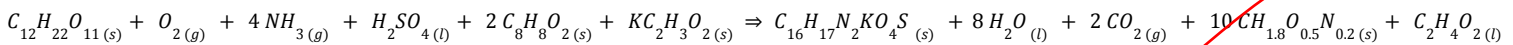
Competency Area		
7. Ability to engage in in life-long learning	Max for this Assignment	Your Score
<i>Effectively use library and online resources for research and are abreast with current developments relating to the project</i>		
(i) Identify the types of information needed for a complete understanding of all aspects of the project (Based on task described in the project planning).	25	20
(ii) Gather information on relevant fundamentals, theory / concept (demonstrate technical competence) and relate them to the design.	50	45
(iii) Provide the sources in a list of references properly cited in the literature review section and relevant sections of the report.	25	15
TOTAL	100	80

(a) An Introduction

Problem Statement (Tiarra)

According to the Centers for Disease Control and Prevention (CDC), 101,567 cases of syphilis were reported in the U.S. in 2017, yielding a rate of 31.4 cases per 100,000 population as compared to previous years. The inception of the pandemic of 2020 is a prime case as well, that is projected to fuel the demand for penicillin antibiotics forecasted for 2026. The demand for medicinal penicillin in the U.S. is approximately 34.3 million kg per year based on the percentage of dependence on China's production. In response to this high demand for Penicillin G, our team will produce a preliminary design of a Penicillin plant to produce 20% of the U.S. demand. The sales department has conservatively estimated that they can sell 6.86 million kg of penicillin per year to various wholesalers and pharmaceutical companies in the United States.

Penicillin G potassium will be synthesized from *Penicillium Chrysogenum* and media containing lactose, ammonium sulfate as a nitrogen source, and an acidic precursor (phenylacetic acid) via aerobic fermentation:



Penicillin is a fungal antibiotic that is derived from the species *Penicillium chrysogenum*; it is used to treat many varieties of bacterial infections. The main two forms of first-generation penicillin – penicillin G and penicillin V – differ in that penicillin V is a derivative of penicillin G and is taken orally, unlike penicillin G, which is intravenous. Potassium acetate is introduced within the extraction phase to contribute potassium ions to the broth and further synthesize Penicillin G Potassium, which is the powder medicine used to treat various bacterial infections. Within the design parameters we have given the annual production, cost parameters, time horizon, thermodynamic properties, and performance models of the units. Our team will present a design proposition that includes equipment sizes and structural alternatives. The facility will present stable operating conditions that simultaneously maximizes the economic performance and minimize the environmental impact.

Client Identification and Recognition of Need (Caleb)

The widespread growth of bacteria with resistance to standard antibiotics has been a topic of concern over the past few decades. Figure 1a shows the growth in the percentage of infectious bacteria that possess this resistance since 2000. Based on the trend, although the data only extends to 2014, it reveals a 2% increase in the concentration of resistant bacteria about every 6-7 years; based on this assumption, it is safe to expect over 12% of infectious bacteria to be resistant to standard antibiotics by 2022. This phenomenon has undoubtedly increased the

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but it is poorly
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demand for higher-level penicillins that are able to eradicate these evolved bacteria. Figure 1b shows the expected growth in the demand for amoxicillin over the course of the next 6 years. Amoxicillin is a penicillin antibiotic that specifically treats stomach ulcers. It is assumed that the market for other high-level penicillins will see similar increases within the decade. The primary goal of the plant is to supply its pharmaceutical clients an adequate amount of penicillin G potassium to synthesize enough high-level penicillins that can reverse this trend.

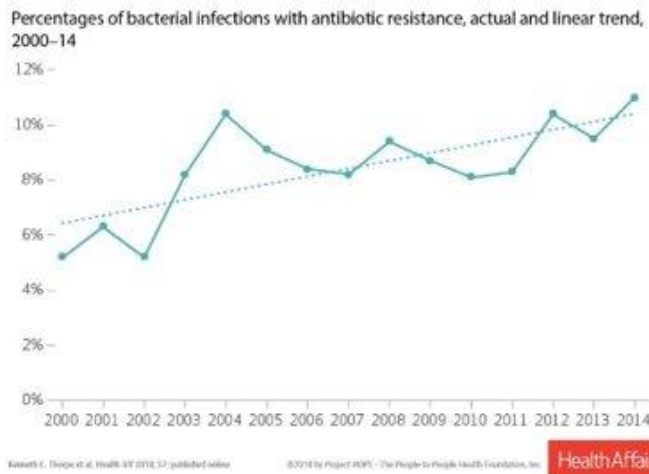


Figure 1a. Growth of bacterial infections with resistance to antibiotics from 2000-2014

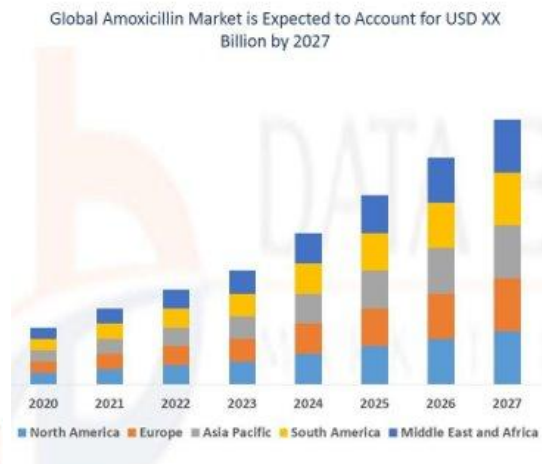


Figure 1b. Expected Growth of the Amoxicillin Market by 2027

The plant's clientele mainly consists of pharmaceutical companies, specifically Pfizer, Baxter, King Pharmaceuticals, and Sandoz. After being dried and grinded, the final penicillin G potassium recovered is in the form of crystal powder which allows for easier and more efficient handling and distribution. The powder is sent to a solid hopper via conveyor belt, and is dispensed into bulk bags that will be transported to clients by road. Once shipped to pharmaceutical buyers, the penicillin G potassium may be diluted with solution to form intravenous benzylpenicillin, or, in most cases, used to synthesize higher-level penicillins that are specialized to treat specific bacterial infections.

Project Goals and Objectives (Tiarra)

1. Determining an optimal process design simultaneously maximizes the economic performance and minimizes the environmental impact.
2. We will be selling biomass which is one of the byproducts from the process. It is created within our production and is great for outsourcing agriculturally. This will be explained further in the report.
3. Our process will also produce a purity of 99.5% Penicillin G Potassium.

Contemporary issues and impact of project on society (Tiarra)

1. Contemporary issues relevant to project

where is [1] - [7]?

The Center for Disease Control and Prevention, more commonly known as CDC, is an American government-based organization that helps stabilize the infrastructure of public health and aid in stopping the spread of diseases. From their statements, antimicrobial resistance is the leading issue concerning antibiotics [8]. The resistance occurs when bacteria evolve and develop counterattacks to withstand the drugs designed for them. These evolved bacteria continue to grow and spread and are very difficult to maintain. In more severe cases, they are impossible to kill. In the United States every year, there are 2.8 million people who become infected with antimicrobial resistant bacteria and they most likely will have to be admitted into hospitals and receive stronger doses of toxic medications [8]. Even still more than 35,000 individuals will die each year from the 2.8 million people infected [8]. Even during the COVID-19 pandemic, the CDC monitors what possible effects antimicrobial resistance could have on the nation. Below is a chart provided by the CDC of antibiotics and their resistant bacteria that evolved over time.

Table 1. List of Antibiotics and their Identified Resistant Bacteria since the Creation of each Antibiotic [8]

Antibiotic Approved or Released	Year Released	Resistant Germ Identified	Year Identified
Penicillin	1941	Penicillin-resistant <i>Staphylococcus aureus</i>	1942
		Penicillin-resistant <i>Streptococcus pneumoniae</i>	1967
		Penicillinase-producing <i>Neisseria gonorrhoeae</i>	1976

Vancomycin	1958	Plasmid-mediated vancomycin-resistant <i>Enterococcus faecium</i> Vancomycin-resistant <i>Staphylococcus aureus</i>	1988 2002
Methicillin	1960	Methicillin-resistant <i>Staphylococcus aureus</i>	1960
Extended-spectrum cephalosporins	1980 (Cefotaxime)	Extended-spectrum beta-lactamase- producing <i>Escherichia coli</i>	1983
Azithromycin	1980	Azithromycin-resistant <i>Neisseria gonorrhoeae</i>	2011
Imipenem	1985	<i>Klebsiella pneumoniae</i> carbapenemase (KPC)-producing <i>Klebsiella pneumoniae</i>	1996
Ciprofloxacin	1987	Ciprofloxacin-resistant <i>Neisseria gonorrhoeae</i>	2007
Fluconazole	1990 (FDA approved)	Fluconazole-resistant <i>Candida</i>	1988
Caspofungin	2001	Caspofungin-resistant <i>Candida</i>	2004
Daptomycin	2003	Daptomycin-resistant methicillin-resistant <i>Staphylococcus aureus</i>	2004

Ceftazidime-avibactam	2015	Ceftazidime-avibactam-resistant KPC-producing <i>Klebsiella pneumoniae</i>	2015
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[9] and [10]

2. Potential impact of project on society

Since our company's goal is to decrease the United States dependency of Penicillin G from China, our impact will come from how much product is created. The United States in theory should buy from our company to save money on import cost and support local businesses. The most damaging greenhouse gas, carbon dioxide, is released into the atmosphere from the burning of fossil fuels. Factory emissions contribute greatly to the release of carbon dioxide into the atmosphere. Industry and electrical generating factories contribute slightly more than 50 percent of greenhouse gases [11]. To combat this epidemic, our company will be implementing a carbon capture system (CCS) in place. There are three steps to this process:

1. **Capture:** the CO₂ is separated from other gases produced in industrial processes, such as those at coal and natural-gas-fired power generation plants or steel or cement factories [11].
2. **Transport:** the CO₂ is then compressed and transported via pipelines, road transport or ships to a site for storage [11].
3. **Storage:** finally, the CO₂ is injected into rock formations deep underground for permanent storage [11].

The mycelium biomass from our process is captured and sold as a byproduct for animal feed. Due to our location, Magnolia, TX, this will play a major role in our economic breakdown. There is a lot of agriculture related businesses that we will sell to. To support a large production scale, the design team must take into account the effect of the production process on the environment while utilizing inexpensive substrates and achieving high production yields. The development of a plant will provide a moderate amount of jobs for engineers, contractors and operators alike be they local or outsourced from different locations.

(b) Review of Literature on Production of Penicillin G Potassium

Penicillin G was first synthesized as..... (Tiarra)

Before the creation of antibiotics, there were no effective treatments for infections like pneumonia, and gonorrhea. Someone could contract a serious disease from a simple cut/scratch. In 1928, Professor Alexander Fleming accidentally discovered the first strain of *penicillium notatum* within his staphylococcus petri dishes. This penicillium was capable of killing a wide range of harmful bacteria. Now that scientists were able to separate the strain and cultivate it, they wanted to increase their yield to a large-scale production to be used during WWII. Penicillin was named the “wonder drug” that saved millions of lives. By 1949, the US successfully industrialized penicillin production to be distributed to pharmacies throughout the nation. After the rise of resistant bacteria, in 1961, scientists sought out alternatives to the original antibiotics. The idea of synthetic drugs formulated from the original properties was executed and this was only the beginning. Modern day penicillin is derived from a newer fungal bacteria strand *penicillium chrysogenum*. Today, penicillin is still used to treat various bacterial infections like syphilis, strep throat, meningitis and so on. Higher level penicillins are used to combat the evolved bacteria.

refs?

Production Route (Katelynn)

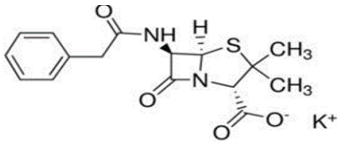
The production of Penicillin G is done through fermentation. All penicillin G is derived from the fermentation of a microorganism, *Penicillium chrysogenum*, with an addition of a precursor, phenylacetic acid. The fermentation process starts with a cell culture, a pure strain of *Penicillium chrysogenum*. In a lab the cells are added to a petri dish to increase their size, from there they are put in a flask with more medium to multiply. Once the cells have reached the max growth phase in the flask, they are transferred to the inoculum. From the inoculum into the fermenter where penicillin is produced. Then the penicillin G is sent to the extraction phase.

include
look
figura

Physical and Chemical Properties (Tiarra)

Table 2. List of Chemical and Physical Properties of the Product Penicillin G Potassium [5]

Chemical Properties	Physical Properties

Chemical Formula	$C_{16}H_{17}KN_2O_4S$	Color	White
Drug Class	Penicillin	Odor	Odorless
pH	6.5	Phase	Solid powder
Stability	Stable	Molecular Weight	372.5 kg/kmol
Solubility	Soluble in Water	Density	1.36 kg/L
Structure		Melting Point	214-217 °C
Flammability	This material is combustible, but will not ignite readily	Particle Size	10 microns
Reactivity	High accumulation results in combustion (dust explosion)	Flash Point	335 C

Handling, Storage and Safety (Tiarra)

1. Handling

- When handling, use appropriate personal protective equipment (ppe listed in safety). Individuals with direct exposure to the product should avoid inhalation and contact with skin, eye, and clothing. This is to ensure that there is no contamination transferred from

the individual to the product. Individuals should wash their hands before and after leaving the facility post PPE removal.

- When handling the product, it would be optimal to minimize dust generation and accumulation by regularly maintaining the facility, equipment, and storage of any exposed areas.

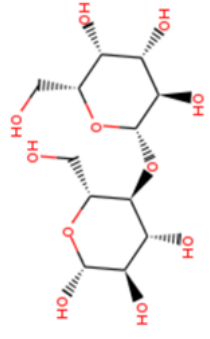
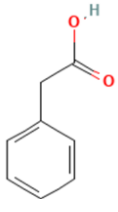
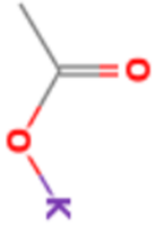
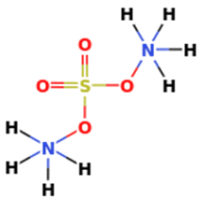
Accidental spills

- **Health and Safety Precautions:** Personnel involved in clean-up should wear appropriate personal protective equipment (listed in Safety) to limit their exposure.
- **Measures To Take for Cleaning / Collecting:** Contain the source of spill if it is safe to do so. Collect spilled material by a method that controls dust generation such as a damp cloth or a filtered vacuum. These ways are great for thoroughly cleaning spills of dry solids.
- **Additional Consideration for Large Spills:** Non-essential personnel should be evacuated from affected areas. Report emergency situations immediately. Clean up operations should only be undertaken by trained personnel.

2. Storage

Table 3 : Raw Process Materials

	Lactose	Phenylacetic Acid	Sulfuric Acid	Potassium Acetate	Ammonium Sulfate
Molecular Weight	342.3 kg/kmol	136.15 kg/kmol	98.079 kg/kmol	98.142 kg/kmol	132.14 kg/kmol
Chemical Formula	$C_{12}H_{22}O_{11}$	$C_8H_8O_2$	H_2SO_4	$C_2H_3KO_2$	$(NH_4)_2SO_4$

Chemical Structure					
Boiling Point	668.9 °C	265 °C	337 °C	117.1 °C	330 °C
Freezing Point	202.8 °C	76.5 °C	10 °C	292 °C	235 °C
Flash Point	357.8 °C	132 °C	-	> 250 °C	-
Critical Temperature	-	-	654 °C	-	250 °C
Density	1.76 kg/L	1.081 kg/L	1.83 kg/L	1.57 kg/L	1.77 kg/L

- Lactose
 - This material should be stored in a cool and ventilated place to replicate dry conditions. This material should avoid any heat source and oxidizing agents. Similar to Penicillin G Potassium, this is a white crystalline powder that if accumulated can become combustible.[4] This will be stored with materials that have similar storage requirements. This material will be transported in bulk and it is classified as not dangerous.[4]
- Phenylacetic Acid
 - This material will be stored in an airtight container with a ventilated and cooled room. This material should be kept away from incompatible substances like strong bases.[10] This will be stored with materials that have similar storage

requirements.[10] This material will be transported in bulk and it is classified as not dangerous.

- Sulfuric Acid
 - This material is a level 8 transport hazard and will be handled as such. Sulfuric acid is typically transported within an high-density polyethylene (HDPE) tank car. When arriving at the facility, this material will be placed in a cool dry room.
- Potassium Acetate
 - This material will be stored in an airtight container with a ventilated and cooled room.[12] This material should be kept away from incompatible substances. This will be stored with materials that have similar storage requirements. This material will be transported in bulk and it is classified as not dangerous.
- Ammonium Sulfate
 - This material should be stored in a cool and ventilated place to replicate dry conditions. This material should avoid any heat source and oxidizing agents. This will be stored with materials that have similar storage requirements. This material will be transported in bulk and it is classified as not dangerous.

3. *Safety*

Personal Protective Equipment:

- **Hands:** Wear suitable protective gloves according to EN 374. It is recommended to test the chemical resistance of the gloves with the supplier. The gloves should be made of nitrile rubber (NBR) and have a 0.11 mm layer thickness. There should be a minimum level 6 permeation of breakthrough.
- **Eyes:** Wear safety glasses or goggles if eye contact is possible.
- **Skin:** Wear protective clothing when working with large quantities.
- **Respiratory protection:** If airborne exposures are within or exceed the Occupational Exposure Band (OEB) range, wear an appropriate respirator with a protection factor sufficient to control exposures to the bottom of the OEB range. Respiratory protective gear is necessary when dust formation is visible. At this point the individual should wear a respirator with a particulate filter (P2) meeting EN 143 standards. The filters should be able to combat 94% of airborne particles.

First Aid Measures:

- **Eye Contact:** If contact is made, the individual must immediately flush their eyes with water for at least 15 minutes. If the irritation occurs or persists, they will need to receive medical attention.[7]
- **Skin Contact:** Any articles of contaminated clothing must be removed. Flush area where the product came in contact with with large amounts of water and use soap (wash clothing).[7]

- **Ingestion:** One should never give anything by mouth to an unconscious person. Rinse out the individual's mouth with water. Lastly, do not induce vomiting unless directed by medical personnel.[7]
- **Inhalation:** The individual should remove themselves from the contaminated environment and move to fresh air and rest. Also they should seek medical attention immediately.[7]

Reactivity: Initially, the state of the product at delivery is not explosive, however, when there is a large accumulation of fine particles this will lead to a dangerous dust explosion.[9] A dust explosion is defined as a combustion of suspended particles in the air within an enclosed area. These dangerous situations can happen where there is a powdered combustible material in high concentrations within the air and another oxidizing gas (i.e., pure oxygen).[9]

Measures for Environmental Protections: Place waste in an appropriately labeled, sealed container for disposal to avoid environmental release. The product should be kept from drains, ground and surface water as well. We are choosing to implement appropriate technical and procedural waste water and waste disposal measures to prevent occupational exposure or environmental releases. Potential points of process emissions of this material to the atmosphere should be controlled with dust collectors, HEPA filtration systems, or other equivalent controllers.

What are process implications?

Uses (Tiarra & Caleb)

The two main uses of Penicillin G Potassium are to treat various bacterial infections like pneumonia, strep throat, and syphilis, and to serve as a precursor to high-level penicillins that may be resistant to natural antibiotics. Because antimicrobial resistance has become one of the greatest global health threats in recent years, new synthetic strains of antibiotics are created to eradicate the bacteria entirely rather than simply inhibiting growth.

Penicillin G in its natural state, is a white powder. The powder can be dissolved in water and injected into a muscle or vein, but the solution may also be administered directly into the lining of the chest cavity, into the fluid surrounding the spinal cord, or into a joint. Conventional antibiotics are derived from natural sources, typically from certain fungi or soil bacteria, and therefore rely on timely fermentation processes that require large-scale bacterial cultures and several subsequent purification stages. They are not designed to avoid resistance. In contrast, synthetic antibiotics are exclusively synthesized in labs to be potent enough to mitigate the threat posed by these evolved bacteria. Unlike their precursor, penicillin G, many synthetic penicillins, such as amoxicillin, may be administered orally.

Product Specification (Tiarra & Katelynn)

Table 4: Product Specification

Purity	99.5% Penicillin G Potassium
Product Recovery	78%

Our product Penicillin G Potassium is a white crystalline powder which is odorless and moderately hygroscopic.[6] Penicillin G potassium is very soluble in water. The pH of the reconstituted product is between 6.0–8.5.[6] The particle size of the will be around 10 microns which is not visible to the naked eye. We chose this size because we wanted a fine particle that is able to be produced consistently and easily stores away. Our product purity is specified as 99.5% Penicillin G Potassium.

(c) Process Selection

Market Analysis and Trends (BUKA)

Natural Penicillin like Penicillin G or V, are major active ingredients for higher-level synthetic penicillin that combat more aggressive bacterial infections/diseases. The global market of penicillin is a very dynamic space, but the demand is forecasted to increase in the coming years due to the increase of drug-resistant bacterial infections. For this project, Penicillin G is our focus. Due to limited market data because most were restricted since it's mostly under China's control, we made a few educational assumptions based on literature study and various historical data that we found. The world production of penicillin was about 105,000 metric tons/year, which is equivalently 95.3 million kg/yr. Based on literature study, China is the main manufacturer of Penicillin G. They produce nearly all of the Penicillin G globally so we assumed a basis of 90 %. Also, the United States is a major importer of Penicillin G from China and they receive about 40-45% of the production [2]. As a desired plant capacity, we assumed 20 % of US demand to fulfill the lack of Penicillin G manufacturing in the United States and to relinquish some percentage of dependence from China in terms of major ingredients to make higher-level penicillin. The calculation to find the desired plant capacity is shown below:

World Production – 105,000 Tons/yr (95.3 million kg/yr)

Nearly all of Penicillin G Production is in China (Assumed 90%)

US demand from China (40% Import)

Desired Plant Capacity (Assumed 20% of US Demand)

To find Plant Capacity ...

*$(95.3 \text{ million kg/yr} * 0.9 * 0.4 * 0.2) = 6.86 \text{ million kg/yr}$*

fermenting

good!

Medium routes to producing products (Katelynn)

- 1. Penicillin G industrial process and lab/patent routes have been reported to be used for producing Penicillin*

The production process to produce penicillin G has two parts, fermentation and extraction. The Fermentation process starts with a cell culture, a pure strain of penicillium chrysogenum. The cell culture is freeze dried and transferred with viable spores of the microorganism. In a lab the microorganism is introduced to a medium that will provide nutrients for it to grow. Once the

cells have reached maximum growth it will be transferred to the inoculum tank to start the production of penicillin G. Once the cells have reached peak production of penicillin G it will be transferred to a fermenter. In the fermenter it will continue to produce penicillin G at its peak production rate, allowing the cells to produce the highest yield possible of Penicillin G. The medium was chosen due to it producing the highest yield of Penicillin G compared to others. A carbon source is needed in the medium most being some type of sugar. A simple sugar is best to use as it is easily absorbed by microorganisms allowing a higher number of primary metabolites to be produced. In figure 3 it shows the relation of 5 mediums, one being potato dextrose broth and the other various carbon sources contain, glucose, lactose, maltose, and sucrose; to the concentration of penicillin G those mediums produce. From figure 3 it shows that the potato dextrose medium broth and lactose medium broth produced the highest concentration of penicillin G.

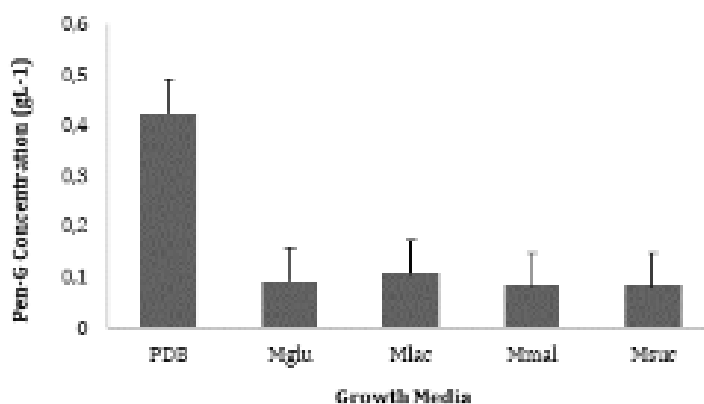


Figure 3. Penicillin G production from *Penicillium chrysogenum* in Various Mediums

In the industry of penicillin G production, a precursor is needed. The precursor allows a higher change of microbes to produce a specific penicillin depending on the precursor. The precursor, phenylacetic acid, acts as a hydrophobic side chain of benzylpenicillin allowing *P. chrysogenum* to specifically produce Penicillin G. The mediums with an addition of a precursor, phenyl acetic acid, give a significantly different result. The penicillin G produced with varied carbon sources have a much lower concentration than the mediums with an addition of PAA. With proper doses the PAA allows optimum Pen G production. The mediums that produced the highest concentration of Pen G without PAA were potato dextrose broth and lactose medium broth. Figure 4 shows the comparison of the 2 mediums with various concentrations of phenylacetic acid and the concentration amount of pen g that they produced. From the graph the Lactose Medium F produced the highest concentration of penicillin G with a PAA concentration of 0.6g/L to be used to derive a relationship in order to find the scaled up concentration for our industrial-size plant.

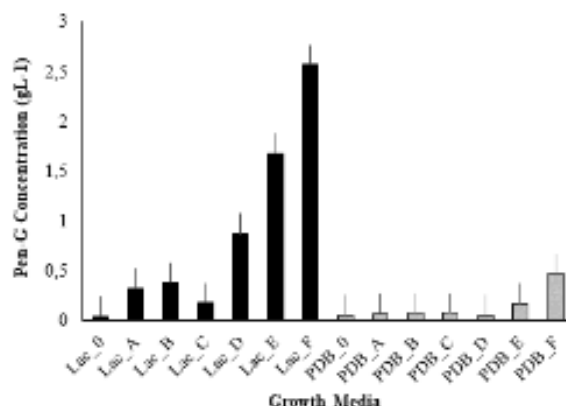


Figure 4. Penicillin Production from *Penicillium chrysogenum* with Various Concentrations of Phenylacetic Acid

2. Medium route 1

The medium is the nutrition factor that governs growth and production of penicillin G by *P. chrysogenum*. The penicillin G medium is first introduced as lab-scale of the process. The medium broth is a standard medium with a lactose carbon source and phenyl-acetic acid precursor. The medium is composed of the following components shown in figure 5. In figure 5 the carbon source chosen is lactose and the composition of the precursor, phenyl-acetic acid, is 0.6g/L. The *penicillium chrysogenum* is inoculated in the medium at room temperature for 48 hours. The medium is then incubated for 10 days with agitation at room temperature. Phenyl acetic acid is added 3 days after the bio production of fungi takes place. Once inoculation is complete the medium produces a 2.46 g/L yield of penicillin G (Sari 2020).

No.	Production medium	Weight (g)
1	KH_2PO_4	0.4
2	$(\text{NH}_4)_2\text{SO}_4$	0.45
3	$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	0.05
4	$\text{Na}_2\text{SO}_4 \cdot 7\text{H}_2\text{O}$	0.15
5	$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$	0.2
6	Yeast Extract	0.5
7	Phenylacetic Acid (PAA)	0-0.6
8	Carbon Source Variation (Lac, Glu, Suc, Mal) and PDB	1.5

Notes: Lac= Lactose, Glu= Glucose, Suc= Sucrose, Mal= Maltose and PDB as standard medium. PAA concentration variation (0, A, B, C, D, E, F). 0= 0 gL⁻¹; A= 0.1 gL⁻¹; B= 0.2 gL⁻¹; C= 0.3 gL⁻¹; D= 0.4 gL⁻¹; E= 0.5 gL⁻¹; F= 0.6 gL⁻¹

Figure 5. Penicillin G Production Medium Composition with Various Carbon Sources

The information from this article was utilized to derive a relationship to create an industry scaled process. The composition of the components in the medium were scaled up to find the mass fractions needed to produce penicillin G in a process plant.

3. *Medium route 2*

Another medium that was reflected upon was a potato dextrose broth medium. This broth is created by the fermentation of potato skins in distilled water. This medium was economically cheaper than the lactose medium selected. The reason this medium was eliminated from the process was due to it producing a smaller yield of penicillin g compared to the lactose medium once the precursor, phenyl-acetic acid, was added. As well the potato dextrose broth medium contains complex sugars that would need to be hydrolyzed by enzymes into simple sugars (Sari 2020). In order for the fungus to hydrolyze these sugars it would have to produce the enzymes to break down the complex sugar into a simple sugar making the fungus work harder.

Process Economy of Overall Reaction (Katelynn)

Overall Reaction Path:

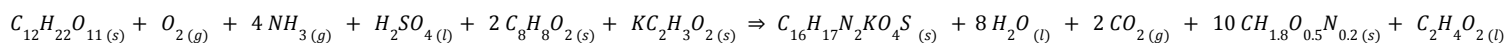


Table 5. Overall Reaction Component Cost

Components	kg-mole	Molecular Weight (g/mol)	kg	kg/kg of Penicillin G Potassium	\$/kg
Lactose	1	342.3	0.342	0.917	
Oxygen	1	16	0.016	.043	
Ammonia	4	17.031	3200 kg/h of ammonium sulfate		
Sulfuric Acid	1	98.079	0.098	0.263	
Potassium Acetate	2	98.15	0.098	0.263	
Penicillin G Potassium	1	372.5	0.373	1	

Martin Team 2

Water	8	18.01528	0.018	0.048	
Carbon Dioxide	2	44.01	0.044	0.118	
Biomass	10				
Acetic Acid	1	60.052	0.060	0.161	

Theoretical Profit = [Cost of Products] - [Cost of Reactants]

$[\$(1) + \$(1) + \$(4) + \$(1) + \$(2) + \$(1)] - [\$(1) + \$(8) + \$(2) + \$(10)] =$

The theoretical profit indicator is about... showing that our process is profitable.

(d) Process Description

Very good

In the creation of penicillin, there are two main reactions that occur within the process. Reaction (1) is the fermentation process occurring with the presence of a carbon source, nitrogen source, oxygen and other components to produce Penicillin G. Reaction (2) is the crystallization reaction that occurs with the addition of potassium acetate to form Penicillin G Potassium crystals from Penicillin G. Each reaction has a letter that corresponds to each component. It has been shown below:

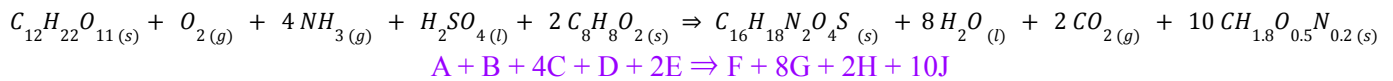
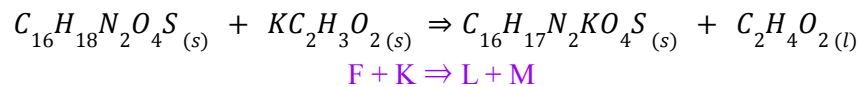
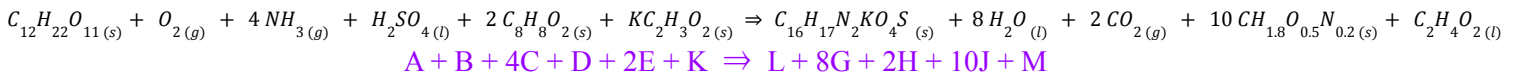
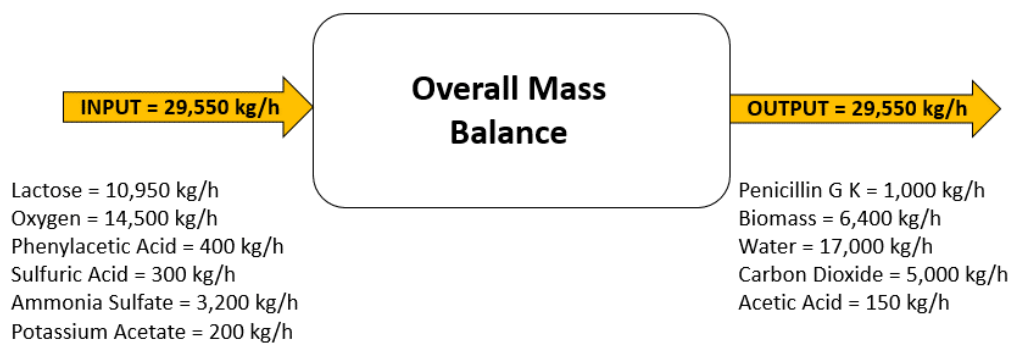
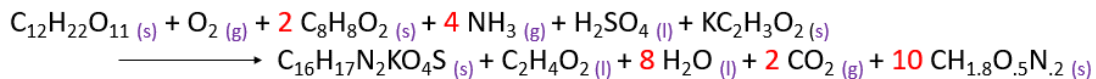
Reaction Mechanisms (BUKA)**Reaction 1: Fermentation****Reaction 2: Crystallization of Penicillin G Potassium****Overall Reaction:****Overall Mass Balance (Buka)**

Figure 6. Overall Mass Balance across the Entire Process

Raw Material Preparation (Caleb)

Raw Materials

- ***P. chrysogenum* cells**
 - Obtained in a freeze-dried state from a laboratory. Cell culture will ultimately be grown to a concentration of 66 g/L before entering the bioreactor.
- **Lactose**
 - Pure lactose solids in powder form. Exists as a solid at room temperature. Being the carbon source for biomass, lactose has a much higher concentration in the medium than the other minerals.
- **Phenylacetic acid**
 - Highly concentrated powder (54.8 g/L). Exists as a solid at room temperature. Is necessary for the growth of penicillin G, but fed at a considerably low concentration to avoid inhibiting fungal growth.
- **Sulfuric acid**
 - Highly concentrated sulfuric acid. Exists as a liquid at room temperature. Centrifugally pumped to tank V-202 to substantially decrease the pH of the agitated mixture.
- **Potassium acetate**
 - Used in powder form. Exists as a hygroscopic solid at room temperature. Potassium ion is necessary to deprotonate penicillin G within the crystallizer.
- **Ammonium Sulfate**
 - Powder that is very soluble in water. Exists as a solid at room temperature. Because it serves as the nitrogen source for biomass, ammonium sulfate is the second-most concentrated species within the design medium, behind lactose.
- **Butyl acetate**
 - Serves as the solvent for the penicillin extraction process. Exists as a colorless liquid at room temperature. Supplied in large amounts for liquid-liquid extraction and in many instances of crystal washing.
- **Air**
 - Approximately 78% N₂ and 22% O₂. Enters with a massive flow rate to satisfy the needs of the aerobic fermentation.

Utilities

- **Cooling water**
 - Used to maintain a steady fermentation temperature within the jacketed bioreactor. Also used as a heat transfer medium to reduce the temperature of penicillin G broth from the bioreactor before passing through the rotary vacuum filter.
- **Chilled water**

- Used to reduce the temperature of the penicillin G broth from the first rotary vacuum filter before entering the mixing tank. Also used in the jacketed heat sterilizers to reduce the streams back to their inlet temperatures after sterilization.
- **Steam**
 - Used to sterilize inlet air and medium impurities before they enter the bioreactor. Also used to slightly increase the temperature of the air and medium to the fermentation temperature after sterilization.

Reaction and Fermenter Operation (BUKA & Caleb)

Prior to the bioreaction, in which *P. chrysogenum* cells will undergo fermentation within bioreactors to produce penicillin G, the raw materials must first be properly prepared. The inlets of the bioreactor include the inoculum and the fermentation medium, which will be fed to the reactor separately from each other.

The growth and multiplication of *P. chrysogenum* cells occurs in four phases: the lag phase, growth phase, stationary phase, and decline phase. In the lag phase, the cells become acclimated to the medium they have been introduced to and undergo the necessary metabolic processes for eventual cell multiplication. After this, they enter the growth phase and the concentration of cells in the inoculum increases exponentially. At a certain point, the cells will have absorbed most of the nutrients in the medium and the concentration will converge to a certain range (stationary phase) before eventually decreasing again due to the absence of adequate carbon and nitrogen sources within the broth. This fungal cell growth from the growth to stationary phase occurs in logarithmic fashion.

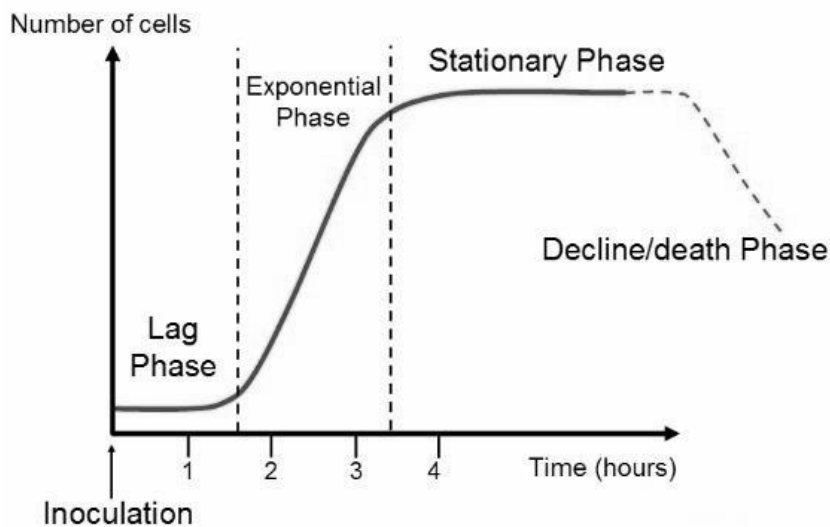
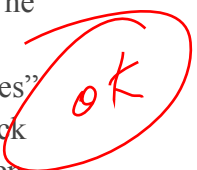


Figure 7. Phased Fungal Cell Growth Curve

In order to thoroughly explain the processes preceding fermentation, both the inoculum and fermentation medium will be discussed independently.

Inoculum

The inoculum, which is a conglomerate of both fungal cell biomass and fermentation medium minerals, must undergo preparation prior to being ready for admission into the bioreactor. The goal of the preceding process is to increase the concentration of cells in broth to a value sufficient enough for a resulting yield of penicillin G by introducing the cells to “food sources” (primarily sources of carbon and nitrogen) that will promote rapid cell growth. Initially, stock cultures of freeze-dried *P. chrysogenum* cells are obtained via laboratory. These cells are then extracted from their stock container and brought to an agar plate, which will serve as the site for the cells’ initial introduction to the fermentation medium. Before the cells can multiply, they must first enter the *lag phase*, in which they may become accustomed to their new environment before being able to multiply. A small amount of medium must be added to the agar plate containing these fungal cells in order to initiate this process. During the lag phase, cells synthesize enzymes necessary for growth; although the cell concentration does not yet increase, the cells do increase in size. 

Following the conclusion of the lag phase is the *growth phase*, in which the cells use nutrients from the fermentation medium to increase in concentration. The new cells, having increased in size after exiting the lag phase, are transferred from the agar plate to a flask and reintroduced to fermentation medium. By this time, the cells have adapted to these conditions and the concentration of cells begins to increase. This process will have to be repeated various times to increase the cell concentration to a level sufficient enough for the full-scale bioreactor. For this specific design, a cell concentration of 66 g/L and temperature of 30 degrees Celsius within the agitated inoculum tank (V-103) are desired before releasing it into the bioreactor. Once this concentration is reached, the contents are pumped to the fermenter (V-104) to eventually coexist with a high concentration of fermentation medium.

The overall material balance across the fermenter is shown below. Because this fungal fermentation is an aerobic process, an inlet stream of air is required to provide an adequate supply of O₂ for the biochemical reaction. The extracted air first enters a compressor (C-101) in order to increase its pressure to 2.04 atm, and is then passed across a heat sterilizer (E-103) to destroy lingering microorganisms. Afterwards, the air reaches a heater (E-104) and its temperature raised from ambient conditions to 30 degrees Celsius before entering the fermenter from the bottom. Another stream to consider is that of the exhaust gas leaving from the top of the fermenter, which is composed of O₂ and N₂ (from inlet air) and CO₂ (fermentation byproduct).

Unit Balance: Fermenter

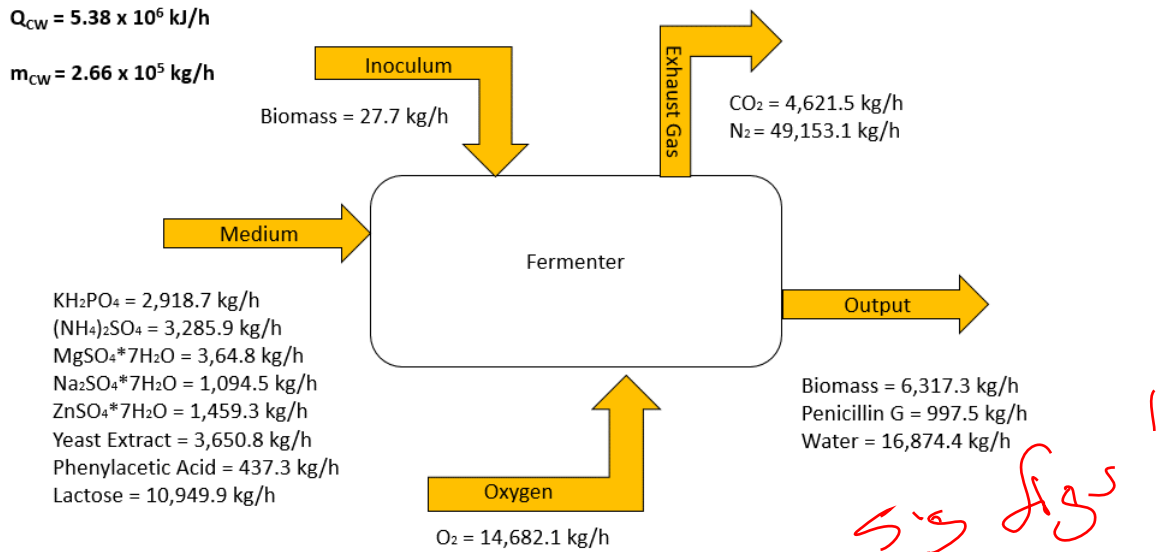


Figure 8. Material Balance across Fermenter

Medium

Because the growth of fungal cells primarily requires an abundance of a carbon source (lactose), it is initially stored separately from the rest of the minerals and phenylacetic acid in the medium, which are stored together.

Lactose will be in solid form stored in a hopper (TK-101) before being transported to an agitated medium tank (V-102) via conveyor belt. The rest of the medium components, before entering the agitated mineral tank (V-101), must be stored in their respective tanks or hoppers; liquid constituents will be pumped through pipes to V-101, while solid constituents, like lactose, must also be stored in solid hoppers and transported via conveyor. The mineral solution will then be pumped into the agitated medium tank. The design will feature multiple batch medium tanks in parallel to compensate for time required for solids to dissolve into the broth. After exiting the medium tank, the complete medium will be pumped to a heat sterilizer (E-101) to eliminate any impurities from the solution and then heated (E-102) to 30 degrees Celsius prior to entering the fed-batch fermenter (V-104). At the same time, the biomass will be entering in the fermenter from the inoculum tank (V-103). The fermentation process will be conducted at 30 degrees Celsius and 1.02 atm. The fermentation time will be 120 hours, which includes the growth phase, production phase, cleaning and so on. The design includes multiple fermenters in parallel to maintain a continuous process, as certain fermenters will undergo cleaning at different times. The fermenter's output stream includes the intermediate product penicillin G, high amounts of water and lots of biomass. The full fermentation phase of the *P. chrysogenum* is shown below:

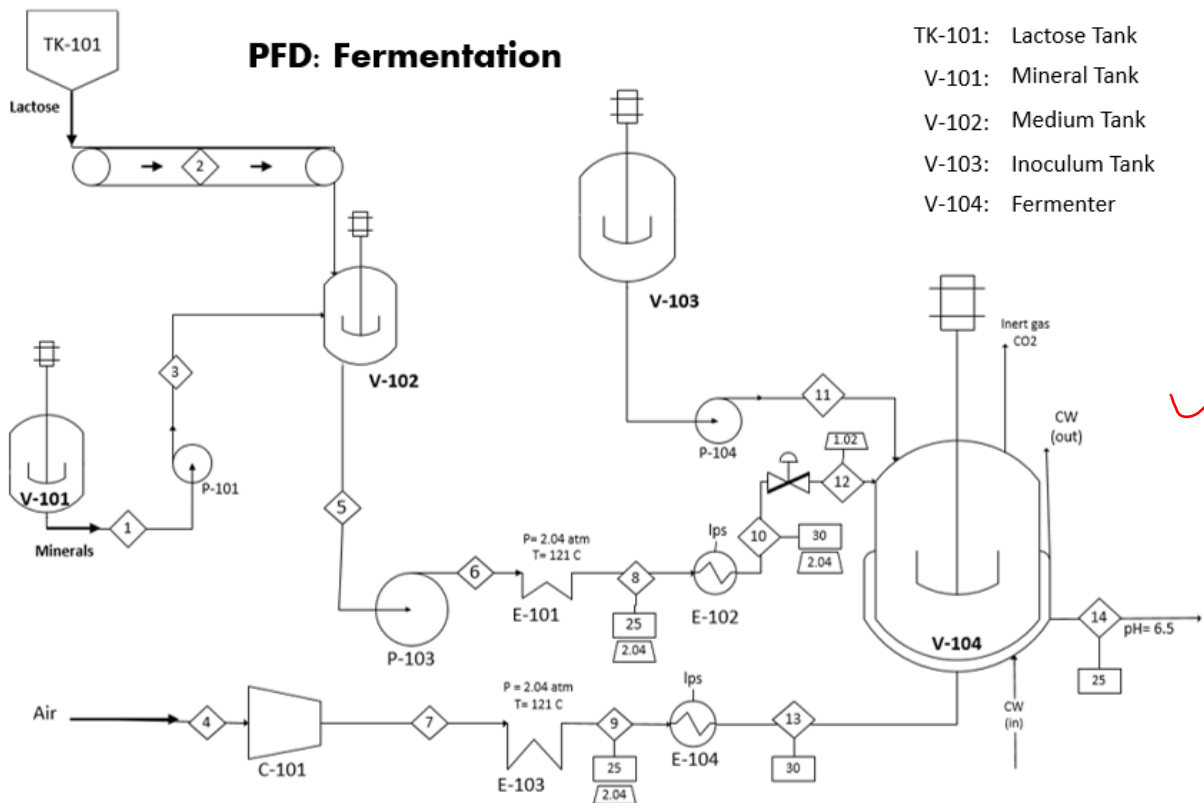


Figure 9. Process Flow Diagram of the Fermentation of *P. chrysogenum* to Produce Penicillin G

Separation Units (BUKA)

The extraction process begins after the fermentation process. The main purpose is to stabilize and isolate our final product at a high purity to be sold to our various clients. This process involves various units and equipment that performs different separations of solids from liquid like rotary vacuum filters, and liquid-liquid extraction like solvent extractor, that can transfer mass based on solubility of desired component from one liquid to liquid. As a result of fermentation, a mixture of biomass, water and Penicillin G goes through a rotary vacuum filter (V-201) to remove the biomass, which will be sold for agricultural purposes and animal feed. It will be cooled with a cooler (E-202) to 2 degrees celsius to prevent the product intermediate to degrade. Next, the mixing tank (V-202) is introduced to add sulfuric acid and butyl acetate (solvent) together, which results in penicillin G being soluble in solvent to be extracted in the solvent extractor (V-201). The carbon adsorption tower (T-201) removes the color and odor for a pure, colorless hue for the broth. Next step is to introduce it in the crystallizer to form crystals of Penicillin G Potassium with the presence of potassium acetate. It will go through the first crystal filter (V-205), re-washed in a crystal washing tank (V-206) and filtered again in another crystal filter (V-207). Finally, it is sent to a vacuum dryer (E-203) to dry off the product crystals before

being sent to a grinder (V-208). It is stored in a hopper (TK-206) and then packaged in bulk bags. The image below shows the process of the Penicillin G broth going through each separation unit until it is ready for product storage:

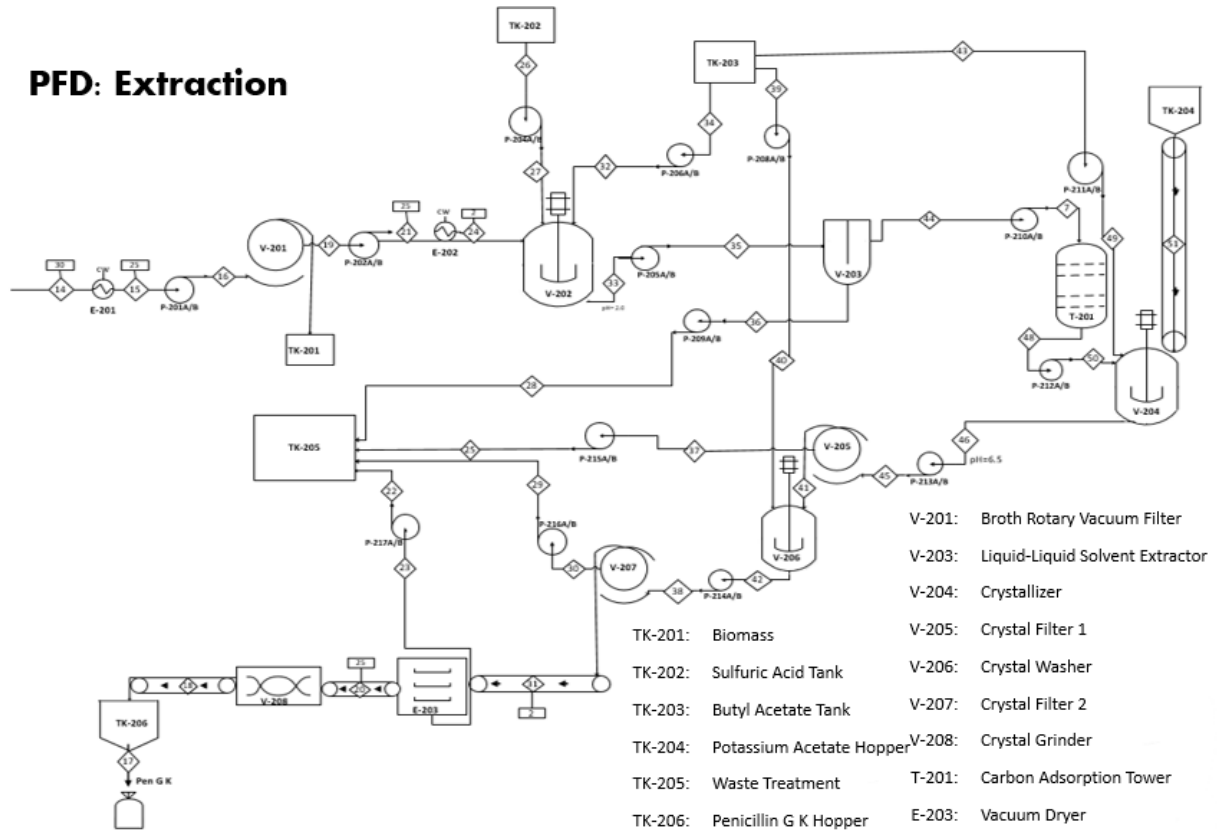


Figure 10. Process Flow Diagram of the Extraction of Penicillin G Potassium

Product Storage (Tiarra & Buka)

The product will be stored in super sacks (bulk bags) post-process and placed in a dry refrigerated room awaiting transportation to our clients. Our product, Penicillin G Potassium, has a 7-day maximum life expectancy at room temperature before it degrades. However, the product will be stored in a refrigerated room at 4 °C. This condition helps extend the shelf life of the product for up to 3 months.

Basis of Calculations and Major Assumptions (Buka & Caleb)

Based on the previously discussed global market analysis conducted by the team of engineers, a production capacity of 6.86 million kg/yr was determined to be feasible to satisfy 20% of the U.S. demand for penicillin. Our plant will have about 90% uptime, based on the fact that it will

operate for 330 days (7,920 hours) out of the year; the other 35 days will be used as a buffer for unscheduled downtime. The plant efficiency was also determined to be 78%, which was obtained from literature analysis for general penicillin processes. Lastly, a feasible specific production rate of 0.15g penicillin G/Lhr was obtained from literature and used to determine the necessary working volume.

The team's basis calculations were obtained for a period of 1 year for simplification purposes. A molar mass ratio of 1.11 was derived from the division of penicillin G potassium's molar mass by that of penicillin G. Dividing the plant capacity by this ratio revealed that 6.18 million kg penicillin G is required as a fermenter output. Because the plant is 78% efficient, it became apparent that more than 6.18 million kg penicillin G is required in order to satisfy the resulting losses of penicillin G potassium. Dividing the plant capacity by 0.78 yields a temporary capacity of 8.80 million kg penicillin G potassium that was solely used to calculate the required production rate of penicillin G. Dividing this plant capacity by the molar mass ratio (1.11) once more yielded a production rate of 7.90 million kg penicillin G, which is the required capacity of the fermenter. Next, dividing this penicillin G by the plant's operating time of 7,920 hours resulted in a required flow rate of 1 million g penicillin G/hr from the fermenter. Finally, the team manipulated the specific production rate of penicillin G (0.15g/Lhr) to obtain a mass flow rate on the basis of 1 L working volume (0.15g penicillin G/hr/1L). A proportional relationship between this production rate and the required flow rate of penicillin G out of the fermenter (1 million g/hr) was used to solve for the required working volume of the full-scale process, which was determined to be about 6.65 million liters.

The extraction process recovers 78% of the desired product output. The extraction process includes various equipment like rotary vacuum filters for both removal of biomass and crystal filtration, mixing tanks, solvent extractor, carbon adsorption tower, crystallizer, and vacuum drying. Based on literature, the product recovery percentage for each major unit was obtained. The first major unit, solid-liquid separator called rotary vacuum filter, recovers 93% of the penicillin G while the rest leaves with the majority of biomass. Following, the solvent extractor recovers 80% - 90% of penicillin G based on current process research so we assumed 86% for our process. The rotary vacuum filters for both of the crystal filters were assumed to have a product recovery of 99%. For the rest of the units being used for the extraction process, we assumed the output was 100%. Our basis with the crystallizer was assumed that all of the penicillin G is converted to penicillin G potassium when introduced to potassium acetate.

Based on these calculations for the required production rate of penicillin G and total working volume, the team worked backwards to find required feed conditions for the fermenter and eventually find material balances across each unit using their product recoveries as well.

Material Balance of each Unit (Buka)

After exiting the fermenter, the resulting mixture of Penicillin G, water and biomass will be heading towards the extraction process. There are several units used to transform the product intermediate of Penicillin G to our desired product of Penicillin G Potassium to be stored and sold to our clients. The units are shown below:

Rotary Vacuum Filter (RVF)

A rotary vacuum filter is used to separate solids from liquids. In this case, we are trying to remove biomass in order to concentrate the Penicillin G in the broth solution. We assumed that the large amount of biomass removed will be 93%, but also small amounts of Penicillin G (7%) and water (8%) are lost at this stage as well.

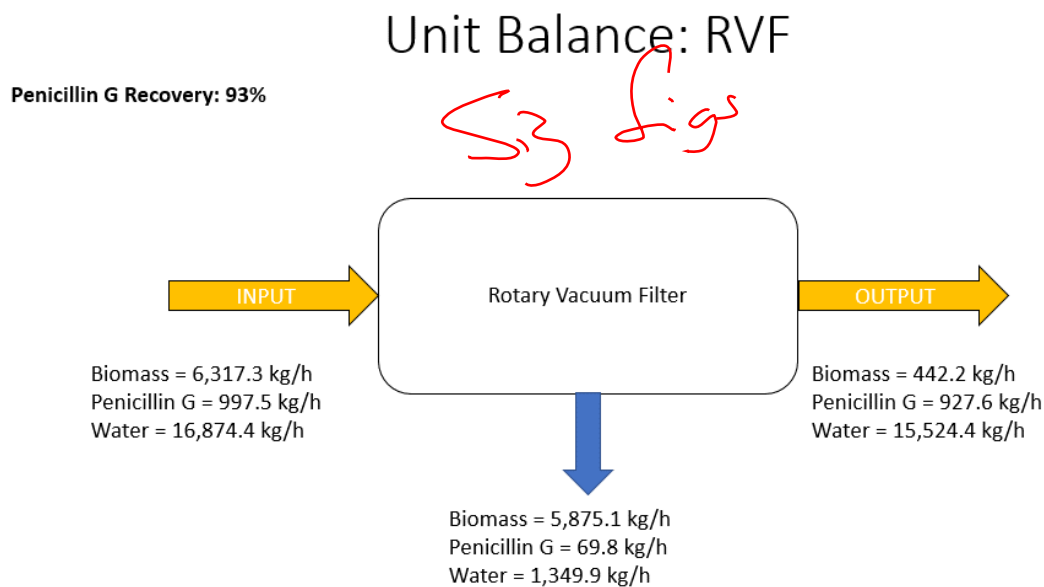


Figure 11. Material Balance across Broth Rotary Vacuum Filter

Mixing Tank

The purpose of this mixing tank is to agitate the combination of Penicillin G broth with the newly added components of sulfuric acid and butyl acetate, which is the solvent. Sulfuric acid was added based on the relationship between itself and Penicillin G produced on Reaction (1). Based on literature review, butyl acetate is added at 0.25 g butyl acetate/ g broth. Adding sulfuric acid is for adjusting the pH level down to 2, which is when Penicillin G exists as an undissociated acid making it soluble in organic solvents like butyl acetate.

Unit Balance: Mixing Tank

Penicillin G Recovery: 100%

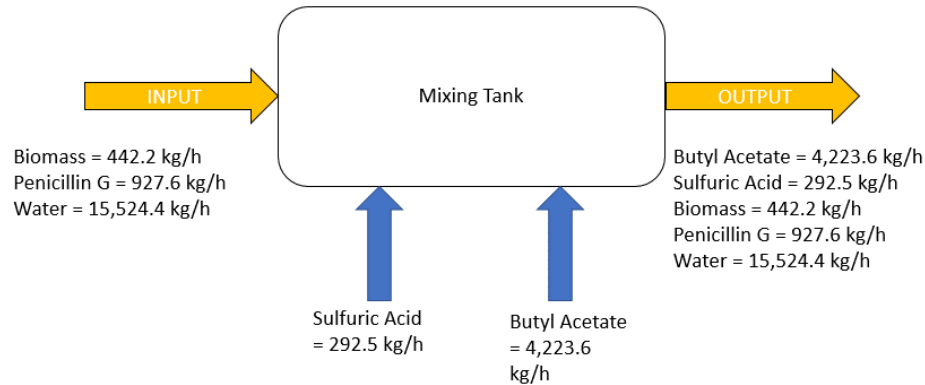


Figure 12. Mass Balance across Mixing Tank

Solvent Extractor

The purpose behind the solvent extractor is to conduct a liquid-liquid extraction which transfers some constituents of one liquid into the other one. In this process, the constituent will be Penicillin G being moved from the broth to the solvent, which will be extracted while the rest is sent to a waste treatment to recover the lost butyl acetate of 10% for reuse. Penicillin G recovery in this unit will be 86% based on literature parameters. However, we made assumptions that 95% of water is lost and all of the sulfuric acid is lost as well because it's very soluble in water. Also, we assumed that 96% of biomass that was left after the rotary vacuum filter is removed at this step.

Unit Balance: Solvent Extractor

Penicillin G Recovery: 86%

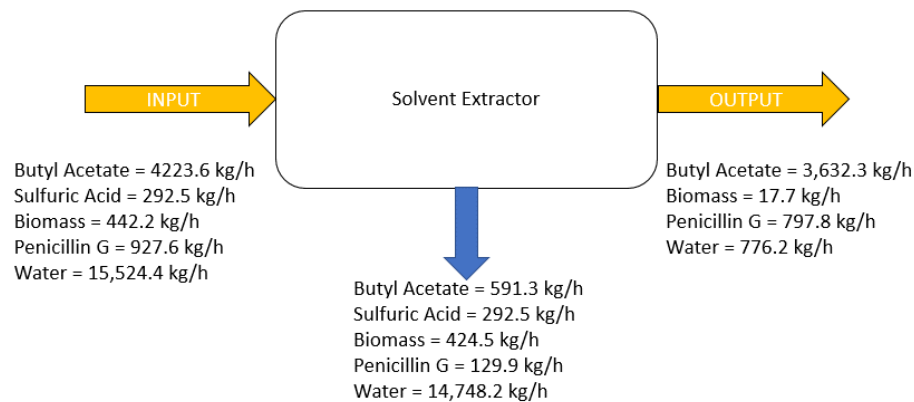


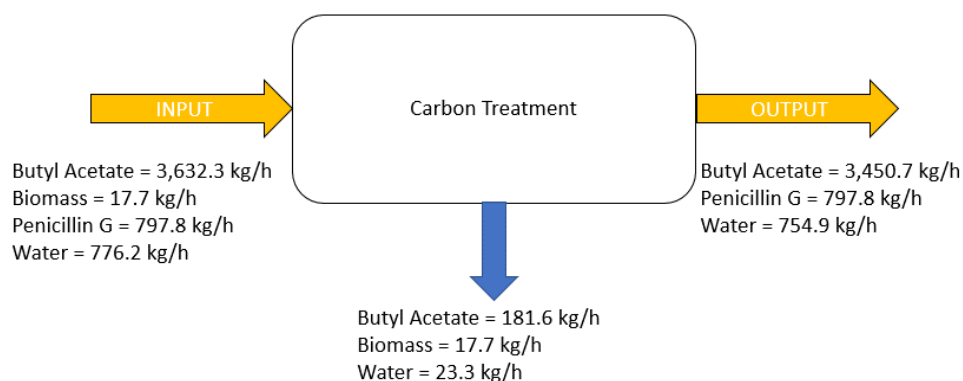
Figure 13. Mass Balance across Solvent Extractor

Carbon Treatment

Carbon treatment is done in an adsorption tower with carbon trays with carbon particle sizes between 10-20 microns. This step focuses on removing the color and odor of the solution coming from the solvent extractor. It also removes impurities like the remaining biomass. Solution particles and impurities stick or adhere to the surface of the carbon molecules on the trays, which can be replaced when the trays are overused. We assumed that there was a 5% loss on butyl acetate and 3% of remaining water. No Penicillin G was lost at this stage.

Unit Balance: Carbon Treatment

Penicillin G Recovery: 100%

**Figure 14.** Material Balance across Carbon Adsorption Tower

Crystallizer

This stage is for creating the crystals. Penicillin G broth is sent into the crystallizer with the addition of butyl acetate and potassium acetate. As Penicillin G is in contact with potassium acetate, Reaction 2 comes into effect making penicillin G a negative ion which also makes it insoluble in butyl acetate. This process is by the deprotonation of penicillin G molecule by the strong base of potassium acetate, which removes the hydrogen atom from penicillin G, and then protonated with the potassium atom to form Penicillin G Potassium crystals. Then, the free-floating hydrogen atoms will bond with the negatively-charged remainder of potassium acetate to form acetic acid.

Unit Balance: Crystallizer

Penicillin G K Recovery: 100%

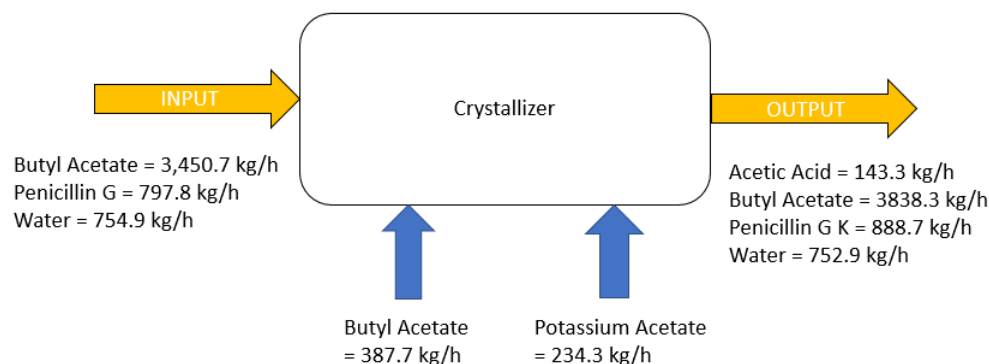


Figure 15. Material Balance across Crystallizer

Crystal Filter 1

Following the crystallizer, the crystal filter is another rotary vacuum filter that separates solids from liquid solution. In this case, we are separating the Penicillin G Potassium crystals from the solvent solution. The solvent solution will be heading off to a waste treatment to re-extract the butyl acetate for re-use in the process. We assumed that 88% of butyl acetate is removed with 95% of water content and all of the acetic acid is gone because it's soluble and fully miscible in water. We assumed that we will experience a 99% recovery of Penicillin G Potassium.

Unit Balance: Crystal Filter 1

Penicillin G K Recovery: 99%

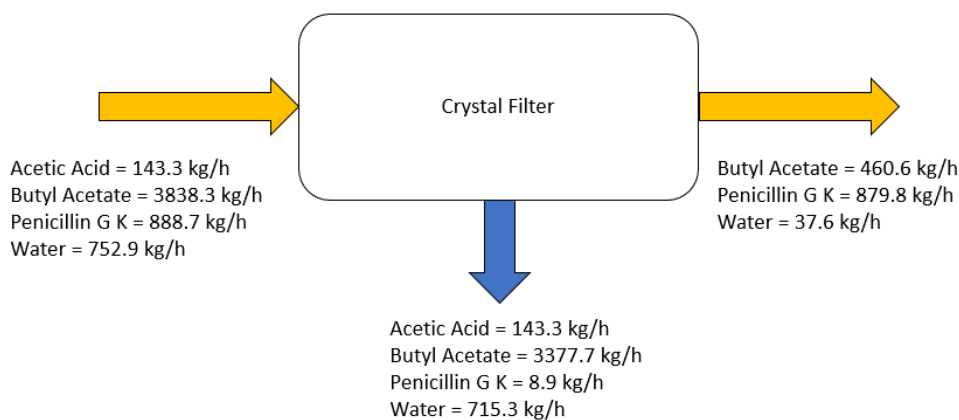


Figure 16. Material Balance across Crystal Rotary Vacuum Filter 1

Crystal Washing

At this stage, the crystals need to be rewashed with more solvent while still using the 0.25 g butyl acetate/ g broth ratio.

Unit Balance: Crystal Washing

Penicillin G K Recovery: 100%

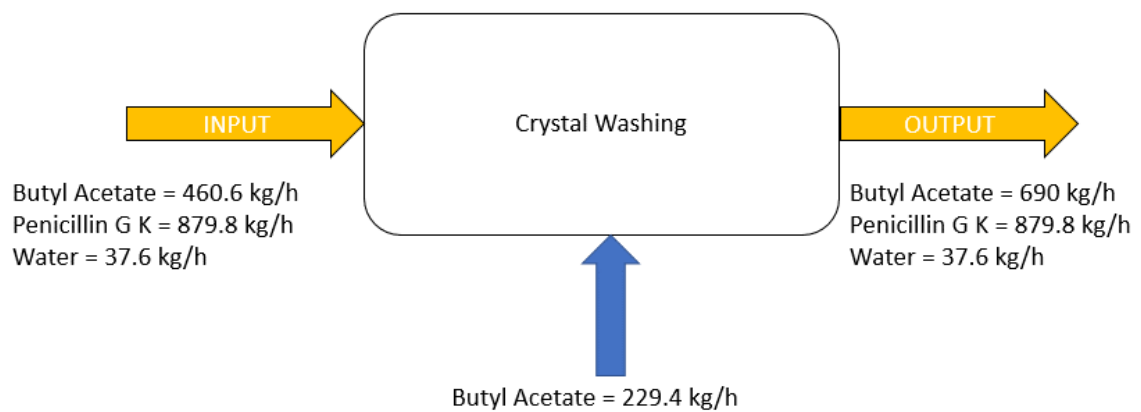


Figure 17. Material Balance across Crystal Washer

Crystal Filter 2

The crystals are re-filtered with the same assumed parameters from the first crystal filter since both equipment are the same.

Unit Balance: Crystal Filter 2

Penicillin G K Recovery: 99%

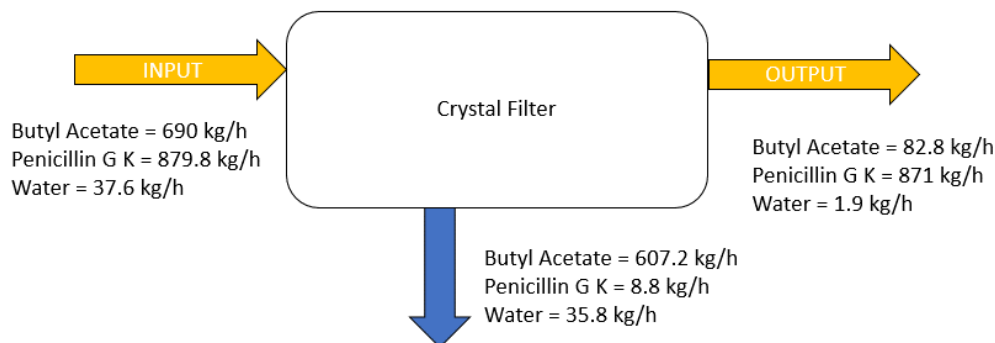


Figure 18. Material Balance across Crystal Rotary Vacuum Filter 2

Vacuum Drying

Finally, the crystals are dried at an ambient temperature with a pressure slightly below atmospheric. Butyl acetate is assumed to be retained at 5% of its content and water is retained at 4 % of its content. At the end, the product is at a purity of 99.5% before being transported to the grinder to be converted to a fine powder.

Unit Balance: Vacuum Drying

Penicillin G K Recovery: 100%

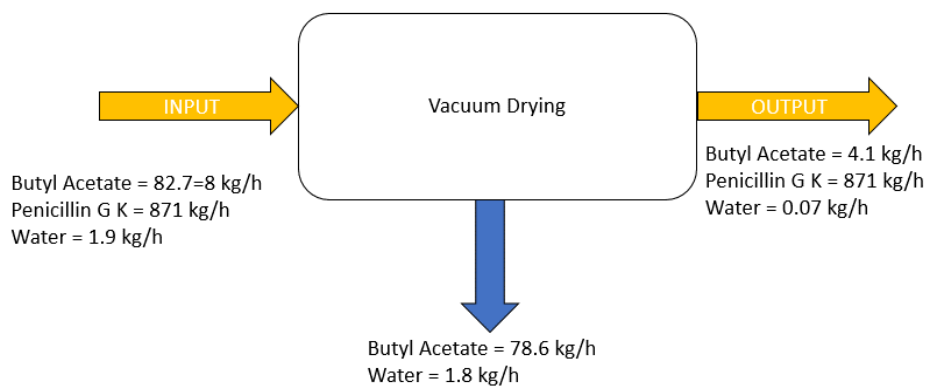


Figure 19. Material Balance across Vacuum Dryer

Degree of Freedom Analysis (Caleb)

According to Gibbs's Phase Rule, the number of degrees of freedom can be calculated using the following relationship:

$$F = C - P + 2$$

Where F = # degrees of freedom; C = # of components; P = # of phases

The following table shows the number of degrees of freedom corresponding to each process unit in the team's design:

Table 8. Degrees of Freedom for all Major Process Units

good!

Process Unit	C [# of components]	P [# of phases]	F [C - P + 2]
V-104	10	2	10
V-201	3	2	3
V-202	5	2	5
V-203	5	2	5
T-201	4	2	4
V-204	4	2	4
V-205	4	2	4
V-206	3	2	3
V-207	3	2	3
E-203	3	3	2

Energy Balance (Caleb)

Figure 16 shows the specifications for all heat exchangers used in the team's design. Each exchanger requires a utility/requires utilities that serve as mediums for heat transfer. The heat duties of the exchangers and the flow rate of the inlet utilities for each exchanger are shown below:

Energy Balance: Utility Equipment Table

Exchanger	Inlet Temp [°C]	Outlet Temp [°C]	Pressure [atm]	Utility	Heat flow [kJ/h]	Utility flow rate [kg/h]
E-101 (jacketed)	25	25	2.04	Steam	-1.33 x 10 ⁷	74,324.9
				Chilled water	1.33 x 10 ⁷	33,112.3
E-102	25	30	-	Steam	-6.02 x 10 ⁵	64,592.3
E-103 (jacketed)	25	25	2.04	Steam	-1.2 x 10 ⁷	67,060.1
				Chilled water	1.2 x 10 ⁷	29,875.7
E-104	25	30	-	Steam	-6.23 x 10 ⁵	66,845.5
E-201	30	25	-	Cooling water	9.44 x 10 ⁵	45,124.3
E-202	25	2	-	Chilled water	3.03 x 10 ⁶	31,486.4

Figure 20. Utility Equipment Table

According to the table, steam utilities all have negative heat flow values, while those of cooling and chilled water are all positive. This is a reasonable occurrence due to the fact that both steam and liquid water serve opposite purposes as utilities for the heat exchangers. Because the steam is supplying the process stream with the heat it needs to see a temperature increase, heat is being transferred from the steam to the process stream. For this reason, heat flow values for steam should be negative because the steam is losing heat while serving as the heat flow medium; conversely, the purpose of cooling/chilled water is to remove heat from the process streams, thus decreasing their temperatures. Moreover, heat flow values for cooled and chilled water should be positive because heat is being transferred from the process streams to the water.

After calculating the heat duties of each heat exchanger unit, utility flow rates were determined by the equation

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

use proper notation

Solving for $\dot{m}$,

$$\dot{m} = \dot{Q}/c_p\Delta T$$

It is important to note that mass, $\dot{m}$, in this situation represents a mass flow rate, not simply a mass. This is true because the calculated heat duty, $\dot{Q}$, is in units of [kJ/hr] or [kW]. c_p represents the specific heat capacity of the water utility (liquid water or steam, depending on the exchanger) and ΔT is the temperature difference between the utility and the inlet stream. The

All variables should be included in a nomenclature section

mass flow rates of the utilities in the heat exchangers appear considerably high, but this is because a large flow of water is needed to facilitate the transfer of so much heat.

In-depth calculations concerning the derived heat flow and utility flow rate values can be found within the appendix of this report.

Aspen Simulation (Buka)

After all process parameters and designing the Process Flow Diagram, the Aspen Simulation was created. Due to the fact that some equipment wasn't available in Aspen, we simulated our process using closely related equipment that was applicable which resulted in our process converging and having practical values close to our hand calculations. Also, our process was a bioprocess which requires a bio-simulator with the correct raw material component and accurate fluid package as well. Aspen Model is visible below:

Aspen Simulation

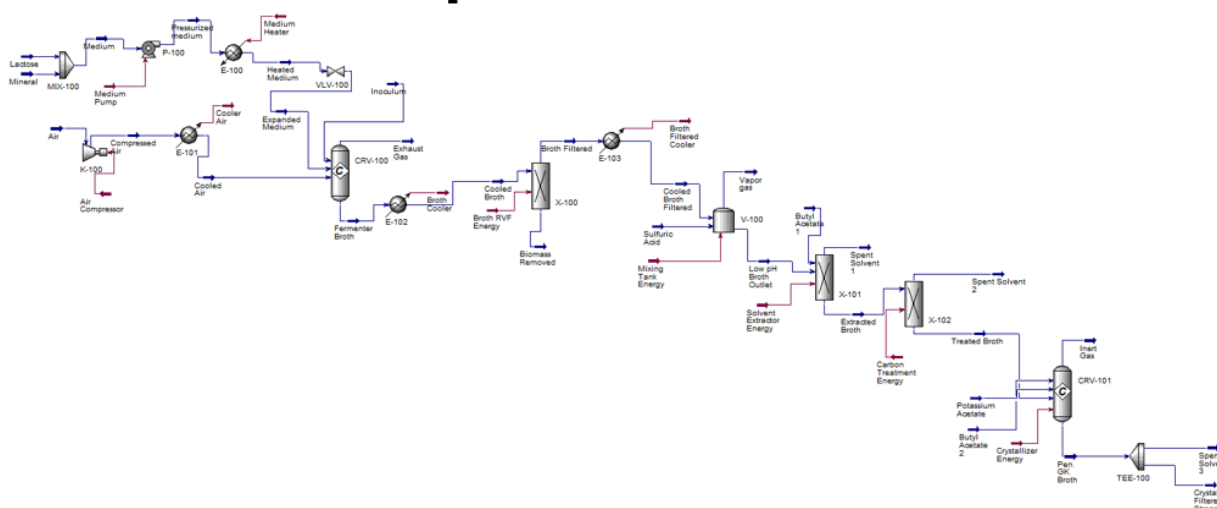


Figure 21. Aspen Simulation

Conclusion and Recommendations *(Buka & Caleb)*

All in all, the design project satisfied all objectives and revealed itself to be feasible. According to the growth profit indicator, the total cost of necessary raw materials (excluding transportation costs) is less than the total value of products manufactured for sale (penicillin G potassium and biomass), indicating that this plant is profitable and thus worth constructing. Although this analysis does not take into account transportation and utility costs, it is useful in determining the validity of a premature design plan. Regardless, the proximity of the plant to its raw material

suppliers on either side of the country significantly reduces the effect of transportation costs on overall profit.

One recommendation the Team has to ultimately increase profit in the long run is to utilize multiple liquid-liquid extractors in series, rather than one extractor for the whole process. As mentioned earlier in the report, the plant has an overall efficiency of 78%, meaning that the remaining 22% represents the extra amount of penicillin G potassium that could be produced in the event of a theoretically seamless process. By attempting to minimize these potential losses and make the process more efficient, less raw materials will be required and more penicillin G potassium can be manufactured with minimal extra effort. The liquid-liquid extractor in the design has an efficiency of 86%, meaning that 86% of incoming penicillin G is admitted onward to the next unit in the process. By placing multiple liquid-liquid extractors in series, the design will permit for the process stream to be more penicillin G-rich. Adding multiple extractors will lead to a 92% - 96% efficient extraction process, which is around an 8% higher efficiency. While adding multiple extraction units does initially cost, that cost will pale in comparison to the total operating cost because it will maximize the amount of penicillin G potassium that can be made from the same amount of raw materials.

No citations!
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I. Introduction

Acetonitrile is a chemical compound with the formula CH_3CN . It is a clear, colorless liquid with a sweet and ethereal odor. It is the simplest organic nitrile and was first prepared by French Chemist Jean-Baptiste Dumas in 1847. Acetonitrile is one of the most frequently used eluents used in reverse phase chromatography and is a critical solvent in pharmaceutical applications for the production of vaccines and antibiotics. In this comprehensive literature review, we will be going over a review of literature on production routes, uses, and handling, as well as process selection and description for our design of production of acetonitrile.

II. Production Literature Review

Many reaction routes for the production of acetonitrile have been studied. Below are the main production routes found in our research.

II.A.1 Production of Acetonitrile from the Sohio Process

A very common way to produce Acetonitrile is via the Sohio process. This process involves the catalytic oxidation of propylene in the presence of ammonia and air. However, we determined this production route was not a route we wanted to take. The primary dealbreaker is because Acetonitrile would be produced as a by-product. Since this would limit our production then it was determined to avoid this process.

II.A.2 Reacting acetic acid with ammonia

II.A.3 Ammoxidation of ethanol

Another way to produce acetonitrile is the ammoxidation of ethanol. The main reaction in this process begins with the reactants entering in a fluidized bed reactor. The process has a low yield without the presence of a catalyst, but with aid from a catalyst the process can achieve high conversions of ethanol. The ideal catalyst to use for this process is vanadium oxide.

II.B. Handling and storage

Acetonitrile is commonly delivered to customers in: ISO tank container, bulk truck, rail car, drum, and ship. Storage capacity should be carefully considered for optimum handling and transport of material. Acetonitrile storage and handling are subject to regulatory policies, and requirements from regulations either local or national must be considered to operate under law. Acetonitrile should be stored in a cool, dry and well ventilated area. The storage area should be out of direct sunlight. The container should be sealed to prevent exposure to air. Temperatures should never exceed 86 degrees Fahrenheit. For quantities larger than a liter, storage should be in a metal container. Acetonitrile should be kept away from oxidants, acids, anhydrides and alkali metals. To prevent accidental explosions or health hazards, several measurements should be taken. Acetonitrile should be handled alongside a colleague. It should be handled under a fume hood if direct contact is required. Fume hoods help minimise exposure. It is important to avoid skin, eyes, inhalation and ingestion. Furthermore, it should be kept away from

Key points:
Sohio process
by-product
dealbreaker
avoid this process

steam, flames, direct heat and combustible substances. Protective clothing such as a long sleeved lab coat or gown, rubber gloves, safety goggles and a face mask are required.

II.C Physical and Chemical Properties

Acetonitrile is a clear colorless liquid with a sweet ethereal odor. Although it is a hazardous chemical, its chemical properties are well understood and is a stable chemical under conditions of normal use. Physical properties include its boiling point at 81.60°C and a flash point at 6°C which makes it a highly flammable fluid. The chemical reactions of acetonitrile are essentially engaged on the nitrile, or -CN, group. Acetonitrile can be utilized to prepare amines, amides, amidines, carboxylic acids and esters, aldehydes, ketones, imines, and many other mixtures. In any case, the essential modern utility of acetonitrile is as a solvent. As a magnificent polar aprotic solvent, with a high dipole movement and dielectric constant. Acetonitrile is preferably appropriate for chemical analysis, extractive purification and organic and biochemical reactions.

II.D Uses

Acetonitrile is utilized to make drugs, perfumes, rubber products, pesticides, acrylic nail removers and batteries. It is also used to remove unsaturated fats from animal and vegetable oils.

III. Process selection

In our process selection we considered three process routes. Our first process is acetonitrile via the sohi process. It is the most common production route as the sohi process in the main widely used production route but due to it making a product of acrylonitrile, it wasn't highly favored in our design in order to produce mass amounts of acetonitrile. Our second consideration is acetonitrile from acetic acid and ammoxidation. This is the least common production route with not much historical literature to build a grass root plant design around. Its purity level is at 98.5% for this process route. Our process was acetonitrile via pressure swing distillation. In this case there was a good selection of literature to study and create a design around. At its highest purity (99%), it is our most favorable specification. Our issues with design were waste treatment issues and excess by-products in process flow.

IV. Process description

Mixing of Ethanol:

The liquid ethanol flows at an ambient temperature of 77°F. The alcohol is then mixed with ammonia. The mixture then passes through a heat exchanger to increase its temperature to 788°F. Air also flows through a heat exchanger to be heated to 788°F in a separate stream.

Ammoxidation reaction:

The heat ethanol and ammonia are fed into the fluidized bed reactor. The heated air is fed into the reactor separately. The reactor operates at a temperature of 788°F and 29psi to provide a conversion of 100 mol% ethanol. The reactor produces vent gas, acetonitrile, water, and co-products.

Separation/purification:

The first gas separator separates carbon dioxide and ammonia from the product mixture. The product mixture consisting of acetonitrile, water and hydrogen cyanide goes through swing distillation for further purification. In the first distillation column hydrogen cyanide with any remaining carbon dioxide and ammonia is extracted. Acetonitrile and water is extracted in the second distillation column. Due to the similar boiling points of acetonitrile and water the second distillation operates at 145psi and involve more trays to achieve the desired 99.9% acetonitrile product.

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missing key information