

**PRAIRIE VIEW A&M UNIVERSITY
ROY G. PERRY COLLEGE OF ENGINEERING
DEPARTMENT OF CHEMICAL ENGINEERING
CHEG 4247-P02 - Senior Design and Professionalism I
FALL 2021**

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Course Description in ABET Format

CHEMICAL ENGINEERING DEPARTMENT CHEG 4247-P02 SENIOR DESIGN & PROFESSIONALISM I

- | | |
|--|--|
| 1. Course number and name: | CHEG 4472-P02 SENIOR DESIGN & PROFESSIONALISM I |
| 2. Credits and contact hours: | 2 credit hours; 4 contact hours |
| 3. Instructor's or course coordinator's name: | Dr. Lealon L. Martin |
| 4. Text book: Title: | None |

Author:

Publisher, Year & Edition:

- | | |
|--------------------------------|--|
| a. Other Supplemental material | (i) Chemical Process Engineering: Design & Economics by Harry Silla, Marcel Dekker, 2003
(ii) Analysis, synthesis and Design of Chemical Processes 4th Edition, by Richard Turton, Richard C. Bailie, Wallace B. Whitting, Joseph A. Schaeiwitz and Debangsu Bhattacharrya, Prentice Hall, 2012
(iii) Plant Design and Economics for Chemical Engineers, 5th Edition, by Max S. Peters Klaus. D. Timmerhaus and Ronald. E. West, McGraw-Hill, 2003
(iv) Senior Design Project Manual by Prairie View A & M University Roy G. Perry College of Engineering |
|--------------------------------|--|

5. Specific course information

- | | |
|---|---|
| a. Brief description of the content of the course (catalog description) | CHEG 4247 Senior Design and Professionalism -I: 2 semester hours. This is the first course of a two-semester capstone experience (CHEG 4248 must immediately follow 4247 or sequence must restart with 4247) involving engineering design of an industrial or advanced team project. Elements of ethics and professionalism in engineering practice are integrated into the project experience. The project will include application of relevant engineering codes and standards, as well as realistic constraints. Design achievements are demonstrated with written reports, and oral presentation, and professional standards and ethics examinations. |
| b. Prerequisites or Co-requisites | CHEG 3301, CHEG 3302, CHEG 3305, and CHEG 3306 |
| c. *Indicate whether a required, elective, or selected elective (as per definition) | Required |

provided) course in the program

6. a. **Specific goals for the course** specific outcomes of instruction (e.g. The student will be able to explain the significance of current research about a particular topic.)

Students will be able to:

1. Design a system, component, or process to meet desired needs with realistic constraints by demonstrating ability to (a) research, identify, formulate and solve engineering problems and (b) conduct research on the economical, global impact, ethical and technical aspects of the process design
2. Demonstrate ability to work in teams; manage themselves as a team by through (i) planning group meetings and time management, assigning team roles (leader, recorder, etc), assign and keep good record of team meetings and activities, and (ii) distribution of project tasks evenly to team members; performance and peer evaluation; tracking and meeting project schedules.
3. Demonstrate ability to communicate effectively in oral and written formats.
4. Demonstrate an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice through the use of EXCEL spreadsheets, MATLAB, POLYMATH, ASPEN/HYSYS process simulator to solve chemical engineering problems.

- b. **Explicitly indicate which of the student outcomes listed in Outcomes 2, 4, and 7** or any other outcomes are addressed by the course.

The specific goals for the course specific outcomes listed on the left column will address the following student learning outcomes:

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 factors.

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.

Outcome 7

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

7. Brief list of topics to be covered

Course overview and review of group dynamics (3 hrs)
Design constraints, tasks and GANTT Chart (3 hrs)
Preliminary material balances and literature review (3 hrs)
Process simulation using ASPEN and safety review (6 hrs)
Product design and raw materials selection - (6 hrs)
Preliminary gross profit analysis (6 hrs)

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

II ASSESSMENT RESULTS FOR CURRENT AND PAST THREE PERIODS

Program Outcomes Assessed in this course

Outcome 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 factors.

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.

Outcome 7:

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

Assessment Summary of Class Semester Averages for Outcomes

Outcomes	2	4	7
Semester	Semester Class Average (%)	Semester Class Average (%)	Semester Class Average (%)
Fall 2021	83	85	80
Fall 2020	78	76	80
Fall 2019	81	85	84
Comments on Trend of Data (Improving or deteriorating)	Students' performance was above average in general compared to the performances in previous semesters. This was also observed by alumni evaluating students at the end of the semester.	The students' performance was well above the expected average and average over the period. The performance was 26 % points above that of Fall 2020.	The students' performance was above the expected average. The performance was 23% points lower compared to the fall 2020.

*Expected Semester Class Average = 70% (or as defined by the program)

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

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

Each summary contains the following Information

1. Performance Statistics

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

2. Implementation Summary

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

3. Perceived Problems

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

4. New Plans for Addressing Problems

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

5. Overall Trend over last three assessment periods

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

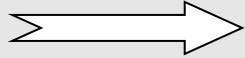
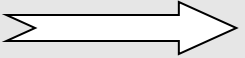
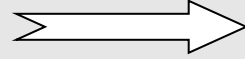
5. Were Expectations Met?

- Answer **YES** if the **class average was above the expected average** and the **stated percentage of students** scored at or above the expected average, else answer **NO**.

END OF SEMESTER COURSE OUTCOME ASSESSMENT REPORT
CHEG 4472-P02 SENIOR DESIGN & PROFESSIONALISM I
FALL 2019 SEMESTER

Report Prepared by: **Dr. Lealon L. Martin**

Report Date: **December 19, 2021**

Semester	Analysis Type	Number of Students	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			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.			Outcome 7 An ability to acquire and apply new knowledge as needed, using appropriate learning strategies		
			Expected Average	Class Average	% Students Meeting Expected Average	Expected Average	Class Average	% Students Meeting Expected Average	Expected Average	Class Average	% Students Meeting Expected Average
Fall 2021	Direct	12	75	83.0	83	75	85.0	83.0	75	80.0	63.5
Fall 2020	Direct	26	75	78	86	75	76	57	75	80	86
Fall 2019	Direct	37	75	81	100	75	85	100	75	84	100
Implementation Summary			The importance of the foundation courses in the curriculum and students' abilities in these courses were stressed at the start of the course. Students were provided handouts briefly outlining the design of chemical plants.			Lectures on professionalism and ethics were to be given to the students during the semester followed by a homework assignment.			The importance of students' abilities to show impact of their grass-roots plant on society as a whole was stressed at the beginning of the course. A lecture on safety was planned for the semester. A lecture on safety was planned for the semester.		
Perceived Problems			Some of the students could not perform simple material and energy balances as part of their preliminary designs. Students' skills in screening process alternatives and process description need improvement.			Although the performance of the met the expected class average, 17 % of the expected performed below the expected average. The students' reports in the homework assignment highlighting ethical issues need further improvement.			Although the students' performance was satisfactory, some of the students only provided a sketchy overview and did not adequately address the global and societal impact of their projects.		
Plans for Addressing Problems			The following will continue to be recommended for implementation. 1. Provide students with reading and homework assignments on designing of units of the process plant, 2. Review process screening and examples of detailed process description and example of material balance concepts such as recycle, purge, and bypass.			The instructor should: Continue providing reading assignments of case studies in ethics			The following is recommended for implementation. More homework assignments should be given early in the semester next time the course is offered and students asked to discuss the positive and negative impact of the process globally and locally.		
Overall Trend over Periods			Students' performance was above average in general compared to the performances in previous semesters. This was also observed by alumni evaluating students at the end of the semester.			The students' performance was well above the expected average and average over the period. The performance was 26 % points above that of fall 2020.			The students' performance was above the expected average. The performance was 23% points lower compared to the fall 2020.		
Were Expectations Met?	Average ≥ 70%? and ≥ 70% students avg. ≥ 70%?		YES			YES			YES		

**SENIOR DESIGN AND PROFESSIONALISM I
FALL 2020**

Title of Assignment: HOMEWORK 1 and 2

TOPICS COVERED IN HOMEWORK 1 and 2

Test 1 covered the following topics:

1. Problem statement
2. Problem definition
3. Drafting memoranda (content and audience)
4. HOMEWORK 2 is a revision of HOMEWORK 1

SENIOR DESIGN AND PROFESSIONALISM I FALL 2019

HOMEWORK #1 (AND #2) QUESTION

Please draft and submit a problem statement and design basis comprising the elements we discussed in class at the beginning of the semester for your group's project (see your group's sharepoint folder for the full description of your project requirements). Use the sample problem statement and sample design basis documents for guidance purposes.

In completing this assignment, please be mindful and follow the parameters and guidelines for your final project to tailor your problem statement and design basis appropriately.

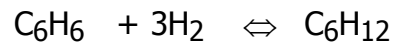
SAMPLE SOLUTION ON NEXT PAGES

September 12, 2021

TO: Prof. L.L. Martin
FROM: YOUR NAMES
RE: Simulation Case Study for the Design of a Cyclohexane Plant

In response to increased demands for polymer-grade cyclohexane, a local petrochemical chemical company is contemplating the addition of a cyclohexane plant. This company has asked our team to come up with preliminary designs for this addition. The sales department has conservatively estimated that they can sell 30×10^6 kg of poly-grade cyclohexane per year.

Cyclohexane will be made from benzene and hydrogen, via the solid-catalyzed gas-phase reaction:



Benzene is an increasingly banned, carcinogenic product formed during the catalytic reforming of naphtha, while cyclohexane is a useful intermediate in the production of nylon. Process development engineers at the company assures us that, with the new RI204 catalyst, the reaction is extremely fast; we can expect near-equilibrium conversions of benzene to cyclohexane, provided that the minimum reaction temperature is 425 K.

Please have your team do preliminary energy and material balances for a cyclohexane plant, including the sizing of all heat exchangers. For the time being, the sizing of the reactors is not critical. However, to ensure favorable equilibrium conversions and to preserve the integrity of the catalyst, the reactor temperatures should not exceed 500 K. Additionally, the molar $\text{H}_2/\text{C}_6\text{H}_{12}$ ratio in the reactor(s) should be nowhere less than 5/1. We have been informed more than once that energy costs must be minimized, so please have your team make every effort to make this an energy-efficient process.

A design basis and some basic data are attached. We will submit a simulation and final report that summarizes our analysis by December 3, 2021.

DESIGN BASIS

Plant Capacity

Design capacity: 30,000,000 kg/yr
Design operating time: 8320 hr/yr

Raw Materials

Hydrogen (gas, 99.95+% pure), at 80°F and 25 psig
Benzene (liquid, 99.95+% pure), at 80°F and 25 psig

Product Cyclohexane Specification

Liquid, 99.9% pure, at 105°F max and 25 psig

Utilities Available at Battery Limits

Steam: High pressure, saturated, at 300 psig
Medium pressure, saturated, at 150 psig
Low pressure, saturated, at 50 psig
Condensate return at 2 psig, min.
Cooling water: Available at 55 psig and 85°F, ave.
Return at 25 psig, min., and 115°F, max.

Pressure Drops for Process Streams

Heat Exchangers: 2 psi for gases (or condensation)
5 psi for liquids (or boiling)
Reactors: 10 psi maximum total

Ambient Conditions

Maximum temperature: 95°F
Minimum temperature: -10°F
Relative humidity: 25-95%
Maximum windspeed: 30 mph

ABOVE AVERAGE

September 14, 2021

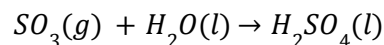
To: Prof. L.L. Martin

From: Tyecia Franklin, Taylor Linton, Wasil Mahmood and Franck Nangomoko

RE: Preliminary design of a Sulfuric acid Plant

With the growing demand for highly concentrated pure grade sulfuric acid, a fertilizer company is looking into the construction of a new sulfuric acid plant. This company has asked our team to begin preliminary designs for this addition. The sales division has estimated that they will be able to sell 2.5 million tons of sulfuric acid per year.

Sulfuric Acid will be produced from sulfur trioxide and water, as shown in the following reaction.



Sulfur trioxide is formed in a plant converter from the oxidation of sulfur dioxide with the use of a catalyst. With the combination of sulfur trioxide, water and a catalyst it leads to the generation of sulfuric acid, which acts as a building block in the formation of phosphoric acid. Process development engineers have assured us that with the use of a catalyst, it greatly decreases the reaction process time. We can expect to maintain near equilibrium conversions, with a minimum reaction temperature of 130°F.

Our team will be carrying out preliminary energy and material balances for a sulfuric acid plant along with the sizing of all reactors and heat exchangers. However, in order to ensure that the final product is in the form of a liquid, the water-treated sulfur trioxide must also be reacted with concentrated sulfuric acid. Therefore, sulfuric acid will not only be our desired product but will also act as a raw material. We are aware that the energy cost must be minimized and will make a strong effort to create an energy efficient process.

Our design basis along with other basic information is attached. We will be submitting a simulation and final report of our analysis by November 30th 2021.

Very good!!

Design Basis

Plant Capacity

Design Capacity : 2.5 million tons/year

Design Operating Time : 7200 hr/ year

Raw Materials

Oxygen (gas, 21%) at STP

Sulfur (liquid, 98.5% pure) at STP

Water (liquid 1.5%) at 77°F and 25 psig

Sulfur Dioxide (gas, 99.95+% pure)

Sulfuric acid (liquid, 98.5% pure)

Product Sulfuric Acid Specification

Liquid, 98.9% pure 250°F max and 30 psig

Utilities Available at Battery Limits

Steam:

High Pressure, saturated, at 350 psig

Medium Pressure, saturated at 150 psig

Low Pressure, saturated, at 50 psig

Cooling Water:

Available at 60 psig and 88°F

Return at 35 psig, min., and 125°F, max.

Pressure Drops for Process Streams

Heat Exchangers: 3 psi for gases (or condensation)
7 psi for liquids (or boiling)

Reactor: 15 psi maximum total

Ambient Conditions

Maximum Temperature: 116°F

Minimum Temperature: 130°F

Relative Humidity: 40-90%

Maximum Wind Speed: 20 mph

good?

To: Dr. L.L. Martin

From: Anh Nguyen
Bryson Marshall
Dayna Butler
Kennedi Henderson

RE: Design of a Phosphoric Acid Plant

In response to increased demands for merchant-grade phosphoric acid, a local fertilizer company is contemplating the addition of a phosphoric acid plant. This company has asked our team to come up with preliminary designs for this addition. The sales department has conservatively estimated that they can sell 200,000 tons of phosphoric acid per year.

Phosphoric Acid will be made from sulfuric acid and naturally occurring phosphate rock,



As the phosphate rock is continuously fed into the reactor with sulfuric acid, the reaction combines calcium, and forms gypsum (calcium sulfate). Filtration is used to separate gypsum from the reaction. Process development engineers at the company assure us that, with 93 percent sulfuric acid, this will produce the strongest product possible and decrease evaporation cost. We can expect near-equilibrium conversions of sulfuric acid to phosphoric acid, provided that the reaction temperature is kept at 340 - 350K.

Our team will do preliminary energy and material balances for a phosphoric acid plant, including the sizing of all heat exchangers and reactors. However, to ensure the gypsum is completely washed away, approximately 0.7 acres of cooling and settling pond area will be needed for every ton of daily P_2O_5 capacity. Additionally, excess H_2SO_4 is fed through several reactors until the desired conversion of phosphoric acid is reached. We have been informed more than once that energy costs must be minimized, so we will make every effort to make this an energy-efficient process.

A design basis and some basic data are attached. We will submit a simulation and final report that summarizes our analysis by November 15th, 2021.

very good

Design Basis

Capacity

Design capacity: 200,000 tons/yr
Design operating time: 8400 hr/yr

Raw materials

Phosphate rock (solid), grounded 0.15 – 2 mm (5.9×10^{-3} – 78.7×10^{-3} in)
Sulfuric acid (liquid, 93%)

Product Specification

Liquid, 75% H_3PO_4 (54% available P_2O_5)

Process

Wet process: Reaction, Filtration, Concentration

Utilities Available at Battery Limits

Reactor: stirring speed 200 rpm, pressure 15 psig
Warehouse: maximum 10% moisture for phosphate rock
Electricity: 110V
Cooling air: Available at 77°F, average
Return at 115°F, average
Wash water: Available at 85°F, 15 psig average
Emission monitor
Fuels: Liquid natural gas

Ambient Conditions

Location: Brandon, Florida
Max Temperature: 90.6°F
Min Temperature: 50.1°F
Humidity: 74%
Rainfall: 51.3 in
Windspeed: 10 mph

Very good.

AVERAGE

September 14, 2021

TO: Prof. L.L. Martin

FROM: Jarred Essissima, Doron Montgomery, Frederick Williams, Ike Anaghara

RE: Simulation Case Study for the Design of a Acetonitrile Plant

no question

Acetonitrile's continued growth worldwide has produced an opportunity to design an Acetonitrile production plant. In response to increasing acetonitrile consumption at a rate of 5-6% over a five year span, There is an increased demand of acetonitrile for use in the pharmaceutical industry as a solvent for use in pharmaceutical drugs. We were asked by one of three major producers of acetonitrile to Construct a plant to meet the increasing demand.

The process of acetonitrile formation from acetic acid and ammonia is equilibrium two-stages reaction:



Preliminary Energy, and Material balances needed for an acetonitrile plant will be completed promptly. Although at this time sizing of reactors is not critical; to ensure favorable equilibrium conversions and preserve purity of product, reaction temperatures should not exceed 400°C. Energy costs and cost efficiency are also highly suggested to be minimized.

Included you will find a design basis for the case study of our acetonitrile plant. A final simulation and report will be submitted on/before December 7, 2021.

How much?

OK

Why 400°C?

Design Basis

Plant Capacity

Design capacity:
Design operating time:

10,000,000 to 50,000,000 lb per yr
2920 hr/yr

ok

lbs? °C?

do not mix
units.

Raw Materials

Acetic acid (liquid, 99.9+% pure), at 25°C
Ammonia (gas, 99.9+% pure), at 25°C
Water (liquid 99.9+% pure), at 25°C
 $\gamma\text{-Al}_2\text{O}_3$

Product Acetonitrile Specification

Liquid, 99.9% pure, 100°C at max and 0.20 MPa

do not
mix
units!

Ideal Pressure for Process Streams

Ammonia Catalyst: 0.217-3.045 partial pressure psi

Reactors: 14.696 psi (Fixed Packed Bed Reactor)

Ambient Conditions

Maximum temperature: 81
Minimum temperature: 60
Relative humidity: 56 - 89%
Maximum wind speed: 9.4 mph

⇒

what temperature
scale?

why?

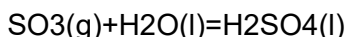
To: Prof. L.L. Martin

From: Tyecia Franklin, Taylor Linton, Wasil Mahmood and Franck Nangomoko

RE: Preliminary design of a Sulfuric acid Plant

With the growing demand for highly concentrated pure grade sulfuric acid, a fertilizer company is looking into the construction of a new sulfuric acid plant. This company has asked our team to begin preliminary designs for this addition. The sales division has estimated that they will be able to sell 200 thousand tons of sulfuric acid per year.

Sulfuric Acid will be produced from sulfur trioxide and water, as shown in the following reaction.



Sulfur trioxide is formed in a catalytic converter from the oxidation of sulfur dioxide with the use of a catalyst. With the combination of sulfur trioxide, water and a catalyst it leads to the generation of sulfuric acid, which acts as a building block in the formation of phosphoric acid. Process development engineers have assured us that with the use of a catalyst, it greatly decreases the reaction process time. We can expect to maintain near equilibrium conversions, with a minimum reaction temperature of 1800°F.

Our team will be carrying out preliminary energy and material balances for a sulfuric acid plant along with the sizing of all reactors and heat exchangers. However, in order to ensure that the final product is in the form of a liquid, the water-treated sulfur trioxide must also be reacted with concentrated sulfuric acid. Therefore, sulfuric acid will not only be our desired product but will also act as a raw material. We are aware that the energy cost must be minimized and will make a strong effort to create an energy efficient process.

Our design basis along with other basic information is attached. We will be submitting a simulation and final report of our analysis by November 30th 2021.

Design Basis

Plant Capacity

Design Capacity : 200 thousand tons/year

Design Operating Time : 8400 hr/ year

Raw Materials

Oxygen (gas, 21%) at STP

Sulfur (liquid, 98.5% pure) at STP

Water (liquid 1.5%) at 77°F and 14.7 psig

Sulfur Dioxide (gas, 99.95+% pure)

Sulfuric acid (liquid, 98.5% pure)

Product Sulfuric Acid Specification

Liquid, 98.9% pure 100°F max and 30 psig

impurity limits?

Utilities Available at Battery Limits

Steam:

High Pressure, saturated, at 350 psig

Medium Pressure, saturated at 150 psig

Low Pressure, saturated, at 14.7 psig

Cooling Water:

Available at 60 psig and 88°F

Return at 35 psig, min., and 125°F, max.

Pressure Drops for Process Streams

Heat Exchangers: 3 psi for gases (or condensation)
7 psi for liquids (or boiling)

Reactor: 15 psi maximum total

Ambient Conditions

Maximum Temperature: 110°F

Minimum Temperature: 15°F

Relative Humidity: 74%

Maximum Wind Speed: 30 mph

BELOW AVERAGE

Date??

TO: Professor Lealon. L. Martin

FROM: Ibrahim Arogundade, Ebonie Henderson, Jacquelyn Fuller, Tyree Madison

RE: Simulated Model for a plant design of L-Methionine

Agreement
or
metric?

L-methionine has been used in various industrial applications such as production of feed and food additives. L-methionine is one of the essential amino acids in all animal species. Most mammals depend on outside sources to replenish themselves with L-methionine as mammals are unable to synthesize it naturally. This has created a huge demand in several industries. In response to this demand our company devises a design of a plant that produces 50,000 tons of L-methionine per year.

L- Methionine is industrially produced from the acetylation of DL-methionine which is manufactured using the following raw materials hydrogen cyanide, acrolein, methyl mercaptan, and ammonium carbonate (All About Feed, 2020). Along with cysteine, these two compounds are the only Sulphur-containing proteinogenic and essential amino acids. Methionine is an intermediate in the biosynthesis of cysteine, carnitine, taurine, lecithin, phosphatidylcholine, and other phospholipids. Figure 1.1 depicts the process of which L-methionine is derived from

red?

??

no figure
needed for
problem statement

statement

what about
production
conditions?

product purity?
Tons? price?

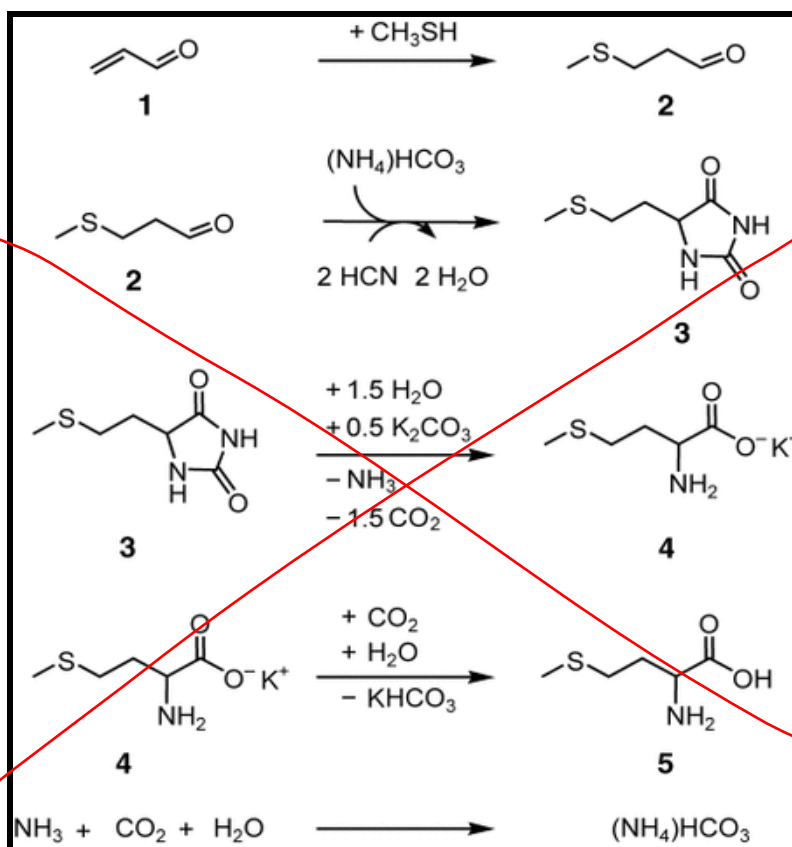


Figure 1.1 Industrial methods for the production of optically active intermediates

The team will complete preliminary energy and material balances for the manufacturing of L-Methionine; for the time being, sizing of the reactors is not critical. Furthermore, environmental factors are always important as well as staying within the guidelines of environmental protection agencies so the team will do so by preserving the amino acid by operating at moderate pressures and temperatures to reduce emission rates. Our team has been informed that operating costs must be minimized. Our team will make an effort to create an efficient process. A design basis and basic data are attached. Our team will submit a simulation and final report that summarizes our analysis by December 18, 2021.

DESIGN BASIS

Plant capacity

Design capacity: 50,000 tons/yr

Raw Materials

Acrolein (solid, pure 99.9% at 20 degrees Celsius)
Methyl mercaptan (solid, pure 99.5% at 20 degrees Celsius)
Hydrogen Cyanide (solid, pure 99.9% at 20 degrees Celsius)
Ammonia Carbonate (solid, pure 99.5% at 20 degrees Celsius)

should be in
AES

Product L-methionine Specification

Dry, 99.9% pure, at 38 degrees C max

Utilities Available

Steam:

Medium Pressure, saturated at 800 kpa

Low Pressure, saturated at 101.0 kpa

Cooling Water:

Available at 20 degrees

Return at 80 degrees Celsius max

Why??

Ambient Temperatures

Maximum Temperature: 80 degrees Celsius

Minimum Temperature: 20 degrees Celsius

80°C ambient
temperature??
This is too
hot!!

Appendix

1. The complex process of manufacturing methionine. All About Feed. (2020, December 18). Retrieved September 15, 2021, from <https://www.allaboutfeed.net/animal-feed/feed-processing/the-complex-process-of-manufacturing-methionine/>.
2. Breuer, M., Ditrich, K., Habicher, T., Hauer, B., Keßeler, M., Stürmer, R., & Zelinski, T. (2004, February 2). Industrial methods for the production of optically active intermediates. Wiley Online Library. Retrieved September 15, 2021, from <https://onlinelibrary.wiley.com/doi/full/10.1002/anie.200300599>.

TO: Prof. L.L. Martin

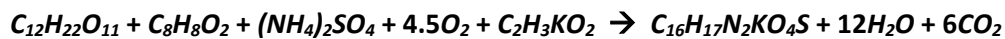
FROM: Tiarra Rodrigues, Katelynn Inman, Chiebuka Ejimadu, Caleb Myers

RE: Simulation Case Study for the Design of a Penicillin Production Plant

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 83 million pounds per year based on percentage of dependence on China's production.

In response to this high demand for penicillin, 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 17 million pounds of penicillin per year to various wholesalers and pharmaceutical companies in the U.S.

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:



It is important to note that phenylacetic acid ($C_8H_8O_2$) serves as a precursor and is fed to the reaction in lesser amounts.

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. Please have your team determine the optimal process design, including equipment sizes, structural alternatives and operating conditions that simultaneously maximizes the economic performance and minimize the environmental impact according to LCA principles.

A design basis is also attached to this problem statement. Our team will submit a simulation and a final report by the conclusion of this course.

What does this mean?

DESIGN BASIS

Plant Capacity

- Design Capacity: 17 million lb./yr.
- Design Operating time: 330 days/yr. (7920 hr./yr.)

low

Raw Materials

- Must provide:
 - An abundant growth of mycelium (a vegetation produced that is later recycled)
 - Maximum penicillin accumulation
 - Simply extraction and purification of the antibiotic
- Penicillin Chrysogenum (high yielding strain)
 - Necessary for antibiotic product
- Medium Materials
 - Nitrogen source - Ammonium Sulfate
 - Mineral sources
 - Oxygen
 - Carbon Source- Lactose
 - Precursor - Phenylacetic acid
- Extraction Process Materials
 - Potassium Source - Potassium Acetate
 - Acid source - Sulfuric acid
 - Solvent source - Butyl acetate
 - Activated Carbon

*no! provide
raw materials
and
conditions
of
availability*

Product Penicillin Specification

- Solid, Penicillin G K (99.5% pure)
 - Fine crystallization

ok

Utilities Available

- Heat Sterilization = 250°F, 30 psi (2.04 atm)
- Fermentation = 68°F-86°F, 15 psi (1.02 atm), pH = 6.5
- Cooling water = 77°F
- Cooler = 36°F
- Heater = 77°F

Pressure Drops for Process Streams

- Heat Sterilization = 30 psi (2.04 atm)
- Fermenter = 15 psi (1.02 atm)

Temperature Conditions

- Maximum Process Temperature = 250°F
- Minimum Process Temperature = 36°F
- Culture & Medium Ambient Temperatures = 77°F

No material balance due to laboratory-scale values. We have not completed the scale-up process based on the articles we utilized.

**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?

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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.

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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

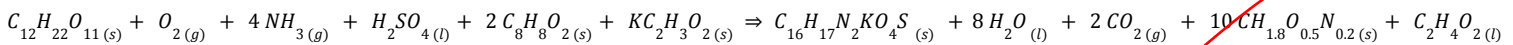
Competency Area		
7. Ability to engage in in life-long learning	Max for this Assignment	Your Score
<i>Effectively use library and online resources for research and are abreast with current developments relating to the project</i>		
(i) Identify the types of information needed for a complete understanding 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

Content is low
but it is poorly
organized and
unclear

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.

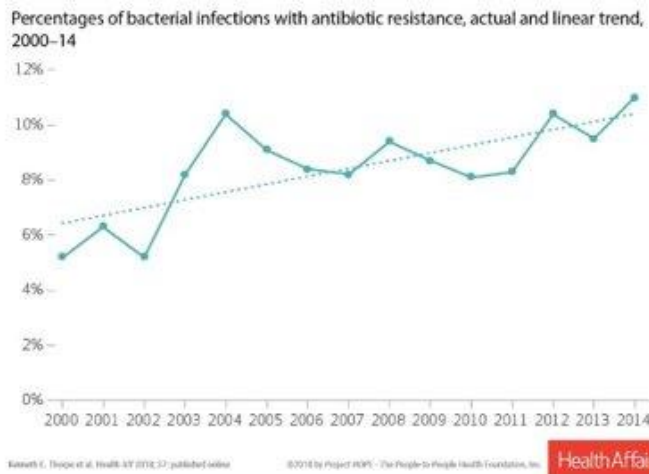


Figure 1a. Growth of bacterial infections with resistance to antibiotics from 2000-2014

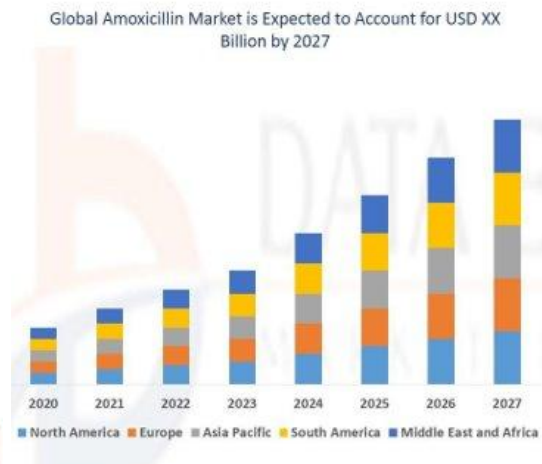


Figure 1b. Expected Growth of the Amoxicillin Market by 2027

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)

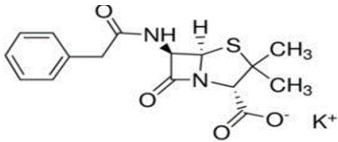
The production of Penicillin G is done through fermentation. All penicillin G is derived from the fermentation of a microorganism, *Penicillium chrysogenum*, with an addition of a precursor, phenylacetic acid. The fermentation process starts with a cell culture, a pure strain of *Penicillium chrysogenum*. 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.

Inclusion
of
Lact
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growth

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.

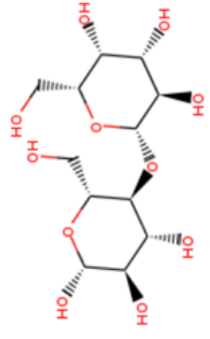
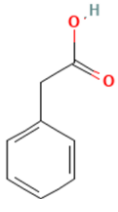
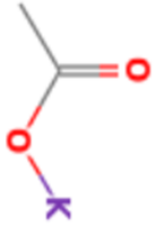
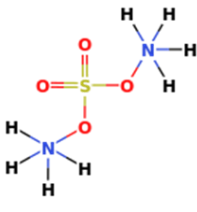
Accidental spills

- **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.

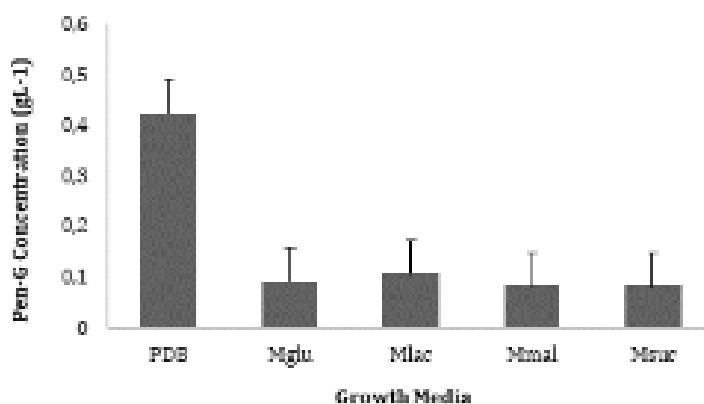


Figure 3. Penicillin G production from *Penicillium chrysogenum* in Various Mediums

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.

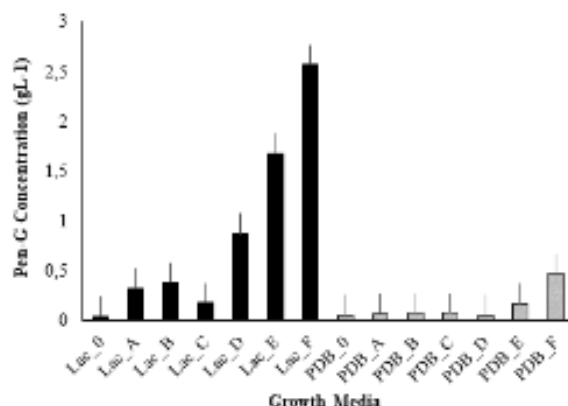


Figure 4. Penicillin Production from *Penicillium chrysogenum* with Various Concentrations of Phenylacetic Acid

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:

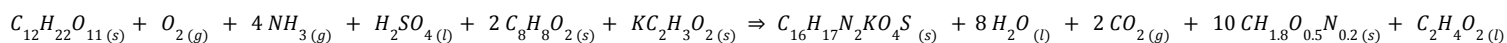


Table 5. Overall Reaction Component Cost

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:

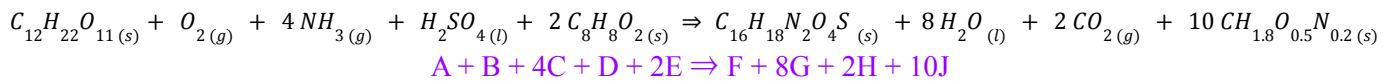
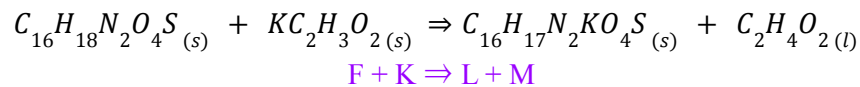
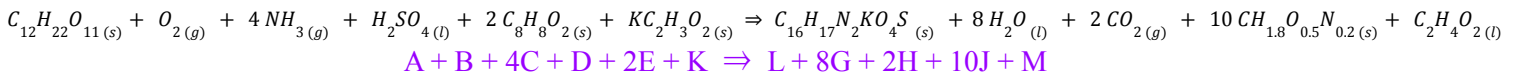
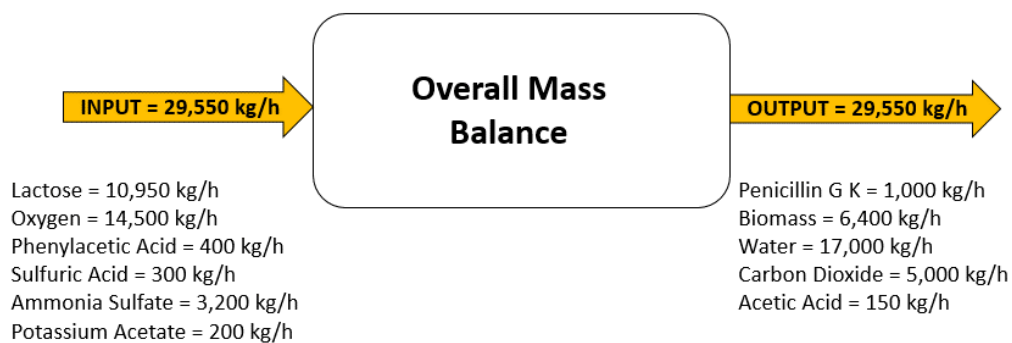
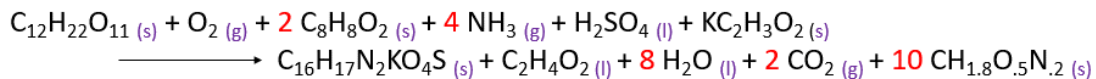
Reaction Mechanisms (BUKA)**Reaction 1: Fermentation****Reaction 2: Crystallization of Penicillin G Potassium****Overall Reaction:****Overall Mass Balance (Buka)**

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.

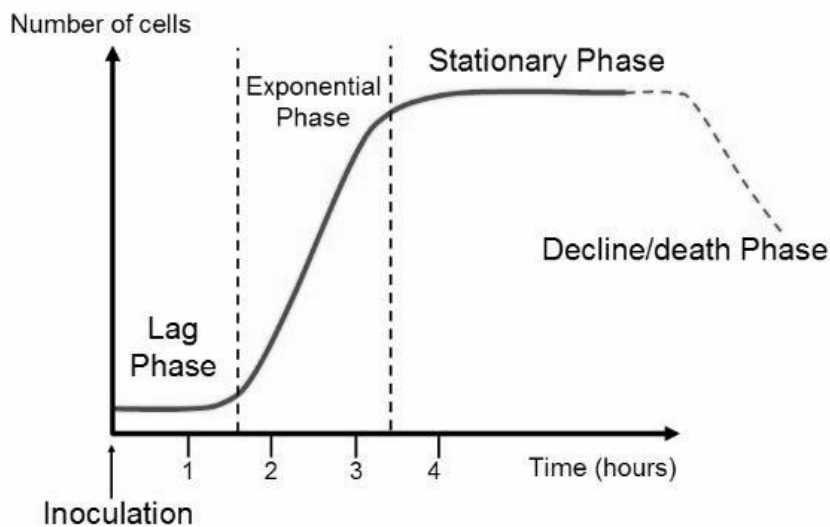
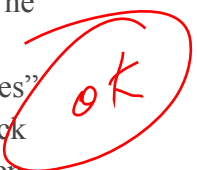


Figure 7. Phased Fungal Cell Growth Curve

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

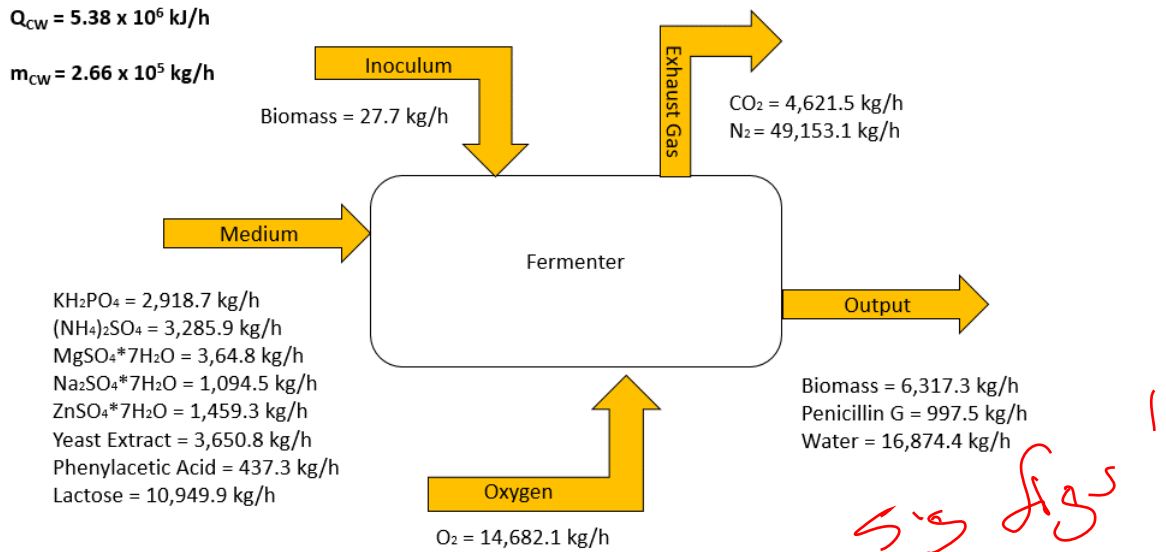


Figure 8. Material Balance across Fermenter

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:

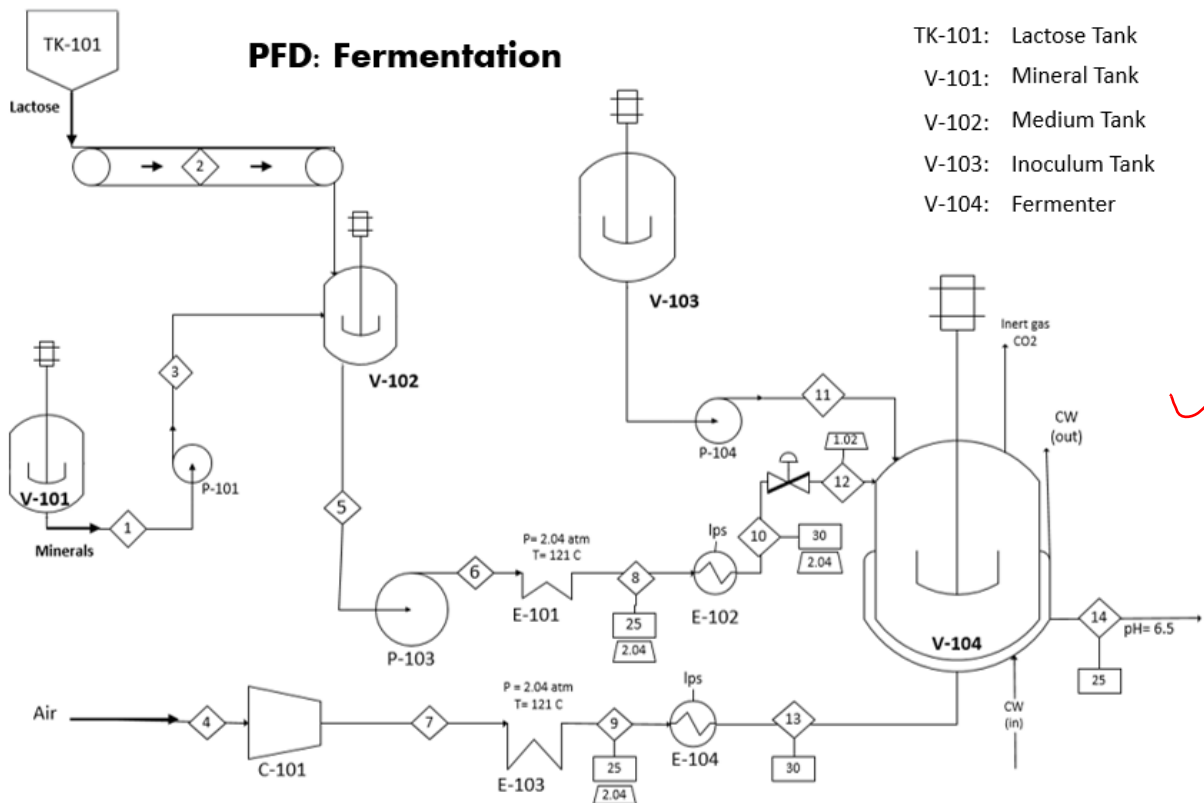


Figure 9. Process Flow Diagram of the Fermentation of *P. chrysogenum* to Produce Penicillin G

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:

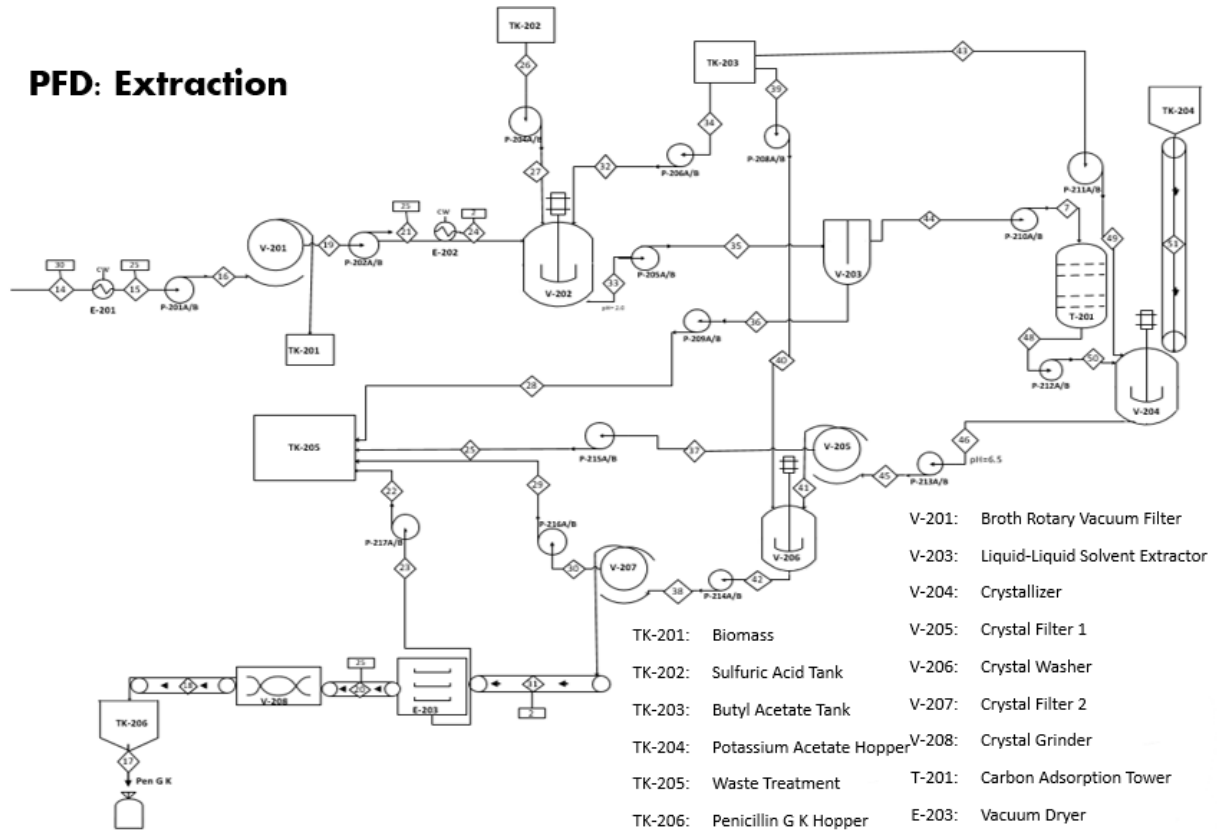


Figure 10. Process Flow Diagram of the Extraction of Penicillin G Potassium

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.

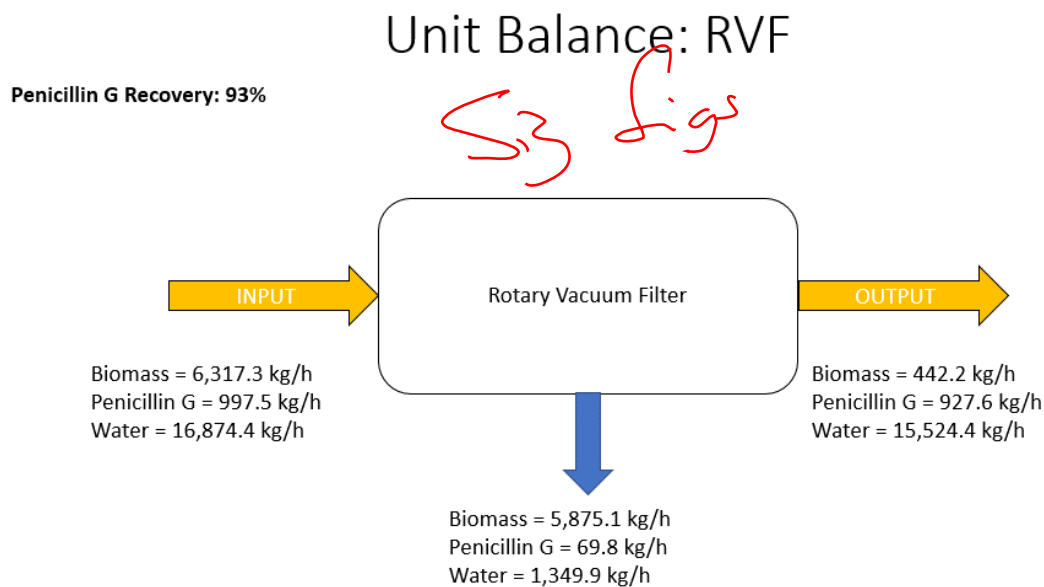


Figure 11. Material Balance across Broth Rotary Vacuum Filter

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%

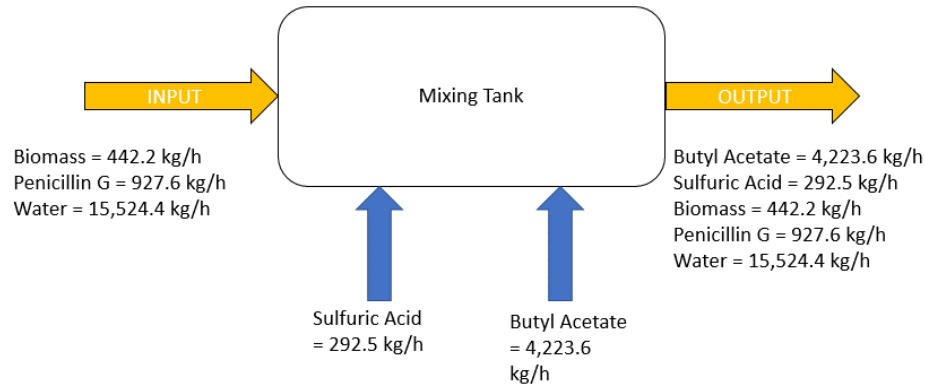


Figure 12. Mass Balance across Mixing Tank

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%

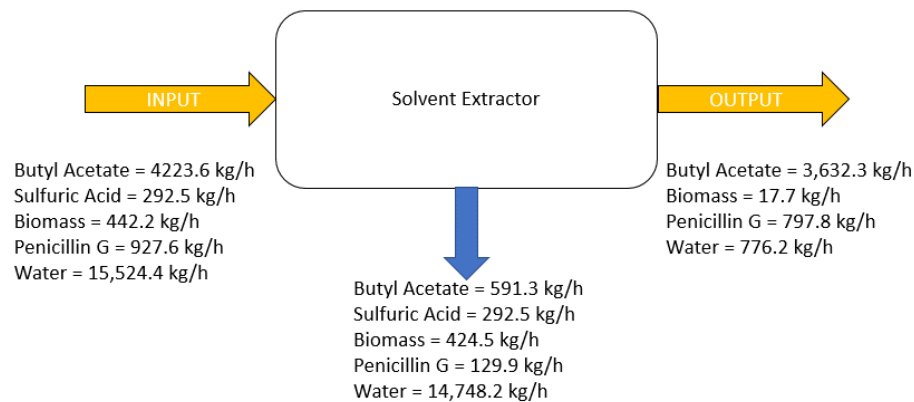


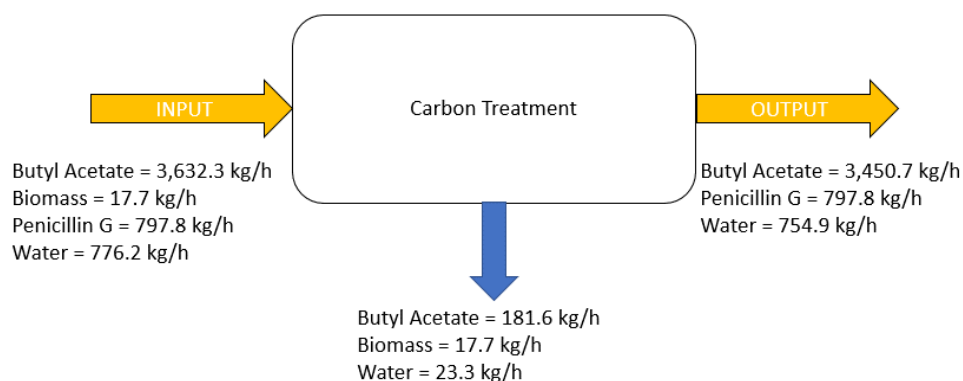
Figure 13. Mass Balance across Solvent Extractor

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%

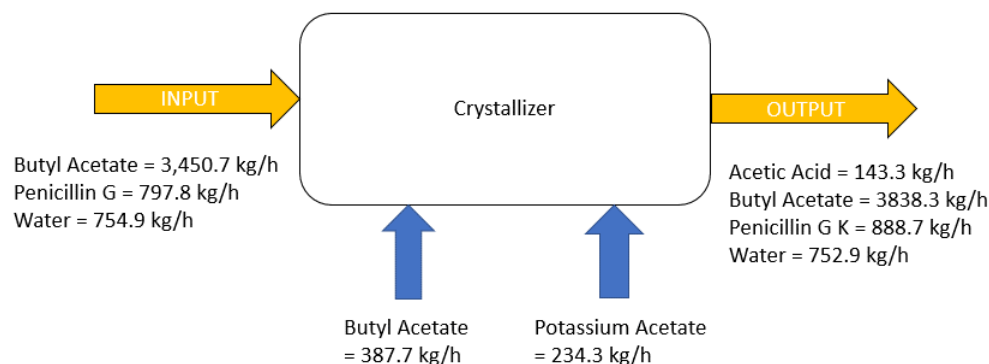


Figure 15. Material Balance across Crystallizer

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%

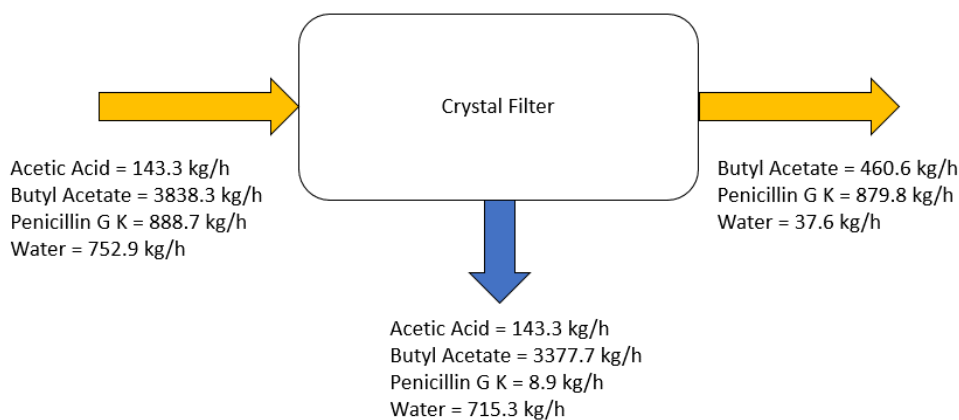


Figure 16. Material Balance across Crystal Rotary Vacuum Filter 1

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%

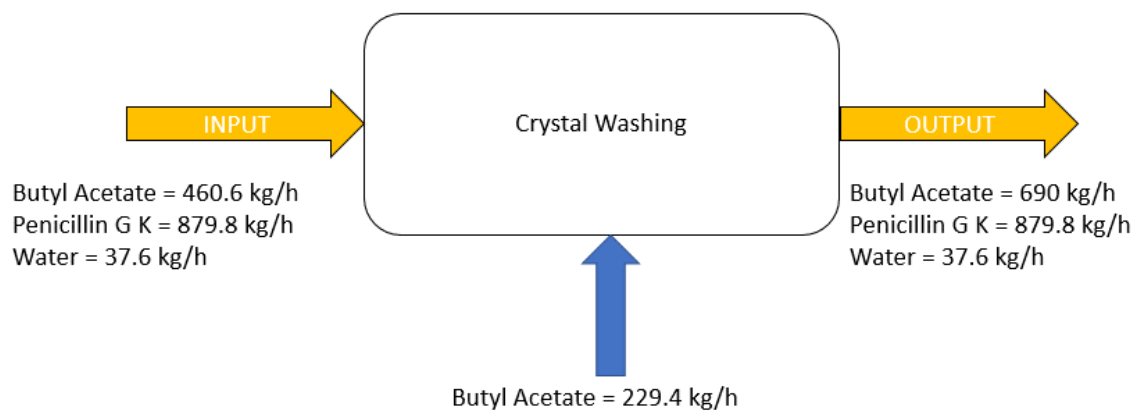


Figure 17. Material Balance across Crystal Washer

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%

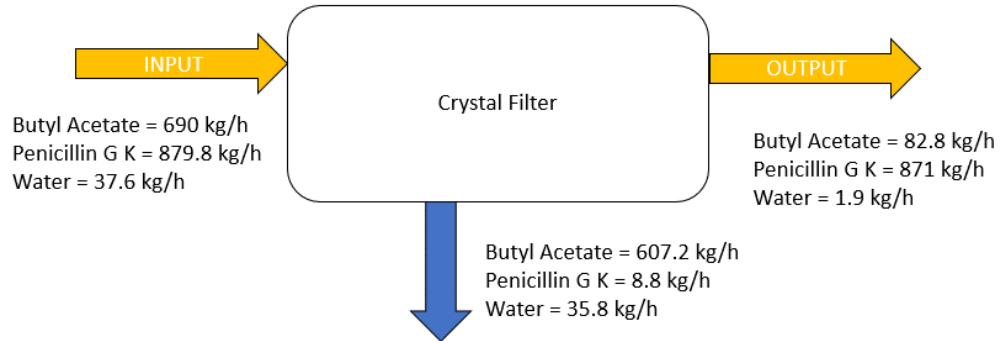


Figure 18. Material Balance across Crystal Rotary Vacuum Filter 2

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%

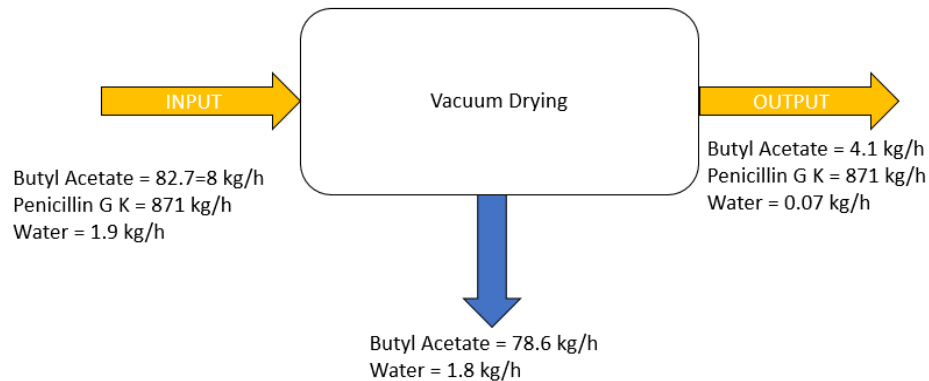


Figure 19. Material Balance across Vacuum Dryer

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

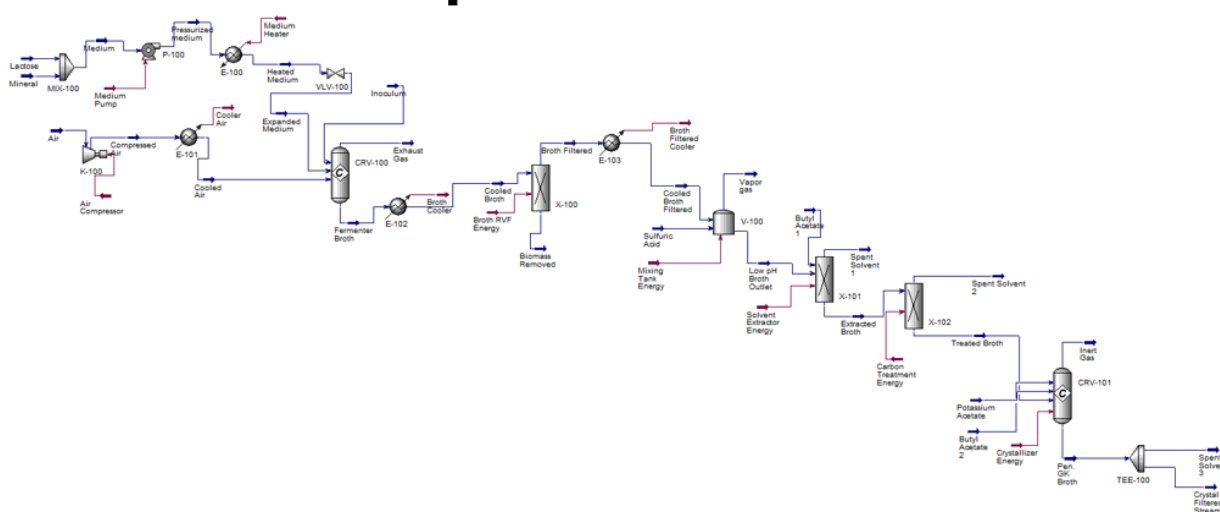


Figure 21. Aspen Simulation

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.

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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
scan for
by-product
Jean-Baptiste
Dumas

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.

- poorly written
missing key information

**SENIOR DESIGN AND PROFESSIONALISM I
FALL 2021**

HOMEWORK 4

TOPICS COVERED IN HOMEWORK 4

1. Ethics

CHEG 4472-P02: 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.

Name: _____

Title of Assignment: _____

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	
TOTAL	100	

ABOVE AVERAGE

CHEG 4247-P01: SENIOR DESIGN & PROFESSIONALISM I FALL 2021

ASSIGNMENT STATEMENT/QUESTIONS

Senior Design & Professionalism I (Fall 2021): Home Work 4 Due: November 16, 2021

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

Facts:

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?

1. Codes of Conduct Synopsis

The National Council of Examiners for Engineering and Surveying, or NCEES, has a code of professional conduct Which was revised in September 2021. The preamble states that these rules protect the health, safety, and wellbeing of the public in engineering professions. These rules shall be followed by every licensee and firm that is able to perform engineering or surveying services. This section contained three sections the first being Licensee's Obligation to the Public, next Licensee's Obligation to Employer and Clients, and last Licensee's Obligation to Other Licensee's.

The AIChE, the American Institute of Chemical Engineers, adopted a code of ethics that contained eleven rules its members must follow to achieve their goals. This code of conduct was approved by the board in November 2015. Their intro states that All members of the shall uphold integrity, honor, and dignity of the engineering profession. It then goes on the explain how the rules should be upheld by actions such as using their knowledge and skill for the enhancement of human welfare.

The NSPE, National Society of Professional Engineers, stated that their code of ethics. The Ethical review background states their standards were first drafted at the end of the nineteenth century. The current code of ethics was adopted in 1964 and has been revised to fit today's standards. It then goes on to the introduction, or preamble of the current code of ethics. This addresses member of the engineering profession. It states that engineering had a direct vital impact on the quality of life for all people, then states the standards an engineer shall act accordingly. This set of codes, like the NCEES, separated its code into three sections. The three sections were Fundamental Canons, which were some of the originals created in 1964, Rules of practice, and professional obligations.

The NCEES, AIChE, and the NSPE all start with the same rule, that being an engineer's responsibility for the protection of the public safety, health, and welfare when performing. Other regulations are written in these codes that they all share are:

- It is an engineer's responsibility to inform and advise their employer if they believe that their duties could possibly endanger the health, welfare, or safety of the public in the present or future.
- Only perform services that they are authorized to do. To give colleagues and coworkers credit for the engineering work they have done and recognize their interests, capabilities, and contributions.
- Always act in a professional matter for every employer, client, or contractor.
- Accept responsibility for professional activities, and seek and heed reviews of their work and offer objective criticism to others.

Along with those stated above, the codes of conduct for each of these organizations are similar in essence. They express ethical values that engineers should uphold. The professional codes of conduct not only help protect the public and the reputation of the profession but also help engineers avoid legal consequences. Following the codes lays the foundation for a minimal consequence in many situations that an engineer may face and allow him/her/them to obtain and build a positive reputation in the profession.

How are the codes different?

2. Ethics Case Study

It was not ethical for engineer C to offer to select Engineer A's firm on a future project for City X according to the NSPE Code of Ethics. Engineer A has expertise in mechanical and electrical engineering. According to NSPE Code of Ethics section 2, rule 2, part a, "Engineers shall undertake assignments only when qualified by education or experience in the specific technical fields involved." Engineer A is not qualified by education or experience to choose necessary treatment equipment. A better source would be An engineer with expertise in chemical engineering.

Reason 2 that the case study is not ethical is Engineer C verbally promised to select Engineer A's firm on a future engineering project for City X. According to NSPE Code of Ethics section 2, rule 5, part b, "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 to secure work. They shall not pay a commission, percentage, or brokerage fee to secure work, except to a bona fide employee or bona fide established commercial or marketing agencies retained by them." The correct way to choose an engineer for a project would be going through a bidding process. Each engineering firm would give estimates and plans for how they will carry out the project and the firm that best serves the project should be chosen.

Reason 3 that the case study is not ethical is because Engineer A's firm is retained on a speculative basis by Engineer B. Engineer B was chosen with no proof of work or reputability.

CHEMICAL ENGINEERING DEPARTMENT
SENIOR DESIGN & PROFESSIONALISM I CHEG 4247
GRADING SCHEME AND OUTCOME ASSESSMENT SHEET FOR FALL
2021

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.

Name: _Shumpert Kirksey, Meredith Meyer, Cherish Vaughn, Garred Essissima

Title of Assignment: _Homework #4: Ethics and Professionalism

Due Date: November 16, 2021

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	
TOTAL	100	93

AVERAGE

CHEG 4247-P01: SENIOR DESIGN & PROFESSIONALISM I

FALL 2021

ASSIGNMENT STATEMENT/QUESTIONS

Senior Design & Professionalism I (Fall 2021): Home Work 4 Due: November 16, 2021

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

Facts:

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 4247
GRADING SCHEME AND OUTCOME ASSESSMENT SHEET FOR FALL 2021

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.

Name: __Tyecia Franklin, Taylor Linton, Wasil Mahmood, Franck Nangomoko_____

Title of Assignment: _____

Due Date: November 16, 2021

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	
TOTAL	100	85

The AIChE code of ethics seems to be targeting the important aspects of developing your character as a chemical engineer. In the beginning of this document, the organization starts with stating that they "...shall uphold and advance the integrity, honor and dignity of the engineering profession..." which proves that they do not just want the ethics to be performed as if someone is just going with the flow. AIChE's code of ethics is based on personal development and safety of oneself and others. Although this code of conduct provides numerous ethics to follow as a chemical engineer, yet it does not thoroughly explain each point. Not being specific can lead to miscommunication between the employers and employees within the work environment.

Unlike the previous code of ethics for engineers, the National Society of Professional Engineers (NSPE) has written out the details about each ethic that should be performed. This code of ethics breaks down each section by the fundamental canons, rule of practices, and professional obligations. Beneath each ethical statement are at least two additional statements that are similar to the rule of practice or professional obligations. For example, the statement "2. Engineers shall perform services only in the areas of their competence" is a common ethics that organizations imply. In the NSPE code of ethics it provides additional ethical behaviors that pertain to the subject such as, "a. Engineers shall undertake assignments only when qualified by education or experience in the specific technical fields involved." Along with statement a, are two other ethical behaviors that carry on the behaviors of the second rule of practice.

The NCEES code stands for the National Council of Examiners for Engineering and Surveying. The purpose of the code is to convey the rules of professional conduct. These specific rules apply to all that hold a certificate of licensure to perform engineering services.

These rules are put in place to protect life, health, and property. It is imperative for licensees to adhere to the regulations and meet the standards of moral and ethical conduct. The NCEES is comprised of three sections, those sections are as follows: Licensee's obligation to society, Licensee's obligation to employer and clients and the Licensee's obligation to other licensees. Section one describes licensees' performance standards as it pertains to their community and all of society. They are obligated to hold themselves accountable for producing quality work that includes safety considerations. Section two involves the licensees quality of work that they provide to clients and employers. Section three describes licensees obligation to complete their own work honestly and provide other credit when it is necessary.

Overall, the code of conduct for AIChE, NSPE, and NCEES are all upholding their members to a high standard. Each of the above codes is unique to the specific group of people that it addresses. As stated the AIChE code of ethics specifically targets chemical engineers. The NSPE code of ethics targets all engineers. While the NCEES code of ethics can apply to anyone that holds a certificate of licensure to perform acts of engineering.

Very good!

Case Study

After taking an honest review of the case study, we concluded that it was unethical for Engineer C to select engineer A's firm on a future engineering project for city X. So, according to NSPE section (II.5.b), "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..." based on this, we can say that it will be unfair to other companies that are not only qualify but also supersede the requirements to receive the contract being offer to Engineer A's firm.

other actions?

BELOW AVERAGE

CHEG 4247-P01: SENIOR DESIGN & PROFESSIONALISM I

FALL 2021

ASSIGNMENT STATEMENT/QUESTIONS

Senior Design & Professionalism I (Fall 2021): Home Work 4 Due: November 16, 2021

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

Facts:

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 4247
GRADING SCHEME AND OUTCOME ASSESSMENT SHEET FOR FALL 2021

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.

Name: _____

Title of Assignment: _____

Due Date: November 16, 2021

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	
TOTAL	100	70

Established in 1934, the National Society of Professional Engineers (NSPE) has always put the interests of professionally licensed engineers first with a central goal of protecting engineers from unlicensed entities and creating a safe inclusive environment for all engineers. Their code of ethics reflects these same ideals to ensure not only those engineers are conducting honest business, but they're also ensuring the safety of the public. Deception is frowned upon within the organization, which is very reasonable, when conducting a business, being as transparent as possible with your consumers is the most ethical you can do, lying or leaving important details out that people should know only creates ignorance to the truth of the matter and could put others at risk. If you're working with another company but you choose to leave important information about certain measurements of chemicals you're working with, you're creating a viral situation that could hurt someone if they don't handle the substances properly due to the information you gave them. The inclusive side of the code of ethics outlaws the criticism or down talking of another engineer to further yourself throughout a company. This is just common courtesy, because if you must rely on making someone who's supposed to be your colleague look bad in order to make yourself look good to boost your stock with a company or to get a job, you're obviously not doing your job right to begin with and deserve you be in the position you're already.

Not sure I understood this

Not the NCEES provides proper examination to grant engineers their license to be able to conduct work legally and properly in that field. Conflicts of interests are outlawed meaning giving someone an engineering license because you know them or just because their family is an extreme violation of ethics and it's grounds for termination and depending on if a accident were to occur based off of that type licensing, jail time. Conflicts of interest are also not allowed in

NSPE and AIChE which is common sense given that the goals of the three are to be honest with how engineers are supposed to operate. For AIChE the main focus of the code of ethics for chemical engineers is to ensure the absolute safety of the public. Given what chemical engineers work with, they work in a field that not only puts them a risk, but general citizens at risk everyday which is why their jobs must be executed to perfection. Chemical leaks or explosions can affect the breathing and water conditions for hundreds of citizens if it isn't contained, a reason why chemical engineers receive high praise for what they do.

After reading the Case Study, engineer C was not acting in an ethical manner for verbally agreeing to select engineer A's firm for a future project. The agreement is only on the basis of an IOU for engineer A securing the grant for engineer B's company which goes down as a conflict of interest. Something like that would require an interviewing process to review the list of candidates that's suitable for the project, so the best output of production can be optimized. Quality over quantity is always valued at with anything, especially in terms of work conducted by engineers, if we had our buddies working important projects for us instead of a highly trained and renowned professional, the result would probably be terrible.

Where are your citations?

Also, there are at least 3 sections for unethical behavior

**SENIOR DESIGN AND PROFESSIONALISM I
FALL 2021**

FINAL PROJECT REPORT

- 1. Apply a systematic design process, incorporate engineering codes, standards, and realistic constraints that include economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political considerations in solving the design problem.**
- 2. Work in groups**

GROUP 4 DESIGN PROJECT

Project: Plant design for production of ethylene oxide

Problem Statement Summary

Design a grass-roots plant for production of ethylene oxide.

Option Sorting:

You will have to defend any decisions you make throughout the design, noting that the best defense is economic justification. You should begin your design effort with a comparative evaluation of published feasible reaction routes to ethylene oxide.

Your comparison between the various process technologies should be a screening but not a rigorous process optimization or design for each published process option or route. Feasible flow sheets for each process option are available in the literature. Some important considerations for these process options include:

- ✓ Availability and cost of raw materials
- ✓ Reaction selectivity: A process with low selectivity will require additional purification and storage units for byproducts, or some means of recycling them. The market values of the byproducts are also very important; some streams may have no salable value and require disposal
- ✓ Reaction yield: A process with low yield will have large recycle streams, requiring larger and higher operating costs for the reaction and crude separation sections
- ✓ Thermodynamic barriers to separating key components: Separating components that form azeotropes and distillation pinches at moderate conditions may require more complicated processes or operation at more extreme conditions
- ✓ Safety and operability

PROCESS DESIGN:

Once you have considered the process options, proceed and select, with justification, your best option for the detailed process design.

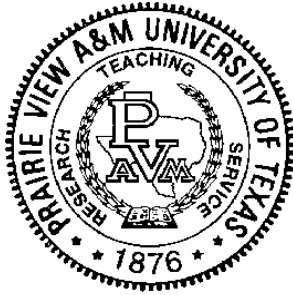
Scope of design work and deliverables

- Set up a HYSYS model of the process and prepare the material and heat balances, using an appropriate thermodynamic fluid property package
- Prepare a complete simulation report of the process
- Assume 80% polytropic efficiency for compressors and the 75% HYSYS default adiabatic efficiency for the pumps
- Assume 5 psi pressure drop for coolers, and for shell and tube heat exchangers such as the water cooler, use 5 psi for both the shell and tube sides
- Prepare material and energy balances of the preferred complete process
- Prepare a complete simulation report of the preferred process
- Provide a process description and prepare a Process Flow Diagram (PFD) for the plant showing the major items of equipment, and indicating the materials of construction and the operating temperatures and pressures
- Prepare a chemical engineering design of any (i) reactor(s), (ii) absorption column(s) and (iii) product distillation units
- Prepare a mechanical engineering design of the reactor(s) with appropriate dimensioned sketch(es)
- Estimate the Major Equipment Capital Cost (Capex)
- Estimate Operating Cost (Opex)
 - Select, with justification, an appropriate operating period of days in a year the plant will be on stream

- Use \$0.05/gal to estimate the annual water cost for cooling water
- For prices of steam and power contact your local utility company, but in the absence of such data from the local company, use data presented in Appendix B of “Plant Design and Economics for Chemical Engineers” by Peters, M.S., K.D. Timmerhaus and R.E. West. The annual power cost estimate should be obtained either as indicated above or based on the value \$0.05/Kwh, whichever is lower. All prices should be escalated with inflation over the life of the project.
- Estimate the Major Equipment Capital Cost (Capex)
- Estimate Operating Cost (Opex)
 - Assume an operating period of 8000 hours on stream
 - Use \$0.05/gal to estimate the annual water cost for cooling water
 - For prices of steam and power contact your local utility company, but in the absence of such data from the local company, use data presented in Appendix B of “Plant Design and Economics for Chemical Engineers” by Peters, M.S., K.D. Timmerhaus and R.E. West. The annual power cost estimate should be obtained either as indicated above or based on the value \$0.05/Kwh, whichever is lower. All prices should be escalated with inflation over the life of the project.
- Prepare a net present value and investor’s rate of return analysis for this investment over the life of the plant. Assume your company’s current capital hurdle rate is 15%.
- Prepare a project milestone schedule
- Prepare a control scheme to ensure safe operation of reactor(s) and absorption units
- Prepare a safety report: Indicate the safety measures required for the plant bearing in mind any toxic and flammable materials handled
- Recommendations

References:

1. Turton R, Bailie RC, Whiting WB, Shaeiwitz , “Analysis, synthesis and design of Chemical Processes”, 2nd edition, Prentice-Hall, Upper Saddle River, NJ, (2003)
2. Felder, RM, Rousseau RW, “Elementary Principles of Chemical Processes”, 3rd edition, Wiley, New York, (2000)
3. Park DW and Gau G (1987) Ethylene epoxidation on a silver catalyst: unsteady and steady state kinetics. Journal of Catalysis 105: 81 – 94
4. Kirk-Othmer Encyclopedia of Chemical Technology, 1991
5. Ullman’s Encyclopedia of Industrial Chemistry, 1994, vol A10 5th edition, pp 117 – 135
6. Chemical Market Reporter: Biweekly newspaper providing up-to-date prices on many chemicals



College of Engineering

Senior Design Project Manual

**Prairie View A&M University
Prairie View, Texas 77446**

Last Revision: 11/20/09

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1. INTRODUCTION TO SENIOR DESIGN PROJECT

Senior Design Project is used to prepare students for professional practice through realistic application of mathematics, science and engineering to an open-ended major design problem in which students are required to design a system, component, or process to meet desired needs.

1.1 Importance of Senior Design

This course is important because it provides the student, an opportunity to practice design in a way that parallels what will be encountered in professional practice. Students are required to apply a systematic design process, incorporate engineering codes, standards, and realistic constraints that include economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political considerations in solving the design problem. In addition, Senior Design Project is the primary course used to satisfy ABET criterion 4 which requires students to be prepared for engineering practice through the curriculum culminating in a major design experience. The latter should be based on the knowledge and skills acquired in earlier course work and should incorporate appropriate engineering standards and multiple realistic constraints. Senior design is also used to satisfy outcome C of criterion 3. This outcome requires students to have the ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.

1.2 Purpose of Manual

The purpose of this manual is to inform students and faculty the importance of Senior Design Project and to clearly present the level of details required in the preparation and presentation of homework assignments, design, analysis, experimentation, presentations, intermediate reports, final oral presentation and final project report that may be required.

2. CAPSTONE DESIGN & DESIGN METHODOLOGY

The ABET accreditation criteria include a requirement that the various elements of each engineering curriculum be brought together in one or more capstone engineering design courses built around comprehensive, open-ended problems having a variety of acceptable solutions and requiring some economic analysis.

Teaching engineering design as a means of preparing students for the practice of engineering has been a tradition of all departments in the College of Engineering at Prairie View A&M University. The curricula have been designed to expose students to the process of engineering design, to integrate design activities throughout the curriculum, and culminate in a year of two-semester senior capstone design course sequence.

The open-ended engineering design projects used for the capstone design experience engage teams of students, drawing on their component-based design experiences, to solve contemporary, real world engineering design problems with exposure to the applicable social, global, environmental, safety and economic issues while demonstrating their oral and written communication skills.

Each team is required to submit a written technical report and to make a public presentation of its design solution. Typically, the projects selected involve corporate representatives as project consultants. Evaluation of the teams' products typically involves both corporate representatives and departmental faculty. The capstone design courses provide a broad, general engineering design experience as well as an in-depth design experience within the each relevant discipline.

3. REQUIREMENTS FOR SELECTION OF PROJECTS

The Senior Design and Professionalism courses are intended to provide capstone design experience. The Senior Design courses draw on the students' skills and knowledge gained from previous years of coursework's in mathematics, sciences, engineering science and design. The senior design project should be sufficient in scope and technical content to demonstrate the students' technical competence in their major area of study. The successful completion of senior design project is indicative of the students' preparedness to pursue professional practice of engineering.

The following guidelines are provided to help faculty and project sponsors identify suitable senior project topics:

- The project should emphasize design, experimentation and/or hands-on skills.
- The project should offer opportunity for creativity.
- The project should allow teamwork among seniors in one or more majors.
- The project should be of sufficient complexity to allow each team member to contribute about 150 hours in class time and 150 hours outside class.
- The project should draw on the students' skills and knowledge gained from previous years of coursework.
- The project should incorporate engineering standards and realistic constraints that include most of the following: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political.
- The project schedule should be limited to eight months (Early September to End of April)
- The project should have concrete and measurable goals.

Projects involving only collection of published materials are unacceptable and projects involving classified materials should be avoided.

4. TEAM FORMATION AND MANAGEMENT

4.1 Team Formation

The instructors will form the teams. Self-selection of teams by students is not used to avoid students teaming with friends and roommates. Research indicates that instructor-formed teams perform better than self-selected teams [1].

Group sizes of 3-4 will be the goal, as this number of members work best. Two is too small because there is not enough diversity of ideas and more than four leads to some members of the group not actively participating. Also, groups larger than four become harder to coordinate and increase non-linearly the possible lines of internal communication.

Groups are intended to be heterogeneous with a mix of ability levels, experiences and skills. However, certain considerations for under represented populations, e.g., women in engineering, on a team to avoid situations where such students will feel outnumbered and then become passive on the project, as research indicates can occur.

The teams will remain intact throughout the capstone experience; certainly for the whole semester and, to the extent practicable, across both semesters.

4.2 Team Contract

Individual behavior as members of a team can raise problems and is often the greatest barrier to team success. For example, differing expectations about communication and meeting attendance can cause a team to miss key deliverables. Therefore, teams will operate under a team contract. Each team will formulate their own contract on team behavior that they will follow for the rest of the project. The instructors will provide resources with good ideas that the students must process to formulate their own contract (however, a sample contract will not be handed out). The process fosters shared ownership by the team.

4.3 Team Roles

Being familiar with team sports we know that individual players have specific roles. In American football, for example, the quarterback throws the ball—while blockers hold off rushing opponents—and a receiver catches it; and if a player fails in his or her role, the whole team suffers. The same principle applies with engineering teams, whether in industry or with student teams. Either way, it is important to learn that team roles are necessary for successful teams.

The instructor will assign different roles to team members, e.g., coordinator or leader, recorder/note taker, timekeeper, devil's advocate and consultant. Various sets of roles are possible, and students are encouraged to propose their own set of roles, with their project in mind. Teams will be encouraged to rotate the roles periodically or for particular assignments.

4.4 Team Management – The Five Tenets of Cooperative Learning

Cooperative learning is an instructor-designed framework for instruction that involves students working in teams to accomplish an assigned task (such as a problem solution or product design) and to produce a final product (such as a prototype or a design report), under particular conditions. The framework includes the following elements:

- *Positive interdependence.* Team members have to rely on one another to achieve the goal. If any team members fail to do their part, everyone on the team suffers adverse consequences.

- *Individual accountability.* Each team member is held accountable both for doing his or her share of the work and for understanding everything in the final product (not just the parts for which he or she was primarily responsible).
- *Face-to-face promotive interaction.* Although some of the group work may be done individually, the nature of the assignment/task is such that some work must be done interactively, with team members providing mutual feedback and guidance, challenging one another, and working toward consensus.
- *Appropriate use of teamwork skills.* Students are helped to develop and exercise leadership, communication, conflict management, and decision-making skills.
- *Regular self-assessment of team functioning.* Each team must set goals, periodically assess how well the team members are working together, and identify changes they will make to function effectively in the future [1].”

Following the above *five tenets*, which provide a good training ground for teamwork, students may expect to see assignments for individuals as well as teams, and be expected to critically evaluate the performance of their team, teammates, as well as themselves.

Information in this section was derived in part from portions of the *Practical Guide to Teamwork* [2]. Students are strongly encouraged to read this guide and use it to maintain excellent team functioning.

5. MAIN PARTS OF REPORTS

The senior project report is the main document that tells the whole story about the project. It should be detailed and well organized enough for a technical reader with no knowledge of the project to completely understand the design presented in the report. To ensure that the important details are included, the report should, in the least, contain the parts listed in this section, and in the order provided here. The initial part of the report should have the following:

- Title Page
- Letter of Transmittal
- Acknowledgements
- Project Summary or Abstracts
- Table of Contents
- List of Figures
- List of Table

The main body of the report should have the following major sections

- PROJECT SCOPE
- PROJECT PLANNING AND TASK DEFINITION
- LITERATURE REVIEW
- PRELIMINARY DESIGN
- DETAILED SYSTEM DESIGN
- RESULTS & DISCUSSION
- CONCLUSIONS
- RECOMMENDATIONS
- List of References
- Appendix

The details of the format and content of each part are provided in section 6 of this manual.

6. DETAILS AND FORMAT FOR PARTS OF REPORT

The details and the formats needed for the parts of the report listed in section 5 are provided in this section. Students are advised to strictly adhere to the information provided here in preparing the project reports. The following format should be used for all formal project reports. Project reports should be neat and accurate.

In general, a report is written in **the past tense and in the third person**. It should be impersonal throughout, personal pronouns (I, You, We) being avoided. The report should be written to enable a reader (who has a general science or engineering background) with no prior knowledge of the project to fully understand what has been designed. The report must be complete in itself. A good report is thorough, concise, orderly, neat, and grammatically correct.

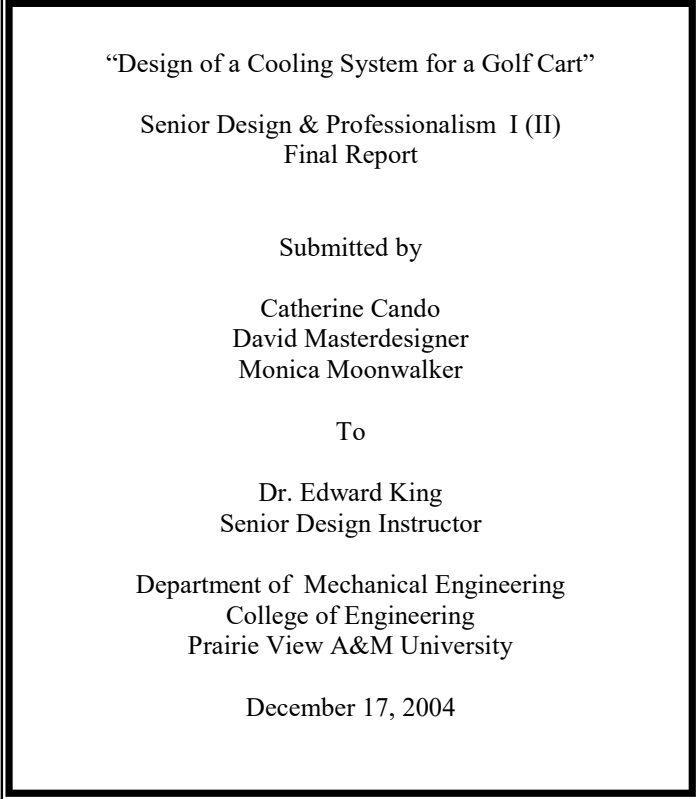
6.1 General Report Specifications

In order to observe the accepted rules of good writing form, the following specifications for the general makeup of the project report should be strictly used.

1. The report should be written in chapters as done in this document. The chapter headings should be capitalized, bolded, and of font size 14. The chapter headings should be centered unless when it covers more than one line in which case it should be left justified. The chapter heading should be preceded by the chapter number as demonstrated in this document.
2. The first letters of major headings should be capitalized except conjunctions, be of font size 11 or 12, bolded, and preceded by the subsection number, the first of which is the chapter number followed by a decimal point, followed by the major section sub-number, as demonstrated in this document
3. Use 8½ x 11 inch white paper.
2. Write the report with a word processor such as MS Word, Word Perfect
3. All equations should be typed using any equation editing feature within the word processor.
4. Use one side of the paper only.
5. Create all drawings and figures using computer drawing package and plotting programs. Scanned images are allowed where appropriate.
6. Use the same font style (Times New Roman recommended) in the report and on drawings. The recommended font size is 11 or 12 points for all text except chapter headings.
7. Use 1" margin on all sides (preferably, 1.5" margin on the left side)

6.2 The Title Page

The title page contains important information about the project including the name of your organization, title of the project, names of members producing the report, name of receiving person and organization, and date of submission. The format should follow that shown in Figure 6.1.



The figure shows a sample title page enclosed in a double-line rectangular border. The text is centered and reads as follows:

“Design of a Cooling System for a Golf Cart”

Senior Design & Professionalism I (II)
Final Report

Submitted by

Catherine Cando
David Masterdesigner
Monica Moonwalker

To

Dr. Edward King
Senior Design Instructor

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

December 17, 2004

Figure 6.1 Sample Details and Format for a Title Page

6.3 Letter of Transmittal

This is a cover letter used to officially inform the recipient (your boss, client, customer) of the completion of the project, and about the accompanying report. Within the company, it is usually a memorandum. In either case, it introduces the report to the person or group for whom it is intended. It may refer to a request or a contract that initiated the study but should not attempt to summarize the contents of the report. The letter of transmittal should be signed. A sample letter of transmittal is shown in the Appendix.

6.4 Table of Contents

The project report should have a Table of content page that lists all chapters and sections of the report, comparable to the table of content page you would normally see in a book.

In any event, be sure that the titles used in the table of content page match those in the text exactly and the page numbers indicated for each section match those in the report. A sample table of contents page is provided in Figure 6.2 All the major sections included in Figure 6.2 should appear in the Table of contents of all senior project reports. In addition to these major sections, each project should have appropriate sub-sections under Literature Review, Preliminary Design and the Detailed Design sections of the report.

TABLE OF CONTENTS

Letter of Transmittal	ii
Acknowledgement.....	iii
Project Summary or Abstracts.....	iv
Table of Contents	v
List of Figures	vi
List of Table	vii
1. PROJECT SCOPE	1
1.1 Problem Statement	1
1.2 Client identification and recognition of need	3
1.3 Project goals and objectives	3
1.4 Contemporary issues relevant to project	3
1.5 Potential impact of project on society (global, national ,local).	3
1.6 Initial Project constraints	4
2. PROJECT PLANNING AND TASK DEFINITION....	5
2.1 Task identification.....	8
2.2 Timeline	10
2.3 Gantt Chart	12
3. LITERATURE REVIEW	13
(Provide sub-sections based on project)	
4. PRELIMINARY DESIGN	25
4.1 Concept Generation	25
4.2 Concept Evaluation and selection	28
4.3 Design Constraints and Applicable Codes and Standards Used in the Design.....	30
4.4 Preliminary Analysis	33
(Provide additional sub-sections based on project)	
5. DETAILED SYSTEM DESIGN	40
5.1 (Provide sub-sections based on project)	40
5.4 Engineering Analysis and Simulation	47
5.5. Layout/Detailed Drawings/Equipment selection and specifications	48
5.6 Application of Engineering Codes and Standards in design .	49
5.7 Economic Analysis	55
6. RESULTS & DISCUSSION	60
6.1 Summary of Goals and Objectives	
6.2 Summary of Constraints and Codes met by Design (Provide additional sub-sections)	
7. CONCLUSIONS AND RECOMMENDATIONS.....	70
LIST OF REFERENCES	75
APPENDIX	85

Figure 6.2 Sample Details, Required Content and Format for Table of Content

6.5 List of Figures and List of Tables

The list of figures is a page that lists the titles of all figures exactly as used in the report and the page numbers for the format for the figures. A similar list is made for all the tables in the report. A sample list of Figures is given in Figure 6.3. The list of Tables is similar to the list of figures in format.

Each figure or table should be placed immediately after the page of first reference. This means that each figure or table included in the report should be referenced and described in the report. In addition, each figure should have a figure number, followed by two spaces, then the title of the figure (which should be centered) and placed one line space BELOW the figure as shown in Figure 6.4.

Each table should have a table number, followed by two spaces, then the title of the table (which should be centered) placed one line space ABOVE the table as shown in Figure 6.5.

If a figure or table does not have a number, title, and not cited and described in the report, then there is no need for that figure or table to be in the report.

6.6 Abstracts

This summarizes the report, including results, in one page so that readers can decide whether they want to read the report in detail. The abstract should contain a summary of the following:

- a brief statement of the problem
- the project definition, goals and objectives
- the method of solution within the stated constraints;
- the significant results; and
- the conclusions drawn from the results.

The abstract is placed on a separate page, single-spaced with no indentions.

LIST OF FIGURES	
Figure 1.1 Gantt Chart for Project	22
Figure 1.2 Effects of Temperature on the Cooling Load.....	30
Figure 2.1 Pump Characteristic Curve used for Pump Selection.....	35
Figure 3.1 Effects of Heat Transfer Coefficient on Heat Exchanger Area Required	38

Figure 6.3 Sample Details and Format for List of Figures and Tables



Figure 2.13 Helium Mass Spectrometer Sample Holder

Figure 6.4 Sample Format for Labeling a Figure in Reports

Table 3.3. Baseline Mechanical Property for T650-35/HPPE-II-52 Material

Material Type	Stress (MPa)	Strain (%)	Modulus (MPa)	Max load (KN)
KC-X-80A-1	868.68	1.102	73049.04	28.807
KC-X-80A-2	852.92	1.116	79838.61	27.541
KC-X-80A-3	907.22	0.830	84347.52	29.382
KC-X-80A-4	958.67	0.907	97627.90	31.111
KC-X-80A-5	920.62	1.075	87055.10	29.816
Mean	901.62	1.006	84383.64	29.331
S. D.	42.1	0.129	9106.02	1.312

Figure 6.5 Sample Format for Labeling a Table in Reports

6.7 The Main Body of the Report

The main body of the report contains the introduction, project planning and task definition, the literature survey, the preliminary design, the detailed design, the conclusion and the recommendations.

This section should be written using active voice. The use of first person pronouns should be avoided, and correct grammar should be used. The detailed content of each section of the main body of the report are provided in Figure 6.2. It is required that each sub-section shown in Figure 6.2 be included in the report.

6.8 Literature Review

In the literature review section, you are required to find out what has been done by others in related areas of the project. To do a good literature review, it is necessary to have a complete understanding of the problem as described under the project scope. Material discussed in the literature review should be directly related to the project, provide advantages and disadvantages of various theoretical and practical concepts applicable to solving the problem.

6.9 Citation of References in a Report

When information is obtained from an external source and used in the report, it should be cited or referenced in the report to give credit to the original authors of the information and to enable readers of your report to directly access the source of the information.

There are several standards available for in text citation and listing references in a report including the American Psychological Association (APA), the Modern Language Association of America (MLA), and the Council of Biology Editors (CBE) standards. The method recommended for use in all project reports is the Council of Biology Editors (CBE) number system, in order of first mention. In this system the reference immediately follows the material that needs to be cited in the text using a reference number in square brackets. The first source cited will be [1], the second source will be [2] and so on as shown in the example in Figure 6.6. In the case of two citations, the numbers should be separated by a comma [1,2]. In the case of more than two reference citations, the numbers should be separated by a dash [5-7].

Each report should have references cited in the report and a complete list of such references should be listed at the section of the report titled “LIST OF REFERENCES” . Providing a list of references at the end of the report means the references have been cited by name and number in the report. All references should be cited in the report followed by the reference number in square brackets. Citations should always follow the example given in the sample in Figure 6.6.

In calculating the heat transfer coefficient, equations obtained from Chapman [1] were used. The manufacturer [2] has provided heat transfer coefficient for various shell side fluids as shown in Figure 1.1.

Figure 6.6 Method for citing and referencing a Reference source in Reports

6.10 List of References.

References cited in the report should be listed together at the end of the report in a section titled “List of References.” Footnotes should not be used for this purpose. References should be arranged in numerical order according to their order of appearance within the report.

The detailed format and examples for listing references from different sources are provided below.

6.10.1 Books.

The citation-sequence system shown below should be used to list book references.

Reference number in square brackets, followed by last name, first and middle initials, of each author separated by commas, followed by the title of the book (in italics or underline), followed by the name of the publisher, city of publication, the year of publication, and the inclusive pages preceded by pp.

Example

- [1] White, F.M., *Fluid Mechanics*, McGraw-Hill, New York, 1999, pp 120-135

6.10.2 Magazine and Journal Articles

The citation-sequence system shown below should be used to list magazine and Journal article references. Reference number in square brackets, followed by last name, first and middle initials, of each author separated by commas, followed by the title of the article in quotation marks, followed by the title of the Magazine or Journal (in italics or underline), followed by the volume number if available, followed by the date of issue of the magazine or journal the article occurs in, and the inclusive pages preceded by pp. If there are more than three authors, use the first one (last name first), followed by "et al.," which means "and others."

Example

- [15] Biney, P.O, Dong, W.G., and Lienhard, J.H., "The use of a cubic equation to predict surface tension and spinodal limits," *Journal of Heat Transfer*, 108, 1986, pp405-410.

6.10.3 Reports.

The citation-sequence system shown below should be used to list report references.

Reference number in square brackets, followed by last name, first and middle initials, of each author separated by commas or the group name, followed by the title of the report (in italics or underline), followed by report number, followed by the name of the publisher or publishing organization, followed by the date of publication of the report, and the inclusive pages preceded by pp.

Example:

- [11] Biney, P.O., *Effects of Service Conditions on the Morphology and Properties of Advanced Composites for Cryogenic Tank Applications*, NASA FAR NCC3-972-2004, PVAMU FAST Center, 2004, pp 25-30.

6.10.4 Personal interviews, correspondence, and other nonprint sources.

The citation-sequence system shown below should be used to list personal interviews, correspondence, and nonprint source references.

Reference number in square brackets, followed by last name, first and middle initials, the person interviewed or the information source, followed by the title and organization of the person interviewed, followed by location of the interview, followed by the type of information (personal interview, personal correspondence, etc.), followed by the date of interview.

Example

- [32] Lin. S.B., Department Head, Mechanical Engineering Department (PVAMU), Prairie View, Texas, personal interview, January 15, 2005.

6.10.5 Encyclopedia articles.

The citation-sequence system shown below should be used to list encyclopedia references.

Reference number in square brackets, followed by last name, first and middle initials of the article's author if shown, followed the title of the article in quotes followed by the name of the encyclopedia, then the date of the edition.

Example

[14] Kazumi, A.M., "Fusion Reactors," Encyclopedia Britannica, 1998 ed.

6.10.6 Product brochures.

The citation-sequence system shown below should be used to list product brochure references. Reference number in square brackets, followed by name of author or company, followed by the title of the brochure information, (in *italics* or underline), followed the type of brochure, followed by the name of publisher, city, and date of publication

Example

[22] PVAMU FAST Center, *Permeability Measurement System*, Research Equipment Brochure, PVAMU FAST Center, Prairie View, 2002.

6.10.7 Borrowed graphics and tables.

The source of the borrowed graphics or Table is indicated in the title of the Figure or the Table as shown in the example in Figure 6.7, and the reference is listed according to the source type described earlier.

Example

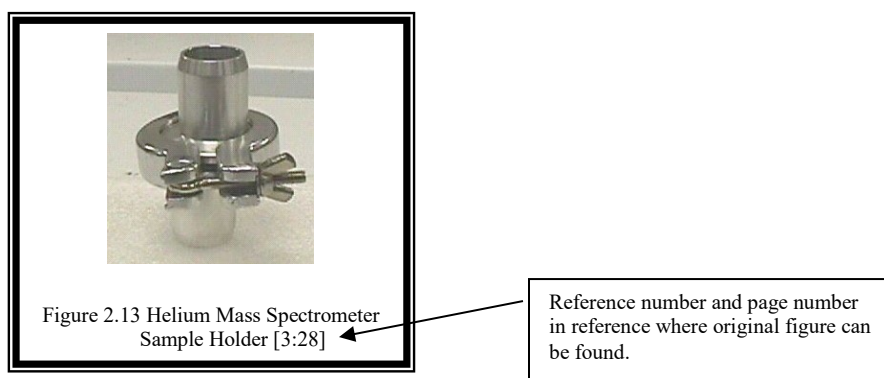


Figure 6.7 Sample Reference for a Borrowed Graphic

6.10.8 WWW Sites (World Wide Web)

Author's name, last name first; the full title of the work (capitalizing only the first word and any proper nouns in quotation marks); the date of the document or last revision in parenthesis. The protocol (e.g., "http") and the full URL, followed by the date of access in parentheses.

Example:

[9] McMurrey, David A; "Documentation: Citing Sources of Borrowed Information", <http://www.io.com/~hcexres/tcm1603/achtml/docu.html#numbersystem> (January 10, 2005)

Students are encouraged to consult David A. McMurrey article on Citing Sources of Borrowed Information [3].

Evaluation of the written communication component of the project report will be based on ability to organize, plan, and properly format a technical report; ability to compose original texts and properly apply the conventions of written language; and ability to provide appropriate discussion, conclusions and recommendations. The form shown in Table 8.2 provides the details of all items used for evaluating students' performance on the written communication under three performance criteria.

Table 8.2 Written Communication Evaluation Form

Outcome Performance Criteria Areas Assessed	MAX POINTS	POINTS RECEIVED
1. Ability to organize, plan and properly format a written technical report		
(i) Students are able to organize report by categorizing ideas for the report into well and logically organized chapters, major sections, subsections and paragraphs blended within the larger units.		
(ii) Students provide Title Page, Abstract, and Table of Contents, list of Figures, and List of Table formatted.		
(iii) Students provide figure number and title for each figure in the report, reference each figure discuss each figure in the report in accord with standards in the project manual.		
(iv) Students provide table number and title for each table in the report in accord with standards in the project manual, reference each table, and completely discuss each table in the report.		
(v) Students properly cite references in the report and provide well formatted reference list at the end.		
(vi) Students prepare the written report in accord with standard report formatting provided in the Senior Projects Report Manual.		
Total for PC1		
2. Ability to compose original texts and properly apply the conventions of written language.		
(i) Properly apply capitalization, punctuation, and penmanship, to communicate clearly		
(ii) Spell proficiently		
(iii) Apply standard grammar and usage to communicate clearly and effectively in writing including • using complete sentences, varying the types such as compound and complex to match meanings and purposes • properly employing standard English usage in writing for audiences, including subject-verb agreement, pronoun referents, and parts of speech • properly using adjectives (comparative and superlative forms) and adverbs appropriately to make writing vivid or precise • properly using prepositional phrases to elaborate written ideas • properly using conjunctions to connect ideas meaningfully		
(iv) Use available technology to support aspects of creating, revising, editing, spell checking, and publishing the report.		
3. Ability to provide appropriate discussion, conclusions and recommendations		
(i) Summarize the goals, objectives, and indicate whether they were met.		
(ii) Summarize the results.		
(iii) Summarize constraints and codes and indicate whether they were met.		
(iv) Provide logical conclusions and recommendations (including strengths and weaknesses).		

9. PROJECT REPORT EVALUATION

There will be at least two formal written reports in each Senior Design Project course consisting of the mid-semester and the final written project reports in addition to any intermediate reports that may be required. The technical/design content of the project will be evaluated based on ability to define/understand the problem and plan the project; ability to conduct relevant literature review, generate ideas and apply creativity; and ability to perform preliminary and detailed design leading to the realization of the system, component or process. Table 9.1 shows the details of all items used to evaluate the technical content of the final project report for Senior Design and Professionalism I and II.

Table 9.1 Project Design Content Evaluation Form

Outcome Performance Criteria Areas Assessed	MAX POINTS	POINTS RECEIVED
1. Ability to Define/Understand the Problem and then Plan the Project		
(i) Identify the customer and the needs.		
(ii) Identify and list the design objectives.		
(iii) Identify the design constraints.		
(iv) Define the design strategy and methodology.		
(v) Identify and break down work into tasks and subtasks and identify the personnel and deliverables for each.		
(vi) Develop a Gantt chart and critical path analysis for managing the project.		
(vii) Establish major milestones for tracking progress and define performance metrics to measure success		
2. Ability to Conduct a Review of the Literature, Generate Ideas and Apply Creativity		
(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).		
(ii) Gather information on relevant fundamentals, theory / concept (demonstrate technical competence) and relate them to the design.		
(iii) Provide the sources in a list of references properly cited in the literature review section and relevant sections of the report.		
(iv) Define functional requirements for design (Specific required actions needed to be performed for the design to be achieved).		
(v) Transform functional requirements into candidate solutions / mathematical modeling.		
(vi) Evaluate candidate solutions to arrive at feasible designs.		
3. Ability to Perform Preliminary and Detailed Design		
(i) Identify applicable codes and standards for the design		
(ii) Perform relevant detailed analysis (engineering, mathematical, economic) in accord with applicable codes and standards.		
(iii) Develop final design specifications		
(iv) Do the design within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability		
(v) Select materials/components/software/test equipment.		
(vi) Fabricate a prototype or a model (physical, software, hardware) of the design.		
(vii) Test or simulate the design and make necessary changes to obtain optimum design.		

10. GENERIC TIMETABLE FOR MAJOR PROJECT EVENTS

The senior design project sequence begins in the Fall semester and ends by the end of April the following Spring semester. A guideline is, therefore, needed to ensure that the various sections of the project design sequence are on schedule. Table 10.1 is a generic time table for major events in the senior design project sequence. Separate schedules are provided for projects that begin in the Fall semester and in the Spring semester. The course instructors are strongly advised to ensure that the schedule in Table 10.1 is followed as closely as possible to ensure successful timely completion of the projects.

Table 10.1 Generic Timetable for Senior Design Project and Professionalism

ITEM NUMBER	MONTH	8-MONTH SCHEDULE FOR PROJECTS THAT BEGIN IN FALL SEMESTER (tentative)	8-MONTH SCHEDULE FOR PROJECTS THAT BEGIN IN SPRING SEMESTER (tentative)	BEGINNING SPRING MAJOR PROJECT EVENT
0	0			Project Identification
1	1	9/7	1/14	Project Selection and Team Formation
2	1	9/30	1/30	Project Definitions and Specifications and Background Research
3	2	10/15	2/15	Project Planning and Task Definition
4	2	10/31	2/28	Literature Review
5	3	11/21	3/21	Preliminary Design and Oral Presentations
6	4	12/1	4/30	Project Report
7	6	2/15	9/15	Detailed Design Development and Parts Acquisition
8	7	3/1	10/15	Mid-semester Design Review and Presentations
9	8	4/8	11/8	System Simulation & Optimization; Design Iteration; and Construction & Testing
10	8	4/15	11/15	Final Design Review (Oral Presentations and Draft Final Report)
11	8	4/30	11/30	Final Senior Design Report

LIST OF REFERENCES

- [1] Felder, R. M. and Rebecca Brent, "How to Improve Teaching Quality," *Quality Management Journal*, Vol. 6, No. 2, 1999, pp. 4-5.
- [2] Csemica, J. et. Al., *Practical Guide to Teamwork* (Version 1.1), Bucknell University, June 26, 2002.
- [3] Murrey, David A; "Documentation: Citing Sources of Borrowed Information", <http://www.io.com/~hcexres/tcm1603/achtml/docu.html#numbersystem> (January 10, 2005).
- [4] Hart, H., *Introduction to Engineering Communication*, Pearson Prentice Hall, 2005.
- [5] Lannon, J.M., *Technical Writing*, Harper Collins College Publishers, 6th Edition, 1994.

APPENDIX: LETTER OF TRANSMITTAL

FIRM IDEAS

100 East 51st

Austin, TX. 78705

(512) 400-3333

May 1, 2004

Mike Parker, Manger of EBC Properties
1000 Summit Lane
Austin, TX 78705

Dear Mr. Parker:

The attached technical report contains Firm Ideas' evaluation of wall designs that control airborne sound transmission. This report includes the descriptions of each wall design, the evaluation process, and the wall design that Firm Ideas recommends EBC Properties use in their new apartment complexes. We used the solution criteria established by EBC Properties and Firm Ideas to evaluate six wall designs:

- Single-Stud Wall with Resilient Channel
- Single- Stud Wall with Sound-Deadening Board
- Staggered-Stud Wall
- Staggered-Stud Wall with Sound-Deadening Board
- Double –Stud Wall
- Double-Stud Wall with Sound-Deadening Board

Firm Ideas recommends that EBC Properties use the Double-Stud Wall in their new apartment complexes. First, the Double-Stud Wall provides moderate performance with an STC value of 53 decibels. Second, the Double-Stud Wall has a relatively low materials cost \$11.98 per linear foot and a relatively low labor cost of \$8.74 per linear foot. Finally, the Double-Stud Wall can support the highest mountable object weight, 110 pounds per linear foot. This wall design best meets the needs of EBC Properties.

Firm Ideas is available to answer any questions you may have concerning this report or the project in general. You can contact Firm Ideas at (512) 400-3333 or by e-mail at engineers@mail-utexas.edu.

Sincerely,

Jeffrey Hunt
Project Engineer

**ABOVE AVERAGE
PROJECT REPORT**

Design Report for the Industrial Production of Penicillin G Potassium

Dr. Lealon Martin

Team 2

Tiarra Rodrigues, Caleb Myers, Katelynn Inman, Chiebuka Ejimadu

December 6th, 2021

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LETTER OF TRANSMITTAL

December 6, 2021

Dr. Lealon Martin
Professor, Roy G. Perry College of Engineering
Prairie View A&M University

Dear Dr. Martin,

Team 2, which comprises Tiarra Rodrigues, Caleb Myers, Katelynn Inman, and Chiebuka Ejimadu, has completed the Fall 2021 semester requirements for Senior Design & Professionalism I. This report includes details on a suggested plant design for the production of penicillin G potassium, or penicillin G K. After conducting research on the global and local markets for penicillin (supply and demand), an extensive literature analysis, and price estimates based on raw material and process costs, the team believes that this process is both feasible and profitable. From extensive economic research, the team has proposed a plant capacity of 6.86 million kg/yr in order to meet 20% of the U.S. demand for penicillin. Moreover, the team suggests building the plant in Magnolia, TX, to take advantage of extensive land for potential expansion, mild ambient temperatures, and due to its proximity to farms and necessary raw materials.

The team hopes that this design proposal will gain your approval, and is available to answer any questions about the project that you may have; please contact our team leader, Tiarra Rodrigues, @ trodrigues1@pvamu.edu.

Sincerely,

Tiarra Rodrigues
Caleb Myers
Katelynn Inman
Chiebuka Ejimadu

Caleb Myers *Katelynn*
Inman

Chiebuka Ejimadu *Tiarra*
Rodrigues

Acknowledgement *(Tiarra)*

We would like to acknowledge and express our utmost thanks and gratitude to each of the individuals who assisted in the completion of our plant design and report. A great thanks goes out to Dr. Martin and Dr. Gyamerah for their exceptional leadership and guidance throughout the design process. Their stewardship and advice played a pivotal role in the development of the proper plant design and report format.

We would also like to thank the staff within the Chemical Engineering Department of the Roy G. Perry College of Engineering. They assisted our team and made sure we had access to all the tools we needed in order to be successful. We would also like to thank our graduate student colleagues for not only paving the way for us to follow but showing us the necessary steps to be successful as we emerge from the department as alumni.

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Project Summary *(Tiarra)*

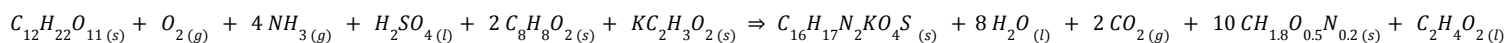
The purpose of this project is to design a plant that produces Penicillin G Potassium. There are various components that have contributed to our project success and semi-completion. Our team has completed an analysis to understand the Penicillin G Potassium market both domestically and internationally and have identified market trends to fulfil the product demand. After the plant's capacity was determined, we selected the production process. Alternate production routes are to be considered, but the highest yield and most economically viable process must be chosen. Once decided, the chosen process must be modeled within simulation software, in this case ASPEN Plus, to analyze process feasibility and steady-state process conditions. Doing so will display the efficiencies and deficiencies of the process in terms of what is necessary for plant capacity to be met and production to occur. Ultimately, our goal is to create a Penicillin G Potassium production plant that is up to date with modern chemical manufacturing plant regulations and standards

Project Scope

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 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.

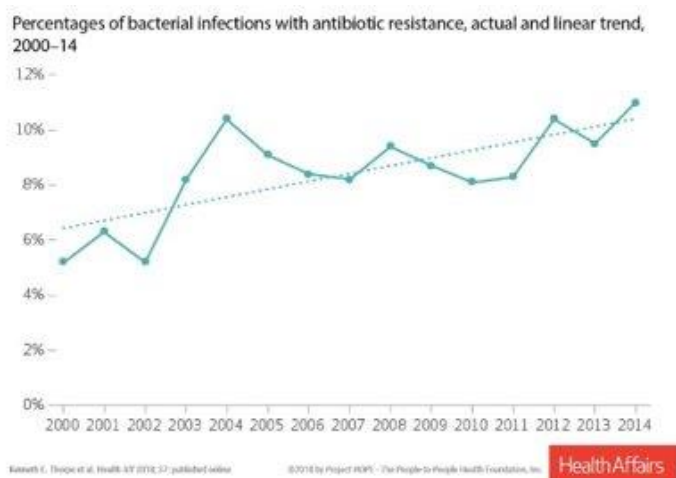


Figure 1a. Growth of bacterial infections with resistance to antibiotics from 2000-2014

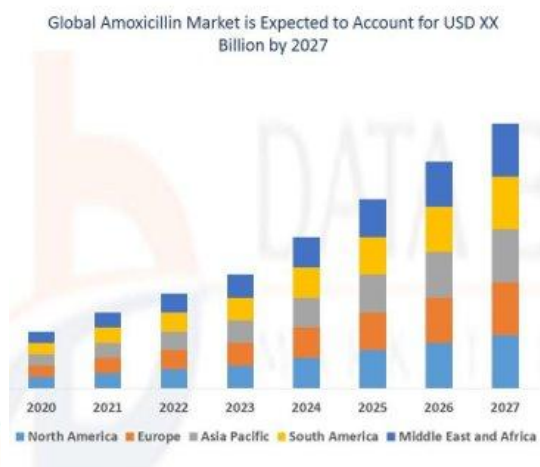


Figure 1b. Expected Growth of the Amoxicillin Market by 2027

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

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>	1988
		Vancomycin-resistant <i>Staphylococcus aureus</i>	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

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.

Project Planning and Task Identification

Task Identification (Caleb)

Team 2 began its project on September 6, 2021. The final fall semester presentation and evaluation was set to November 20, 2021, and the fall semester report will be due December 6, 2021; consequently, the group had roughly three months to complete tasks for the fall semester. In order to effectively and efficiently meet the demands of this design project, it was divided into three phases, each requiring its own set of tasks and most tasks requiring sub-tasks. Given the three-month time constraint and identified deliverables, the group was able to develop a long-term schedule based on assumptions of how much time each deliverable was believed to have required.

Project Phases:

- Phase 1 - Project Initiation & Conceptual Design
- Phase 2 - Flow Sheet Development
- Phase 3 - Project Term Assessments and Reporting

Timelines (Caleb)

As previously mentioned, the major tasks outlined on the gantt chart were further divided into sub-tasks to ensure all parts of each major task were satisfied. The timeline below lists the required tasks for the fall semester and the amount of time allocated for each one:

1. Process Initiation & Conceptual Design

- a. Project Overview & Market Data: 24 days (9/6/21 - 9/29/21)
- b. Process Parameters: 32 days (9/10/21 - 10/11/21)
- c. Process Safety: 21 days (10/29/21 - 12/19/21)

2. Flow Sheet Development

- a. Process Description: 13 days (9/21/21 - 10/3/21)

- b. Block Flow Diagram: 10 days (9/24/21 - 10/3/21)
 - c. Preliminary Process Flow Diagram: 13 days (9/29/21 - 10/11/21)
 - d. Material Energy Balances: 11 days (10/1/21 - 10/11/21)
 - e. ASPEN Simulation: 17 days (10/3/21 - 10/19/21)
 - f. Final Process Flow Diagram: 9 days (10/11/21 - 10/19/21)
- 3. Project Term Assessments & Reporting**
- a. Weekly Meetings with Dr. Lealon Martin (9/9/21 - 11/25/21)
 - b. Assessments/Homework Assignments (9/21/21 - 11/30/21)
 - c. Midterm Presentation: 23 days (9/27/21 - 10/19/21)
 - d. End of Term Presentation: 30 days (10/22/21 - 11/20/21)
 - e. End of Term Report: 46 days (10/22/21 - 12/6/21)

Gantt Chart (Caleb)

The gantt chart shown below was constructed to show the team's plan for executing deliverables during the fall semester (Figure 2). Detailed views of the individual sections of the gantt chart are provided below the full view.

FALL 2021 SEMESTER GANTT CHART

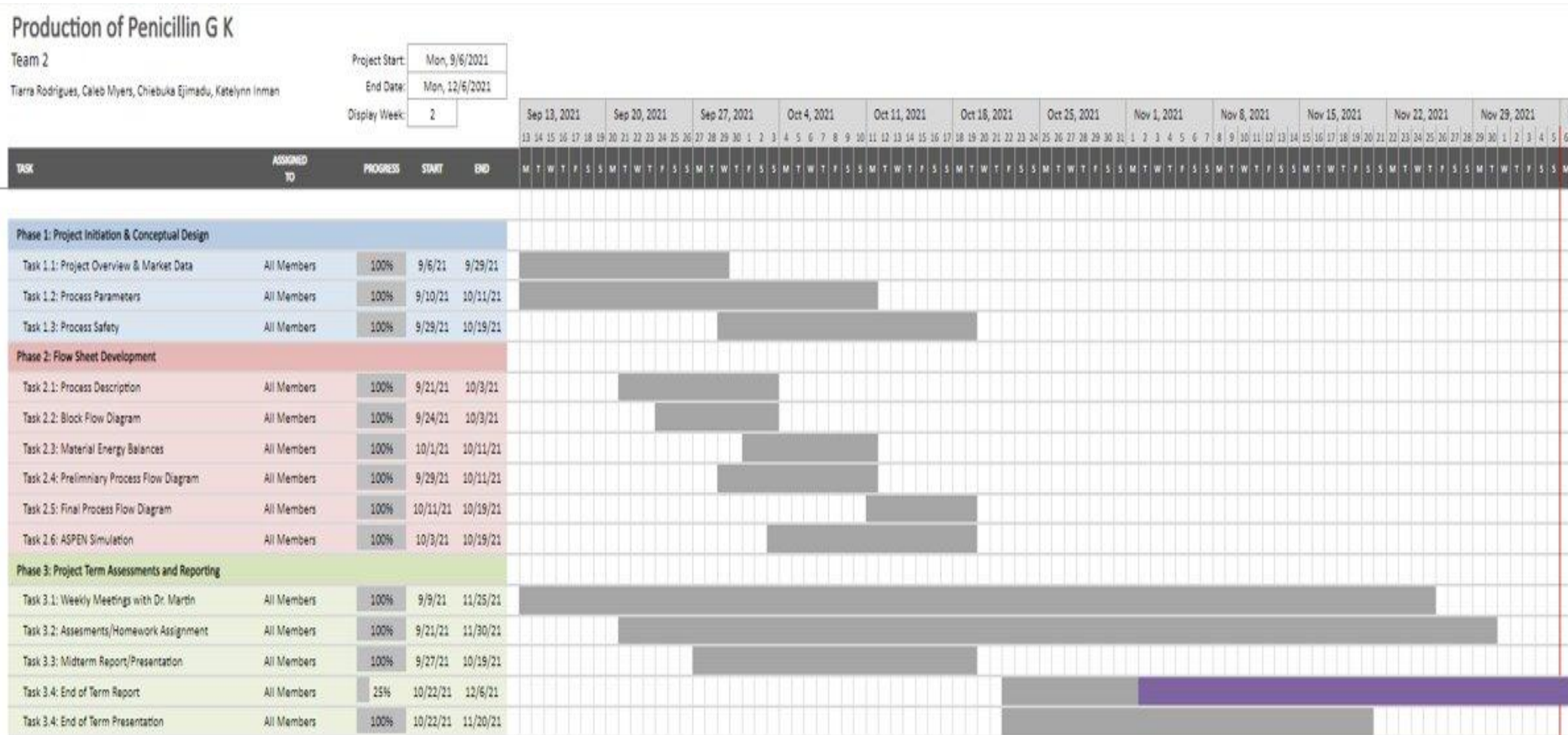


Figure 2. Fall Semester Gantt Chart

Literature Review

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 bacterias.

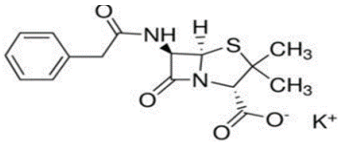
Production Route (Katelynn)

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.

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 ₂ O ₄ S	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.

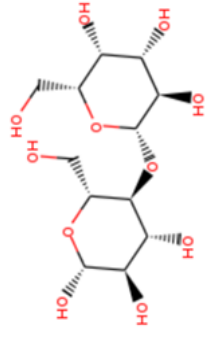
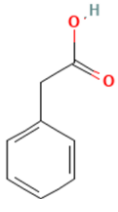
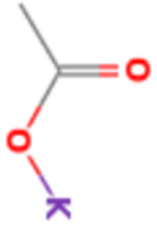
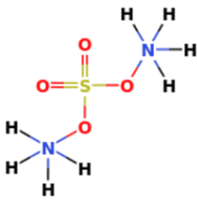
Accidental spills

- **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.

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.

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 ...

$$(95.3 \text{ million kg/yr} * 0.9 * 0.4 * 0.2) = \textbf{6.86 million kg/yr}$$

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.

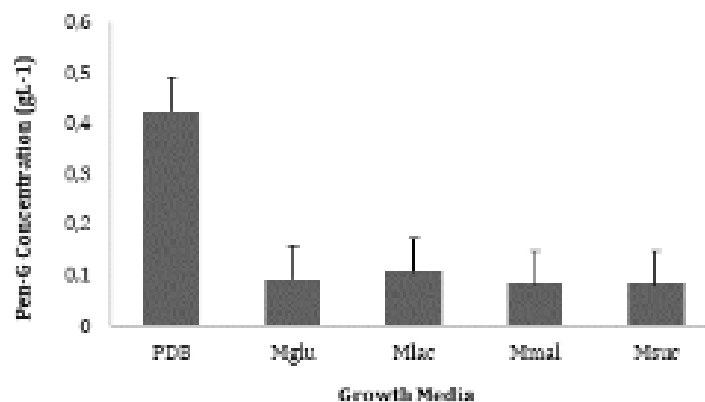


Figure 3. Penicillin G production from *Penicillium chrysogenum* in Various Mediums

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.

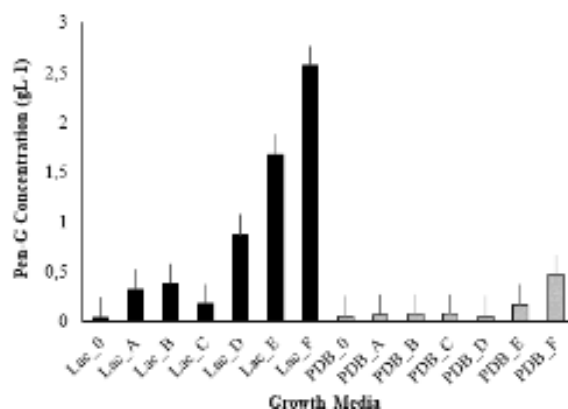


Figure 4. Penicillin Production from *Penicillium chrysogenum* with Various Concentrations of Phenylacetic Acid

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 ₂ PO ₄	0.4
2	(NH ₄) ₂ SO ₄	0.45
3	MgSO ₄ ·7H ₂ O	0.05
4	Na ₂ SO ₄ ·7H ₂ O	0.15
5	ZnSO ₄ ·7H ₂ 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:

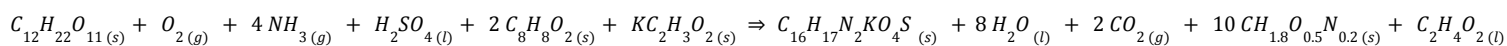


Table 5. Overall Reaction Component Cost

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	
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]

$[\$(1) + \$(1) + \$(4) + \$(1) + \$(2) + \$(1)] - [\$(1) + \$(8) + \$(2) + \$(10)] =$

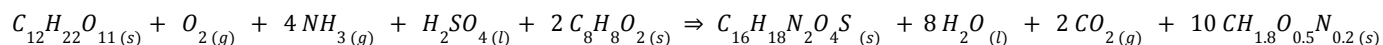
The theoretical profit indicator is about... showing that our process is profitable.

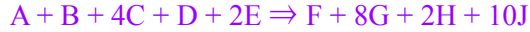
Process Chemistry

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:

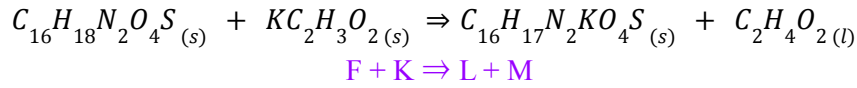
Reaction Mechanisms (BUKA)

Reaction 1: Fermentation

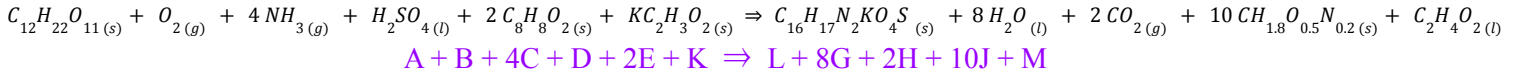




Reaction 2: Crystallization of Penicillin G Potassium



Overall Reaction:



Overall Mass Balance (Buka)

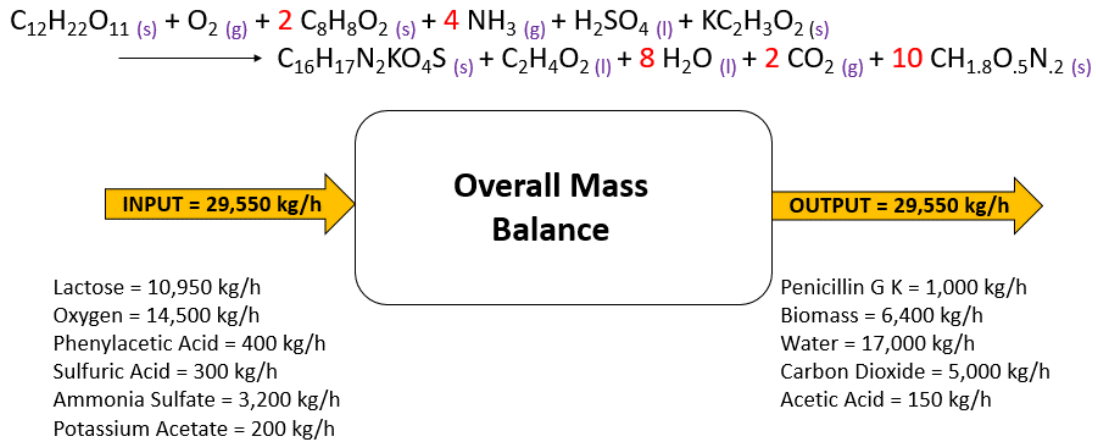


Figure 6. Overall Mass Balance across the Entire Process

Stoichiometry of Overall Reaction (BUKA)

The stoichiometry table depicts the relationship between the reactants and products. The overall reaction is based on the production of one mole of Penicillin G Potassium.

Table 6. Stoichiometry Table

Component	Stoichiometry
Lactose (A)	-1
Oxygen (B)	-1

Ammonia (C)	-4
Sulfuric Acid (D)	-1
Phenylacetic Acid (E)	-2
Potassium Acetate (K)	-1
Penicillin G K (L)	+1
Water (G)	+8
Carbon Dioxide (H)	+2
Biomass (J)	+10
Acetic Acid (M)	+1

Kinetics and Rate Law Equations (BUKA)

This process will be using a semi-batch process fermenter. Semi-batch equation is shown below:

$$v_{in} C_{i.in} + r_i V_R = V_R \left(\frac{dC_i}{dt} \right) + C_i \left(\frac{dV_R}{dt} \right)$$

It shows the input flow with a generation factor coming from the reaction giving us accumulation that factors when there's a change in both reactor volume and concentration of species i. The rate laws for each component is found below in regards to the overall reaction equation:

Table 7. Rate Law Equations

Component	Rate Law Equation
Lactose (A)	$r_A = -k C_A C_B C_C^4 C_D C_E^2 C_K$
Oxygen (B)	$r_B = r_A = -k C_A C_B C_C^4 C_D C_E^2 C_K$
Ammonia (C)	$r_C = 4 r_A = -4 k C_A C_B C_C^4 C_D C_E^2 C_K$
Sulfuric Acid (D)	$r_D = r_A = -k C_A C_B C_C^4 C_D C_E^2 C_K$
Phenylacetic Acid (E)	$r_E = 2 r_A = -2 k C_A C_B C_C^4 C_D C_E^2 C_K$

Potassium Acetate (K)	$r_K = r_A = -kC_A C_B C_C^4 C_D C_E^2 C_K$
Penicillin G K (L)	$r_L = -r_A = kC_A C_B C_C^4 C_D C_E^2 C_K$
Water (G)	$r_G = -8r_A = 8kC_A C_B C_C^4 C_D C_E^2 C_K$
Carbon Dioxide (H)	$r_H = -2r_A = 2kC_A C_B C_C^4 C_D C_E^2 C_K$
Biomass (J)	$r_J = -10r_A = 10kC_A C_B C_C^4 C_D C_E^2 C_K$
Acetic Acid (M)	$r_M = -r_A = kC_A C_B C_C^4 C_D C_E^2 C_K$

Process Description

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.

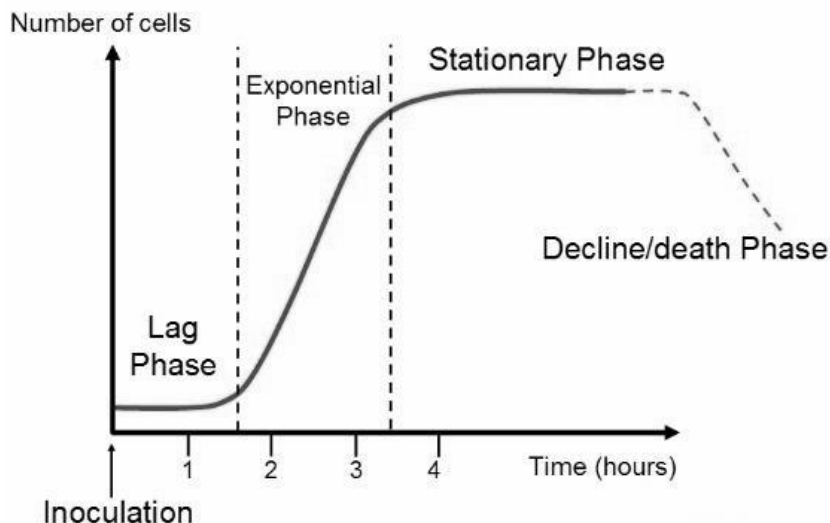


Figure 7. Phased Fungal Cell Growth Curve

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).

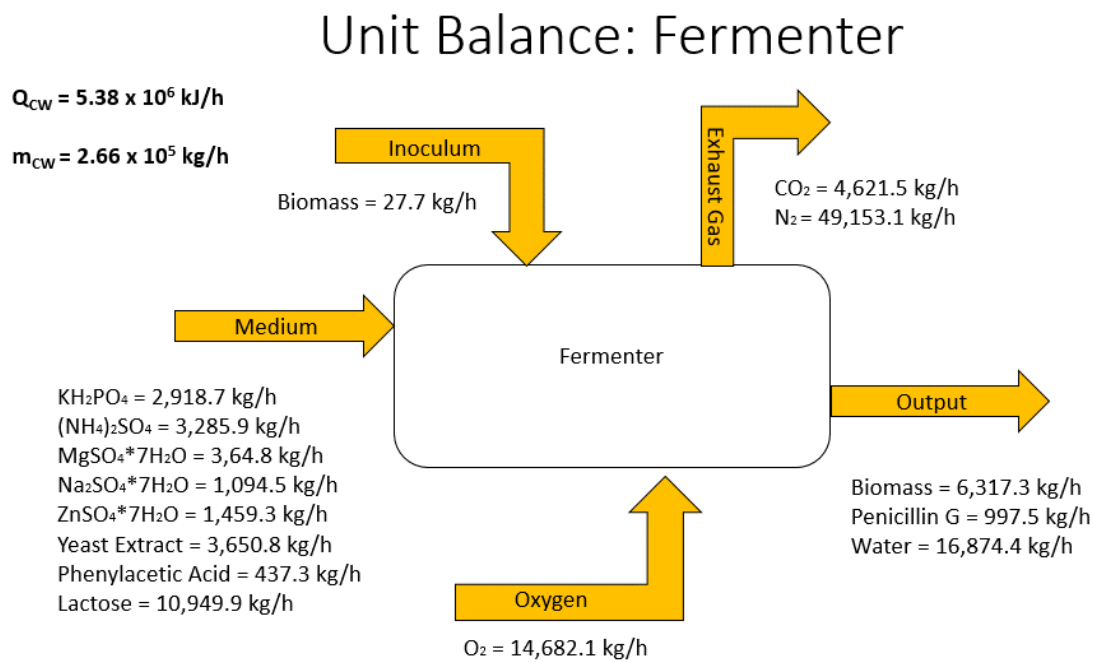


Figure 8. Material Balance across Fermenter

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:

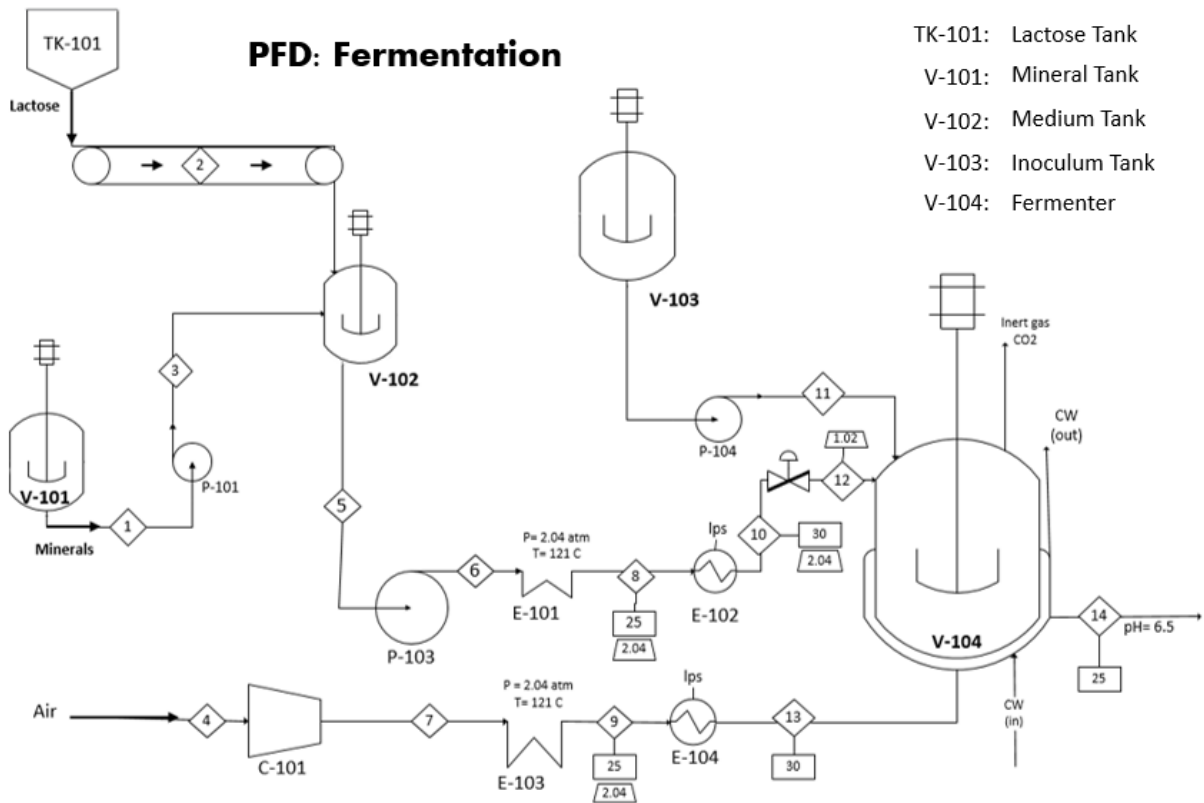


Figure 9. Process Flow Diagram of the Fermentation of *P. chrysogenum* to Produce Penicillin G

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:

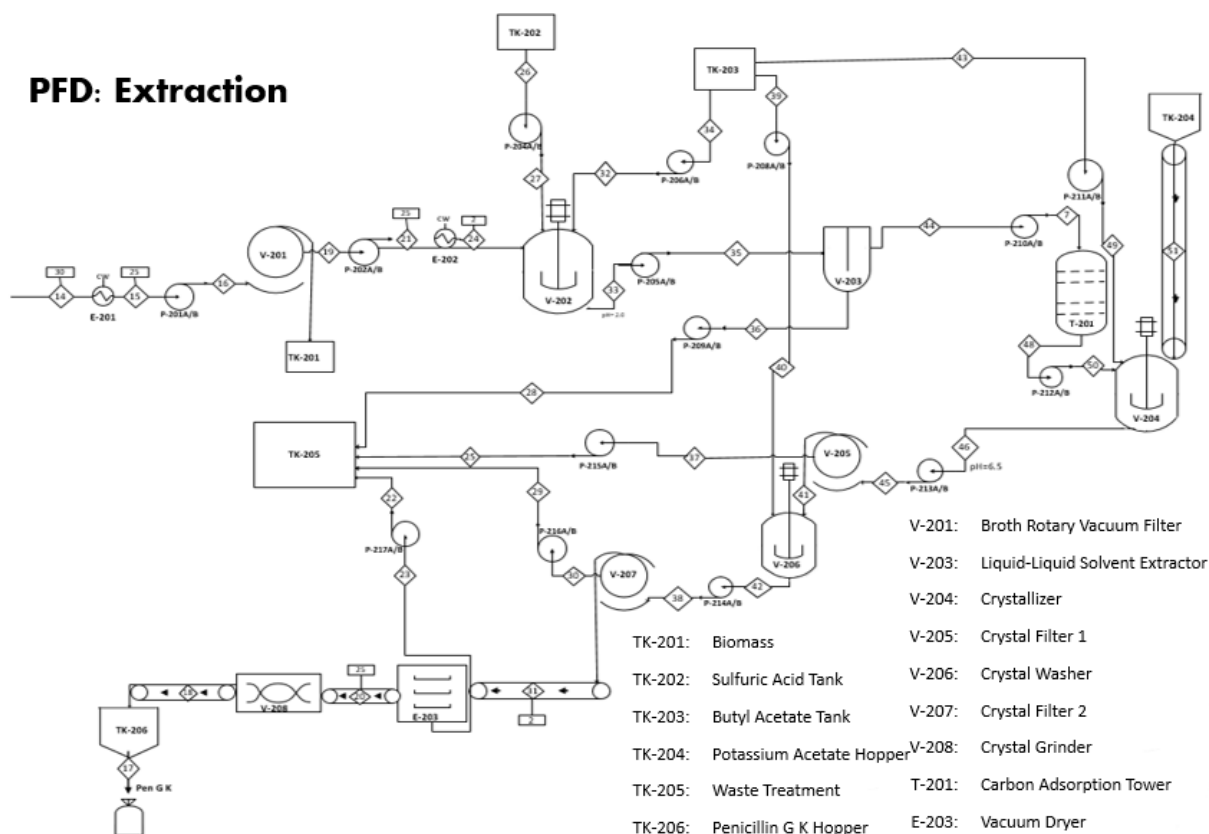


Figure 10. Process Flow Diagram of the Extraction of Penicillin G Potassium

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.

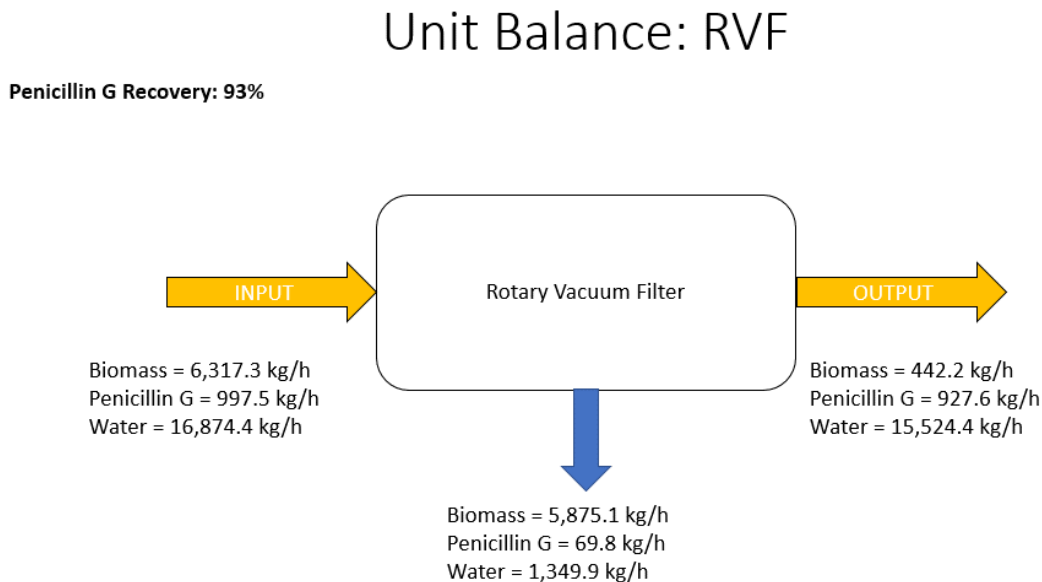


Figure 11. Material Balance across Broth Rotary Vacuum Filter

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%

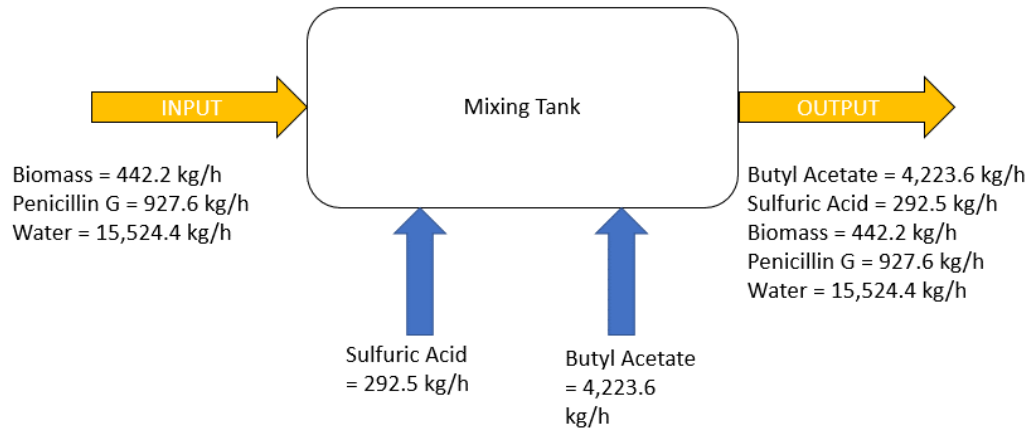


Figure 12. Mass Balance across Mixing Tank

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%

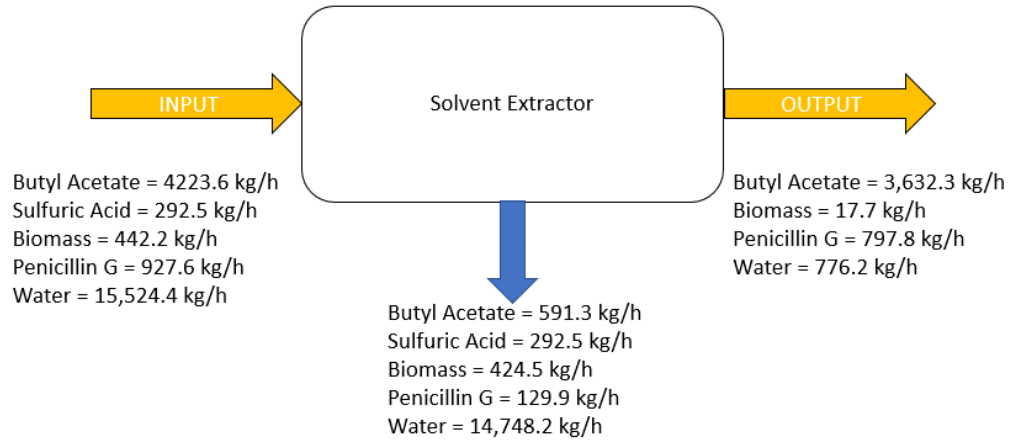


Figure 13. Mass Balance across Solvent Extractor

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%

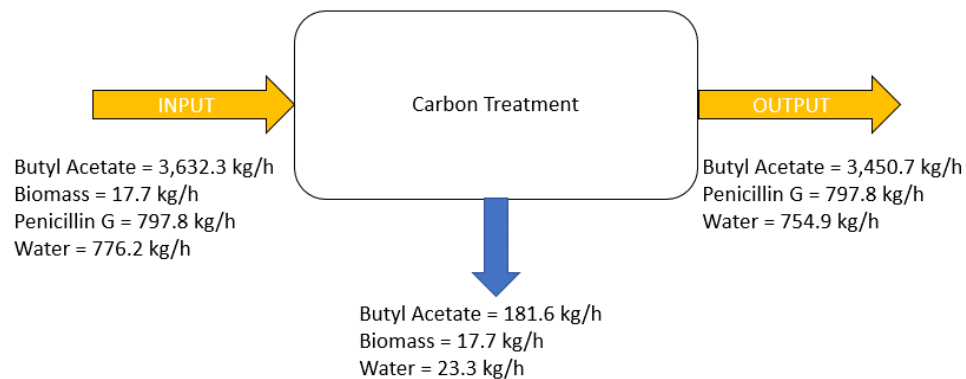


Figure 14. Material Balance across Carbon Adsorption Tower

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%

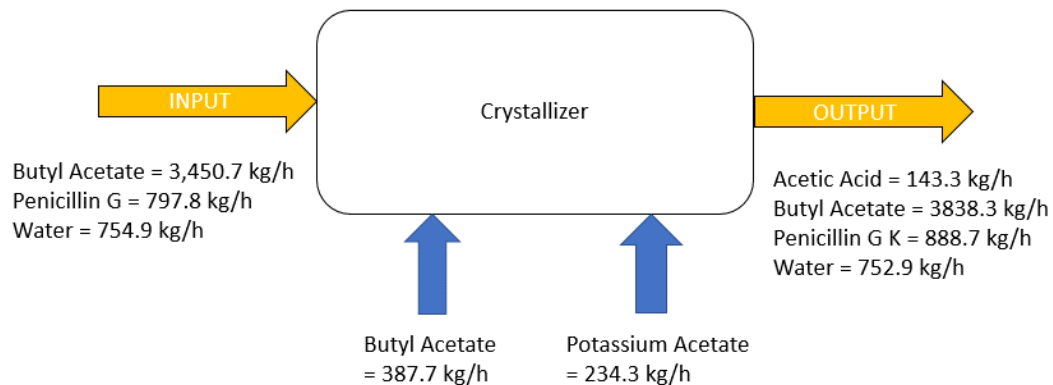


Figure 15. Material Balance across Crystallizer

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%

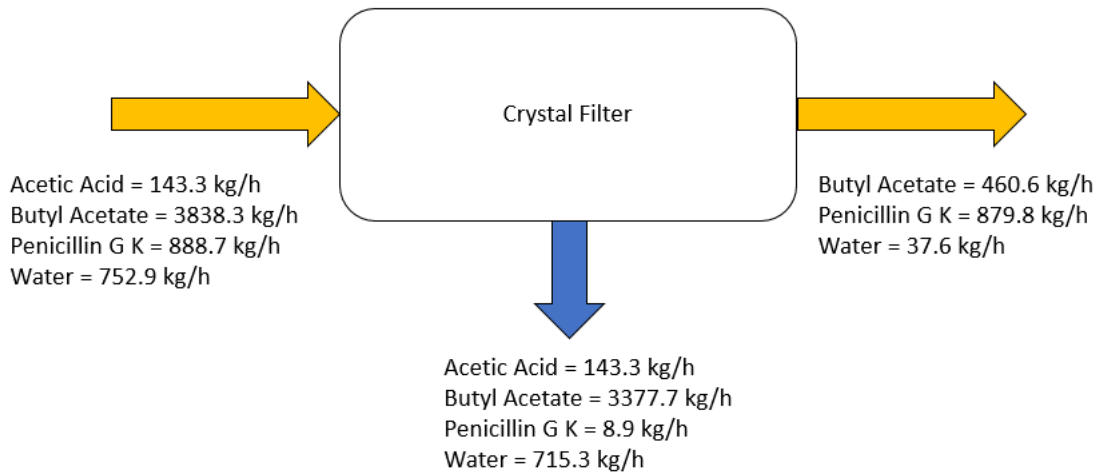


Figure 16. Material Balance across Crystal Rotary Vacuum Filter 1

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%

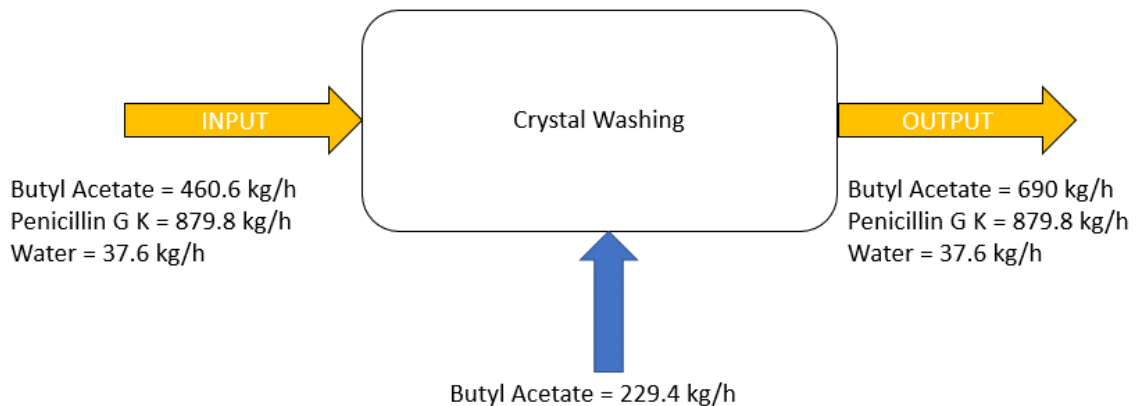


Figure 17. Material Balance across Crystal Washer

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%

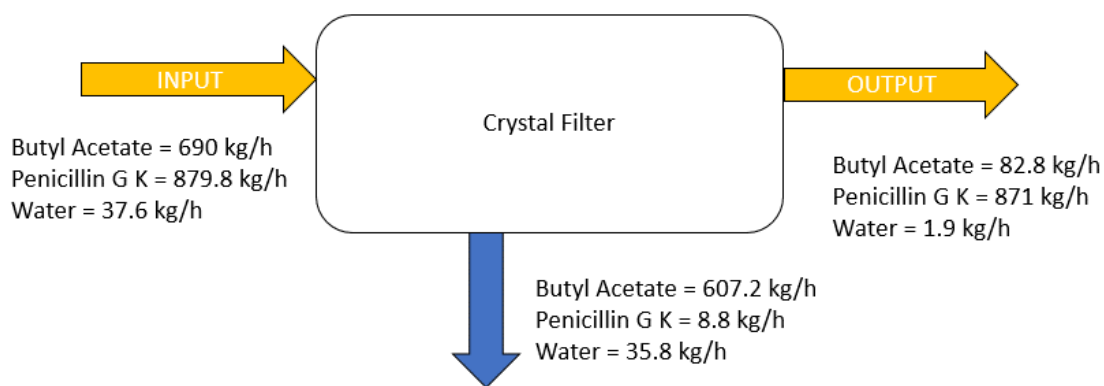


Figure 18. Material Balance across Crystal Rotary Vacuum Filter 2

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%

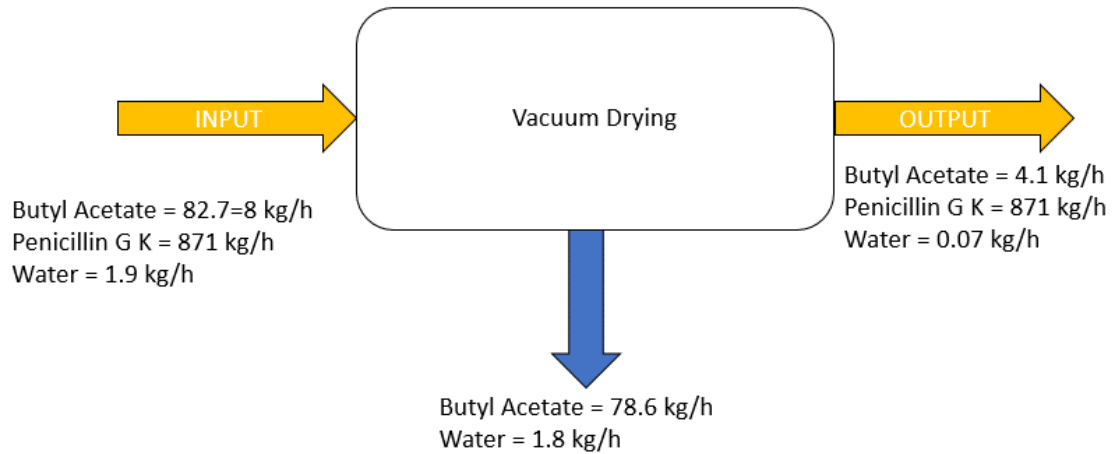


Figure 19. Material Balance across Vacuum Dryer

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

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

$$Q = mc_p\Delta T$$

Solving for m ,

$$m = Q/c_p\Delta T$$

It is important to note that mass, m , in this situation represents a mass flow rate, not simply a mass. This is true because the calculated heat duty, 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 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

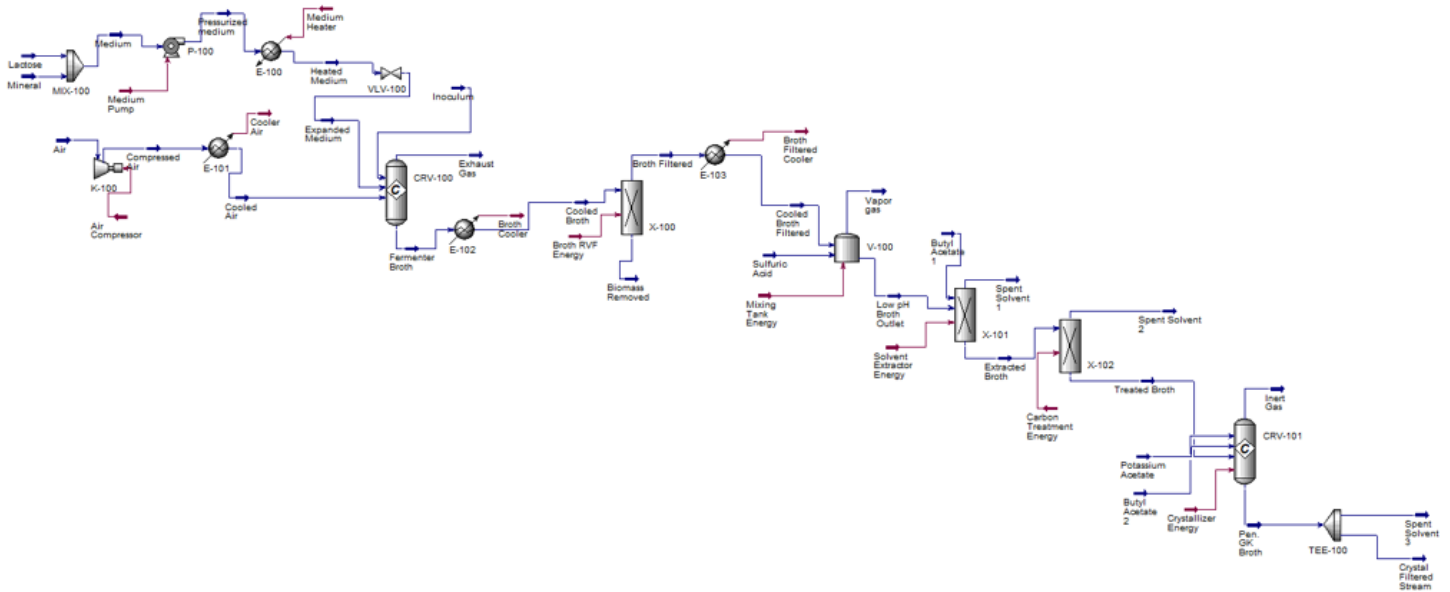


Figure 21. Aspen Simulation

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.

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Appendix

E-101
Energy Balance across ~~Heat Exchanger~~ (Heat Sterilizer)

25°C → 201 mol/min → 121°C → 25°C

$C_{12}H_{22}O_{11}(s)$:
 $C_6H_6O_2(s)$:
 $NH_3(g)$:
 $H_2SO_4(l)$:

$C_{12}H_{22}O_{11}(s)$:
 $C_6H_6O_2(s)$:
 $NH_3(g)$:
 $H_2SO_4(l)$:

A
B
C
D

similar velocities
no elevation
no moving parts

$$\dot{n}(\hat{H} + \hat{E}_k + \hat{E}_p)_{in} - \dot{n}(\hat{H} + \hat{E}_k + \hat{E}_p)_{out} + \dot{Q} + \dot{W}_s = 0$$

$$\dot{Q} = \dot{n}\hat{H}_{out} - \dot{n}\hat{H}_{in}$$

$$\dot{Q} = \dot{n}\Delta\hat{H}$$

$$= \dot{n}[\sum \hat{H}_{products} - \sum \hat{H}_{reactants}] \text{ or } \dot{n}\sum \Delta\hat{H}$$

$$\dot{Q} = \dot{n} \sum_i C_p^i \left(\frac{121^\circ C - 25^\circ C}{25^\circ C - 121^\circ C} \right)$$

where $\dot{Q}$ = J/s of heat required from sterilizer to bring temp up to 121°C

$T_M^* = 202.8^\circ C$; $T_B^* = 337^\circ C$; $T_{in}^* = 76.5^\circ C$; $T_{out}^* = 2105.5^\circ C$

Phenylacetic acid ($C_8H_8O_2$) will phase chg
s → l

$$\Delta\hat{H}_A = \int_{25^\circ C}^{121^\circ C} C_p^A dT$$

$$\Delta\hat{H}_B = \int_{25^\circ C}^{76.5^\circ C} C_p^B dT + \Delta\hat{H}_{fus}^B + \int_{76.5^\circ C}^{121^\circ C} C_p^B dT$$

$$\Delta\hat{H}_C = \int_{25^\circ C}^{121^\circ C} C_p^C dT$$

$$\Delta\hat{H}_D = \int_{25^\circ C}^{121^\circ C} C_p^D dT$$

* $C_p^A = 417.6 \text{ J/mol}\cdot K$

* $C_p^B = 36.8 \text{ J/mol}\cdot K$

* $C_p^C = 131.4 \text{ J/mol}\cdot K$

* $C_p^D = 35.5 \text{ J/mol}\cdot K$

$\Delta\hat{H}_{fus}^B = 9730 \text{ J/mol}$

$$C_p^E = \left(\frac{21630 \text{ J}}{\text{kg}\cdot K} \right) \left(\frac{1000 \text{ J}}{1 \text{ kJ}} \right) \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \left(\frac{17.031 \text{ g}}{1 \text{ mol}} \right)$$

$$C_p^F = \left(\frac{1314 \text{ J}}{\text{kg}\cdot K} \right) \left(\frac{1000 \text{ J}}{1 \text{ kJ}} \right) \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \left(\frac{98.072 \text{ g}}{1 \text{ mol}} \right)$$

$C_p^E = 359.99 \text{ J/mol}\cdot K$

$C_p^F = 1339.83 \text{ J/mol}\cdot K$

$$\Delta \hat{H}_A = (129.99 \text{ J/kg}^\circ\text{C})(121^\circ\text{C} - 25^\circ\text{C}) = 117.12 \text{ kJ/kg}$$

$$\begin{aligned} \Delta \hat{H}_B &= \cancel{(260.74 \text{ J/kg}^\circ\text{C})(121^\circ\text{C} - 25^\circ\text{C})} \\ &= (260.74 \text{ J/kg}^\circ\text{C})(76.5^\circ\text{C} - 25^\circ\text{C}) + 71509.36 \text{ J/kg} \\ &\quad + (260.74 \text{ J/kg}^\circ\text{C})(121^\circ\text{C} - 76.5^\circ\text{C}) \\ &= 96.54 \text{ kJ/kg} \end{aligned}$$

$$\Delta \hat{H}_C = (2160.77 \text{ J/kg}^\circ\text{C})(121^\circ\text{C} - 25^\circ\text{C}) = 207.43 \text{ kJ/kg}$$

$$\Delta \hat{H}_D = (1339.83 \text{ J/kg}^\circ\text{C})(121^\circ\text{C} - 25^\circ\text{C}) = 128.62 \text{ kJ/kg}$$

$$\Delta \hat{H}_T = \Delta \hat{H}_A + \Delta \hat{H}_B + \Delta \hat{H}_C + \Delta \hat{H}_D$$

$$\begin{aligned} &= 117.12 \text{ kJ/kg} + 96.54 \text{ kJ/kg} + 207.43 \text{ kJ/kg} + 128.62 \text{ kJ/kg} \\ &= 549.72 \text{ kJ/kg} \end{aligned}$$

$$\dot{n} = 24161.4 \text{ kg/hr}$$

$$\begin{aligned} \dot{Q} &= \dot{n} \Delta \hat{H}_T = (24161.4 \text{ kg/hr})(549.72 \text{ kJ/kg}) \\ &= 1.33 \times 10^7 \text{ kJ/hr} = \text{heat input required from E-JT} \end{aligned}$$

$$\begin{aligned} \dot{Q}_s &= \text{Heat brought in by steam} \\ \dot{Q}_{cw} &= \text{Heat absorbed by cooling water} = -1.33 \times 10^7 \text{ kJ/hr} \end{aligned}$$

$$\dot{Q} = -\dot{Q}_s$$

$$\dot{Q}_s = \dot{n}_s C_{p,H_2O}^{(g)} (25^\circ\text{C} - 121^\circ\text{C})$$

$$\dot{n}_s = \frac{\dot{Q}_s}{C_{p,H_2O}^{(g)} [25^\circ\text{C} - 121^\circ\text{C}]} = \frac{-1.33 \times 10^7 \text{ kJ/hr}}{(1.864 \text{ kJ/kg}^\circ\text{C})(-96 \text{ K})}$$

$$\dot{n}_s = \text{flow rate of incoming steam} = \boxed{74324.93 \text{ kg/hr}}$$

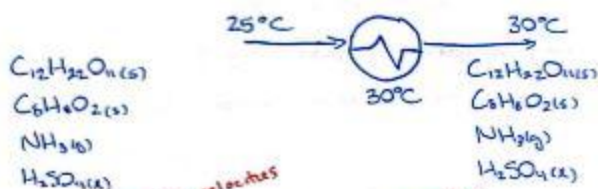
Cooling mechanism:

$$\dot{Q}_{cw} = \dot{Q} = 1.33 \times 10^7 \text{ kJ/hr} = \dot{n}_{cw} C_{p,H_2O}^{(l)} (121^\circ\text{C} - 25^\circ\text{C})$$

$$\dot{n}_{cw} = \frac{\dot{Q}_{cw}}{C_{p,H_2O}^{(l)} [121^\circ\text{C} - 25^\circ\text{C}]} = \frac{1.33 \times 10^7 \text{ kJ/hr}}{(4.184 \text{ kJ/kg}^\circ\text{C})(96 \text{ K})}$$

$$\dot{n}_{cw} = \text{flow rate of incoming cooling water} = \boxed{33112.25 \text{ kg/hr}}$$

Energy Balance across E-102 (Heat Exchanger)



A
B
C
D

$$\dot{n}(\hat{H} + \hat{E}_k + \hat{E}_p)_{in} - \dot{n}(\hat{H} + \hat{E}_k + \hat{E}_p)_{out} + \dot{Q} + \dot{W}_s = 0$$

$$\dot{Q} = \dot{n}\hat{H}_{out} - \dot{n}\hat{H}_{in} - \dot{W}_s$$

$$\dot{Q} = \dot{n}\Delta\hat{H}$$

$$= \dot{n} \sum \Delta\hat{H}$$

$$\dot{Q} = \dot{n} \sum c_p (30^\circ\text{C} - 25^\circ\text{C})$$

where $\dot{Q}$ = % of heat required from sterilizer to bring temp up to 30°C

$$T_H^* = 202.8^\circ\text{C}, T_C^* = 337^\circ\text{C}; T_H^* = 76.5^\circ\text{C}; T_C^* = 265.5^\circ\text{C}$$

$$\Delta\hat{H}_H = \int_{25^\circ\text{C}}^{30^\circ\text{C}} c_p dT \quad \Delta\hat{H}_C = \int_{25^\circ\text{C}}^{30^\circ\text{C}} c_p dT \quad \Delta\hat{H}_C = \int_{25^\circ\text{C}}^{30^\circ\text{C}} c_p dT$$

$$\Delta\hat{H}_C = \int_{25^\circ\text{C}}^{30^\circ\text{C}} c_p dT$$

$$c_p = 1219.99 \text{ J/kg}\cdot\text{K} \quad \Delta\hat{H}_H = (1219.99 \text{ J/kg}\cdot\text{K})(30^\circ\text{C} - 25^\circ\text{C}) = 6.10 \text{ kJ/kg}$$

$$c_p^* = 240.74 \text{ J/kg}\cdot\text{K} \quad \Delta\hat{H}_C = (240.74 \text{ J/kg}\cdot\text{K})(30^\circ\text{C} - 25^\circ\text{C}) = 1.30 \text{ kJ/kg}$$

$$c_p = 2160.77 \text{ J/kg}\cdot\text{K} \quad \Delta\hat{H}_C = (2160.77 \text{ J/kg}\cdot\text{K})(30^\circ\text{C} - 25^\circ\text{C}) = 10.80 \text{ kJ/kg}$$

$$c_p = 1339.83 \text{ J/kg}\cdot\text{K} \quad \Delta\hat{H}_C = (1339.83 \text{ J/kg}\cdot\text{K})(30^\circ\text{C} - 25^\circ\text{C}) = 6.70 \text{ kJ/kg}$$

$$\Delta\hat{H}_T = \Delta\hat{H}_H + \Delta\hat{H}_C + \Delta\hat{H}_C + \Delta\hat{H}_C$$

$$= 6.1 \text{ kJ/kg} + 1.3 \text{ kJ/kg} + 10.8 \text{ kJ/kg} + 6.7 \text{ kJ/kg}$$

$$= 24.9 \text{ kJ/kg}$$

$$\dot{n} = 24161.4 \text{ kg/hr}$$

$$\dot{Q} = \dot{n}\Delta\hat{H}_T = (24161.4 \text{ kg/hr})(24.9 \text{ kJ/kg})$$

$$= 6.02 \times 10^6 \text{ kJ/hr} = \text{heat absorbed by broth}$$

$$\dot{Q}_s = -\dot{Q} = \text{heat brought in by steam}$$

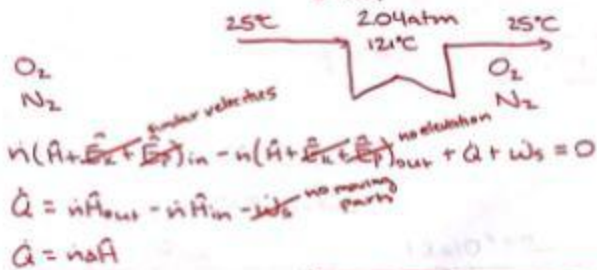
* c_p of water vapor @ 300 K

$$\dot{Q}_s = \dot{n}_s c_{p,s} [25^\circ\text{C} - 30^\circ\text{C}]$$

$$\dot{n}_s = \frac{\dot{Q}_s}{c_{p,s} [25^\circ\text{C} - 30^\circ\text{C}]} = \frac{-6.02 \times 10^6 \text{ kJ/hr}}{(1861 \text{ J/kg}\cdot\text{K})(-5\text{K})}$$

$$= \text{flow rate of incoming steam} = 64592.27 \text{ kg/hr}$$

Energy Balance across ~~H-103~~ (Heat Sterilizer) E-101



$$\dot{Q} = n \sum_i c_{pi} (121^\circ\text{C} - 25^\circ\text{C})$$

where $\dot{Q}$ = % of heat required from sterilizer to bring temp up to 121°C

$$\Delta\hat{H}_{O_2} = \int_{25^\circ\text{C}}^{121^\circ\text{C}} C_{p,i} dT \quad \Delta\hat{H}_{N_2} = \int_{25^\circ\text{C}}^{121^\circ\text{C}} C_{p,i} dT$$

$$C_{p,i}^{O_2} = (29.1 \text{ J/mol}\cdot\text{K}) \left(\frac{1 \text{ mol}}{31.998 \text{ g}} \right) = 0.91 \text{ J/g}\cdot\text{K}$$

$$C_{p,i}^{N_2} = (1.042 \text{ J/g}\cdot\text{K}) = 1.042 \text{ J/g}\cdot\text{K}$$

$$\Delta\hat{H}_{O_2} = (0.91 \text{ J/g}\cdot\text{K}) \left(\frac{1000 \text{ g}}{1 \text{ kg}} \right) (121^\circ\text{C} - 25^\circ\text{C}) = 87.36 \text{ kJ/kg}$$

$$\Delta\hat{H}_{N_2} = (1.042 \text{ J/g}\cdot\text{K}) \left(\frac{1000 \text{ g}}{1 \text{ kg}} \right) (121^\circ\text{C} - 25^\circ\text{C}) = 100.03 \text{ kJ/kg}$$

$$\Delta\hat{H}_T = \Delta\hat{H}_{O_2} + \Delta\hat{H}_{N_2}$$

$$= 87.36 \text{ kJ/kg} + 100.03 \text{ kJ/kg}$$

$$= 187.39 \text{ kJ/kg}$$

$$\dot{n} = 63655.2 \text{ kg/hr}$$

$$\dot{Q} = n\Delta\hat{H}_T$$

$$= (63655.2 \text{ kg/hr}) (187.39 \text{ kJ/kg}) = 1.2 \times 10^7 \text{ kJ/hr} = \text{heat absorbed by incoming air}$$

$$\dot{Q}_s = \text{heat leaving steam} = -\dot{Q} = -1.2 \times 10^7 \text{ kJ/hr}$$

$$\dot{Q}_s = \dot{n}_s c_{p,s}^{(9)} [25^\circ\text{C} - 121^\circ\text{C}]$$

$$\dot{n}_s = \frac{\dot{Q}_s}{c_{p,s}^{(9)} [25^\circ\text{C} - 121^\circ\text{C}]} = \frac{-1.2 \times 10^7 \text{ kJ/hr}}{(1.864 \text{ kJ/kg}\cdot\text{K}) (-96 \text{ K})}$$

= flow rate of incoming steam = 67060.1 kg/hr

Cooling mechanism:

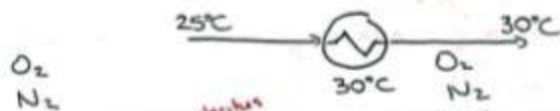
$$\dot{Q}_{cw} = \dot{Q} = 1.2 \times 10^7 \text{ kJ/hr}$$

$$\dot{Q}_{cw} = \dot{n}_{cw} c_{p,cw}^{(9)} [121^\circ\text{C} - 25^\circ\text{C}]$$

$$\dot{n}_{cw} = \frac{\dot{Q}_{cw}}{c_{p,cw}^{(9)} [121^\circ\text{C} - 25^\circ\text{C}]} = \frac{1.2 \times 10^7 \text{ kJ/hr}}{(4.184 \text{ kJ/kg}\cdot\text{K}) (96 \text{ K})}$$

= flow rate of incoming cooling water = 29875.72 kg/hr

Energy Balance across ~~E-104~~ (Heat Exchanger)



$$\dot{n}(\hat{H} + \cancel{\hat{E}_k} + \cancel{\hat{E}_p})_{in} - \dot{n}(\hat{H} + \cancel{\hat{E}_k} + \cancel{\hat{E}_p})_{out} + \dot{Q} + \dot{W}_s = 0$$

similar velocities *no calculation*

$$\dot{Q} = \dot{n}\hat{H}_{out} - \dot{n}\hat{H}_{in} - \cancel{\dot{W}_s}$$

no moving parts

$$\dot{Q} = \dot{n}\Delta\hat{H}$$

$$= \dot{n}\sum\Delta\hat{H}$$

$$\dot{Q} = \dot{n}\sum_i c_p(30^\circ\text{C} - 25^\circ\text{C})$$

Where $\dot{Q} = 3/5$ of heat required from exchanger to bring temp up to 30°C

$$\Delta\hat{H}_{O_2} = \int_{25^\circ\text{C}}^{30^\circ\text{C}} c_p^{O_2} dT \quad \Delta\hat{H}_{N_2} = \int_{25^\circ\text{C}}^{30^\circ\text{C}} c_p^{N_2} dT$$

$$c_p^{O_2} = 0.91 \text{ J/gK}$$

$$c_p^{N_2} = 1.042 \text{ J/gK}$$

$$\Delta\hat{H}_{O_2} = (0.91 \text{ J/gK}) \left(\frac{1000 \text{ g}}{1 \text{ kg}} \right) (30^\circ\text{C} - 25^\circ\text{C}) = 4.55 \text{ kJ/kg}$$

$$\Delta\hat{H}_{N_2} = (1.042 \text{ J/gK}) \left(\frac{1000 \text{ g}}{1 \text{ kg}} \right) (30^\circ\text{C} - 25^\circ\text{C}) = 5.21 \text{ kJ/kg}$$

$$\Delta\hat{H}_T = \Delta\hat{H}_{O_2} + \Delta\hat{H}_{N_2}$$

$$= 4.55 \text{ kJ/kg} + 5.21 \text{ kJ/kg}$$

$$= 9.76 \text{ kJ/kg}$$

$$\dot{Q} = \dot{n}\Delta\hat{H}_T, \dot{n} = 63835.2 \text{ kg/hr}$$

$$= (63835.2 \text{ kg/hr}) (9.76 \text{ kJ/kg}) = 6.23 \times 10^6 \text{ kJ/hr} = \text{heat absorbed by incoming air}$$

$$\dot{Q}_s = -\dot{Q} = \text{heat brought in by steam} = -6.23 \times 10^6 \text{ kJ/hr}$$

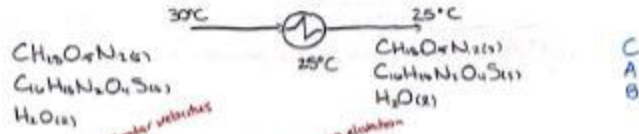
$$\dot{Q}_s = \dot{n}_s c_{p,H_2O}^{(g)} (25^\circ\text{C} - 30^\circ\text{C})$$

$$\dot{n}_s = \frac{\dot{Q}_s}{c_{p,H_2O}^{(g)} [25^\circ\text{C} - 30^\circ\text{C}]} = \frac{-6.23 \times 10^6 \text{ kJ/hr}}{(2.01 \text{ kJ/kgK}) (5 \text{ K})}$$

18.14

$$\dot{n}_s = \text{flow rate of incoming steam} = \frac{-6.23 \times 10^6 \text{ kJ/hr}}{18.14} = 34345.5 \text{ kg/hr}$$

Energy Balance across E-201 (Heat Exchanger)



$$n(\hat{H} + \hat{E}_k + \hat{E}_p)_{in} - n(\hat{H} + \hat{E}_k + \hat{E}_p)_{out} + \dot{Q} + \dot{W}_s = 0$$

$$\dot{Q} = n\hat{H}_{out} - n\hat{H}_{in} \quad \text{no kinetic energy}$$

$$\dot{Q} = n\Delta\hat{H}$$

$$\dot{Q} = n \sum_i c_{p,i} (25^\circ\text{C} - 30^\circ\text{C})$$

where $\dot{Q}$ is heat that the exchanger must remove to bring temp down to 25°C

$$\Delta\hat{H}_A = \int_{30^\circ\text{C}}^{25^\circ\text{C}} c_p^A dT \quad \Delta\hat{H}_B = \int_{30^\circ\text{C}}^{25^\circ\text{C}} c_p^B dT \quad \Delta\hat{H}_C = \int_{30^\circ\text{C}}^{25^\circ\text{C}} c_p^C dT$$

$$c_p^A = 4.184 \text{ kJ/kg}\cdot\text{K} \quad c_p^B = c_p^C = 1.81 \text{ kJ/kg}\cdot\text{K} \quad \text{Assumption that } c_p^B = c_p^C \text{ found via literature}$$

$$\Delta\hat{H}_A = (1.81 \text{ kJ/kg}\cdot\text{K})(25^\circ\text{C} - 30^\circ\text{C}) = -9.05 \text{ kJ/kg}$$

$$\Delta\hat{H}_B = (4.184 \text{ kJ/kg}\cdot\text{K})(25^\circ\text{C} - 30^\circ\text{C}) = -20.92 \text{ kJ/kg}$$

$$\Delta\hat{H}_C = (1.81 \text{ kJ/kg}\cdot\text{K})(25^\circ\text{C} - 30^\circ\text{C}) = -9.05 \text{ kJ/kg}$$

$$\Delta\hat{H}_T = \Delta\hat{H}_A + \Delta\hat{H}_B + \Delta\hat{H}_C = 2(-9.05 \text{ kJ/kg}) - 20.92 \text{ kJ/kg} = -39.02 \text{ kJ/kg}$$

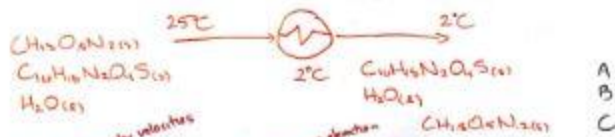
$$\dot{Q} = n\Delta\hat{H}_T; n = 24189.1 \text{ kg/hr} \quad \dot{Q} = (24189.1 \text{ kg/hr})(-39.02 \text{ kJ/kg}) = -9.44 \times 10^5 \text{ kJ/hr} \quad \text{lost heat absorbed from brats by cooling water}$$

$$\dot{Q}_{cw} = -\dot{Q} = \text{heat absorbed by cooling water} = 9.44 \times 10^5 \text{ kJ/hr}$$

$$\dot{Q}_{cw} = n_{cw} c_{p,cw} (30^\circ\text{C} - 25^\circ\text{C})$$

$$n_{cw} = \frac{\dot{Q}_{cw}}{c_{p,cw} (30^\circ\text{C} - 25^\circ\text{C})} = \frac{9.44 \times 10^5 \text{ kJ/hr}}{(4.184 \text{ kJ/kg}\cdot\text{K})(5 \text{ K})} = \text{flow rate of incoming cooling water} = 45124.28 \text{ kg/hr}$$

Energy Balance across E-202 (Heat Exchanger)



$$n(\hat{H}_A + \hat{H}_B + \hat{H}_C)_{in} - n(\hat{H}_A + \hat{H}_B + \hat{H}_C)_{out} + \dot{Q} + \dot{W}_s = 0$$

$$\dot{Q} = n\hat{H}_{out} - n\hat{H}_{in} - \dot{W}_s$$

$$\dot{Q} = n\Delta\hat{H}$$

$$= n\sum \Delta\hat{H}$$

$$\dot{Q} = n\sum c_p(2^\circ C - 25^\circ C)$$

Where $\dot{Q}$ = % of heat that the exchanger must remove to bring temp down to $2^\circ C$

$$\Delta\hat{H}_A = \int_{25^\circ C}^{2^\circ C} c_p^A dT \quad \Delta\hat{H}_B = \int_{25^\circ C}^{2^\circ C} c_p^B dT \quad \Delta\hat{H}_C = \int_{25^\circ C}^{2^\circ C} c_p^C dT$$

$$c_p^A \approx 1.81 \text{ kJ/kg} \cdot K = 1.81 \text{ kJ/kg} \cdot K$$

$$c_p^B = (4184 \text{ J/kg} \cdot K) \left(\frac{1 \text{ kJ}}{1000 \text{ J}} \right) (2^\circ C - 25^\circ C) = 4.184 \text{ kJ/kg} \cdot K$$

$$\rho_A = \left(\frac{1400 \text{ kg}}{1 \text{ m}^3} \right) \left(\frac{1 \text{ m}^3}{1000 \text{ kg}} \right)$$

$$= (1400 \text{ kg/m}^3) \left(\frac{1 \text{ m}^3}{1000 \text{ kg}} \right) = 1400 \text{ kg/m}^3$$

$$\rho_C = (1095 \text{ kg/m}^3) \left(\frac{1 \text{ m}^3}{1000 \text{ kg}} \right) = 1095 \text{ kg/m}^3$$

* $c_p^A = c_p^B = 1.81 \text{ kJ/kg} \cdot K$ - Assumption that $c_p^A = c_p^B$, c_p^B found via literature

$$\Delta\hat{H}_A = (1.81 \text{ kJ/kg} \cdot K) (2^\circ C - 25^\circ C) = \Delta\hat{H}_C = -41.63 \text{ kJ/kg}$$

$$\Delta\hat{H}_B = (4.184 \text{ kJ/kg} \cdot K) (2^\circ C - 25^\circ C) = -96.23 \text{ kJ/kg}$$

$$\Delta\hat{H}_T = \Delta\hat{H}_A + \Delta\hat{H}_B + \Delta\hat{H}_C$$

$$= 2(-41.63 \text{ kJ/kg}) + (-96.23 \text{ kJ/kg})$$

$$= -179.49 \text{ kJ/kg}$$

$$\dot{Q} = n\Delta\hat{H}_T, n = 168943 \text{ kg/hr}$$

$$= (168943 \text{ kg/hr}) (-179.49 \text{ kJ/kg})$$

$$= -3.03 \times 10^4 \text{ kJ/hr} = \text{heat lost from broth}$$

$$\dot{Q}_{CW} = -\dot{Q} = \text{heat absorbed by cooling water}$$

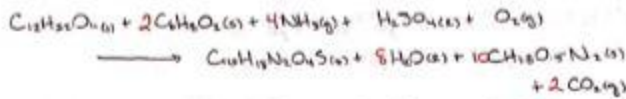
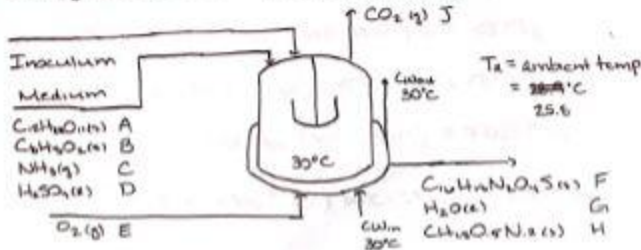
$$= 3.03 \times 10^4 \text{ kJ/hr}$$

$$\dot{Q}_{CW} = n_{CW} c_p^{in} [25^\circ C - 2^\circ C]$$

$$n_{CW} = \frac{\dot{Q}_{CW}}{c_p^{in} [25^\circ C - 2^\circ C]} = \frac{3.03 \times 10^4 \text{ kJ/hr}}{(4184 \text{ J/kg} \cdot K) (23^\circ C)}$$

$$= \text{Flow rate of incoming cooling water} = 31486.41 \text{ kg/hr}$$

Energy Balance across V-104 (Fermenter)



$$\dot{n}(\hat{H} + \hat{E}_k + \hat{E}_p)_{in} - \dot{n}(\hat{H} + \hat{E}_k + \hat{E}_p)_{out} + \dot{Q} + \dot{W}_s = 0$$

$$\dot{Q} + \dot{n}\hat{H}_{in} - \dot{n}\hat{H}_{out} + \dot{W}_s = 0$$

$$\dot{Q} = \dot{n}\hat{H}_{out} - \dot{n}\hat{H}_{in}$$

$$\hat{H}_{out} = \hat{H}_F + 2\hat{H}_B + 4\hat{H}_C + \hat{H}_D + \hat{H}_E, \quad \hat{H}_{in} = \hat{H}_A + 2\hat{H}_B + 4\hat{H}_C + \hat{H}_D + \hat{H}_E$$

$$C_p^A = 1.22 \text{ kJ/kg}\cdot\text{K}; \quad C_p^B = 0.261 \text{ kJ/kg}\cdot\text{K}; \quad C_p^C = 2.161 \text{ kJ/kg}\cdot\text{K}$$

$$C_p^D = 1.341 \text{ kJ/kg}\cdot\text{K}; \quad C_p^E = 0.91 \text{ kJ/kg}\cdot\text{K}; \quad C_p^F = 1.81 \text{ kJ/kg}\cdot\text{K}$$

$$C_p^G = 4.184 \text{ kJ/kg}\cdot\text{K}; \quad C_p^H = 1.81 \text{ kJ/kg}\cdot\text{K}; \quad C_p^J = 0.844 \text{ kJ/kg}\cdot\text{K}$$

$$\dot{n}\hat{H}_A = \int_{25.5}^{30} C_p^A dT = (1.22 \text{ kJ/kg}\cdot\text{K})(30^\circ\text{C} - 25.5^\circ\text{C}) = 5.124 \text{ kJ/kg}$$

$$\dot{n}\hat{H}_B = \int_{25.5}^{30} C_p^B dT = (0.261 \text{ kJ/kg}\cdot\text{K})(30^\circ\text{C} - 25.5^\circ\text{C}) = 1.071 \text{ kJ/kg}$$

$$\dot{n}\hat{H}_C = \int_{25.5}^{30} C_p^C dT = (2.161 \text{ kJ/kg}\cdot\text{K})(30^\circ\text{C} - 25.5^\circ\text{C}) = 9.05 \text{ kJ/kg}$$

$$\dot{n}\hat{H}_D = \int_{25.5}^{30} C_p^D dT = (1.341 \text{ kJ/kg}\cdot\text{K})(30^\circ\text{C} - 25.5^\circ\text{C}) = 5.125 \text{ kJ/kg}$$

$$\Delta \hat{H}_E = \int_{25.8^\circ\text{C}}^{30^\circ\text{C}} C_p^E dT = (0.91 \text{ kJ/kgK})(30^\circ\text{C} - 25.8^\circ\text{C}) = 3.822 \text{ kJ/kg}$$

$$\Delta \hat{H}_F = \int_{25.8^\circ\text{C}}^{30^\circ\text{C}} C_p^F dT = (1.81 \text{ kJ/kgK})(30^\circ\text{C} - 25.8^\circ\text{C}) = 7.602 \text{ kJ/kg}$$

$$\Delta \hat{H}_A = \int_{25.8^\circ\text{C}}^{30^\circ\text{C}} C_p^A dT = (4.184 \text{ kJ/kgK})(30^\circ\text{C} - 25.8^\circ\text{C}) = 17.573 \text{ kJ/kg}$$

$$\Delta \hat{H}_H = \int_{25.8^\circ\text{C}}^{30^\circ\text{C}} C_p^H dT = (1.81 \text{ kJ/kgK})(30^\circ\text{C} - 25.8^\circ\text{C}) = 7.602 \text{ kJ/kg}$$

$$\Delta \hat{H}_S = \int_{25.8^\circ\text{C}}^{30^\circ\text{C}} C_p^S dT = (0.846 \text{ kJ/kgK})(30^\circ\text{C} - 25.8^\circ\text{C}) = 3.55 \text{ kJ/kg}$$

$$\begin{aligned} \Delta \hat{H}_T &= \sum_i \Delta \hat{H}_i \\ &= 5124 \text{ kJ/kg} + 1.076 \text{ kJ/kg} + 9.08 \text{ kJ/kg} + 5.126 \text{ kJ/kg} + 3.822 \text{ kJ/kg} \\ &\quad + 2(7.602 \text{ kJ/kg}) + 17.573 \text{ kJ/kg} + 3.55 \text{ kJ/kg} \\ &= 61.077 \text{ kJ/kg} \end{aligned}$$

$$\begin{aligned} \dot{m} &= \dot{m}_{\text{meat}} + \dot{m}_{\text{meat}} + \dot{m}_{\text{water}} \\ &= 27.7 \text{ kg/hr} + 24461.4 \text{ kg/hr} + 63835.2 \text{ kg/hr} \\ &= 88024.3 \text{ kg/hr} \end{aligned}$$

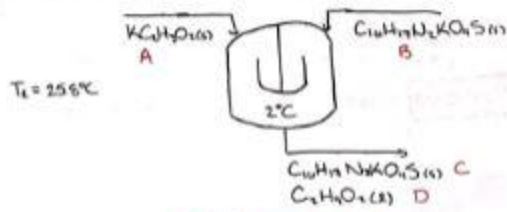
$$\begin{aligned} \dot{Q} &= \dot{m} \Delta \hat{H}_T \\ &= (88024.3 \text{ kg/hr})(61.077 \text{ kJ/kg}) \\ &= 5.38 \times 10^6 \text{ kJ/hr} = \text{heat absorbed by broth during rxn} \end{aligned}$$

$$\begin{aligned} \dot{Q}_{\text{cw}} &= -\dot{Q} = \text{heat that must be removed by water} \\ &= -5.38 \times 10^6 \text{ kJ/hr} \end{aligned}$$

$$\dot{Q}_{\text{cw}} = \dot{m}_{\text{cw}} C_p^{\text{cw}} [25.8^\circ\text{C} - 30^\circ\text{C}]$$

$$\begin{aligned} \dot{m}_{\text{cw}} &= \frac{\dot{Q}_{\text{cw}}}{C_p^{\text{cw}} [25.8^\circ\text{C} - 30^\circ\text{C}]} = \frac{-5.38 \times 10^6 \text{ kJ/hr}}{(4.184 \text{ kJ/kgK})(-4.2\text{K})} \\ &= \text{flow rate of incoming cw} = \boxed{2.62 \times 10^5 \text{ kg/hr}} \end{aligned}$$

Energy Balance across V-205 (Crystallizer)



$$\dot{n}(\hat{H} + \hat{E}_k + \hat{E}_p)_{in} - \dot{n}(\hat{H} + \hat{E}_k + \hat{E}_p)_{out} + \dot{Q} + \dot{W}_s = 0$$

Similar velocities *no elevation*

$$\dot{n}\hat{H}_{in} - \dot{n}\hat{H}_{out} + \dot{Q} + \dot{W}_s = 0$$

neglect kinetic

$$\dot{Q} + \dot{n}\hat{H}_{in} - \dot{n}\hat{H}_{out} = 0$$

$$\dot{Q} = \dot{n}\hat{H}_{out} - \dot{n}\hat{H}_{in} = \dot{n}\Delta\hat{H}$$

$$\dot{Q} = \dot{n} \sum c_p (2^\circ C - 25.8^\circ C)$$

$$C_p^A = 1.11 \text{ kJ/kgK}; C_p^B = 1.81 \text{ kJ/kgK}; C_p^C = 1.81 \text{ kJ/kgK}; C_p^D = 2.05 \text{ kJ/kgK}$$

$$\Delta\hat{H}_A = \int_{25.8^\circ C}^{2^\circ C} C_p^A dT; \Delta\hat{H}_B = \int_{25.8^\circ C}^{2^\circ C} C_p^B dT; \Delta\hat{H}_C = \int_{2^\circ C}^{25.8^\circ C} C_p^C dT; \Delta\hat{H}_D = \int_{25.8^\circ C}^{2^\circ C} C_p^D dT$$

$$\Delta\hat{H}_A = (1.11 \text{ kJ/kgK})(2^\circ C - 25.8^\circ C) = -26.418 \text{ kJ/kg}$$

$$\Delta\hat{H}_B = \Delta\hat{H}_C = \int_{25.8^\circ C}^{2^\circ C} (1.81 \text{ kJ/kgK})(2^\circ C - 25.8^\circ C) = -43.076 \text{ kJ/kg}$$

$$\Delta\hat{H}_D = (2.05 \text{ kJ/kgK})(2^\circ C - 25.8^\circ C) = -46.79 \text{ kJ/kg}$$

$$\Delta\hat{H}_T = \Delta\hat{H}_A + \Delta\hat{H}_B + \Delta\hat{H}_C + \Delta\hat{H}_D$$

$$= -26.418 \text{ kJ/kg} - 2(43.076 \text{ kJ/kg}) - 46.79 \text{ kJ/kg}$$

$$= -161.364 \text{ kJ/kg}$$

$$\dot{Q} = \dot{n}\Delta\hat{H}_T; \dot{n} = 5235.7 \text{ kg/hr}$$

$$= (5235.7 \text{ kg/hr})(-161.364 \text{ kJ/kg})$$

$$= -8.45 \times 10^5 \text{ kJ/hr}$$

$$\dot{Q}_{cw} = -\dot{Q} = 8.45 \times 10^5 \text{ kJ/hr}$$

$$\dot{Q}_{cw} = \dot{m}_{cw} C_{p,cw} [25.8^\circ C - 2^\circ C]$$

$$\dot{m}_{cw} = \frac{\dot{Q}_{cw}}{C_{p,cw} [25.8^\circ C - 2^\circ C]} = \frac{8.45 \times 10^5 \text{ kJ/hr}}{(4.184 \text{ kJ/kgK})(23.8^\circ C)}$$

$$= \text{flow rate of incoming cooling water} = 8485.71 \text{ kg/hr}$$

AVERAGE
PROJECT REPORT



Senior Design & Professionalism

CHEG 4247 P02

Dr. Martin Team #3

The Production of Single Cell Protein

Kaylon Atkinson

Shanelle Bryant

Chad Gardner

Oluwatoyosi Idowu

December 3, 2021

Letter of Transmittal

Prairie View A&M University
Department of Chemical Engineering
100 University Dr.
Prairie View, TX 77446

December 3, 2021

Dear Dr. Martin,

The following report details a design process that utilizes *Methylococcus capsulatus*, a methanotrophic bacteria, to produce single-cell protein. The process yields 150,000 MT of single-cell protein per year. This design process includes a batch operation, extraction, purification, and packaging of the final product.

The economic analysis and the feasibility for the process indicate very favorable results, especially given the high quality and purity of the final product. With a global market for SCP production predicted to reach US\$ 27.3 billion by the end of 2027, with a CAGR (Compound Annual Growth Rate) of 7% and global demand of 600 million pounds each year, we recommend the implementation of the design detailed in this report. Additional research should be performed to guarantee the safe implementation of the design, as well as analyzing a wider range of market applications for greater financial success.

Thank you for the guidance given throughout the duration of this project.

Sincerely,

Oluwatoyosi Idowu

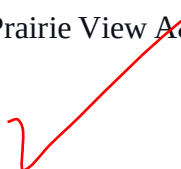
Kaylon Atkinson

Chad Gardner

Shanelle Bryant

Acknowledgement

We would like to express our sincerest gratitude to our advisors Dr. Martin and Dr. Gyamerah and the chemical engineering faculty at Prairie View A&M University for their invaluable guidance, comments, and suggestions throughout the course of this project. Finally, we would like to say thank you to the Prairie View A&M Industrial Council for their advice and inputs during this presentation.



Project Executive Summary

The purpose of this project was to design a Single Cell Protein plant to produce high-quality protein. Single-cell protein (SCP) is a microbial protein that is extracted from unicellular organisms such as bacteria, yeast, fungi, and algae. With a broad amino acid profile and an ability to produce essential organic compounds and vitamins, SCP is a promising alternative to classical protein. SCP is commonly used in animal feedstocks, food additives, and the pharmaceutical industry. With an increase in the demand for SCP for use in feedstock for aquaculture and farming for fish, the process outlined in this report produces 150,000 MT of SCP per year using *Methylococcus capsulatus*, a methanotrophic bacteria with Methanol and Nitric Acid as the carbon and nitrogen sources, respectively. The final product of SCP is sold at an average of \$1,650/MT. As the global market for SCP production is predicted to reach US\$ 27.3 billion by the end of 2027, with a CAGR (Compound Annual Growth Rate) of 7% and global demand of 600 million pounds each year, the profitability of the process is promising.

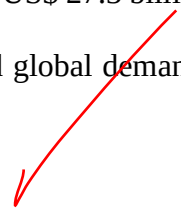


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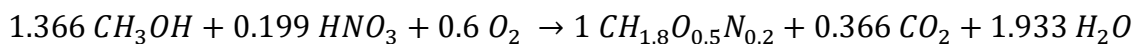
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1. Project Scope

1.1 Problem Statement

There is a growing awareness and popularity in today's world for single cell protein (SCP) as an alternative source of protein due to malnutrition being more prevalent. Prominent countries such as the United States, China, India, Indonesia, Vietnam, and Bangladesh are projecting an increase in SCP production by 2050. According to a recent report conducted by Transparency Market Research (TMR), the global market for SCP production is to reach US\$ 27.3 billion by the end of 2027, with a CAGR (Compound Annual Growth Rate) of 7% and global demand of 600 million pounds each year.

Consumers today demand nutritious foods with higher protein content, and high quality to encourage good health practices such as lowering overall body weight and cholesterol. There is also an increased demand for protein in aquaculture and animal feed, which require this specimen for the preservation of their stock to support market growth. Due to the increased demand for (SCP) in the United States and these nations, a new company has been established in Austin, Texas, to generate (SCP) through the bacteria cultivation of the *Methylococcus capsulatus* strand. The chosen method of production utilizes a methanotrophic bacteria, *Methylococcus capsulatus*, as the strain of choice, methanol as the carbon source, and nitric acid as the nitrogen source. The chemical reaction for this highly exothermic reaction is as follows:



Our goal is to establish a reliable supply of cost-effective, high-quality SCP that will successfully generate the much-needed protein to address the growing problem of malnutrition and protein deficit by operating a plant at a capacity of 150,000 metric tons per year.

REFERENCES/CITATIONS

1.2 Client Identification and Recognition of need

From our research of various literature reviews, we gathered that the global protein scarcity is at an all-time high, and the agricultural sector is being overwhelmed by the demand of meat and dairy it has to produce per year to maintain the growing population of people. Much of the recent interest in SCP is centered on the use of microbes to boost the protein content of side streams, which may then be used in animal feed and food additives. Countries like the United States, India, and China are interested in developing healthier foods with an optimal composition of low but high-quality amino acids and fats, combined with ethically sustainable production.

We will be providing Tyson (Houston, Texas) and Bluehouse Salmon (Sparks Nevada or Florida) our SCP products. Tyson is most known for its chicken, beef, and pork. They have one of the largest protein portfolios in their industry. In 2020 their net revenues were 43.2 billion which is a 2 percent increase from 2019. The seafood industry will always be a popular and growing industry, therefore, with Bluehouse salmon's main location being on the coast of Florida, there will not be a lack of resources. Although they are somewhat in the early stage of being in the fish industry, they supply about 400 thousand tons of salmon consumed each year. Their revenue increased from 5.5 million in 2019 to 6.3 million in 2020. This increase in revenue for both clients highlight the increased need for SCP in the market.

1.3 Project Goals and Objectives

Focus on the project activities

Our goal is to produce a reliable supply of cost-effective, high-quality SCP that will solve the growing problem of hunger and protein deficiency by providing much-needed protein. To achieve this goal, we came up with some objectives. We needed to research information about SCP; what it is, what it can be used for or what it is used in. We also thought about the location of our plant, what our feedstock would consist of and what the process is of producing single cell protein.

1.4 Contemporary Issues and Impact project society

1.4.1 Contemporary issues relevant to project

REFS

In previous years, finding alternative ways of providing food for people did not become such a concern until the population began to double unexpectedly and global protein scarcity became a growing issue. Research done by many concluded that if options are not thought of to take the pressure off the agricultural sector in providing various other protein options, then the growing malnutrition and protein deficiency will become worse. We hope that by producing high-quality and protein-rich SCP, we can contribute to lowering the global malnutrition problem that is safe and cost-effective for all.

How does this relate to SCP plants?

1.4.2 Potential impact of project on society

With a broad amino acid profile, a high protein content, and the ability to produce essential organic compounds and vitamins, SCP is a promising alternative to other classical sources of animal feed. Aquaculture and farming of fish are one of the fastest-growing food markets that heavily rely on the manufacturing of SCP. When used as a feed supplement for farmed salmon, one of the largest sectors of aquaculture, SCP serves as a nutritional additive and ensures that the salmon possesses its expected pigmentation. By implementing this project, we will be tackling 0.05% of the global demand for needed SCP to help tackle the increasing protein deficiency and the gap being created from the inability of classical protein sources to keep up with the growing populations' demand.

1.5 Project Constraints

capacity
economics
environmental
purity
safety

Since our research on SCP began, we have come across several constraints. Firstly, we considered yeast as our working microorganism from which SCP would be extracted, but we ran into difficulties finding detailed steps on the processes that could be used as a reference. After

consulting with our professor, we decided to use bacteria as our microorganism. Secondly, when choosing bacteria, we contemplated the raw materials that would be best suitable to efficiently grow our bacteria. Since the bacterial strain we decided on, *Methylococcus capsulatus* requires an adequate carbon source for optimum growth, extensive research was executed before concluding on the appropriate carbon source. Thirdly, we had to decide where our plant would be located. We debated whether it was more beneficial to be near our raw materials, or near our consumers. After much research, a decision was made that addressed both options. With a heat-sensitive product such as SCP, the different unit operating parameters we use can also have an impact on the quality of the final product. If we use an elevated temperature in our spray dryer to dry our product, then we risk damaging our product. After careful consideration, we concluded on our location, raw materials, and our unit operating parameter as they can have adverse effects on our process and final product.

2. Project Planning and Task Identification

2.1 Task Identification

The following is a detailed guide that lists the major tasks that we needed to achieve in order to complete this project.

Table 1. Task Identification list for project planning

Task Identification
Project Definition
Business Analysis and Cost Estimation
Safety and Environmental Regulations
Preliminary Process Design / simulation
End of semester presentation
End of semester report

2.2 Timelines

The main tasks were also broken down into subtasks along with their durations to obtain optimal planning toward the completion of the project.

Table 2. Detailed task identification table with included timeline

Task Identification Timeline	
Outlined Task	Timeline (Weeks)
• Project Definition ○ Literature Review ○ Microorganism and Process Research/Selection	10
• Business Analysis and Cost Estimation ○ Market and consumer interest ○ Raw material/production source ○ Plant Location	7
• Safety and Environmental Regulations ○ Storage & Handling ○ Packaging & Waste Disposal ○ OSHA, FDA, EPA Regulations	10
• Preliminary Process Design ○ Preliminary BFD & PFD/ Visio / Process Flow Sheet Development ○ Material and Energy Balances ○ Process Chemistry ○ Preliminary Simulation	6
• End of semester presentation	2
• End of semester report ○ Submission of fall report	2.5

I CAN'T SEE THIS

2.3 Gantt Chart

The organization of this fall semester project can be seen in the Gantt chart below in figure

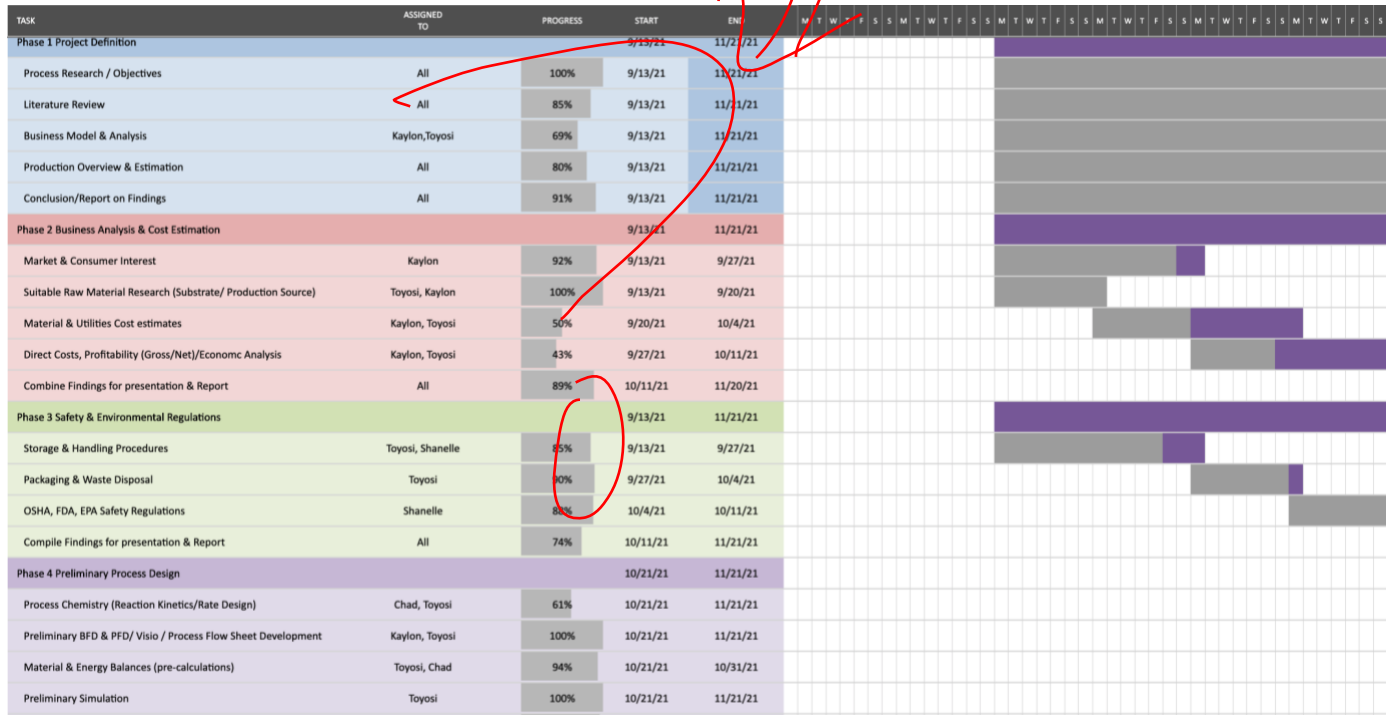


Figure 1. Gantt Chart for fall project detail

3. Overview of Manufacture of Single Cell Protein

3.1 Production of routes

What are the routes

Production of Single Cell Protein can be made from different microorganisms such as yeast, bacteria, fungi, and algae. The production routes for producing SCP are the same, it is dependent on the type of microorganism that is chosen. We initially chose yeast to grow our SCP, when we were unable to find adequate information to be used as a source of reference on the specific strain of yeast and the process carried out, we hit a roadblock. The attention of our advisor was brought to this issue, and we were advised to review our microorganism selection process. By doing this, we found a more suitable route for our production of SCP. Below is a table containing the different deciding factors for which microorganism is best suitable to produce our final product.

Table 3. Macromolecular composition and general properties of Microorganisms

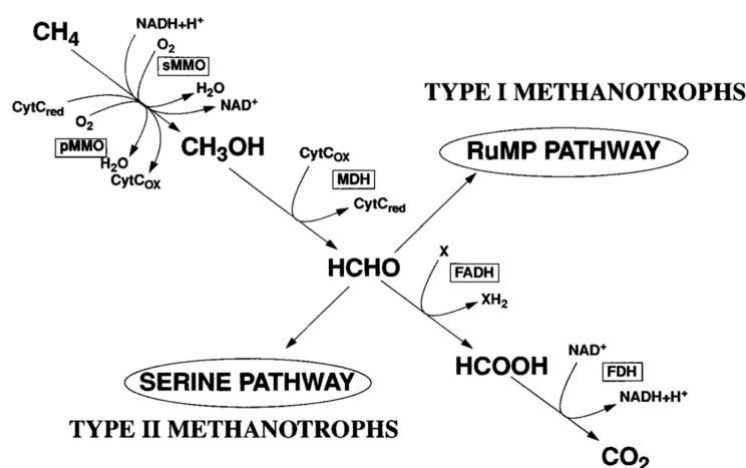
PARAMETERS	BACTERIA	YEAST	FUNGI	ALGAE
Doubling time (hours)	1-3	2-6	5-12	6-24
Crude protein (% dry cell weight)	40-80	40-60	30-45	40-50
Nucleic acids (%)	8-20	5-15	6-13	45-51 ^a
Carbohydrates and fats (%)	10-30	10-40	10-45	34.6-45
Ash content (%)	4-10	4-10	4-10	5-8
Temperature range (°C)	22-55	25-40	25-50	25-32
pH range	5-7	3-5	6-8	6.9-9.6

After careful consideration of the options given, we decided on using a bacterial strand as our choice of unicellular microorganism.

3.1.1 Methanol as carbon source

Written in wrong person.

With further research, we selected a methanotrophic bacteria known as *Methylococcus capsulatus*. Methanotrophic bacteria employ the use of methanol as a carbon source, and we chose nitric acid as our nitrogen source. The chemistry for methanotrophic bacteria using methane as a carbon source and converting it to carbon dioxide, one of the byproducts of the reaction, is outlined below in Figure 2. In this reaction, it is seen that methane is first converted to methanol. Methanol is then converted to formaldehyde and formic acid before being released as carbon dioxide.

Figure 2. Chemical pathway of methane converted to methanol as a carbon source

The decision to use methanol rather than methane as the source of carbon was made for several reasons. Methanol is easier to prepare and handle than methane, which helps in safety considerations. The cooling requirement for methanol when compared to methane is much lower as methane produces more heat than methanol. This is because the heat of conversion of methane to methanol is highly exothermic, therefore, contributing to the overall heat in the reaction. The overall cost of handling methanol is also much lower when compared to that of methane. Methane requires a greater amount of oxygen to be fed into the process. By doing so, there is a greater concern for flammability and explosivity. As methane is a natural gas product, it is much more difficult and expensive to handle gas. Methanol on the other hand can be handled as a liquid. As a large quantity of methanol is needed for this process, the storage and delivery of methanol are more economical and convenient.

3.1.2 Nitric acid as nitrogen source

Nitric acid was selected as the source of nitrogen for this process. It is a highly corrosive and strong mineral acid. Ordinary nitric acid has a concentration of 68% with water occupying the other 32%. This percentage causes the acid to be readily safer for usage. Nitric acid is often used as the starting material in industrial processes that require nitrogen sources for things such as fertilizers. They are also excellent neutralizers when mixed with ammonia to form ammonia nitrate. Nitric acid in this concentration is readily available in bulk quantities and is cheaper due to its common usage. The decomposition of nitric acid results in water, nitrogen dioxide, and oxygen. This contributes to the increased amount of water being generated in this reaction.

IMPROPER VOICE
FOR Technical Report.

3.2 Physical and chemical properties

Below is the physical and a chemical property of our raw materials.

Table 4. Physical and Chemical Property of Methanol

Parameters	Value
Molecular Weight	32 g/mol
Chemical Formula	CH ₄ O or CH ₃ OH
Color	Colorless
Physical State	Liquid
Odor	Slight alcoholic when pure
Boiling Point	64.7°C
Melting Point	-97.6°C
Vapor Pressure	18.7 Kpa @ 27°C
Solubility	Miscible with water @ 20°C

Table 5. Physical and Chemical Properties of Nitric Acid

Parameters	Value
Molecular Weight	63 g/mol
Chemical Formula	HNO ₃
Color	Transparent
Physical State	Liquid
Odor	Sweet
Boiling Point	83°C
Melting Point	-41.6°C
Vapor Pressure	6.4 Kpa
Solubility	Miscible with water

3.3 Handling, storage, and safety

Handling, storage, and safety is unarguably the most important aspect of this design process. Not only is it essential to adequately handle the raw materials involved in the production

of SCP, but the final product must also be carefully handled because it is being consumed/ingested by living organisms.

3.3.1 Handling

Correctly handling methanol and nitric acid are very vital in ensuring that we have a safe environment for everyone. Both chemicals are considered highly flammable, toxic if swallowed, and corrosive. They can cause severe damage to the skin and eyes. Safe work practices include avoiding ignition sources and ensuring that all personnel are equipped with the proper protective equipment (PPE).

3.3.2 Storage

Methanol, Nitric Acid, and SCP storage are overly critical in ensuring safety for everyone. Highly flammable methanol has to be stored at 20°C in 300 series stainless steel alloy tanks and ventilated to prevent accumulation of oxygen vapors. Additionally, the use of proper electrical grounding and bonding is essential when storing methanol. Nitric acid also has similar storing requirements. It must be stored below 0°C in a tightly closed stainless steel container in a cool, dry, and well-ventilated location away from light. Our product SCP must be stored in an airtight bin with less than 10% of moisture to prevent spoilage. Our bacteria *Methylococcus capsulatus* must be stored in a freezer that is -80°C or lower.

3.3.3 Safety

Exposure to methanol can cause severe and sometimes acute toxic effects even from a single exposure. General symptoms can include irritation of eyes, skin, respiratory tract, dizziness, headaches, and vomiting. Even though methanol is poisonous, it is consumed unknowingly in trace amounts by humans in some foods and beverages. As a result, when handling methanol, it is best to wear the appropriate personal protective equipment to prevent contact with the skin and other organs. Nitric acid can also cause severe issues to the body if it ever encounters it. It is

recommended that in the workplace, chemical safety glasses should be always worn, splash protection shield, gloves, and a vapor respirator to further prevent any respiratory issues.

3.3.3.1 EPA, OSHA regulations and environmental impact

The Hazardous Air Pollutant (HAP) identifies methanol as being hazardous. It is dangerous to aquatic life in concentrations but can be biodegradable in soil and water very rapidly. Methanol is also listed in the US Toxic Substance Control Act but is only hazardous when it is above 5000lbs. The Occupational Safety and Health Administration (OSHA) has nitric acid exposure limit set to 5mg/m³, if there is exposure above that level then it causes serious health issues for life. Nitric Acid is also considered highly corrosive by the Center for Disease Control and Prevention (CDC). Our Single Cell Protein process gives off copious amounts of CO₂. According to OSHA, it is considered hazardous and 40,000 is considered dangerous to life. Our biomass and water that is given off from various equipment, can be used as fertilizer in the agricultural sector.

3.4 Uses

Single Cell Protein can be used in a variety of products and can also be used to make a variety of products. Some of those products include animal feed to fatten cattle, chicken, pigs, and fish. Pharmaceutical companies as well use SCP in supplements for hair and the face. We plan to make SCP that can be used in food additives such as vitamins and to enhance foods such as soups and ready-made meals.

3.5 Product specification

Single Cell Protein derived from a unicellular microorganism such as bacteria, yeast, fungi, and algae are a high protein content alternative to plant-based proteins for animal feed and aquaculture. According to the literature, SCP has the potential to replace approximately 50% of

AWKWARD

fish meals. The market for SCP is globally growing to meet the increasing demand. The utilization of bacteria to produce our SCP results in a minimum to 20% more protein content when compared to the other alternatives. With the processes selected for harvesting our cells, further concentrating them, extracting the protein from the cell biomass, and purifying it, the expected purity for our SCP is 99.9% in its final and solid-state with a plant operating with a capacity of 150,000 MT per year operating for 340 days.

4. Process selection

4.1 Market analysis and trends

Single Cell Protein production is vastly growing over the years and is expected to continue increasing. The Transparency Market Research (TMR) team stated that the market for SCP production is projected to cross US\$ 27.3 billion by the end of 2027. We also have a Compound Annual Growth Rate (CAGR) that provided the rate of return to be 9.3% annually and estimated global demand for SCP to be 600 million pounds per year.

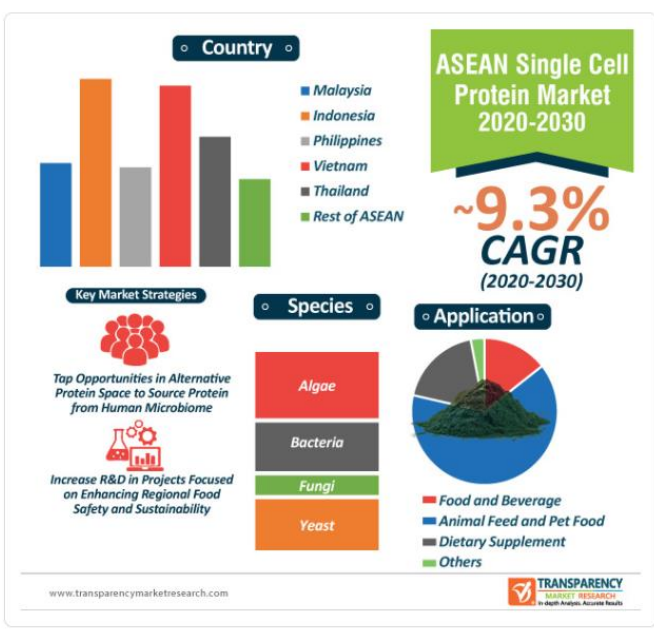


Figure 3. Compound Annual Growth Rate (CAGR) graphs

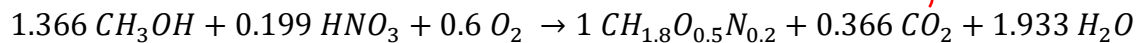
The above figure displays the CAGR of SCP's rate of return annually and the estimated global demand per year.

4.2 Reaction routes to producing the product

Awkward language

Even though Single Cell Protein can be extracted from different microorganisms, the reaction routes are similar for all of them because the products are the same for all reactions.

Below is the formula for production of SCP. As shown, the products are biomass where we extract protein from carbon dioxide and water. This process does not produce other reactions other than the products.



Really?

4.2.1 Industrial process and lab/patent routes have been reported to be used for producing Single-Cell Protein

Several patents for the production of SCP utilizing a methanotrophic bacteria is existent. U.S Patent 4,048,013, titled Process for producing single-cell protein from methanol using methylomonas sp. DSM 580, was established in 1976. The patent describes a process for preparing single cell protein from methanol. The process utilizes the bacteria Methylomonas sp. DSM 580 as the obligate methanol-assimilating bacterium for the extraction of single cell protein. Several companies like Cargill and Calysta have highly effective processes in place for producing high quality SCP from either methanol or methane.

4.2.2 Reaction route 1

The production of Single Cell Protein does not produce any side reactions.

Really?

4.3 Process screening by comparing the process economy of the reaction routes (the monetary difference between the value of the products and costs of the raw materials)

Reaction	1.366CH ₃ OH + 0.199HNO ₃ + 0.6O ₂ → CH _{1.8} O _{0.5} N _{0.2} + 0.366CO ₂ + 1.933H ₂ O					
lb.mol	1.366	0.199	0.6	1	0.366	1.933
Molecular weight	32	63	16	24.6	44	18
Lb.	32	63	16	24.6	44	18
\$/gal	50		0	402 each	0	0

4.4 Process comparison and selection

In order to achieve cost efficient single cell protein, the prices of each raw material needed for production have an extraordinarily strong impact. Since we are specifically producing single cell protein from our bacteria strand "*Methylococcus capsulatus*," that it will be affordable and worth the amount that will be given. From one of our sellers the American Type Culture Collection (ATCC) we are able to get the strand for \$402. The microorganism competitor to bacteria is yeast, in which with their most commonly used strand being the *Saccharomyces cerevisiae*, we would have been charged over \$140 more that could have gone to another area that needed more attention.

Our process specifically uses a batch reactor instead of a continuously stirred reactor or CSTR as our fermenter. This plays an important role in ensuring the purity of our production so that no contamination can be found. With the CSTR reactor, our process would continue to be running the contaminant through our equipment which we will as a result, we will need to stop each individual system in order to clean it out. This will take more time out of our scheduled production day and will cost us money that could have been made. All of the raw materials that was used in that contamination incident would have just gone to waste, and more labor work will have to be done for the cleaning process. However, with our batch reactor if a similar case was to occur, there would not be much stress. The batch reactor, like in its name, is only used to create one batch which allows us to clean and sterilize the reactor before the next production is set to

run. During this process, less raw materials will be wasted if there is contamination and will only be a minor setback.

phase review and revise

5. Process description

Many raw materials must be introduced into our bioreactor systems that will enable pH control, protein creation and aerobic cell growth of our choice of bacteria. The raw materials consist of methanol, nitric acid, and oxygen must be carefully prepared and stored in appropriate conditions to enhance maximum growth of cells and ensure safety. There will be storage tanks for nitric acid and methanol along with minerals, the design specification that are described in section 3.3.2. Air will be compressed and filtered before use of oxygen source for fermentation, which will require careful handling to avoid contamination and prepare the gas for inlet to the bioreactors. With the use of air instead of pure oxygen, a significant amount of nitrogen gas will be introduced into the system and will have vented for release to the atmosphere.

5.1 Process chemistry

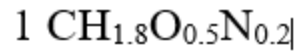
nothing else produced?!

Since there is only one reaction for the production of single cell protein, the following reaction occurs:



5.1.1 Reaction stoichiometry

The balanced single cell protein reaction (1) shows that for every mole of methanol, 1 mole of biomass along with carbon dioxide and water will be formed. This stoichiometric relationship can be shown below as:



5.1.2 Kinetics and rate equations

The Batch model constitutes a liquid phase in the bioreactor, where oxygen from compressed air is transferred from a gas to the liquid phase which is therefore sufficient to model the liquid phase. From this we were able to develop reactor designs for our process which are displayed below:

$$dN_x/dt = r_x \cdot V \text{ (Biomass)}$$

$$dN_s/dt = r_s \cdot V \text{ (Methanol)}$$

$$dN_o/dt = r_o \cdot V \text{ (Oxygen)}$$

$$dN_n/dt = r_n \cdot V \text{ (Nitrogen)}$$

use equation editor

5.2 Process (Block) flow diagram and process description

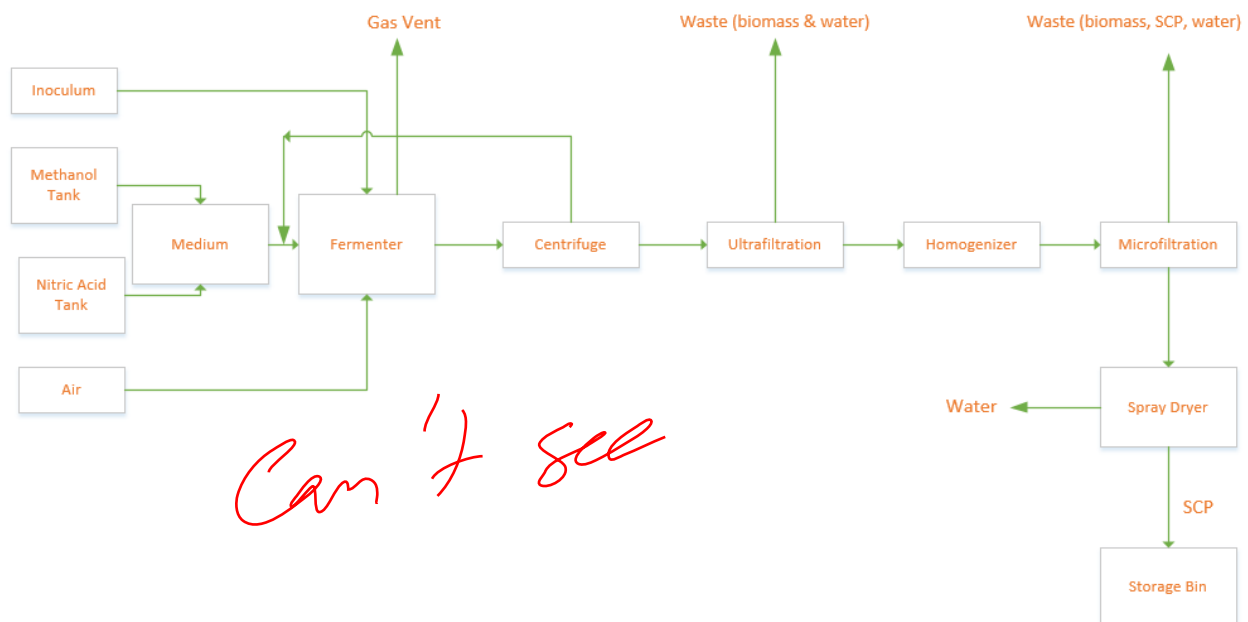


Figure 4. Block Flow Diagram for the production of Single Cell Protein

This block flow diagram gives a clear overview of the production of Single Cell Protein in a plant. In this block flow diagram, only the major units are represented in order to show the important process functions.

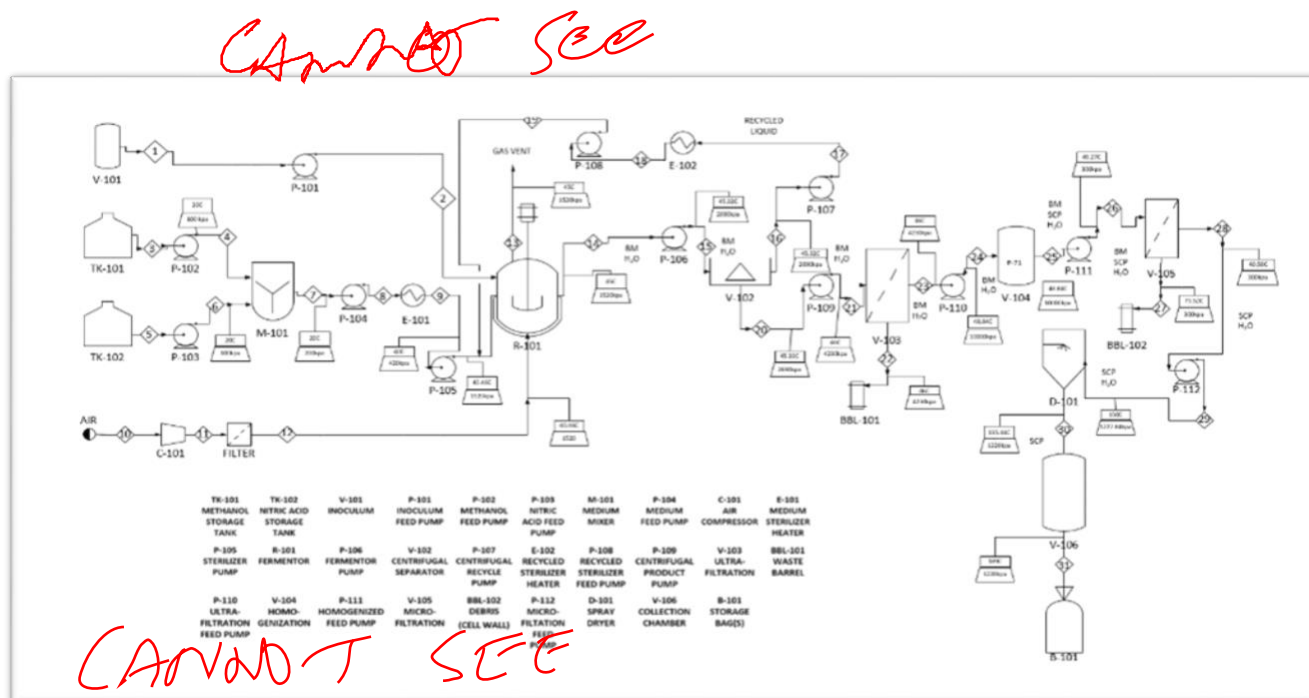


Figure 5. Process Flow Diagram for the Production of Single Cell Protein

For our process, we needed a medium that would contain our minerals such as magnesium, and phosphorus which are some of the essential minerals needed in protein. With our raw materials methanol and nitric acid, our oxygen, and inoculum all going into our batch fermenter, this is where the actual process begins. After being mixed, it is then sent to a centrifugal separator where the biomass is separated. The recycled liquid is ~~then recycled back to the fermenter to be used again in the process but will go through a sterilizer first before going back into the fermenter.~~ After separation, the biomass is then sent to an ultrafilter where it is then filtered more into our desired product, some of the biomass, and more water is given off as waste. Biomass is then sent to a

homogenizer; this is where the biomass is then lysed, and we get our SCP. Exiting the homogenizer, biomass, SCP, and water is pumped to a microfilter where the biomass and SCP are further filtered, and we are now left with our SCP. Unused biomass, SCP, and water are also given off from the microfiltration system as waste which can be used as fertilizer. Our SCP is then pumped to a spray dryer, where SCP is dried at 150°C. After it is dried, we have our desired product.

5.2.1 Raw material preparation

The raw materials that will be utilized in the production of single-cell protein require a source of carbon, nitrogen, and oxygen along with nutrients such as magnesium, phosphorus, and additional minerals required for production. Our choice of carbon source for production is methanol, as it is the main driving force for production when reacted with the bacteria *Methylococcus capsulatus* due to its high productivity. Typically, in the industry, most companies producing single-cell protein prefer using simple sugars such as glucose as their carbon source for production. However, for our process, methanol has proven to be even more successful in protein production using bacteria without any harmful outcomes and trials based on research. Our source of nitrogen will be an azeotropic mixture of Nitric acid and our Methanol will be sourced from Lab Alley in Austin, Texas.

5.2.2 Reaction and reactor operation

The process to produce Biomass from our bioreactors was carried out at a temperature of 45°C (113°F). Since our reaction is exothermic, a vast amount of heat will be released from the bioreactor, which will then be quenched by cooling water to maintain the quality of the effluent leaving the bioreactor for further purification and separation purposes to attain our desired product of SCP. For our process, we will use a Fed-Batch reactor instead of a continuous process.

The many reasons for using a fed-batch process focus on its multi-use capabilities when dealing with biological processes as well as quality control and waste reduction. Because our process requires a pre-prepared inoculation of bacterial cells before it is used within the reaction, it has the potential of causing contamination which would degrade the quality of our desired product or flooding within the vessel if too much feedstock is fed into the reactor, which would result in the cells being washed out. Batch processes mitigate this issue by allowing for scheduling of cleaning time periodically to maintain the quality of our product. The pressure of the reactor was around 2.5 bar (36.3 psia) with an increased air pressure of 10 bars (145 psia). The reactor is maintained at these conditions to improve cell-mass yield and specific growth rate of the Biomass produced. In the production of single-cell protein, there is no alternative catalysis involved in making our product, however, a metabolic catalytic reaction occurs within the reactor when the carbon, nitrogen, and oxygen source are introduced to the medium along with the inoculated cells. The fed-batch reactor is very efficient for microbial processes such as the production of SCP and has low operating costs. Stainless steel would serve as the ideal material component to build the reactor to avoid corrosion.

5.2.3 Separations

There are 4 main vessels for the separation processes occurring in the process. The first, V-102, represents the centrifugal separator. This equipment handles the concentrated biomass and water generated from the bioreactor. The concentrated biomass with some water is sent to V-103. V-103 represents our ultrafiltration unit with the primary function of further concentrating our biomass and eliminating more water from the process. This process occurs similarly to reverse osmosis, using hydrostatic pressure to force water through a semi-permeable membrane to retain solutes and suspended solutes of high molecular weight. V-104 is our homogenization unit that is

operated at high pressure to lyse the suspended solids of biomass to extract our desired product, SCP. V-105, Microfiltration separates the cell debris left from the biomass from our SCP product. The latter is then sent to D-101, our spray dryer to get the SCP in its final form before packaging.

5.2.4 Product to storage

Following the final processing step, SCP is sent from the spray dryer and divided into storage bags located in a safe, humidity-controlled building. The product is stored in this manner because any moisture higher than 10% can cause spoilage to the product. If this occurs, we would be unable to transport that batch of SCP to our clients.

6. Material & Energy Balances

The overall material balances for this process were done to determine the flow rates of all the feed components. We did this to ensure that we had the right amount of feed to produce our target flow rate. This also allowed us to know how much waste our process will be producing. The material balances were also done around each unit in our process including the fermenter, centrifuge, ultra and microfiltration, homogenizer, and spray dryer.

6.1.1 Basis of calculation

By analyzing the market, and looking into other plants that produce SCP, the annual growth rate indicates that the need for SCP will increase. Our goal was to produce 150,000 metric tons of SCP per year. The plant will be operating at 93% in a year which translates to a production run time of 8,160 hours (about 11 months) or 340 days during the year. The time that is set aside will be for maintenance and if any downturns may encounter. Based on how much SCP the plant needs to produce in an hour, the required feed was calculated, and the material balance was done around each unit.

6.1.2 Material Balance around each unit

Bioreactor

In the bioreactor, the feed streams from our inoculum, sparged oxygen and medium mixer which has our nitric acid, methanol, and minerals are combined. An illustration is displayed in Figure 6 below.

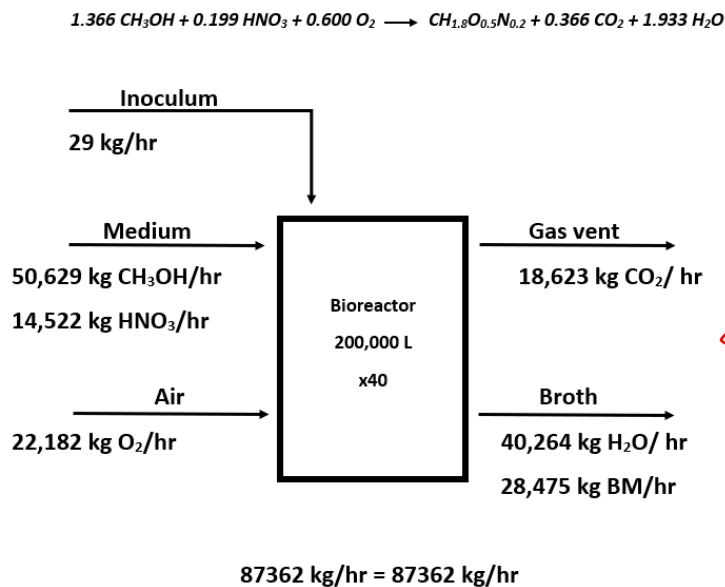


Figure 6. Bioreactor Material Balance

Centrifuge

The combined raw materials create a broth which contains biomass and water, that is then fed into a centrifuge to be separated. The flow rate of

6.1.3 Assumptions and use of heuristics

6.1.3 Overall material balance with process streams

6.2 Energy Balances

7. Discussion

8. Conclusions & recommendations

9. References

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BELOW AVERAGE
PROJECT REPORT

Plant Design of Production of Urea using Natural Gas

Prairie View A&M University

Roy G.Perry College of Engineering

Department of Chemical Engineering



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Submitted To: Dr. L.L. Martin

Date: December 6, 2021

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Letter of Transmittal

December 8, 2021

Roy G. Perry College of Engineering-Chemical Engineering Department

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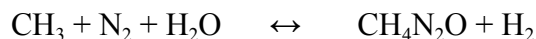
TO: Prof. L.L. Martin

FROM: Meredith Meyer, Cherish Vaughn, Garred Essissima, Shumpert Kirksey

RE: Simulation Case Study for the Design of a Urea Plant

In response to demand for Urea, a local manufacturing company is considering the addition of a urea plant. This company has asked our team to come up with preliminary designs for this addition. The sales department has estimated that they can sell 100,000 tons of urea per year looking at a price of \$.60/lb.

Urea will be made from natural gas, air, and water, via a synthesis reaction:



The natural gas, air and water are used to create ammonia and carbon dioxide using the Haber process. Ammonia is a highly corrosive chemical in the gaseous form, but this process uses the liquid form produced by the catalytically reacting hydrogen from natural gas and nitrogen. The reaction is accelerated with the use of an iron catalyst. We can expect near equilibrium conversions of ammonia and gaseous carbon dioxide to urea with a minimum temperature of 435K.

Please have your team do the preliminary energy and material balances for a urea plant, including the sizing of all heat exchangers. The sizing on reactors is not critical at the time being. The reactor temperature should not exceed 500K. The molar NH_3/CO_2 ratio in the reactors should be between 1.5:1 and 3.5:1. We have been informed that energy costs must be minimized, so please make every effort to make this an energy-efficient process. The members of Martin Team 7 are available to answer any questions regarding this report.

Best regards,

Cherish Vaughn, Meredith Meyer, Garred Essissima, Shumpert Kirksey

Make this shorter.
It should not provide details, only the major points.

Acknowledgements

We would like to express our deepest appreciation to individuals who assisted our team in completing Senior Design & Professional I. Thank you to our senior design professors, Dr. Lealon Martin and Dr. Emmanuel Dada for their constant and consistent support throughout this semester.

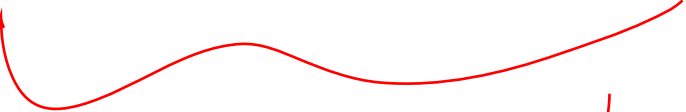
We would also like to thank the Prairie View A&M University Department Of Chemical Engineering Alumni and Industrial Advisory Council for their advice, future consideration, and encouragement given to us to help improve our project.

Project Summary

The objective of this project is to design a profitable urea plant using natural gas. A project's success and completion is dependent on several factors and criteria. A market analysis and knowledge of the urea production in the United States is essential to design a plan with an appropriate capacity to satisfy product demand.

Following the determination of the plant capacity, the production must be chosen by the economic indicator which determines if the process is feasible and efficient. The most sustainable production method will be selected. Material and energy calculations are conducted around each unit and the entire process.

Next, the selected production route and the calculated values are used to simulate the process through HYSYS Aspen. The simulation gives a visual presentation of the process feasibility in steady state conditions. The overall goal for the project was creating a practical urea plant after considering factors such as raw materials availability, economic feasibility and plant safety.


clean-up language.

1. Project Scope

1.1 Project Statement

Due to the increase in demand of urea globally, the fertilizer market, and wide ranges of applications, our team decided to develop a urea plant design using steam methane reforming (SMR) to produce synthetic ammonia. Synthetic ammonia will react with carbon dioxide to create urea. In our overall process, ninety eight percent of synthetic ammonia is produced by catalytic steam reformers. Hydrogen is the lightest element on the periodic table and the most abundant substance in the universe. Natural gas is a feedstock primarily because it decreases air pollutants and greenhouse gas emission. Hydrogen is a clean energy source which only generates water and heat as co-products. Our plant will operate at a production capacity of 100,000 tons of urea and this will be produced three hundred and fifty days a year.

Our product will be sold to fertilizer makers or directly used as ammonia nitrate and monoammonia or diammonia phosphates which are raw materials in polymeric resins, explosives, and nitric acid (1). Natural gas is reduced to carbon and hydrogen which is purified by nitrogen to make synthetic ammonia. The chemicals that are produced as by-products in the steam reforming process include hydrogen sulfide (found in natural gas), carbon monoxide and water. Our team will research how to provide proper handling, safety, and storage which will be explained further in the report. We decided to locate our plant in Louisiana due to natural gas pipelines and fresh water access.

1.2 Client Identification and Recognition Of Need

The demand for urea is projected to continue to increase to 800 million tons by 2021, the agriculture market plays an important role in (Good 2021). Our team plans to meet 5% percent of this demand , therefore our production capacity was estimated to be 100,000 tons of urea. The global market for granular urea is expected to reach 2600 tons due to the large production in India and China. The United States imports more urea than produce due to the weather conditions in Louisiana. Our customer base is the agriculture industry and targeted consumers are National Fertilizers, Neuchem and Yara.

We are focusing on selling our product to the companies stated above as the development of urea increases. Our determination and communication of urea plant production has on the environment and the agriculture industry provides a profitable selling point in the Louisiana area.

1.3 Project Goals and Objectives

The goal of this project is to design a urea plant that produces 100,000 metric tons.

Objective / Deliverables

1. Create a process flow diagram (PFD) of the plant
2. Provide a detailed process description with safety considerations for chemicals used
3. Perform material and energy balances of overall process and around each unit of major equipment
4. Obtain a converged simplified Aspen HYSYS simulation of the process.
5. Present a final presentation and complete a final report detailing our project progress.

focus this around design activities. For example you determined plant capacity

good.
you have
customers

1.4 Contemporary Issues and Impact of Project on Society

1.4.1 Contemporary Issues Relevant to Project

Urea is a synthetic nitrogen fertilizer that helps grow fresh produce to feed a large portion of the world's population. Its production requires a complex reaction between ammonia and carbon dioxide. Approximately eighty percent of all ammonia globally is used to produce urea. The Haber-Bosch process, the process that produces ammonia, requires high temperature and pressure. The production of urea consumes a great amount of energy. It also discharges the most carbon dioxide of all industrial chemical reactions due to its fossil fuel feedstock of natural gas. (Patel 2020)

1.4.2 Potential Impact of Project on Society

Nitrogen fertilizers are essential for agriculture and necessary for food production around the world. When crops grow, they remove nutrients from the soil. The limiting nutrient in soil is nitrogen, and N-fertilizers are important because they help replenish the lost nutrients. Without them, food production would only be able to support an estimated 50% of the world's population. N-fertilizers, such as urea, provide food security for the globe. (Driver, et al. 2019)

1.5 Project Constraints

For this project, there were numerous challenges. Information on process operating parameters is scarce regarding urea production. From literature review, it was difficult to obtain temperatures and pressures for equipment that were consistent. The operating parameters varied by equipment size and feed flow rate. Another constraint was that our reactor could not exceed 500K.

2. Project Planning and Task Identification

2.1 Task Identification

To complete semester project, we divided our project into phases three which are shown below:

1. Phase 1- Lecture Search and Process Selection
2. Phase 2- Project Design & PFD
3. Phase 3 - Report

2.2 Timelines

Each phase has a subset task with assigned deadlines.

1.Phase 1- Lecture Search and Process Selection (9/11/21-10/2/2021: 21days)

A) Complete preliminary in depth research on the product

- i) Research process methods and alternatives process to gain understanding over project

B) Create an problem statement & design brief

- i) Introduce the project and its purpose, constraints/limitations & design parameters

C) Provide an economic indicator & pick the final process

- i) Evaluate the best production routes and pick the most profitable design

D) Identify the client & demand of the product

- i) Determine the demand of our chemical plant & find plant capacity

2. Phase 2 -Process Design (10/9/2021-11/19/21: 41 days)

A) Design a block flow diagram (BFD) of the production of process

- i) Provide an simple drawing of the process to understand each major equipment
- ii) Identify inputs, outputs and recycle streams

B) Design a process Flow Diagram (PFD) of the production of process

- i) Determine process layout for flow streams and equipment.

C) Perform material and energy calculations for the complete process

- i) Determine how much material is coming and leaving the system
- ii) Energy balance determines the temperature and heat coming out of major equipments

D) Determine process safety considerations

- i) Ensure proper safety, storage, and handling of chemical used in our process

3. Phase -Reporting (11-19/21-12/6/21: 18 days)

A) Homework assignments

- i) Test knowledge on concepts taught in class

B) Final end of semester presentation

- i) Showcase understanding of process

C) Final Report

- i) Detail summary of the overview of project and accomplishments

2.3 Gantt Chart

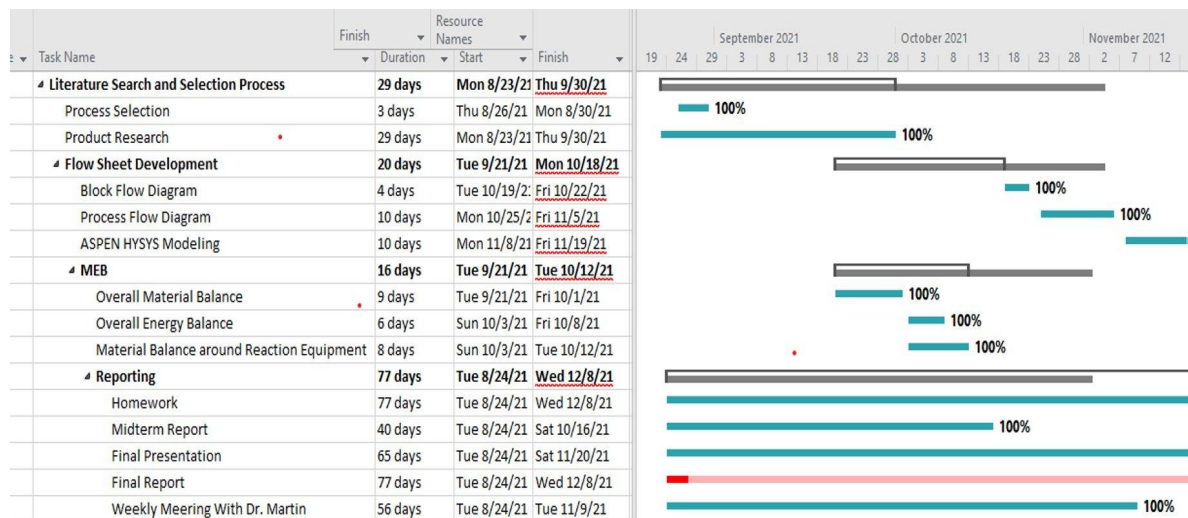


Figure 1: Gantt Chart (Semester I)

3. Overview of Manufacturing Urea using natural gas

Citation missing.

Urea is a low cost fertilizer with the highest nitrogen concentration. Urea production is a two step process, where ammonia and carbon dioxide are reacted to form ammonia carbamate

which is dehydrated to form urea. The urea solution is evaporated into a priller to form pure granules. Ammonia can be produced from many fossil fuels (natural gas and fuel gas) or even renewable resources(eg, biomass and biomass gasification).Natural gas is synthesized in the ammonia/ urea production which requires maximum H₂ production. The most common synthesis gas production is steam reforming, partial oxidation, and autothermal reforming. In the overall process we pick steam reforming due lower energy consumption and cost. All techniques has offer valuable results in product urea, however production via steam reforming is widely favored in the chemical industry,

3.1 Routes of Production

Producing urea from natural gas is a complex process. The first portion of the process produces hydrogen. Hydrogen can be produced by steam reformation, partial oxidation, and autothermal reformation. All the processes utilize natural gas as the primary feedstock, but they differ in secondary feedstock. Steam reformation uses steam as the secondary feed. Partial oxidation uses oxygen as the secondary feed. Autothermal reformation uses both steam and oxygen as secondary feed stocks. The next step in the process is ammonia production. Ammonia can be produced using the Haber-Bosch process, indirect electrochemical synthesis processes, and membrane reactors. The last step in the process is urea production. Technologies for urea production include Kansai Mitsubishi Carbon Dioxide Recovery Process (KM CDR Process ®), Stamicarbon process, and Snamprogetti process.

3.2 Physical and Chemical Properties

Urea appears to be light brown or yellow odorless and crystallized solid. Hydrogen is nontoxic, nonmetallic, nontonic, tasteless, odorless, colorless and highly combustible gas that can be found almost anywhere in the world in the form of chemical compounds. Tables 2 and 3 will show the chemical and physical properties of urea. Hydrogen gas is the byproduct of the production of ammonia and will be properly handled.

Table 1: Physical Properties of Urea

Color	White crystals or pellets
Phase	Melting point of 407°K
Odor	Odorless

Taste	Cooling, saline taste
Density	1.32 g/cm ³
Solubility	Soluble in water ethanol and ammonia

Table 2: Chemical Properties of Urea

Chemical Formula	NH ₂ CONH ₂
Oxidation	Decomposition of urea by strong oxidants When heated to decomposition it emits toxic fumes of nitrogen oxides
Reactivity	Oxalic acid and urea react at high temperatures to form toxic and flammable ammonia and carbon monoxide gases, and inert CO ₂ gas.
Flammability	non flammable
Combustion	Urea decomposes to ammonia and isocyanic acid, the latter leading to biuret, cyanuric acid and ammeline formation

3.3 Handling, Storage and Safety

When operating at a chemical plant, it is very important to have a deep understanding of how chemical species within the process should be handled in order to operate safely and efficiently.

3.3.1 Handling

When handling urea provide a well ventilated area and do not smoke and eat when handling the product. In the steam reformation process hydrogen will be handled, do not smoke where hydrogen is generated or being used. Remove all possible sources of flame and sparks. Hydrogen should be generated and used in well ventilated areas. Precautions must be taken to remove all positives or fire explosives (Hydrogen Data Sheet).

Crossin)
units!!

3.3.2 Storage

Urea can be stored at ambient temperatures and stable at normal conditions. Hydrogen can be stored as either gas or liquid. Storage as gas typically requires high pressure tanks 5,000-10,000 psia tank pressure. Storage of hydrogen as liquid requires cryogenic temperatures because the boiling point of hydrogen at atmospheric pressure is -252.8°C. (Hydrogen Storage).

In the SMR process H₂ gas needs to be properly handled and stored properly to carry out a safe process. Table 4 shows a list of major by-products that are carried in the process.

Table 3: Handling and Storage for Major Chemicals in Urea

Species	Phase	Handling	Storage
H ₂	Gas	Keep away from heat, sparks, and open flame. Use only spark-proof tools explosion-proof equipment	Store with adequate ventilation. Store where temperature will not exceed 125°F
CO ₂	Gas	Avoid breathing gas Do not get in eyes, on skin, or on clothing. Ventilate space before entry. Verify sufficient oxygen concentration	Store away from directed sunlight in a dry, cool, and well ventilated area away from incompatible material and ignition sources
CO	Gas	Do not get contact with eyes or skin. Use only in adequate ventilation Do not breathe gas and only use non-sparking tool	Store away from directed sunlight in a dry, cool and well ventilated area, away from incompatible material and ignition sources

Table 4: Safety Hydrogen Gas Hazardous,First Aid & Prevention

Hazard Statements	Fire/Accidental Release Measures	Prevention Controls	First Aid
● Extremely flammable gas. ● Contains gas under pressure may explode if heated ● May displace oxygen and cause rapid suffocation ● Burns with invisible flame	● If involved in fire, shut of completely ● Fight fire from protected location ● Wear respirator when ventilation is not available ● Keep necessary PPE when entering	● Engineering controls keep the gas, vapor or dust concentrations below any lower explosive limits ● Emissions from ventilation should be checked or work process equipment should be checked to ensure they meet requirements of environmental protection legislation.	● Eye Contact- Immediately flush with plenty of water ● Inhalation- If too dangerous to give mouth-to-mouth resuscitation. Get medical attention ● Skin contact- To avoid risk of static discharge and gas ignition soak contaminated clothing with water

3.3.4 EPA , OSHA Regulations and Environmental Impact

During the steam methane reformation process, large amounts of CO₂ are co-produced and small amounts of hydrogen emissions escape the plant which increases global warming. OSHA states that atmosphere with greater than 10% of lower flammability is immediately dangerous to health and life and entry is not allowed (OSHA, 2016). In the urea process, ammonia gas and carbon dioxide are flared out into the environment.

Due to hydrogen being lighter than air which makes it difficult to recognize. Hydrogen as low minimum ignition energy, it can ignite with any small ignition source. OSHA recommends hydrogen storage tanks to be permanently labeled. OSHA also states the venting piping must be designed so that “moisture cannot collect or freeze in a manner which would interface with propeller operation of the device” (OSHA Part 1910). Urea is

As environmentally stable, hydrogen will be stored in ventailed areas. Any effect on animals would be related to an oxygen deficient environment.

3.4 Uses

Urea product is primarily used in the fertilizing industry which has wide ranges of applications. Some of the applications include feedstock, glue and commercial products. Urea fertilizer has a high nitrogen concentration which promotes faster growth to plant life .

3.5 Product Specifications

Our urea product is analysed for its concentration and granule size. Our urea product is checked for; moisture, biuret, formaldehyde, and pH. We make these checks to make sure our product meets customer standards.

Table 3: Urea Specification Table 3

Components	Concentration
Nitrogen	46% Minimum by weight
Biuret	1% by weight
Moisture content	0.3 Maximum by weight
Sizing	2-4mm by weight
pH	3.6 to 7.2

How is this determined?

4.Process Selection

4.1 Market Analysis and Trends

In recent forecasts, the market for urea is to have an upward trend, especially in the agriculture sector. The trend is driven by an increased demand in nitrogen fertilizers, population increase, feedstock availability for urea production, and low prices. From 2020-2026, the urea market is expected to have an increasing compound annual growth rate of 2.2%. The mass equivalent of this CAGR is approximately a 233 million ton increase in urea demand.

4.2 Reaction Routes to Producing Product

4.3 Process Screening by Comparing the Process Economy of the Reaction Routes

Table 4: Theoretical Profit Indicator

	CH ₄	+ N ₂	+ H ₂ O	= H ₂	NH ₂ CONH ₂
	1	1	11	1	1
MW	16	28	18	2	60
lb	16	28	18	2	60
/lburea	.27	.46	.3	.03	1
\$/lb	.08	0	0	1.08	.59

Gross Profit:

Selling hydrogen: $.59 + .03(1.08) - .27(.08) = .60$ \$/lb of Urea

Without selling hydrogen: $.59 + .27(.08) = .56$ \$/lb of Urea

4.4 Process Selection

Due to scarcity of information for alternative urea production methods, a conventional method of urea production was chosen. The conventional method used for each process is:

- Hydrogen – Steam Reformation
- Ammonia Synthesis – Haber-Bosch process
- Urea Synthesis – Stamicarbon process

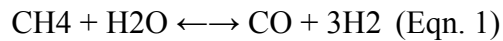
These methods were used in the creation of Figure 5 and Figure 6.

5. Process Description

5.1 Process Chemistry

For the production of urea from natural gas, methane undergoes steam reformation to produce hydrogen (H₂) and carbon monoxide (CO) (Eqn. 1). The carbon monoxide is then reacted with steam to produce more H₂ and carbon dioxide (CO₂), which is sent to the urea synthesis portion (Eqn. 2). CO₂ is removed, and the remaining H₂ is reacted with nitrogen (N₂) taken from the atmosphere to produce ammonia (NH₃) using the

Haber-Bosch process. The NH_3 and redirected CO_2 react to form ammonium carbamate ($\text{H}_2\text{NCOONH}_4$) (Eqn. 4). The ammonium carbamate then forms urea (NH_2CONH_2) and water (H_2O) (Eqn. 5).



Fix equation.

Write a better overview description

5.2 Process (Block) Flow Diagram & Process Description

The figure below represents the block flow diagram (BFD) of our plant process for the production of urea via steam methane reforming. There are six main sections in the production of ammonia which are the steam reforming section where high temperature steam reacts with natural gas, the high temperature water-gas shift (WGS) reaction that improves the yield of our hydrogen product, the CO_2 remover (carbon capture) and ammonia synthesis reactor process that separates our final product (ammonia). Figure 6 will show how carbon dioxide reacts with ammonia to create liquid urea (ammonia carbamate) which is dehydrated to produce liquid urea. The urea solution is evaporated and separated to produce granules urea.

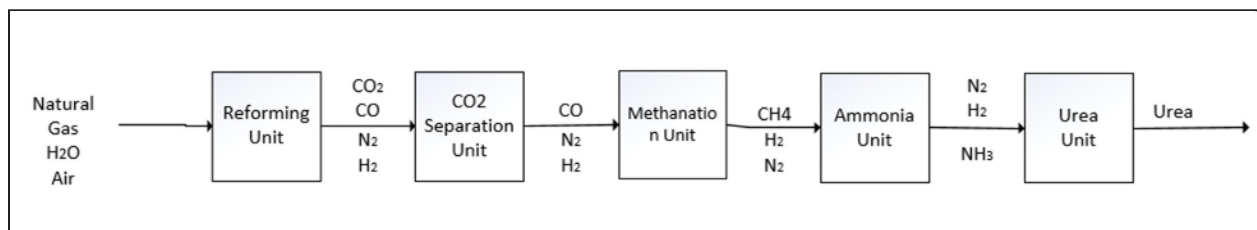


Figure 5: Block Flow Diagram

Figure 5 & 6 shows our process flow diagram (PFD) which gives a detailed layout of our production process including the selection equipment for our unit operations.

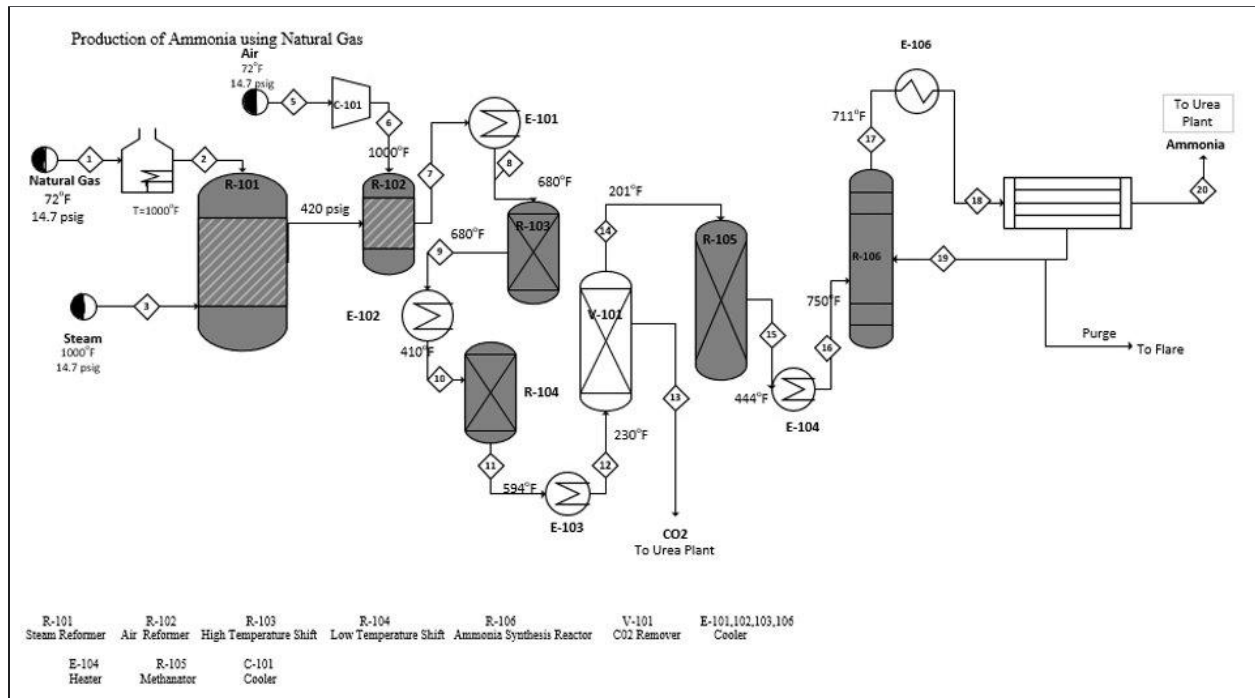


Figure 6: Production of Ammonia using Natural Gas (PFD)

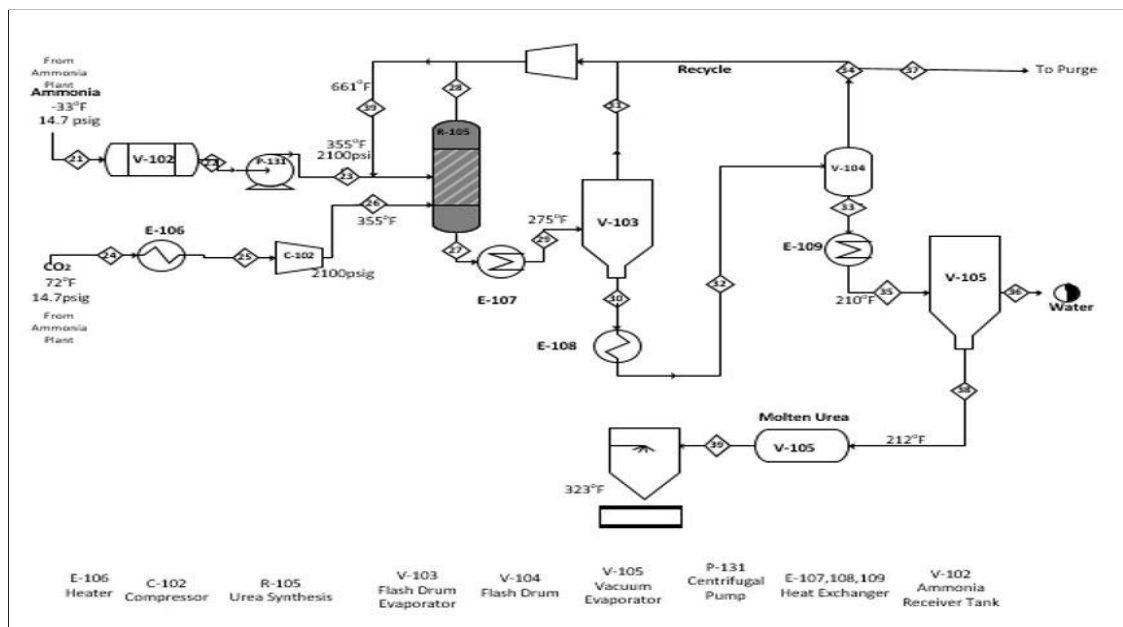


Figure 7: Production of Urea (PFD)

Reference the unit names in the text.

5.2.1 Raw Material Preparation

The two raw materials involved in the production of urea are natural gas whose main component is methane, and superheated steam. During the raw material preparation sour gas is passed through a desulfurization unit to remove hydrogen sulfide from natural gas. In the urea process we have carbon dioxide compressed with ammonia being pumped into the urea synthesis reactor. In both raw material preparations they operate at high temperatures and with iron based catalysts. The figure below shows the inlet temperature of steam reformation and urea process.

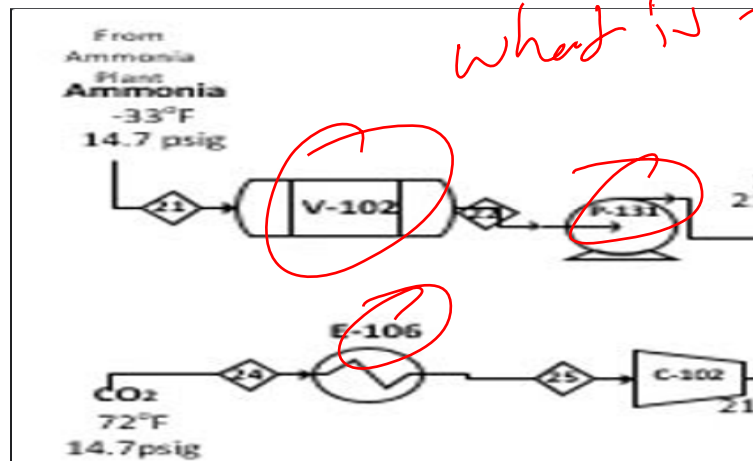


Figure 8: Process Flow Diagram for Raw Material Preparation

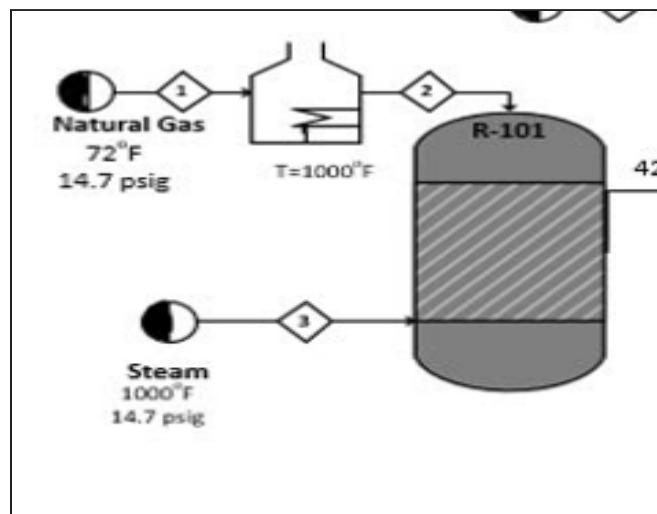


Figure 9: Process Flow Diagram for Raw Material Preparation

5.5.2 Reaction and Reactor Operation

The three major reactions in the plan design occur at urea synthesis, ammonia synthesis and methane reformer reactor. We have a total of five reactors in the overall process

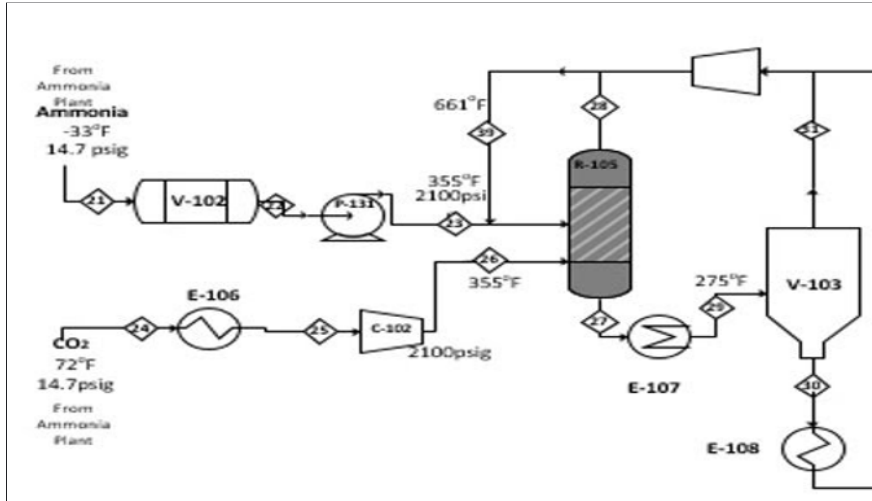


Figure 10: Process Flow Diagram for the Urea Synthesis Reactor and Vacuum Evaporator

Ammonia is inserted into a compressor and pump and CO₂ goes into a heat exchanger and reacts with urea synthesis with zinc oxide. The temperature is heated up to react in the reactor at 661°F. Then urea liquid undergoes a vacuum evaporator to separate the urea liquids and waste products which are flared and recycled back to the raw materials. This process dehydrates the liquid urea to its purity. Which produces 96.8 % pure urea which is prilled to granules.

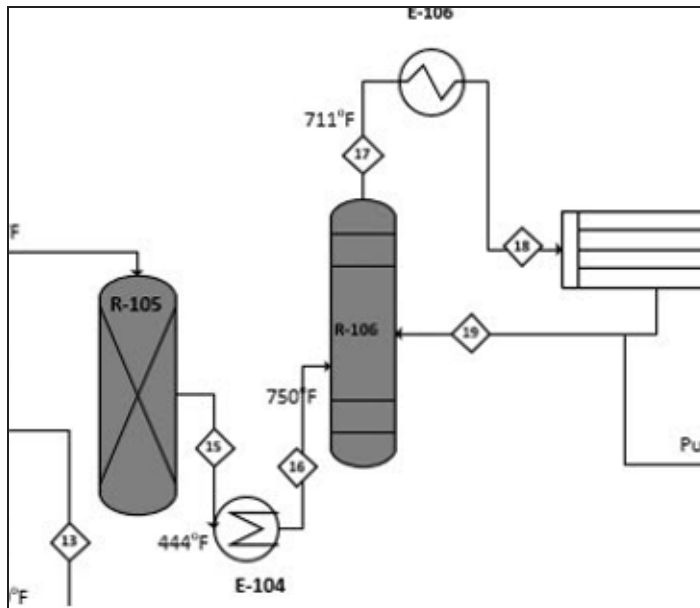


Figure 11: Process Flow Diagram for the Ammonia Synthesis Reactor

The figure above shows an ammonia synthesis reactor, which has a temperature of 750°F. Ammonia synthesis reactions with nitrogen and hydrogen. The by-products of this reactor is hydrogen which will be sold in the market with urea .

5.2.3 Separations

The separation stage goal is to isolate the off gases (NH_3 and CO_2), so it can be recycled back in the process. A flash drum separator removes all off gases and any poisons from the reaction. Biuret is impurity in urea fertilizer caused by a side reaction, which has a huge effect on plant growth. Figure 11 shows a diagram showing the separator.

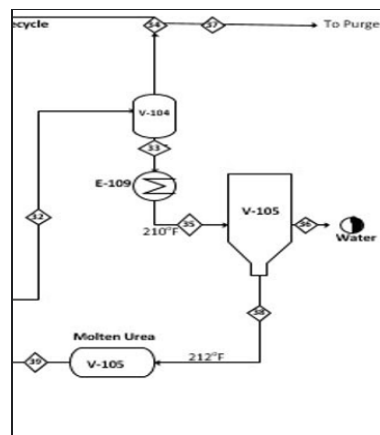


Figure 12: Process flow diagram for Separation Operations

5.2.4 Production to Storage

The final step in our plant process of urea is inserting the hot liquid urea in a prill tower. Air is sucked out the bottom heated and blown to the shaft of the tower. As the fertilizer falls down the shaft it dries and solidifies to form granules which are directed by conveyor belts to be packaged and shipped.

Where are your material
balances
and energy
around each unit??

Not bad - Need to include
missing information.

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