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Design of a Full-Scale Plant for Plastic Pyrolysis

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Sponsoring Company

Gulf Coast Environmental Systems

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Senior Design Project (AE 4800)

Certification

This is to certify that the project “Design of a Full-Scale Plant for Plastic Pyrolysis” has been submitted to the Western Michigan Department of Mechanical and Aerospace Engineering to meet the requirements of a Bachelor’s of Science in the major of Aerospace Engineering by the following students:

Kaden Allen

David Lont

Hannah Sargent

Christopher Weaver

Disclaimer

Acknowledgement

We would like to express our gratitude to all the individuals that helped us complete this project. Due to our lack of engineering experience many challenges and obstacles were faced, but these individuals helped us overcome these to complete the final project.

We would like to thank Dr. Parviz Merati for the mentorship and counseling during this project. With this our project would not have progressed in the manner it did.

We would also like to thank Chad Clark, “Carbon Expert”, for this opportunity and the guidance and direction throughout this project. Without this we would have not had the chance to work on such a revolutionary project

We would lastly like to thank Cary Allen for his instruction and training over the course of this project. Without this we would not have been able to gain the experience and wealth of knowledge required to complete a project such as this.

Finally, we would like to thank Jerrel Branson from Liquid Extractions for his contributions to developing the chemical process of plastic pyrolysis (which he has a provisional patent for) in an auger reactor. His expertise and recommendations for this project were key throughout the development of this project.

Abstract

With over thirty million tons of plastic accumulating in the United States every year, the need for an environmentally safe means of disposal is increasing. Only ten percent of this plastic is recycled while the majority is disposed of via landfill. With recent advances in pyrolysis research, a permanent solution is presented. By creating a pyrolysis plant, not only could billions of pounds of plastic be prevented from contributing to landfills, but also be converted to oil resulting in an environmentally beneficial and lucrative solution to plastic waste.

Figure 1: Plastic on a Beach

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1. Introduction

1.1. History

Manufacturing char through carbonizing wood has happened throughout the entirety of human history. The goal of producing char grew to other products such as tar and methanol as mankind advanced. Though some mild advances occurred throughout history, the oil crisis of the 1970s caused an increase in research and experimentation with the pyrolysis process in hopes of finding a solution to dependency on fossil fuel. Soon after, the commercial batch-by-batch systems that used brick ovens with low oxygen and indirect heat had to be emptied of char after each use and were replaced with fixed Bed and fluidized bed systems. These had the drawback of hazardous tar or char byproducts but showed a great advance in the efficiency of the process. The process was even further advanced at the turn of the century with the implementation of augurs, circulating fluidized beds and many others. This has led to many pyrolysis plants being created in the past decade with the most common being tire pyrolysis plants, one of which in 2017 received the first "C2C" certification given to a pyrolysis plant, signifying safety and energy efficiency. This leads to today where the continuous research and application of the pyrolysis process gives opportunity for eradicating the current plastic waste problem. A schematic of the history of pyrolysis is shown in Figure 2.

1.2. Introduction to pyrolysis

The pyrolysis of plastic is the thermal degradation of plastic waste at temperatures ranging from 250°C to 900°C. This is done in the absence of oxygen to produce liquid oil. For this process to occur, the plastic material is fed into a reactor which creates liquid oil through heat transfer. The char is then extracted and filtered from the oil so that the oil can be condensed and cooled for storage and later use.

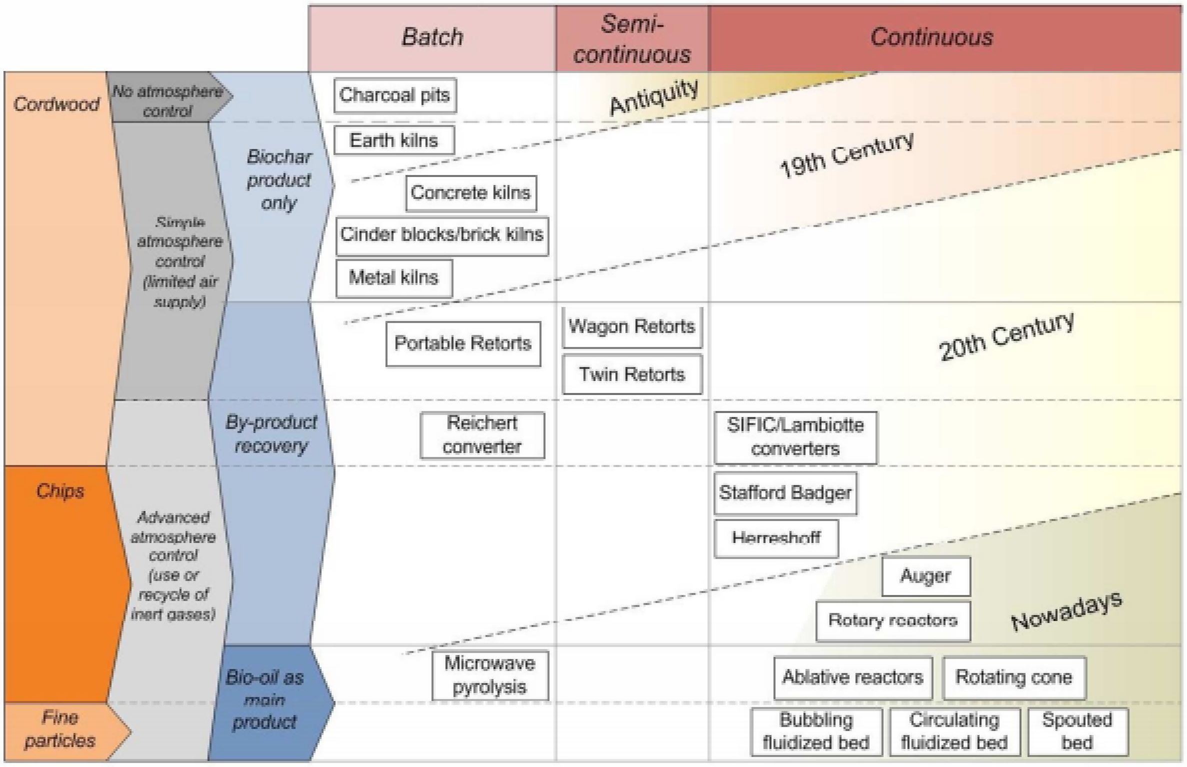

Figure 2: History of Pyrolysis

1.3. Company

Gulf Coast Environmental Systems (GCES) is an environmental abatement solutions provider based in Conroe, Texas. GCES specializes in Industrial Air Pollution Control but also supplies products, consultation, and services for other thermal and energy processes. The company provides complete solutions to over 30 industries across 17 countries and takes pride in its overall flexability.

GCES was responsible for the conception of this project as they believe this system has potential for environmental change as well as economic advantage.

2. Design Requirements

The following requirements have been set by GCES to ensure that the plant is operating at its best performance while ensuring that the system is both sustainable and that safety specifications are being met.

2.1. Processing Rate

The plant will be processing 10 US tons of recycled plastic per day. The plastic will go into a hopper that then slowly feeds into an extruder before entering the reactor where the pyrolysis takes place. The plant will be operating 24 hours a day. Therefore, the design mass flow rate through the reactor is 833.3 lbs/hr (378 kg/hr), or equivalently, 0.105 kg/s. This value was recommended by GCES and was used in determining the sizing of the pilot plant.

With 20 thousand pounds of plastic passing through the reactor a day, it is estimated that only 15,586 lbs will be converted into API 51° oil. The remaining mass will be converted into 2,412 lbs of gaseous hydrocarbons and 2,002 lbs of char. The oil will be collected and sold while the hydrocarbons can either be sold or used to help power the plant. The char can also be sold and will not contribute to power.

2.2. Temperature requirements

Ensuring the proper temperature gradients in the plant is key to the plant’s successful operation. The most crucial part of this plant is its reactor as this is where the plastic is pyrolyzed into crude oils. It has been determined that the ability to regulate and control the temperature gradient within the reactor should be implemented in its design to ensure that the plant has the most flexibility for making adjustments as needed.

The plastic in the hopper will be fed into an extruder which will shred and preheat the plastic to its melting temperature. This ensures the plastic going into the reactor will have a higher density and more uniform temperature distribution. It is expected that this will increase the efficiency of the reactor. The extruder should preheat the plastic to about 536°F (280°C), which is higher than the melting temperatures of high density polypropylene (HDPE), low density polypropylene (LDPE), and polyethylene (PE) which are the plastics of interest, which will be converted into fuel. Melting the plastic to this temperature is estimated to require 5.5 MMBTU/day (58E6 J/day).

The reactor will be designed for an inlet temperature of 500°F (260°C). The reactor will then gradually increase the temperature gradient along its length to a final temperature of 896°F (480°C). Further increasing the temperature of the reactor is expected to decrease the formation of coke and char in the crude oils. At this temperature, the fuel will be in the gaseous phase and, therefore, a condenser is required. The char collected is expected to require a dedicated cooling system as well. This system will consist of another screw conveyor that is immersed in water.

The crude oil and hydrocarbon byproduct gas leaving the reactor will then be filtered with a centripetal filter to remove any char mixed with the oil. The oil will then be cooled with a condenser using city water to remove the heat. The city water is estimated to have an average input temperature of 70°F (21°C) which can be used to bring the temperature of the fuels produced to 200°F (93°C) before the output fuels can be stored. Both the liquid oil and gas hydrocarbon collectors are expected to be at this temperature or below.

2.3. Facilities available

Since Gulf Coast Environmental Systems is located in Texas, their facilities were not readily available for our use. By contrast, Western Michigan Universities resources were available and used often for different programs including, but not limited to, AutoCAD and Fluent.

2.4. Fabrication

Fabrication of this plant is outside the scope of this project, however, the plans for fabrication are well within. GCES has it's very own fabrication shop with all the equipment needed to make the plant. Because of this, they will be responsible for fabrication. In order to fabricate this system, the shop at GCES needs the proper documentation. This documentation includes technical drawing of the reactor as well as purchase orders for all relevant part drawings for fabrication. It is expected of the team to create the drawings, find price estimates of the parts, and part drawings that will then be reviewed and approved by GCES.

2.5. Safety

The main safety hazard of this plant will be due to the hot temperatures inside of the reactor. The reactor will be well insulated so that any exposed surfaces of the reactor and plant do not exceed 140°F (60°C). This complies with the U.S. Occupational Safety and Health Administration (OSHA).

A second potential hazard will be related to any excess pressure which could cause an explosion. Careful consideration will be taken in the design of the plant to include explosion vents as necessary. The type and size of these explosion vents, however, is outside of the scope of this project and left to GCES to decide. Proper warning labels and signs will also be used to comply with OSHA to minimize any risks of injury to the personnel.

2.6. Cost constraints

This plastic pyrolysis plant will be the most profitable if the total cost of design and manufacturing of the plant can be minimized. It was ensured that the parts to be purchased or manufactured for the pyrolysis plant are within the allocated budget set forth by GCES. Something that was also considered was purchasing used parts for the extruder screws to lower the overall cost. The total cost of designing and manufacturing the completed pilot plant should not exceed $2M USD according to GCES.

3. Approach

The approach for designing the reactor was set up in multiple steps. The first step was researching the different reactor geometries that are in use in the industry. Next, a decision matrix was created to compare the different geometries and ultimately choose one for the plant. Then, three concepts were drawn up for the heating source for the reactor and one was chosen for the design. Next, an analysis was done regarding the self-sustaining ability of the reactor based on the products collected at the end of the pyrolysis process. Lastly, Figure 3 shows the Gantt chart which gives a timeline of the group's tasks for the project.

3.1. Reactor choice

The major element of design for this plastic pyrolysis plant is the reactor which will melt the plastic on a temperature gradient from 500 °F to 896 °F. The first step in designing the reactor was to choose the type and geometry of the reactor. The geometries investigated were rotary kiln, fluidized bed reactor, conical spouted bed reactor, ablative, and screw. Table 1 below shows the decision matrix created to aid in the decision for the reactor geometry. Based on the decision matrix and discussions with GCES, it was concluded that a screw reactor would be best for this design.

3.1.1. Rotary Kiln

The rotary kiln pyrolyzer is a drum that has blades located circumferentially along the walls and rotates to mix the plastic and is heated externally. The drum is also usually inclined by a couple degrees to help with the movement of the plastic. The benefits of a rotary kiln geometry are that it can handle high operating temperatures and involves a continuous mixing of the plastic. However, the downsides of this kind of geometry are that it is very costly to operate and maintain due to the high temperatures exposed to moving parts.

3.1.2. Fluidized Bed Reactor

The fluidized bed reactor involves an inert bed where a fluidization medium is passed through a bed of solid reactants and the bed is heated externally. The shredded feedstock is fed through the top of the reactor while the heated bed flows in through the bottom. Some advantages of the fluidized bed reactor are that it involves uniform particle mixing and temperature gradients. However, some of the disadvantages of this geometry are that it can be costly to construct and maintain specifically with the catalyst.

3.1.3. Conical Spouted Bed Reactor

The conical spouted bed reactor operates similar to the fluidized bed reactor but uses a conical spouted geometry to filter the plastic feedstock through instead. The advantages of this geometry is that it creates a higher collision rate and has a much smaller pressure drop compared to the fluidized bed reactor. The disadvantages of the conical spouted bed reactor are that the more complicated design results in issues with the catalyst feeding and entrainment and the product collection.

3.1.4. Ablative

The ablative pyrolyzer consists of two electronically heated grinding discs where the upper disc is fixed and the lower disc is pressed by a spring and rotated by a vertical shaft. Some of the benefits of an ablative reactor is that the reaction system is more intense comparatively and that it can be easily scaled up. However, some of the disadvantages of this type of geometry are that it creates less heat transfer than the other reactors and requires a lot of maintenance.

3.1.5. Screw

The screw reactor, also known as an auger reactor, is a reactor geometry consisting of a screw inside a shaft that is externally heated. The advantages of the screw reactor geometry is that it is a simple system and can easily be scaled up for larger amounts of feedstock. However, some of the downsides of this type of reactor are that it has poor heat transfer between the heated reactor wall and the cold screw shaft and it has a slower speed.

Reactor type	Economic feasibility	Heat transfer	Durability	Scale up flexibility	Risk	Speed	Factors
Weight	5	6	4	3	2	1	**Total score**
Rotary Kiln	3	1	2	3	3	2	**46**
Fluidized Bed	3	5	1	4	5	5	**76**
Conical Spouted Bed	3	5	1	4	5	5	**76**
Ablative	3	2	1	5	3	1	**53**
Screw	5	2	5	5	5	2	**84**

Table 1: Decision Matrix for Reactor Geometry

3.2. Heating source selection

Once the reactor geometry was decided, the heating source then needed to be selected. Three concepts were developed for how to heat the screw reactor for the plastic pyrolysis plant which can be found in Appendix 1. The three concepts were electric band heating, induction heating, and electric resistance heating. The first option, electric band heating, has bands wrapped around the reactor jacket. The bands will have multiple circuits connected to it to gradually increase the temperature along the reactor. The second option, induction heating, has heat induced at each end of the auger and the middle section of the inner tube is heated through conduction. The third option, electric resistance heating, has resistance heaters placed inside the auger to allow for uniform heating. After discussions with the company, it was decided that the first concept of electric band heating would be best for this reactor design. The band heating allows for the most feasible heat transfer with the ability for having a gradual temperature increase along the reactor.

3.3. Self-sustainment

One of the goals of this project was to determine if the plant could run solely off the combustion of the output hydrocarbon gas in a generator. To approach this, calculations were done to determine the amount of energy needed to run the two main power sinks: the plastic extruder and the pyrolysis reactor. Assuming 100% thermal efficiency, the heat required for these two components is 22.24 MMBTU/day (22.887 GJ/day). Once this was found, a few assumptions were made about the composition of the output gas (see section 4.1). The heat released through the combustion of all of the output gas was estimated to be 55.997 MMBTU/day (59.13 GJ/day).

After researching the typical efficiency of a natural gas generator (found to be between 30% and 40%), it was determined that this plant would not be self-sufficient and would require external sources of energy to function. This conclusion was made based on the fact that, given the calculations, a generator needed to have an efficiency of 38.7% in order to power the plant. This is far too close of a margin for safe operation. Furthermore, the heat requirement calculated above assumes a thermal efficiency of 100% and that the reactor and extruder were the only devices to be powered; this is very unrealistic.

3.4. Timeline

Figure 3 below shows the overall schedule for the design of the plastic pyrolysis plant. These tasks are shown on the left, and the two colors for the bars represent the two different semesters: blue for the fall semester and green for spring semester.

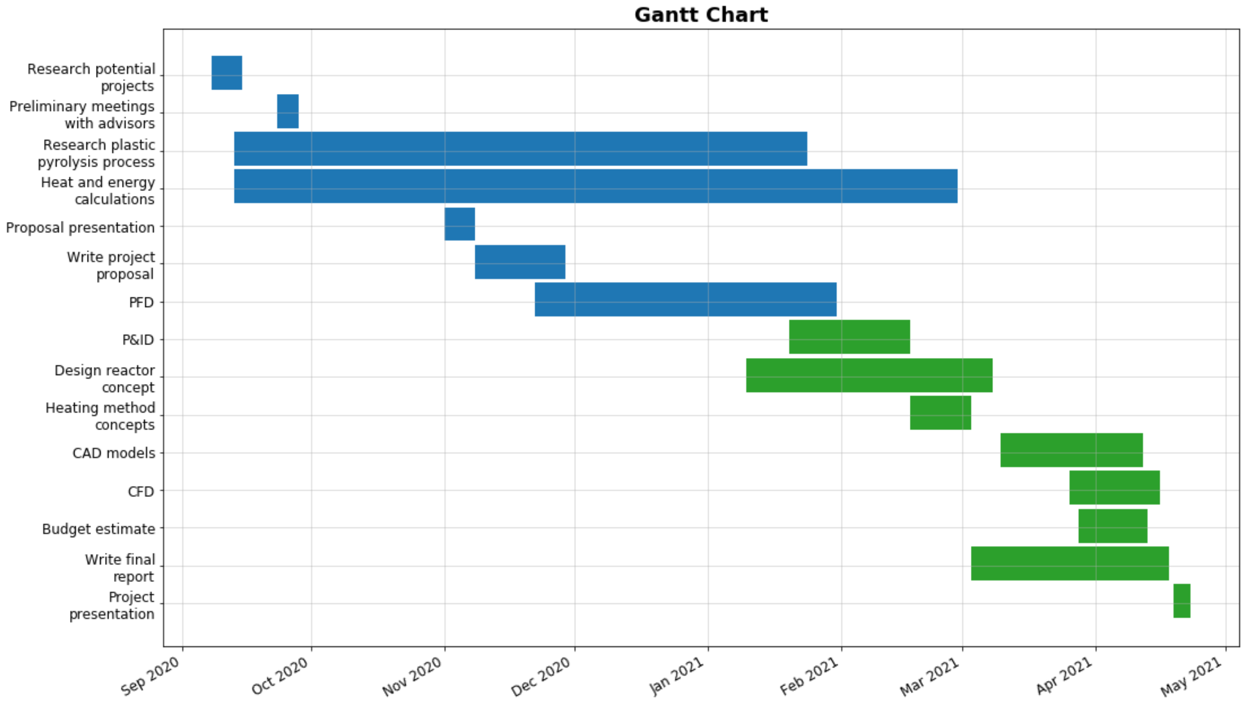

Figure 3: Gantt Chart

4. Design

The overall design of the plastic pyrolysis plant was done in three steps: initial heat calculations, a process flow diagram, and a piping and instrumentation diagram. The heat calculations were done to document temperature, mass flow rate, and volumetric flow rate at certain points in the plant. These values were then used to create the process flow diagram and the piping and instrumentation diagram.

4.1. Initial calculations

The initial calculations were done with regards to heat, estimated molar mass of the gases produced, estimated molar mass of the oils produced, and volumetric flow rate. These were used to create the PFD and P&ID.

4.1.1. Heat calculations

The plastic to be pyrolyzed is first fed into a hopper. It then goes into the extruder which grinds and heats the plastic until it is melted and of a consistent mixture before entering the reactor. The target temperature of the plastic is 536°F at the end of the extruder after entering the hopper at room temperature. The reactor will gradually increase the temperature of the pyrolyzed plastic until it reaches a temperature of 896°F. At this point, all of the plastic will have been converted to fuel and a small amount of char. To obtain these desired changes in temperature, the following required head calculations were made.

The change in heat per mass of plastic going into the extruder was determined using Equation (1) and Equation (2) below.

$$\Delta q_{Extruder} = (C_p \Delta T + \Delta h^{\circ}_{fus})_{plastic} \tag{1}$$

$$\Delta Q_{Extruder} = q m_{in} \tag{2}$$

The change in heat in the reactor was calculated in a similar way using Equation (3) and Equation (4) below.

$$\Delta q_{Reactor} = (C_p \Delta T + \Delta h^{\circ}_{vap})_{plastic} + (C_p \Delta T + \Delta h^{\circ}_{vap})_{oil} \tag{3}$$

$$\Delta Q_{Reactor} = q_{Reactor}(m_{in} + m_{Feedback\ Oil}) \tag{4}$$

The total change in heat required was then determined by taking the sum of the changes in heat for the extruder and reactor. This is shown in the following equations, Equation (5) and Equation (6).

$$\Delta q_{Total} = \Delta q_{Extruder} + \Delta q_{Reactor} \tag{5}$$

$$\Delta Q_{Total} = \Delta Q_{Extruder} + \Delta Q_{Reactor} \tag{6}$$

According to GCES, it is predicted that 2,412 lbs (1094 kg) of gas will be produced by pyrolysis. The company estimates 90% of this gas will be methane. The heat released by the combustion of methane was then determined to be 54 MJ/kg. Therefore, the total heat released by methane is

$$q_{CH_4} = 23{,}215{,}842 \text{ BTU/lb}$$

$$Q_{CH_4} = q_{CH_4} m_{gas} = 55.99\text{MMBTU}$$

In order for the plant to be self-sustaining, we need a natural gas generator with 38.7% efficiency which is typically between 35%-40% and this is assuming the system is 100% efficient otherwise (an unrealistic assumption). Because of this, we can conclude that the system will not be self-sustaining based on the produced gas and will need other sources of energy in order to operate. A complete table of all of the heat values can be found in Table 6 in Section 13.1 in the Appendix.

$$\eta_{Reactor} = \frac{Q_{CH_4}}{Q_{Total}} = 0.387 \tag{7}$$

4.1.2. Estimated Molar Mass of Gases Produced

The average molar mass of the gas produced was determined from the sum of the products of the theoretical gases released with the percentages as shown in Table 2 below.

Gases produced	methane	ethane	propane	butane	avg
Molar mass (g/mol)	16.04	30.07	44.1	58.12	18.495
percentage	90.00%	5.00%	2.50%	2.50%	

Table 2: Average Molar Mass of Gases Produced

4.1.3. Estimated Molar Mass of Produced Oil

Molar masses of certain distillates of this oil are hard to estimate. A safety margin of 150 g/mol was used since it is better to underestimate the molar mass (in turn, underestimate the density) as it is safer to have pipes that are able to handle a larger volume than needed than pipes that cannot handle enough. Table 3 below shows the estimated molar mass values for the produced oil.

API 51° grade oil	gasoline	kerosene	diesel	Heavy oil	Safety margin
Molar mass (g/mol)	~100	~170	~175	NA	150

Table 3: Molar Mass of Oil Produced

4.1.4. Volumetric Flow Rate Calculations

In order to determine how big the plant needs to be, it is important to understand the volumetric flow rate within each pipe and component. As has been observed, the volume of different substances changes as heat is added. Because of this phenomena, the coefficient of linear thermal expansion of each material needed to be found. This value is used to calculate the new density of a substance. From here, the volume can easily be found.

To start this calculation, the density of the melted plastic entering the reactor, its coefficient of linear thermal expansion (α), and the change in temperature needed to be known.

$$\rho_{Extruder,\, out} = \rho_{Reactor,\, in} = \frac{\rho_{Melted\ plastic}}{1+\alpha(T_{new} - T_{m.p.})} \tag{8}$$

Here, Equation (8) above, is used to find the density of the plastic at the inlet of the reactor, however, this equation can be used to find the density at any point within the reactor that sees solid or liquid flow.

The reactor output density was found using the ideal gas law using the crude oil and hydrocarbon output as the gas.

Using the mass flow rate and densities found using the method above, the volume flow rate can be calculated using the following Equation (9).

$$\dot{V} = \frac{\rho m}{t} \tag{9}$$

From here, the flow rate was converted into standard cubic feet per minute (SCFM) as it is easily communicated within the industry.

4.2. Process Flow Diagram (PFD)

As with any process, the process flow diagram serves as a backbone for the rest of the project. A PFD shows the conditions of the inputs, outputs, and at every step in between. Many calculations have to be done in order to ensure that this diagram is as accurate as possible. Any mistake made on this document will result in further mistakes down the road resulting in expensive changes and/or catastrophic events. That being said, a large percentage of the time spent on this project was spent perfecting the process flow diagram.

As stated above, this PFD serves as the backbone for the project and is referred to by all that are involved in order to communicate the proper conditions and so that the team is acting as one. Any new finding causes an immediate update to the PFD to ensure that the team is up to date. Figure 4 below shows the PFD for the designed plastic pyrolysis plant.

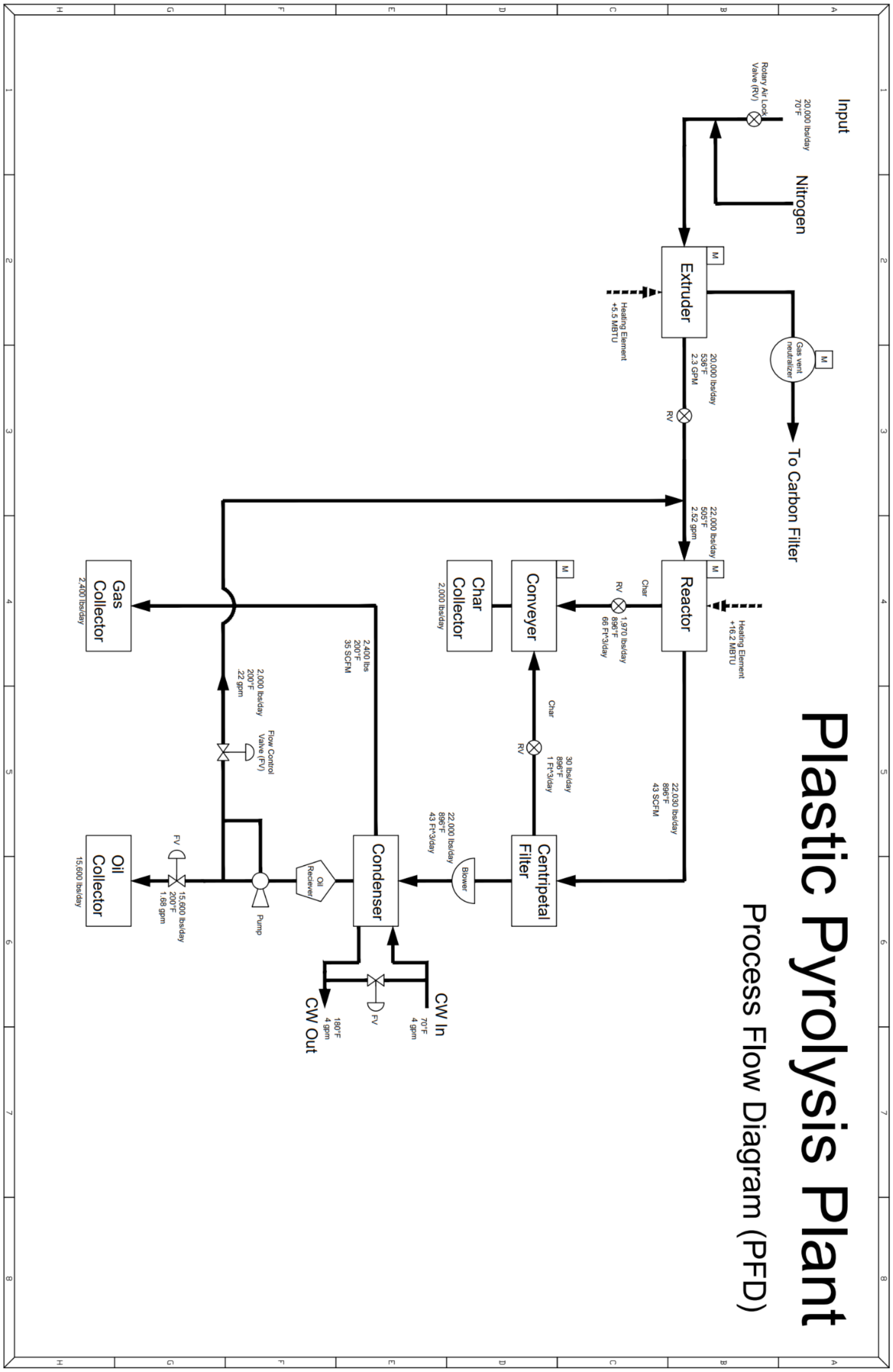

Figure 4: Process Flow Diagram

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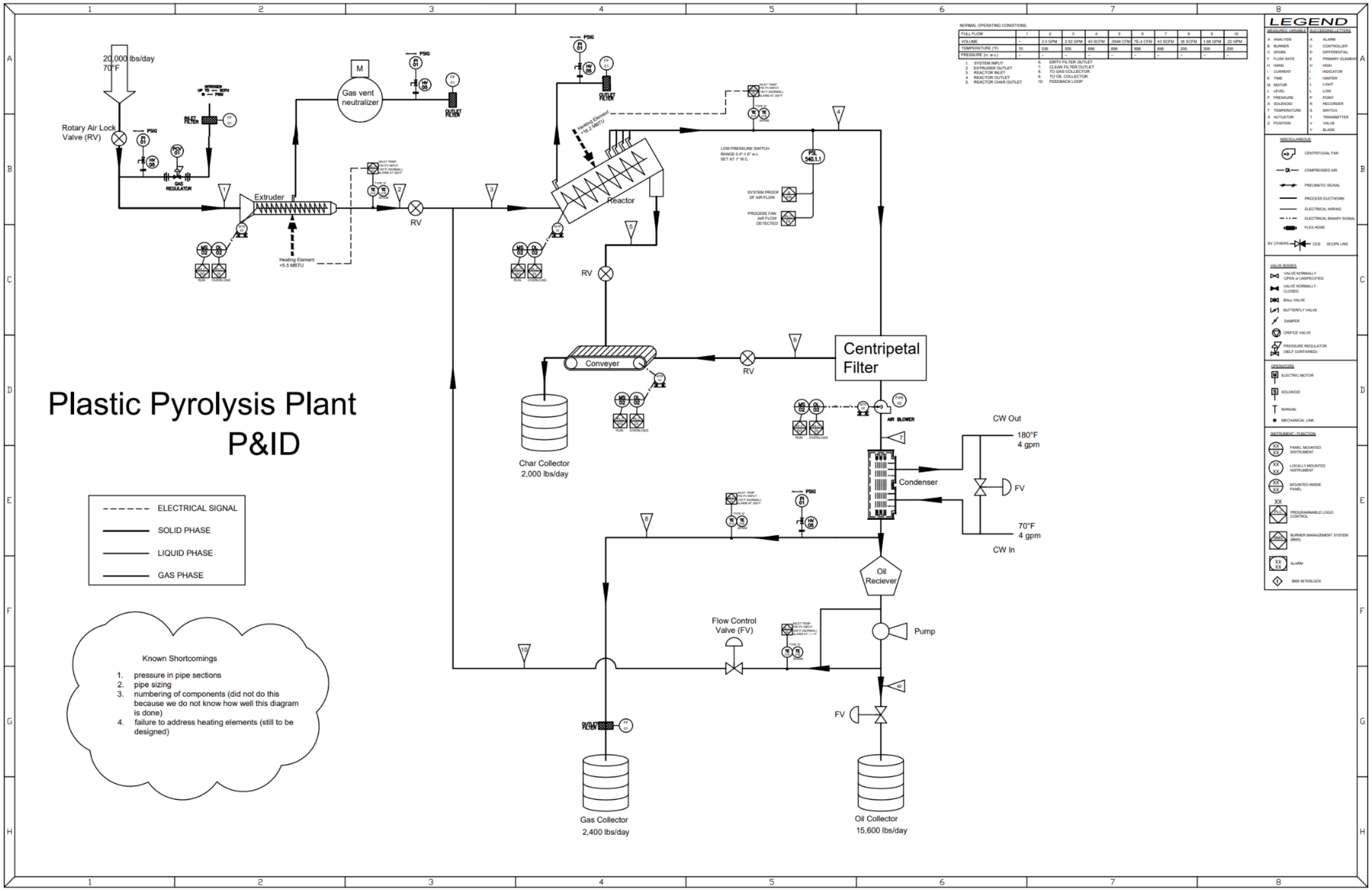
4.3. Piping and Instrumentation Diagram (P&ID)

The piping and instrumentation diagram is essentially a more detailed PFD. This diagram shows all the same information as the PFD while adding all the instruments, pipe sizing, and more detail about the process itself. The P&ID in this report is incomplete as it was mostly outside the scope of the project, however, Gulf Coast Environmental System insisted on an attempt being made to create it for its educational value. The shortcomings of this particular document are the pipe sizing as well as many of the instruments, as the team was not experienced in this field. Figure 5 below shows the P&ID for the designed plastic pyrolysis plant.



NORMAL OPERATING CONDITIONS

FULL FLOW	1	2	3	4	5	6	7	8	9	10
VOLUME	–	2.3 GPM	2.52 GPM	43 SCFM	.0548 CFM	7E-4 CFM	43 SCFM	35 SCFM	1.68 GPM	.22 GPM
TEMPERATURE (°F)	70	536	536	896	896	896	896	200	200	200
PRESSURE (in. w.c.)	–	–	–	–	–	–	–	–	–	–

1. SYSTEM INPUT
2. EXTRUDER OUTLET
3. REACTOR INLET
4. REACTOR OUTLET
5. REACTOR CHAR OUTLET
6. DIRTY FILTER OUTLET
7. CLEAN FILTER OUTLET
8. TO GAS COLLECTOR
9. TO OIL COLLECTOR
10. FEEDBACK LOOP

Known Shortcomings

1. pressure in pipe sections
2. pipe sizing
3. numbering of components (did not do this because we do not know how well this diagram is done)
4. failure to address heating elements (still to be designed)

Figure 5: Piping & Instrumentation Diagram

5. Reactor CAD model

Design models were made in 2D using AutoCAD. Due to the hazardous nature of this reactor and the overall inexperience of the group, it is highly recommended that all aspects of this design be checked and approved by the responsible parties before manufacturing begins.

5.1. Process Inputs and Outputs

In this design, there is one input and three outputs. The process inlet carries liquid plastic from the extruder to the reactor and is placed on the underside at the beginning of the reactor (far left). The first system of outlets (two ports) is located at the top left of the reactor and is meant to vent off any dirty gas and nitrogen that made it through the initial purge, ensuring a clean, contaminant free environment for the melted plastic to react. The second set of output ports are located on the top right of the reactor. Here, all crude oil and natural gas is sucked out by a blower downstream and is to be treated and collected. The third and final output of this system is located on the bottom right of the reactor. This output's purpose is to rid the system of any coking that has built up in the system. The coke is carried to the output via the auger.

The inputs are all welded to the reactor jacket at 30° angles from the horizon in the direction shown in the drawing. 30° angles were chosen for these outputs so that the system would continue to run properly as the inclination moves from 0-30°. The inlet is welded at this angle as an attempt at keeping the plastic flowing to the right. Ideally, this creates a low pressure zone in the top left section of the reactor. The low pressure zone will help to pull all remaining gases out of the plastic before being sucked out of the system. Similarly, the nitrogen outputs are applied to the left and at the same angle as the input. This ensures that the liquid will have a more difficult time moving into and out of the ports. Furthermore, the process outputs are welded at 30° and opposing flow, again, this makes it difficult for liquids to move up the ports while still allowing easy venting of gas. The coke output (located at the bottom right) is placed at this similar angle to ensure coking is easily evacuated as the inclination of the system increases.

The nitrogen and process outlets are 10 inch long, ½ in NPT (national pipe thread) TOE (threaded one end) so that pipe fittings, such as valves, can be fitted to one end while the other end can be butt welded to the reactor. Multiple of these pipes are welded on so that an operator can open and close ports to dial in the process.

5.2. Hot Side Seal (Detail 1)

In order to ensure a proper seal on the hot side (right side) of the reactor. A sealing strategy must be used. The difficulty in this lies in the fact that the temperatures inside the reactor are far too high for any O-ring to withstand. Because of this, a bushing, or sleeve bearing, was used. This is because it can be welded in place and will not leak process gas to the outside. Furthermore, ball bearings become less effective at these temperatures due to the thermal expansion of the balls within their sleeve. An alternative to this bushing could be a slightly larger pipe that the end of the screw can rest in. As the system is inclined, this bushing will not carry as much load as the cold side, and therefore, does not need to have the same reinforcement.

The end plate on the hot side will also be welded to a piece of circular angle that is then welded to the jacket of the reactor. This will be done early in the assembly process where water can be poured into the closed jacket to check for leaks.

5.3. Cold Side Seal (Detail 2)

The cold side (left side) sealing system is difficult to design as there is a rotating shaft that must exit the system. Like the hot side, the cold side's temperature (536°F) is still a major design consideration. The design chosen features a double mechanical seal with a bushing inside the reactor and bearing outside. Here, an 8 inch pipe is welded to the outside of the reactor end plate. Inside this pipe will be a circular piece of angled steel that will work to push the O-ring housing inward as force is applied via a spring. This system is designed to be redundant with two O-ring housings in order to maintain a seal if one becomes damaged.

The end plate is then secured to the jacket by bolting to a flange that is welded to the jacket. A high temperature, metal reinforced fiber gasket is placed between the end plate and the flange to ensure a proper seal.

As stated above, heat is still a major consideration so the O-rings chosen are made out of kalrez. This material has many advantageous properties but most importantly, can withstand temperatures up to 635°F. Given the fact that the auger will conduct heat toward the O-rings, an engineering decision was made to start the application of the heating element two feet from the end plate. This makes it so less heat will be conducted to the O-rings which ultimately protects them.

5.4. Auger

Because the auger is very difficult to manufacture, its creation will need to be carried out by another company. This, however, did not stop the auger from being designed. Basic calculations were done to create a preliminary design. From here, the design was further idealized. Because of this, the center shaft (shown as the dark shaft down the center of the reactor in Figure 6) was assumed to be 6 inches in diameter. The effects of this idealization can be seen in the design as both the hot and cold side sealing mechanisms are designed around the 6 inch shaft.

The blades of the auger (shown as the gray boxes surrounding the shaft in Figure 6) will have an outer radius that is ⅙ of an inch smaller than that of the reactor jacket. This is intended to allow the auger to rotate without any direct friction with the jacket, however, this gap is small enough that the auger will push all coke toward the aft end of the reactor.

5.5. Heating Element

To maintain a reactor temperature of 896°F, electric band heaters are applied to the area around the outside of the reactor. The electric band heaters are gradually applied in greater volume in order to provide a gradual increase in temperature from 500°F at the inlet to 896°F at the outlet. This area is insulated in order to maintain this temperature gradient. The power required for this is found by finding the volume, density, specific heat, change in temperature and the time allowed to achieve the desired temperature.

5.6. Insulation and End Cap

To keep the reactor running as efficiently and as safely as possible, 6 inches of mineral wool (8 lb/cu ft density) is to be placed around the reactor jacket. This is then held on by 18 gauge embossed aluminum. As per the request of GCES, the input and output pipe insulation does not show on the drawings as they will be wrapped later on.

Due to the design of the hot side jacket end plate, insulation is difficult to add and hold in place. This problem resulted in the design of a handheld exterior end cap. The cap is filled with 6 inches of insulation and has a slightly larger diameter than the exterior wall of the reactor. This is so the cap can be quickly placed and removed from the reactor.

5.7. Parts to be Fabricated

Figure 7 features all the parts that can be fabricated in the GCES shop. All parts start as metal stock that is purchased from various vendors. The parts are then cut, bent, and crafted to the exact specs shown in the drawings. The drawings list the part number as well as the material, quantity, and exact dimensions needed (aside from cut to fit parts, these are reserved for the shop's best judgment).

5.8. Assembly

The entire design was made with accessibility and the assembly procedure in mind. The manner of which parts are connected is carefully considered. To start, all flanges should be welded to their respective location. Then, the hot side bushing is welded to the end plate before the end plate is welded to the jacket. From here, the weld is checked by filling the bottom of the jacket with water and checking for leaks. Then, the input and output pipes are butt welded to the jacket. As this is all being done, the one angled bar can be welded to the inside of the cold side sealing pipe. This can then be welded to the cold side jacket end plate. The cold side end plate can be bolted on after the auger is loaded in and meets the bearing at the hot side. The reactor is then covered in 6 inches of mineral wool insulation. The O-ring housing, spring, then second O-ring housing are loaded into the sealing mechanism on the cold side end plate. The exterior end plate is then bolted in place before the 18 gauge, embossed aluminum is cut to fit around the reactor.

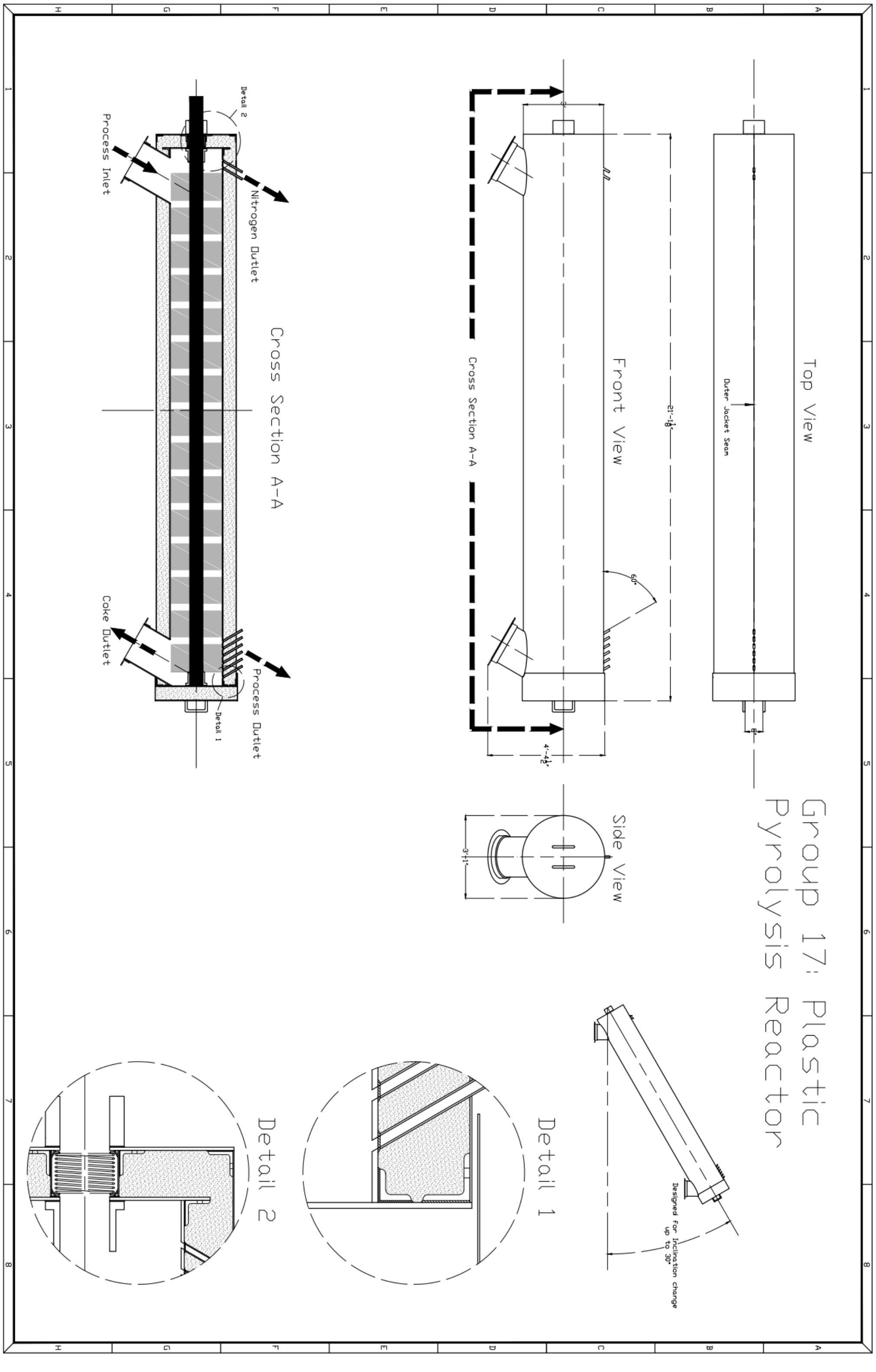


Figure 6: Reactor CAD Drawings

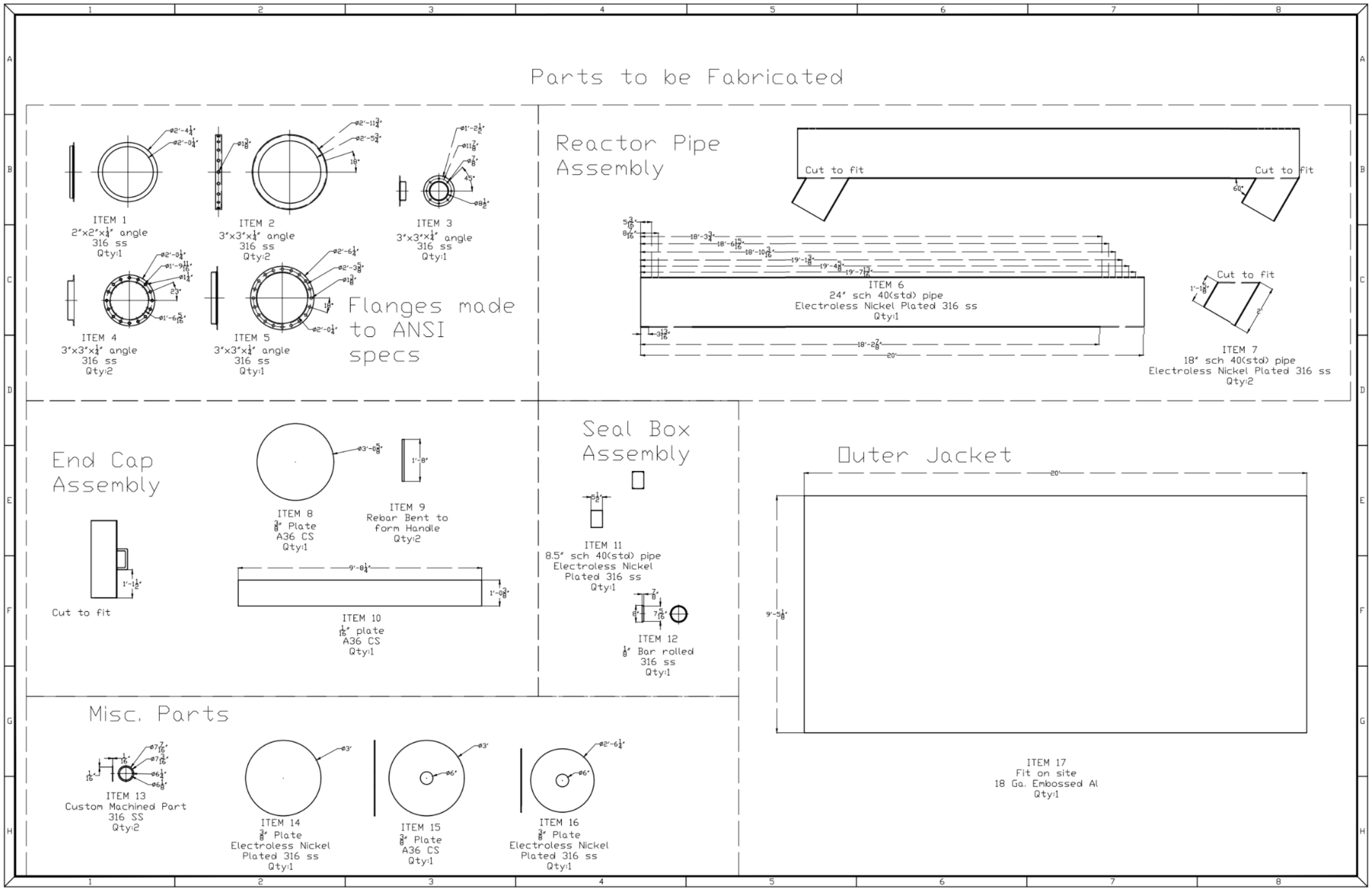


Figure 7: Parts to be Fabricated Drawings

6. Reactor CFD Analysis

Both ANSYS Fluent and ANSYS CFX were used for the analysis of the flow and heat transfer of the reactor, and they provided near-identical results. The images shown in this report are from ANSYS Fluent. Figure 8 below shows the 3D CAD model. The auger was created in Inventor and the jacket of the reactor in SpaceClaim in ANSYS.

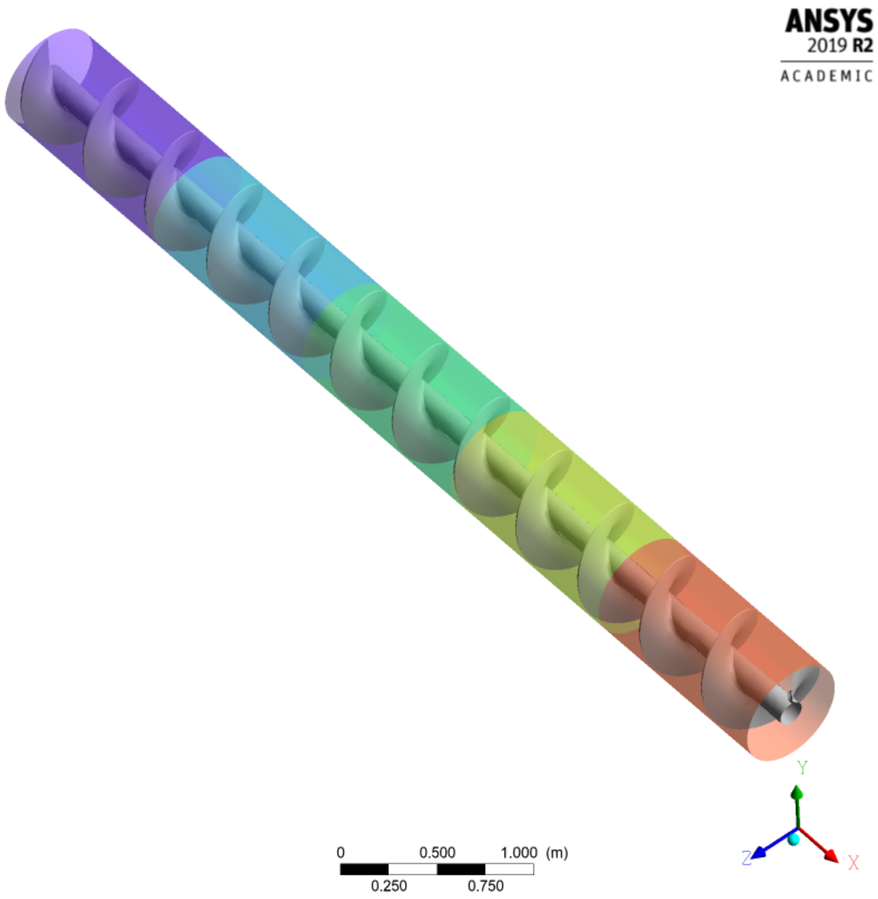


Figure 8: Simplified Reactor CAD Model for CFD Analysis

The reactor was first modeled as 7 parts: the auger, fluid volume, and five thin tubes representing the outer jacket of the reactor. This jacket was sliced into sections as shown by the colored regions in Figure 8 above where a different temperature was applied as the boundary conditions along the length of the reactor. The heating coil wrapped around the jacket of the reactor will be broken into several sections to have a good temperature gradient control along the length of the reactor. This should ensure an efficient pyrolysis of the plastic with minimal charring. In this case, the reactor has been split into five equally spaced heating sections (1.2 m each). Going from left to right, the temperatures applied in discrete steps are 533, 590, 645, 699, and 753 [K]. It is expected that the actual length and number of divisions for these temperature sections will have to be determined experimentally by GCES.

Figure 9 below shows the velocity component of the fluid along the axial direction. The fluid used in this model was water, since at these very high temperatures, the heat distribution along the reactor was very similar to that of plastic as will be shown later.

The purpose of the auger is to mix the pyrolyzed plastic and to force any char out of the reactor. The number of turns in the auger will have to be determined by GCES, as the actual flow along the reactor is mixed, chemically reactive, and thus very complicated to model. To obtain a general idea of the flow along the reactor, the auger was modeled as having a constant blade pitch of 0.5 m along the length of the reactor. As advised by GCES, it is very likely that an increasing pitch along the direction of the flow may result in better control of the pyrolysis such that the plastic that has been fully pyrolyzed near the hottest section along the reactor is extracted quickly, thus preventing charring. The radius of the auger core was modeled to be one-quarter the radius of the outer wall housing the reactor. This ratio was determined from the ratio of various extruders used for pyrolysis. The reactor is spun such that the direction of travel of chemicals in the reactor is along the positive x-axis.

Figure 9 below shows velocity along the x direction on the cross section of the flow on the xy plane. The fluid modeled here is water, and the auger is rotating at -5 RPM along the x-axis. This figure shows that the auger is effective in mixing the fluid as can be shown by the coloration of the velocity.

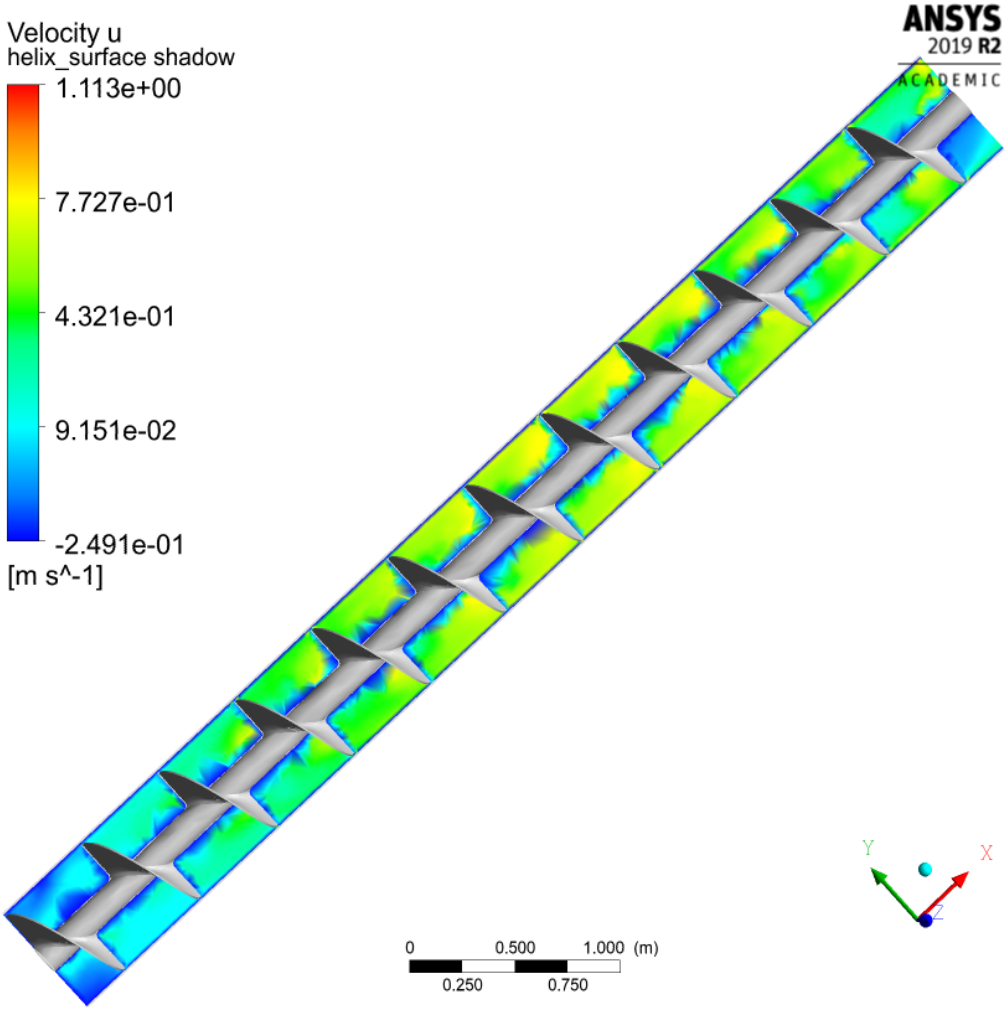


Figure 9: Velocity of the Fluid during Mixing

The heat transfer with the mixing of the auger proved challenging to model. The heat transfer was therefore modeled without the auger. To compensate for the mixing, the walls of the auger were rotated, and a 50% setting of k-epsilon turbulence was used as a boundary condition at both the inlet and outlet of the reactor. The walls were spinned at much higher angular velocities. These were 10 RPM at the core and -50 RPM at the outer wall surface. A comparison of the velocity profile of these two models is shown in the following figure. Note that though the wall rotations are at relatively high angular velocities in the simplified model, an angular velocity of 5 RPM by the auger produces higher velocity of the fluid.

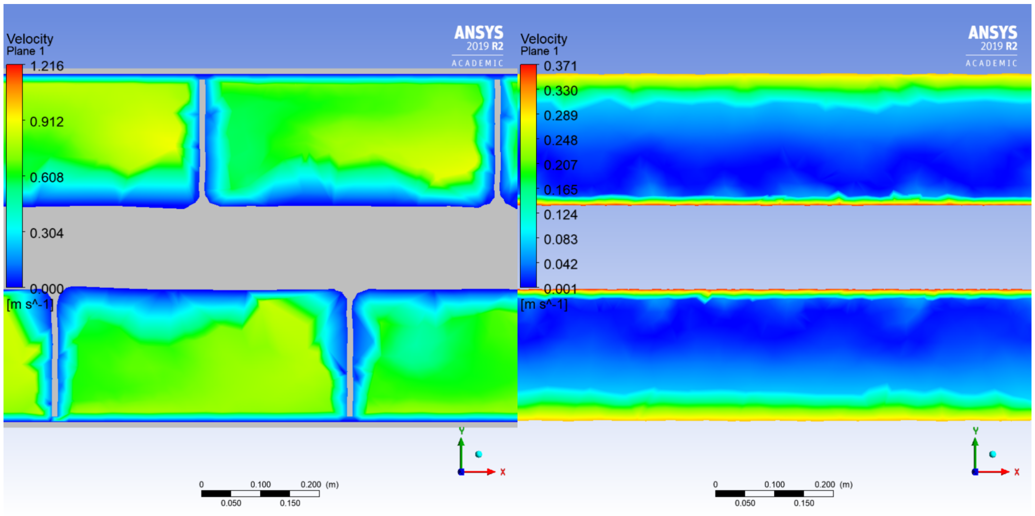


Figure 10: Velocity Magnitude Profile for the cross sections of both models of the reactor. Left: model with auger. Right: model with spinning walls.

This simplified model was then used to visualize the temperature distribution along the reactor assuming a homogeneous liquid. Figure 10 (above) shows the temperature distribution of the liquid along the reactor with the boundary conditions described above. The top half shows the temperature distribution of polypropylene (PP) and the bottom half shows the temperature distribution of liquid water. Polypropylene was chosen to be compared with water because PP has the lowest thermal conductivity of the different types of plastics that will enter the reactor, thus ensuring a uniform temperature distribution can be reached at the end of the reactor for the fluid in question. The properties for PP were modeled as a custom fluid with the following properties (note the properties of HDPE and LDPE are shown in the appendix):

Specific heat [J/kg·K]	Thermal conductivity [W/m·K]	Density [kg/m^3]	Viscosity [Pa·s]
1800	0.15	900	1.4E-3

Table 4: Polypropylene Properties

It is important to note that the density and viscosity of PP vary with temperature. Thus these temperature distributions in the reactor serve only as a rough initial visualization analysis.

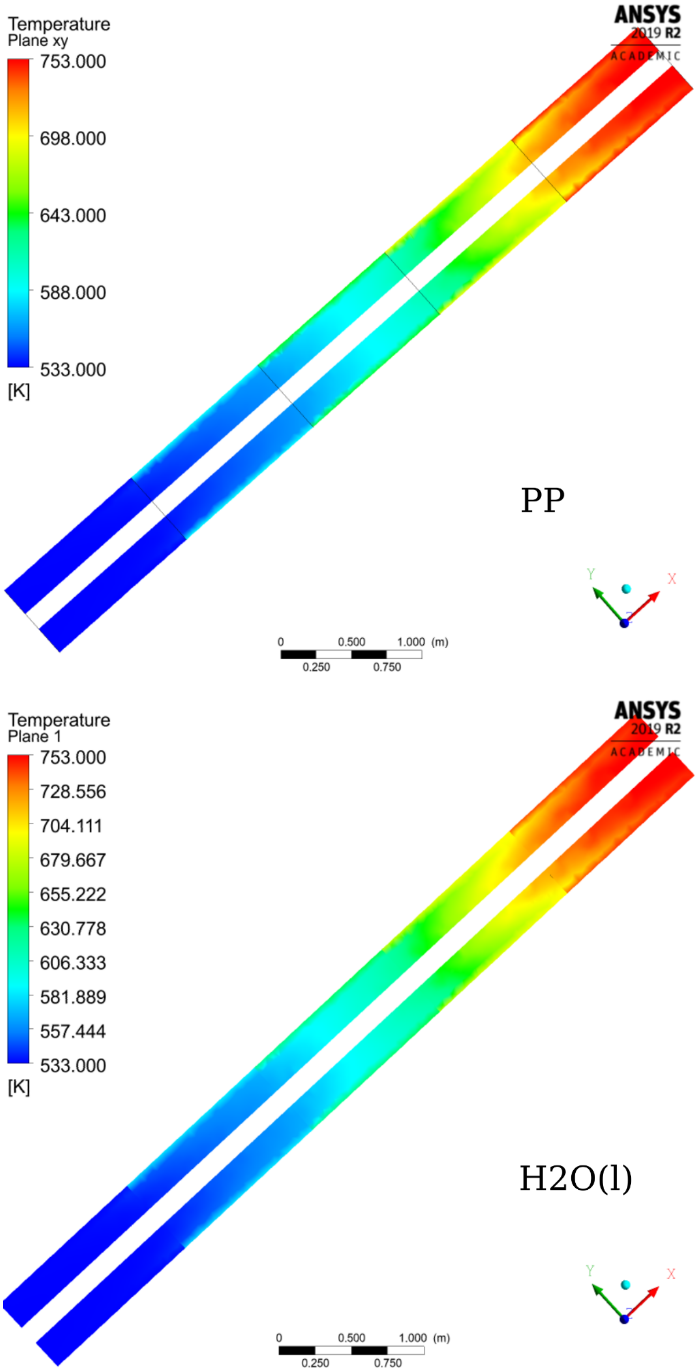


Figure 11: Temperature Distribution in Simplified Reactor model with 50% k-epsilon turbulence at the inlet and outlet as boundary conditions

Note in Figure 11 above that the temperature distribution of PP and liquid water is nearly identical. The right-most section shown in red does show that water archives a uniform temperature distribution of 753 K sooner before the PP does as indicated by the merging colors yellow and red.

Also note that at the outer wall surface, where the heat is applied via coils wrapped around the reactor, the temperature remains constant along this boundary layer. In reality, the auger will have a small gap between the auger and the tube containing it. Plastic that has been pyrolyzed into the gas and liquid phases may affect this boundary layer as it escapes either upstream or downstream of the inclined reactor.

Gravity was not taken into account in this CFD analysis. The inclination of the reactor will thus also have an impact on the heat transfer and temperature distribution along the reactor as gases rise to the top.

7. Cost and Weight Estimate

A copy of the most up-to-date bill of materials can be seen below in Table 5. Costs were found by finding quotes or price of the stock needed to make each part. Links to specific parts and suppliers are provided as well. This is a simplified list and does not include fasteners.
The weight estimation was found by using the density and volume of each part.

item	QTY	Cost (USD)	Weight (lbs)	related link
Parts to be Purchased				
1/2 inch NPT x 10 inch length TOE 316 Stainless Steel	10	165.7	7.2	Pipe Fittings Direct. 1/2 inch NPT x 10 inch length TOE 316 Stainless Steel
graph alloy bearing 453-120.9624-XXX	1		20	Graphalloy High Temperature Bearings Type 453
6" bushing	2		20	Special Order
6.5" ID spring	1		10	Special Order https://screwconveyor.com/product-solutions/screw-conveyors/
Mineral Wool Insulation (2 in x 48 in x 24 in Mineral Wool High Temperature Insulation, Density 8#, Green)	17	307.7	156.4	ROXUL 2 in x 48 in x 24 in Mineral Wool High Temperature Insulation, Density 8#, Green - 19NE78|40205 - Grainger
Mineral Wool Insulation (4 in x 48 in x 24 in Mineral Wool High Temperature Insulation, Density 8#, Green)	17	723.86	302.6	ROXUL 4 in x 48 in x 24 in Mineral Wool High Temperature Insulation, Density 8#, Green - 19NE80|40225 - Grainger
Auger	1			Special Order
FFKM 6" O-rings	2		1	Standard O Rings - AS568 O-Rings | Rocket Seals, Inc.
high temperature gasket for 24 inch ANSI class 150 flange	1	97.31	1	Pipe Fittings Direct. high temperature full face gasket for 24 inch ANSI class 150 flange
Parts to be Fabricated				
item 1 (2"x2"x1/4" angle)	1	287.1	22	Metals Depot® - 316L Stainless Angle | Shop Online!
item 2-5 (20 ft 316ss 3"x3"x1/4" angle)	2	1222.46	196	Metals Depot® - 316L Stainless Angle | Shop Online!
item 2-5 (10 ft 316ss 3"x3"x1/4" angle) cont.	1	305.8	15	Metals Depot® - 316L Stainless

				Angle | Shop Online!
item 6 (20' long 316 ss 24" schedule 40 pipe)	1		1937	Welcome to Lone Star Supply Co - (281) 339-5800
item 7 (22' long 316 ss 18" schedule 20 pipe)	2		258	Welcome to Lone Star Supply Co - (281) 339-5800
item 8 & 15 (3/8 inch THICK A36 Steel Plate) 4'x4'	2	1047.68	215	MetalsDepot® - Buy A36 Steel Plate Online!
item 9 (1 inch Dia. Hot Rolled A-36 Steel Round) 4'	1	23	8.9	MetalsDepot® - Buy Steel Round Bar Online!
item 10 (0.04" Aluminum Sheet 6061-T6) 144"x48"	1	206.24	60	
item 11 (8" 316ss pipe)	1	463.11	13.1	Buy Pipe Online (onlinemetals.com)
item 12 (1/8" x 1" 316/316L Stainless Flat Bar) 3'	1	25.45	0.528	Metals Depot® - 316 Stainless Steel Flat
item 13 (Custom Machined Part)	2		5	Special Order
item 14 & 16	2	3610.68	295.18	316L Stainless Steel Plate | Stainless Supply
item 17 (0.04" Aluminum Sheet 6061-T6) 144"x48"	5	1031.2	137	https://www.onlinemetals.com/en/buy/aluminum-sheet-plate
Total		8486.09	3543.908	

Table 5: Bill of Materials

8. Economic and Environmental Impact

The development of this plastic pyrolysis plant design will have both environmental and economic impacts on society. As of 2017, 348 million tons of plastic are produced globally and it is estimated that this number will quadruple by the year 2050 (Qureshi et al., 2020). The amount of plastic produced for our society will only increase, so a new technology has to be developed to lessen its environmental impact on the planet. Currently, plastic waste is either mechanically recycled, left in landfills, or incinerated. However, only a small amount of plastic waste can be mechanically recycled because it has to be sorted and washed first, and only homogenous and high quality materials can be processed in this way. Pyrolysis of plastic waste would be able to recycle those plastics that are more heterogeneous and are multi-layered since through the process the waste gases are collected. A study was done in Finland using life cycle assessment (LCA), and it was found that through the combination of mechanical and chemical recycling, the carbon footprint of plastic landfilling can be reduced by up to 67% to 76% (Qureshi et al., 2020). The downside of pyrolysis is that it does result in a release of CO2. A solution for these CO2 emissions is that they can be mitigated with CO2 scrubbers. However, the amount of CO2 emitted from pyrolysis has been found to be 1/30th the amount that a normal landfill releases. In addition to this, pyrolysis does not emit harmful dioxins as are released from the incineration of plastics (Resynergi).

Economically, plastic pyrolysis is beneficial as it would be a key player in increasing the petro-chemical and plastic industries. However, one of the major roadblocks in commercializing this kind of technology is the legislative aspect. The framework for policies related to circular economy, waste management, product safety, and fuels can be complex and extensive. Therefore, even once the technology for plastic pyrolysis has been perfected and fabricated, it will still take some time before it can be commercialized and globalized, especially since these laws and regulations vary between countries.

This plant will allow for approximately 3,650 tons of plastic waste to be converted into oil per year. Though pyrolysis plants have been created before, this is one of the first to be used for plastic waste. This will make a noticeable change in plastic waste disposal but this single plant will not solve the plastic waste crisis alone. It is hoped that successful operation of this pilot plant will encourage future investment in the creation of more plastic pyrolysis plants and thus create a profitable means of disposing of plastic.

The profitability of this plant comes both from the oil that it creates and the disposal of plastic. This being the first plastic pyrolysis plant of its kind will allow GCES to have an advantage in the market for plastic disposal. In addition to the profit made from companies paying for plastic disposal, that plastic can be converted into 15,586 lbs of oil per day or 5,588,890 lbs per year. Based on the U.S. Energy Information Administration, the current price prediction for 2022 is $60.494 per barrel and therefore the plant would earn 1.13 million U.S. dollars. This results in not only a positive environmental impact but a plant that is highly profitable.

9. Shortcomings

Over the course of the year, the true scale of this project became more apparent. Because of this, the scope of the project had to be narrowed on several different occasions resulting in a more achievable goal of designing the reactor. As time progressed, certain aspects of the reactor were finished, however, other aspects did not see the attention they truly needed. Below is a list of known shortcomings.

- Showing electrical heating element in CAD drawings
- Including all fasteners needed for assembly
- Addressing instrumentation within the reactor

10. Conclusion

During the process of designing a full-scale pyrolysis plant, the initial heat calculations were needed as a baseline to decide how this plant would operate and if it was feasible. With these calculations established, the process flow diagram and piping and instrumentation diagram were then created as a schematic representation of the pyrolysis plant design. Then the CAD model and CFD analysis were done while simultaneously contacting companies to find parts and instruments for this pyrolysis plant to be created. Each of these steps allowed the group to apply the knowledge that was gained over their time studying engineering. This additionally allowed the group to expand upon that knowledge through working with a company and creating a real product that will impact the world.

11. Future Work

The creation of this pyrolysis plant will allow for millions of pounds of plastic to be recycled every year. With this plant demonstrating a safe, efficient and profitable means of recycling plastic, this should allow for additional plants to be created. With enough plastic pyrolysis plants being created at a large scale, this technology should greatly improve the plastic waste crisis in the United States and the world. After this plant successfully demonstrates the technology can be used at an industrial scale, the plant could be improved by implementing a more complex reactor such as the fluidized bed reactor or conical spouted reactor, which could improve the production rate and offer a more uniform heat transfer distribution of the pyrolyzed plastic.

12. References

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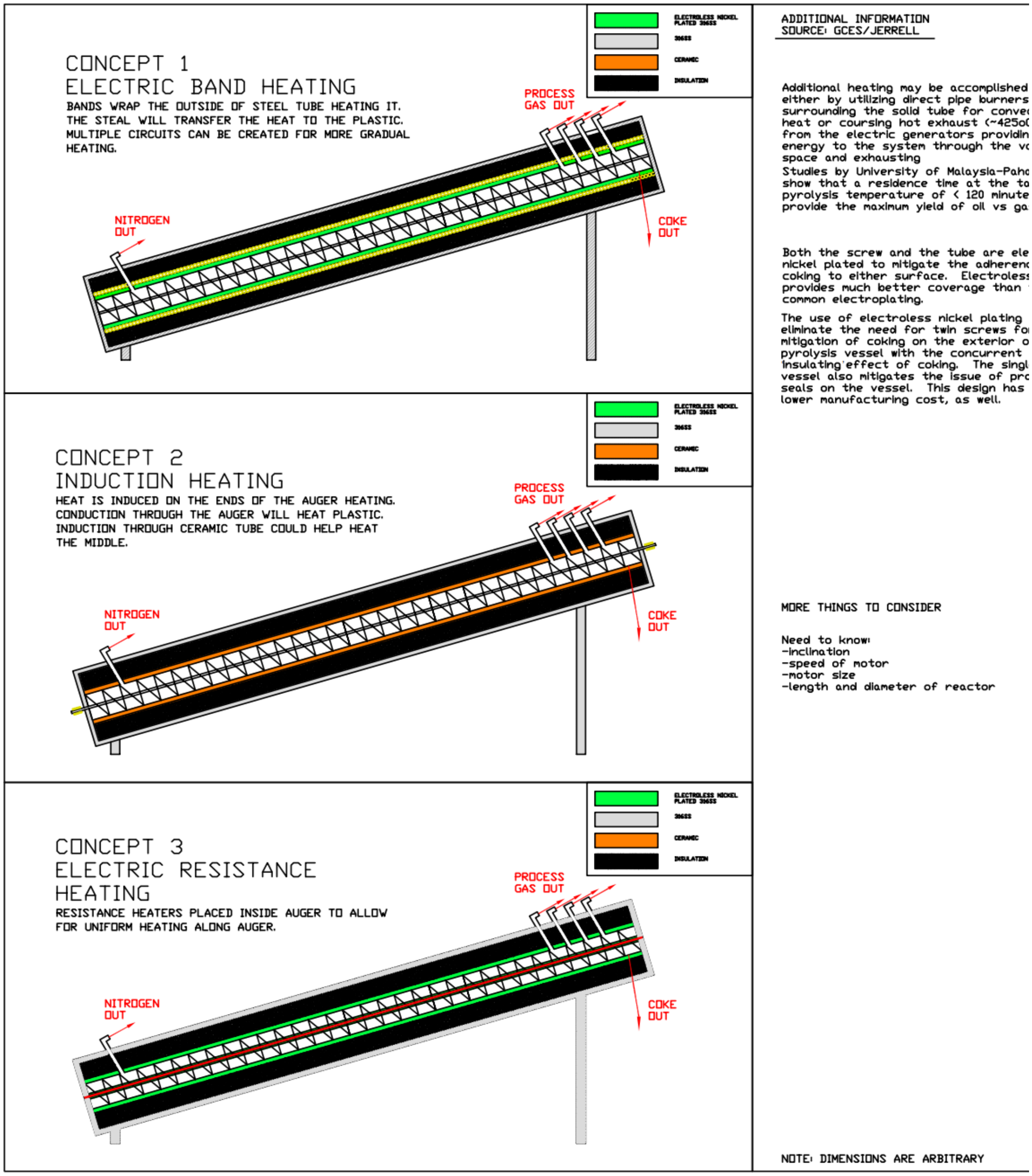
13. Appendices

13.1. Heat calculations

	HDPE	LDPE	PP	Oil	Gas	Char
Percentage Out (%)				77.93	12.06	10.01
Melting Point (℉)	267.44	253.4	266			
Specific Heat (BTU/lb·℉)	0.454	0.502	0.43			
Thermal Conductivity (BTU/h·ft· °F)	0.26	0.21	0.087			
Heat of Combustion (BTU/lb)	17445	18960	18960	18966	19820	9367
Density (kg/m^3)	59.3	57.43	56.19			
Change in Heat (BTU/lb)	477.22592	527.4602	452.1088			
Change in Heat (BTU/lb)	360.17051	398.0832	341.2142			
Total Change in Heat (BTU/lb)	837.39643	925.5434	793.3229			
Energy in (MBTU)	348.9	379.2	379.2			
Heat for Process (MBTU)	16.747929	18.51087	15.86646			
Average Energy Out (MBTU)	362.16265	362.1627	362.1627	295.6041	47.80584	18.75273

Table 6: Heat Calculation Values

13.2. Heating method ideas



CONCEPT 1
ELECTRIC BAND HEATING
BANDS WRAP THE OUTSIDE OF STEEL TUBE HEATING IT. THE STEAL WILL TRANSFER THE HEAT TO THE PLASTIC. MULTIPLE CIRCUITS CAN BE CREATED FOR MORE GRADUAL HEATING.

CONCEPT 2
INDUCTION HEATING
HEAT IS INDUCED ON THE ENDS OF THE AUGER HEATING. CONDUCTION THROUGH THE AUGER WILL HEAT PLASTIC. INDUCTION THROUGH CERAMIC TUBE COULD HELP HEAT THE MIDDLE.

CONCEPT 3
ELECTRIC RESISTANCE HEATING
RESISTANCE HEATERS PLACED INSIDE AUGER TO ALLOW FOR UNIFORM HEATING ALONG AUGER.

ADDITIONAL INFORMATION
SOURCE: GCES/JERRELL

Additional heating may be accomplished
either by utilizing direct pipe burners
surrounding the solid tube for conve
heat or coursing hot exhaust (~425o
from the electric generators providin
energy to the system through the v
space and exhausting
Studies by University of Malaysia-Pah
show that a residence time at the t
pyrolysis temperature of < 120 minute
provide the maximum yield of oil vs ga

Both the screw and the tube are ele
nickel plated to mitigate the adheren
coking to either surface. Electroles
provides much better coverage than
common electroplating.

The use of electroless nickel plating
eliminate the need for twin screws fo
mitigation of coking on the exterior o
pyrolysis vessel with the concurrent
insulating effect of coking. The singl
vessel also mitigates the issue of pr
seals on the vessel. This design has
lower manufacturing cost, as well.

MORE THINGS TO CONSIDER

Need to know:
-inclination
-speed of motor
-motor size
-length and diameter of reactor

NOTE: DIMENSIONS ARE ARBITRARY

Figure 12: Initial Concepts for Pyrolysis Reactor. Note that the gas out tubes would not be connected to 90° elbows as shown in this figure. It was also found that Concept 2 infringes on a patent, so it does not present a viable heating method.

13.3. Additional CFD images

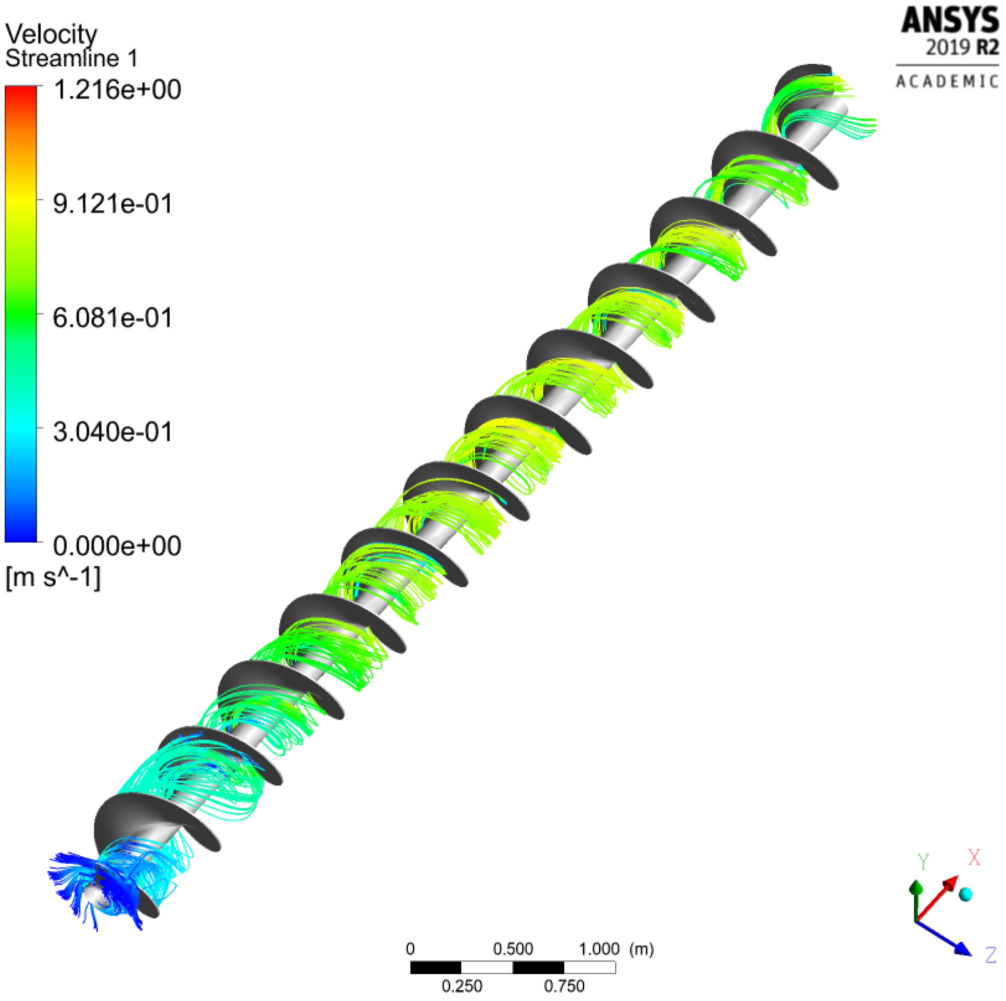


Figure 13: Flow of Water through Rotating Auger at -5RPM

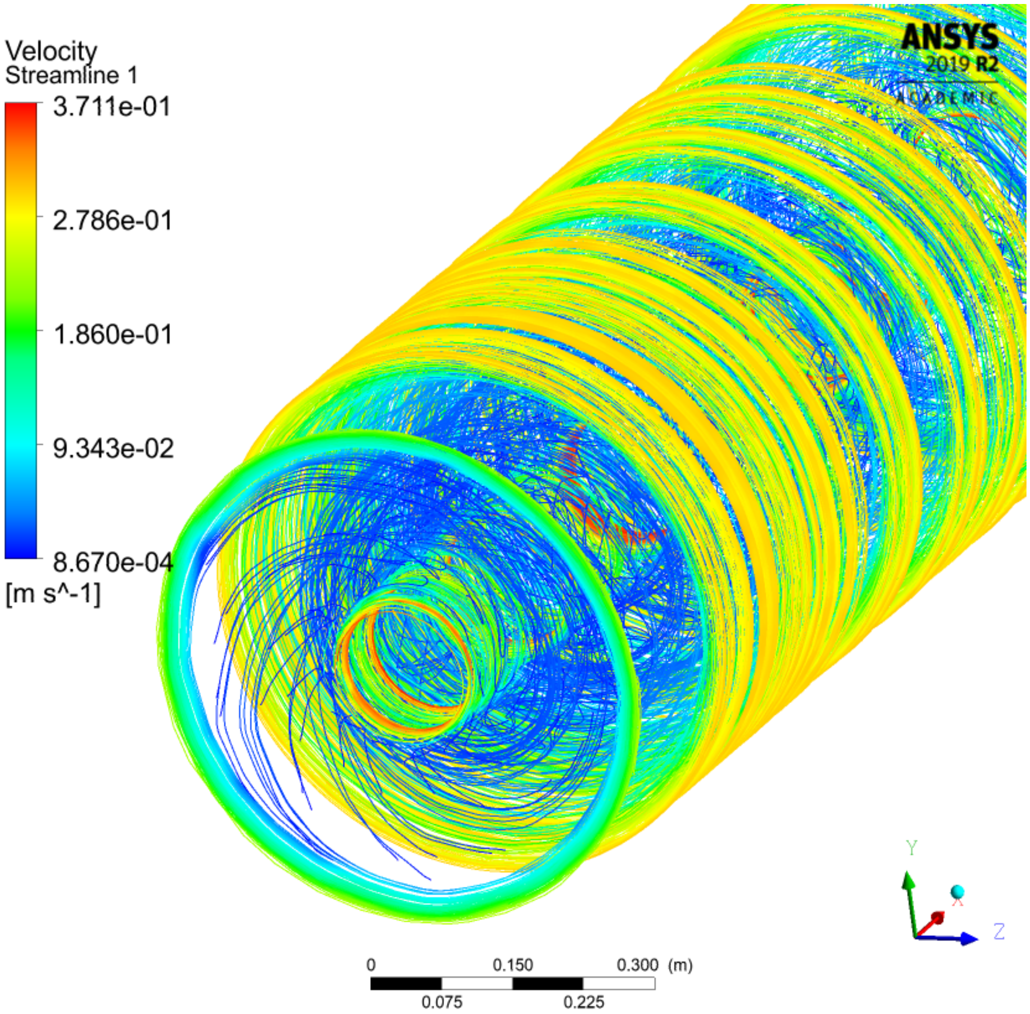


Figure 14: Flow of Water through Reactor without Auger. The outer wall is rotating at 10 RPM while the core is rotating at -50 RPM to simulate the flow with the auger.

13.4. Responsibilities Table

Task	Kaden Allen	David Lont	Hannah Sargent	Chris Weaver
CFD for velocity mixing and heat transfer		X		
Chemical properties/reaction research	X	X		
Complete project review forms				X
Contact suppliers	X	X	X	
Cost and weight estimates	X			
Decision matrix for reactor selection		X	X	
Economic and environmental impact analysis			X	
Ethics group presentation paper				X
Gantt chart		X		
Heat and flow calculations	X			
Heating element research and selection				X
Individual parts CAD and material selection	X			
Organize weekly progress forms				X
P&ID conception and CAD	X			
PFD calculations, conception, and CAD	X			
Reactor 2D CAD	X			
Reactor 3D CAD		X		
Reactor selection research		X	X	
Reactor structure, sealing mechanisms, and plant connection design	X			

Table 7: Group Responsibilities

Signatures

David Jeremiah Lont

Kaden Beatty Allen

David Jeremiah Lont

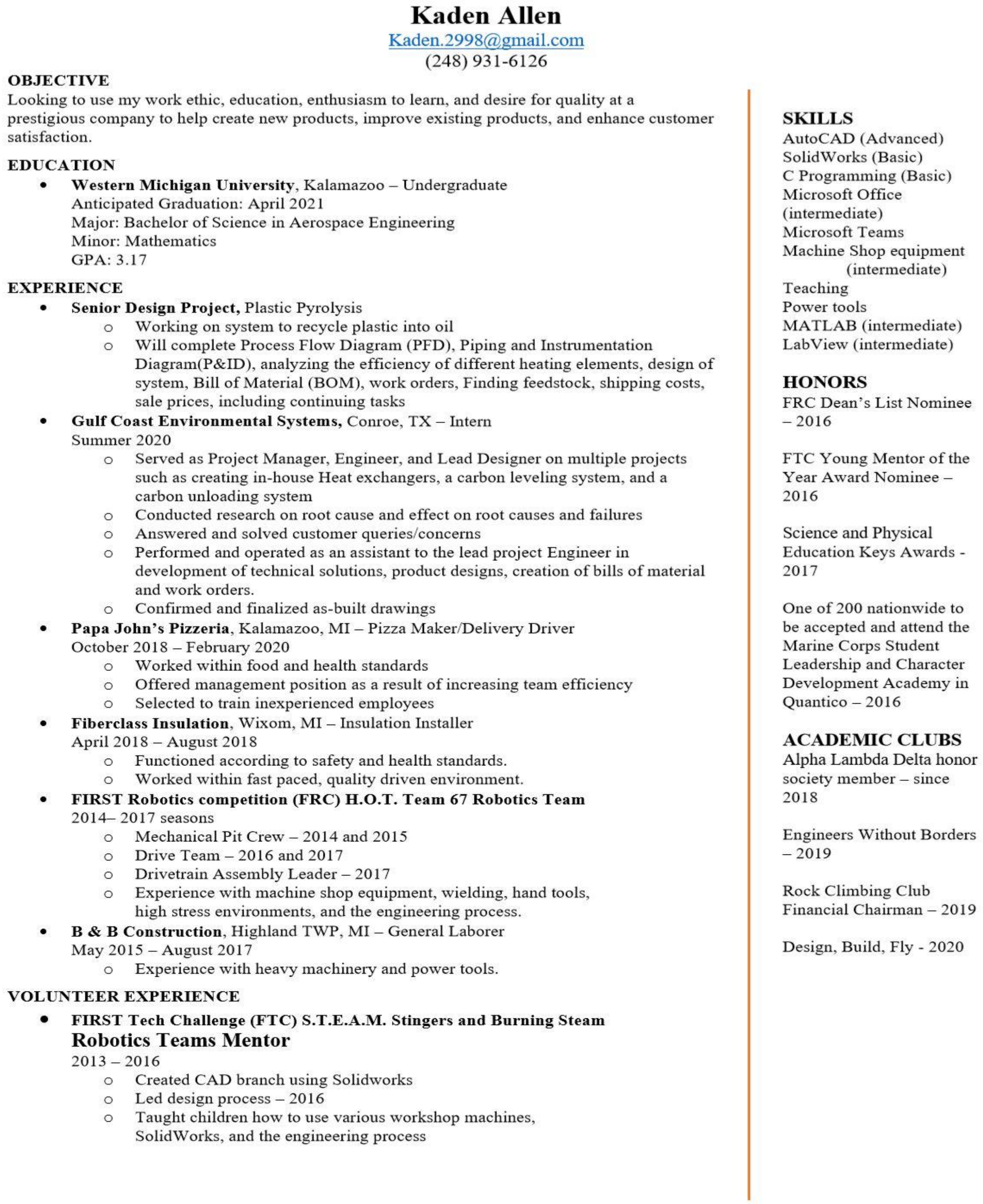
Hannah Sargent

Hannah Grace Sargent

Christopher N Weaver

Christopher Nathan Weaver

13.5. Resumes



Kaden Allen

Kaden.2998@gmail.com
(248) 931-6126

OBJECTIVE

Looking to use my work ethic, education, enthusiasm to learn, and desire for quality at a prestigious company to help create new products, improve existing products, and enhance customer satisfaction.

EDUCATION

- **Western Michigan University**, Kalamazoo – Undergraduate
  Anticipated Graduation: April 2021
  Major: Bachelor of Science in Aerospace Engineering
  Minor: Mathematics
  GPA: 3.17

EXPERIENCE

- **Senior Design Project,** Plastic Pyrolysis
  - Working on system to recycle plastic into oil
  - Will complete Process Flow Diagram (PFD), Piping and Instrumentation Diagram(P&ID), analyzing the efficiency of different heating elements, design of system, Bill of Material (BOM), work orders, Finding feedstock, shipping costs, sale prices, including continuing tasks
- **Gulf Coast Environmental Systems,** Conroe, TX – Intern
  Summer 2020
  - Served as Project Manager, Engineer, and Lead Designer on multiple projects such as creating in-house Heat exchangers, a carbon leveling system, and a carbon unloading system
  - Conducted research on root cause and effect on root causes and failures
  - Answered and solved customer queries/concerns
  - Performed and operated as an assistant to the lead project Engineer in development of technical solutions, product designs, creation of bills of material and work orders.
  - Confirmed and finalized as-built drawings
- **Papa John's Pizzeria**, Kalamazoo, MI – Pizza Maker/Delivery Driver
  October 2018 – February 2020
  - Worked within food and health standards
  - Offered management position as a result of increasing team efficiency
  - Selected to train inexperienced employees
- **Fiberclass Insulation**, Wixom, MI – Insulation Installer
  April 2018 – August 2018
  - Functioned according to safety and health standards.
  - Worked within fast paced, quality driven environment.
- **FIRST Robotics competition (FRC) H.O.T. Team 67 Robotics Team**
  2014– 2017 seasons
  - Mechanical Pit Crew – 2014 and 2015
  - Drive Team – 2016 and 2017
  - Drivetrain Assembly Leader – 2017
  - Experience with machine shop equipment, wielding, hand tools, high stress environments, and the engineering process.
- **B & B Construction**, Highland TWP, MI – General Laborer
  May 2015 – August 2017
  - Experience with heavy machinery and power tools.

VOLUNTEER EXPERIENCE

- **FIRST Tech Challenge (FTC) S.T.E.A.M. Stingers and Burning Steam Robotics Teams Mentor**
  2013 – 2016
  - Created CAD branch using Solidworks
  - Led design process – 2016
  - Taught children how to use various workshop machines, SolidWorks, and the engineering process

SKILLS

AutoCAD (Advanced)
SolidWorks (Basic)
C Programming (Basic)
Microsoft Office (intermediate)
Microsoft Teams
Machine Shop equipment (intermediate)
Teaching
Power tools
MATLAB (intermediate)
LabView (intermediate)

HONORS

FRC Dean's List Nominee – 2016

FTC Young Mentor of the Year Award Nominee – 2016

Science and Physical Education Keys Awards - 2017

One of 200 nationwide to be accepted and attend the Marine Corps Student Leadership and Character Development Academy in Quantico – 2016

ACADEMIC CLUBS

Alpha Lambda Delta honor society member – since 2018

Engineers Without Borders – 2019

Rock Climbing Club Financial Chairman – 2019

Design, Build, Fly - 2020

David Jeremiah Lont

david.j.lont@wmich.edu (269) 421-1923 linkedin.com/in/david-lont

Education

Western Michigan University, Kalamazoo, MI Exp. graduation: Aug. 2021

B.S. in **Aerospace Engineering,** minor in **Mathematics** **GPA: 3.77**

Work Experience

WESTERN MICHIGAN UNIVERSITY, Kalamazoo, MI

Undergraduate Research Assistant **May 2019 - August 2019**

- Investigated alongside Ph.D. students in the Fluid Mechanics Lab the effects of wind on the evaporation rate of water as it is heated to describe this relationship mathematically
- Analyzed the characteristics of the air-water interface using particle image velocimetry (PIV)
- Created program using MATLAB to prepare, analyze, and concatenate data for study
- Redesigned diffuser of wind tunnel to provide laminar flow necessary for the experiment
- Improved seeding for PIV by redesigning olive oil diffusing system

Tutor/Learning Assistant **August 2018 - Present**

- Increase student comprehension and retention rate through personalized review sessions
- Teach material with emphasis on concepts difficult for students to master
- Guide students in finding the adequate resources to succeed in their college career
- Collaborate with professors weekly to tailor review sessions to meet the professors' needs

LOWE'S, Kalamazoo, MI

Seasonal Cashier/Back end Receiver **June 2020 - August 2020**

- Adapted to a fast-paced and demanding environment to meet the needs of the store
- Coordinated truck arrival schedule and loading dock traffic to ensure efficient stocking of the store

STARBUCKS, Kalamazoo, MI

Barista **May 2018 - September 2018**

- Maintained customer satisfaction by placing customers first with speed and accuracy
- Multi-tasked taking customers' orders while efficiently and accurately handling beverages

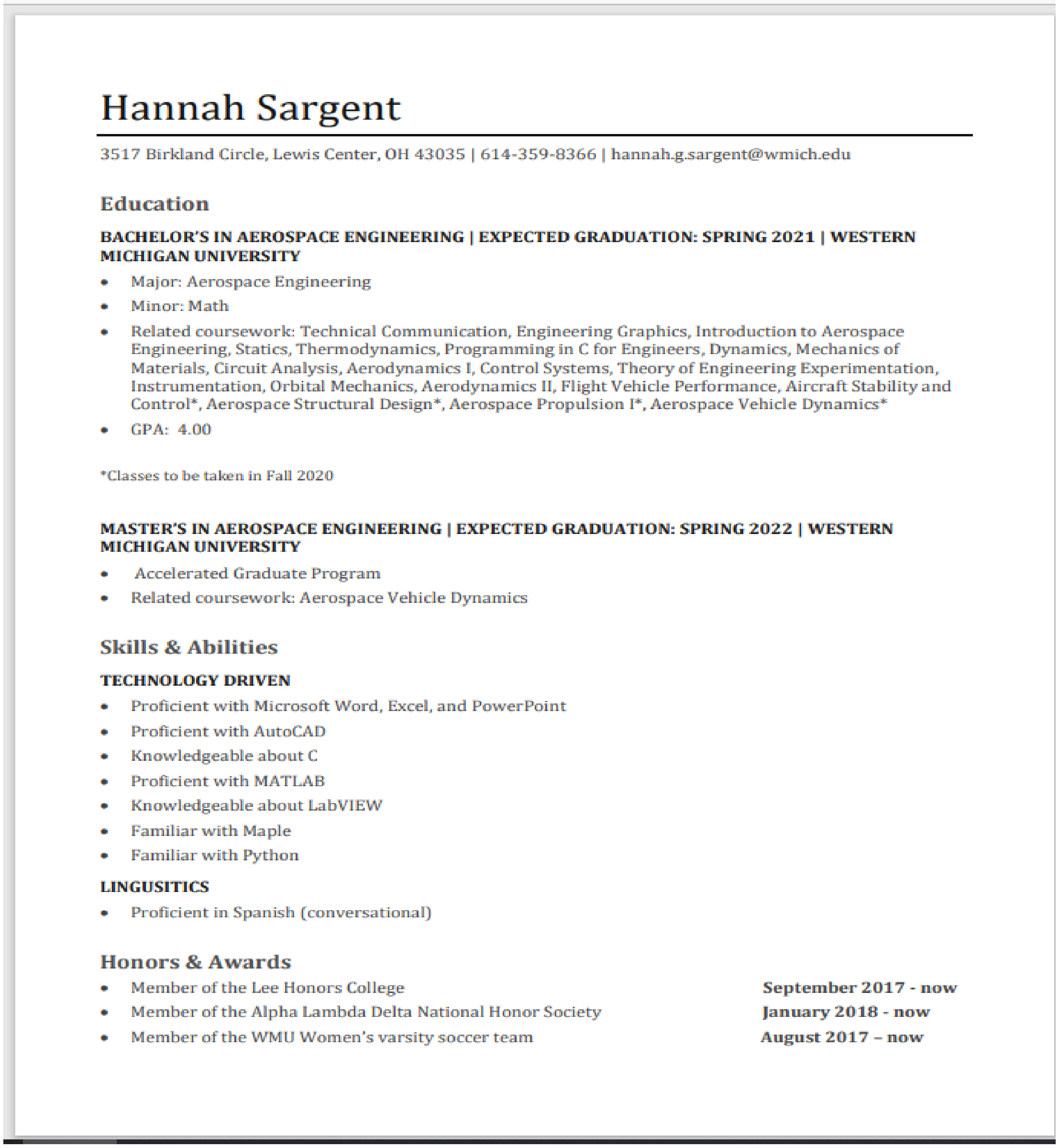
MATRIX ENTERPRISES, Grand Rapids, MI

Electronic Parts Assembler **June 2017 - August 2017**

- Prepared, soldered, and assembled a wide variety of cable types and electronic parts
- Exceeded required quota of cables to be stripped and soldered per day

Honors and Accomplishments

- Mechanical and Aerospace Merit Scholarship 2019-2020, 2020-2021
- Recipient of merit-based Kenneth Knight Scholarship 2020-2021
- Recipient of LSAMP grant to conduct research in fluid mechanics, 2019
- Nominated "Student Employee of the Year" 2018-2019
- Dean's List (all semesters except Spring 2020-COVID-19 Impacted)
- Participated in AutoCAD competition and received invitation to be a TA for Engineering Graphics (EDMM 1420) based on performance; declined in order to accept position as Learning Assistant
- Translated book, *The Power of the Gospel*, 2017 by Gerda Brown from Spanish into English
- Student contributor to the book *Keeping us Engaged: Student Perspectives (and Research-Based Strategies) on What Works and Why,* 2021 by Christine Harrington



Hannah Sargent

3517 Birkland Circle, Lewis Center, OH 43035 | 614-359-8366 | hannah.g.sargent@wmich.edu

Education

BACHELOR'S IN AEROSPACE ENGINEERING | EXPECTED GRADUATION: SPRING 2021 | WESTERN MICHIGAN UNIVERSITY

- Major: Aerospace Engineering
- Minor: Math
- Related coursework: Technical Communication, Engineering Graphics, Introduction to Aerospace Engineering, Statics, Thermodynamics, Programming in C for Engineers, Dynamics, Mechanics of Materials, Circuit Analysis, Aerodynamics I, Control Systems, Theory of Engineering Experimentation, Instrumentation, Orbital Mechanics, Aerodynamics II, Flight Vehicle Performance, Aircraft Stability and Control*, Aerospace Structural Design*, Aerospace Propulsion I*, Aerospace Vehicle Dynamics*
- GPA: 4.00

*Classes to be taken in Fall 2020

MASTER'S IN AEROSPACE ENGINEERING | EXPECTED GRADUATION: SPRING 2022 | WESTERN MICHIGAN UNIVERSITY

- Accelerated Graduate Program
- Related coursework: Aerospace Vehicle Dynamics

Skills & Abilities

TECHNOLOGY DRIVEN

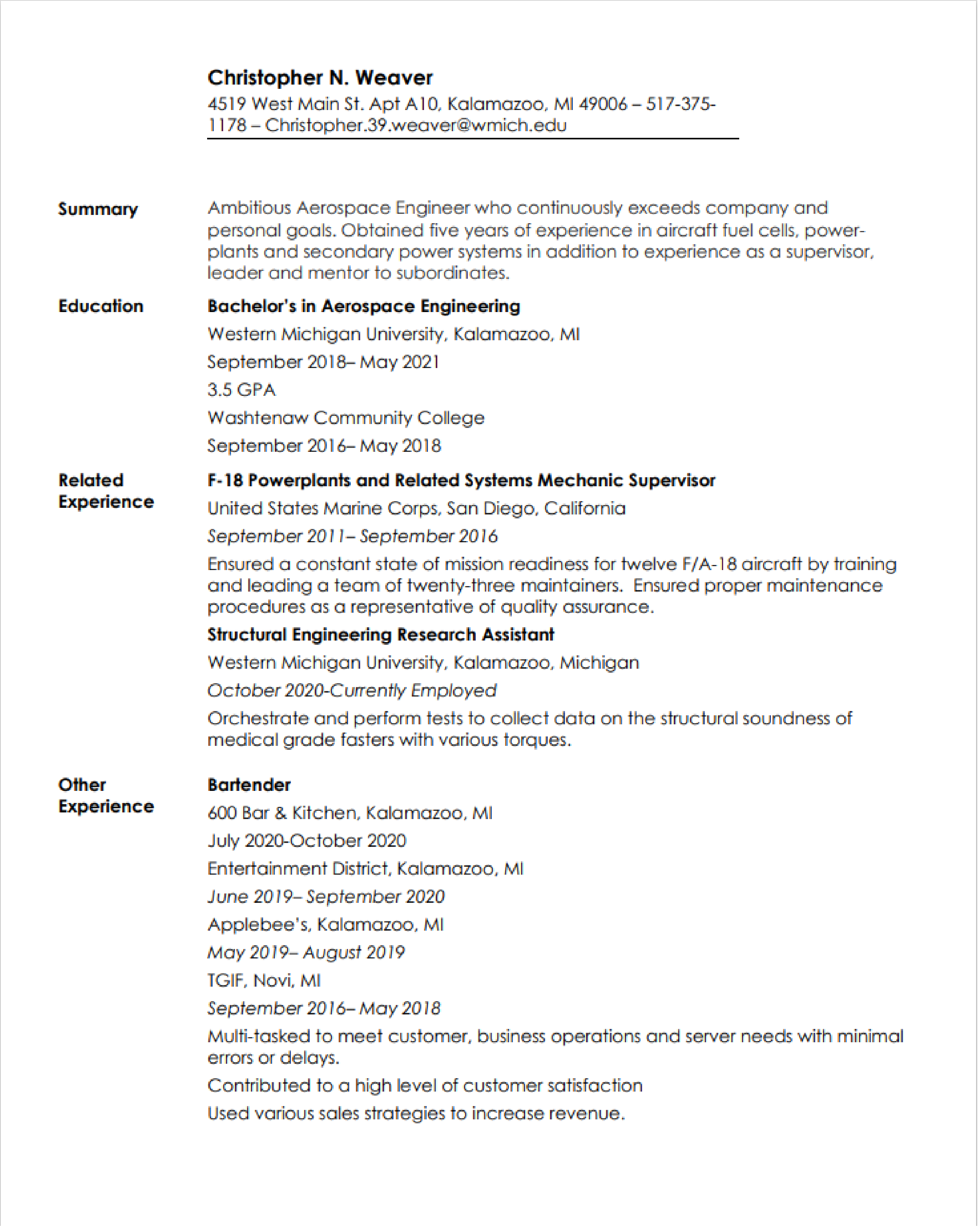
- Proficient with Microsoft Word, Excel, and PowerPoint
- Proficient with AutoCAD
- Knowledgeable about C
- Proficient with MATLAB
- Knowledgeable about LabVIEW
- Familiar with Maple
- Familiar with Python

LINGUSITICS

- Proficient in Spanish (conversational)

Honors & Awards

Member of the Lee Honors College	**September 2017 - now**
Member of the Alpha Lambda Delta National Honor Society	**January 2018 - now**
Member of the WMU Women's varsity soccer team	**August 2017 – now**



Christopher N. Weaver

4519 West Main St. Apt A10, Kalamazoo, MI 49006 – 517-375-1178 – Christopher.39.weaver@wmich.edu

Summary

Ambitious Aerospace Engineer who continuously exceeds company and personal goals. Obtained five years of experience in aircraft fuel cells, power-plants and secondary power systems in addition to experience as a supervisor, leader and mentor to subordinates.

Education

Bachelor's in Aerospace Engineering

Western Michigan University, Kalamazoo, MI

September 2018– May 2021

3.5 GPA

Washtenaw Community College

September 2016– May 2018

Related Experience

F-18 Powerplants and Related Systems Mechanic Supervisor

United States Marine Corps, San Diego, California

September 2011– September 2016

Ensured a constant state of mission readiness for twelve F/A-18 aircraft by training and leading a team of twenty-three maintainers. Ensured proper maintenance procedures as a representative of quality assurance.

Structural Engineering Research Assistant

Western Michigan University, Kalamazoo, Michigan

October 2020-Currently Employed

Orchestrate and perform tests to collect data on the structural soundness of medical grade fasters with various torques.

Other Experience

Bartender

600 Bar & Kitchen, Kalamazoo, MI

July 2020-October 2020

Entertainment District, Kalamazoo, MI

June 2019– September 2020

Applebee's, Kalamazoo, MI

May 2019– August 2019

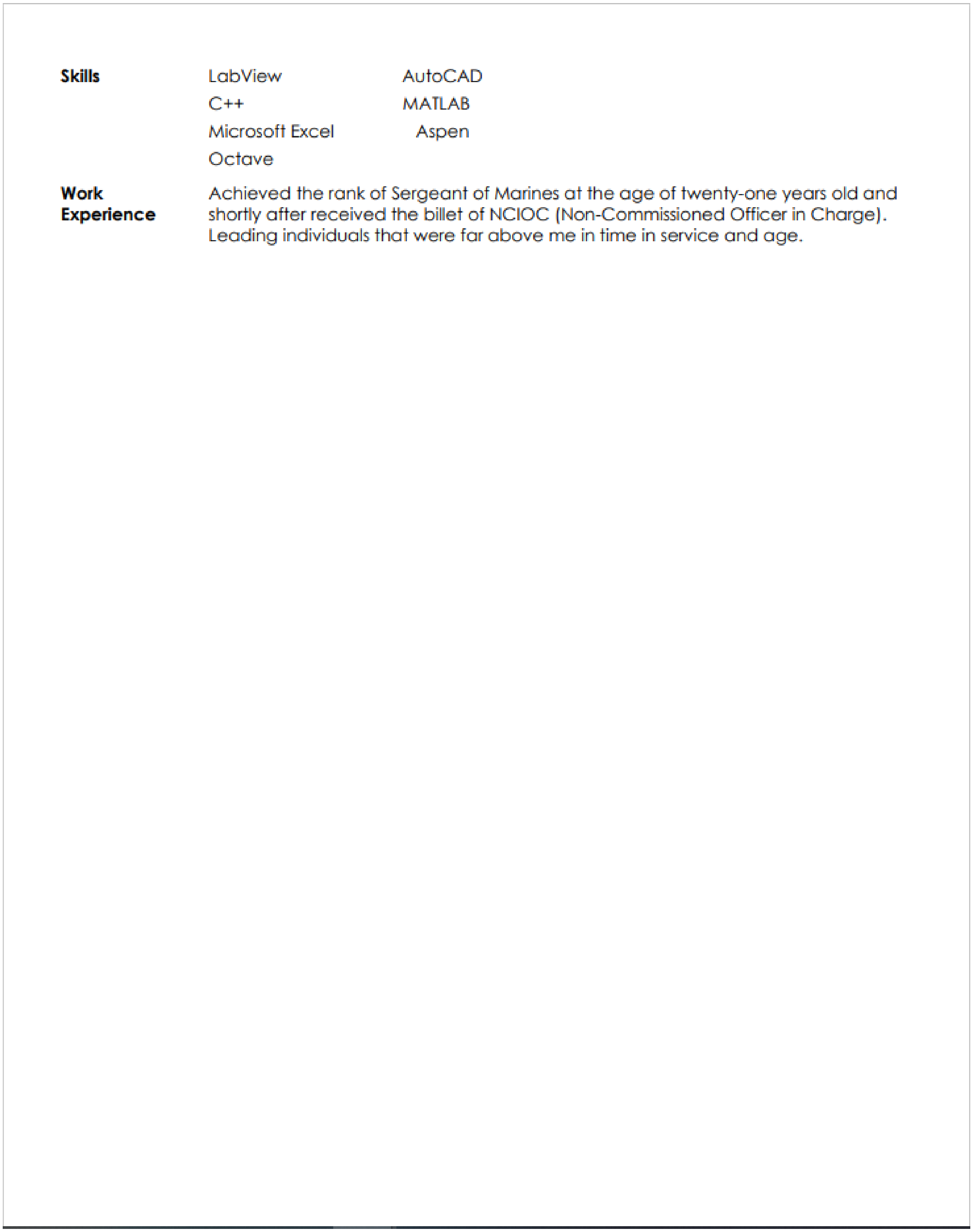
TGIF, Novi, MI

September 2016– May 2018

Multi-tasked to meet customer, business operations and server needs with minimal errors or delays.

Contributed to a high level of customer satisfaction

Used various sales strategies to increase revenue.



Skills	LabView C++ Microsoft Excel Octave AutoCAD MATLAB Aspen
Work Experience	Achieved the rank of Sergeant of Marines at the age of twenty-one years old and shortly after received the billet of NCIOC (Non-Commissioned Officer in Charge). Leading individuals that were far above me in time in service and age.