This B.S. thesis is written in partial fulfillment of the requirements in EML 4551. The contents represent the opinion of the authors and not the Department of Mechanical and Materials Engineering.
Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Rainer Rodriguez, Harrison Mejia, and Favyan Torres and it is original. Excerpts from others’ work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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ABSTRACT

Obtaining an appropriate product that is suitable for biodiesel production is the desired outcome of this senior thesis. Biodiesel is a form of diesel that is produced mainly from Waste Vegetable Oil, and unlike diesel from fossil fuels it is fully renewable. Biodiesel is non-toxic and environmentally friendly; as fossil fuels become more expensive, this particular Biofuel’s usage increases. WVO contains high contents of water and debris, and it must be properly treated prior to being used to produce biodiesel. The Pre-Treatment Station prototype that has been created separates the water and debris from the oil. The prototype ensures that the WVO being processed exits at a purity level acceptable by biodiesel producing companies. The expectation is to obtain an end product that is at least 99% pure oil, in order to proceed into the biodiesel production stage. Under the direction of Dr. Tremante, and assistant advisor Javier Palencia, the team is committed to obtaining the desired expectations and standards of the industry, in researching, designing, building and testing a prototype which will meet the required obligations.
1. INTRODUCTION

1.1 Problem Statement

It is well understood that fossil fuels are a depleting resource found around the world. In many industries, common petrol and diesel fuels are used to move products and resources around the world. One of the answers to the depletion problem is an alternative combustion fluid. Petrol and diesel fuels produce excessive pollution and are non-reusable. Fossil fuels also require various methods of extraction and filtering that can be quite costly.

The clear alternative is a green fuel that allows for quick acquisition in any area of the world. Biodiesel is a possible clean alternative that allows for a change in common combustible systems. It allows for a clean alternative to fossil fuels. It can be mainly based from waste vegetable oil used in cooking by many restaurants all over the world. The problem with “dirty” oils is there are various degrees of required filtration for those used oils because of the variety of uses for the cooking oil. Such impurities may include a high concentration of water or burnt food particles. These impurities can cause major problems when it comes to the actual production of the biodiesel. The challenge is finding the proper medium between filtration and cost, in a scaled prototype set to be used by biodiesel producing companies.

1.2 Motivation

For decades, fossil fuels have always been a prime source for producing energy. It has been a natural resource that is necessary to everyday lives. Unfortunately, the dependence of this resource has caused conflict and disdain between nations and people. Fossil fuels have also been a primary reason to global warming, a detrimental effect on the natural ecosystem of the world. To push towards a healthier life for the world and the living organisms a part of it, scientists and researchers have sought alternatives to such resources, in other words, renewable resources. Biodiesel is a renewable resource that will one day replace fossil fuels. It is a source of energy that is environmentally friendly and less toxic to the world and the air necessary to organismal life.

For this senior thesis, the main focus is to provide companies with clean oil generated from cooking and waste vegetable oil. The senior team is dedicated to working in order to meet industry qualifications and standards, and investigating the requirements biodiesel producing
companies require when it comes to clean oil using vegetable and other sorts of feedstock. The resulted clean oil can then be tested at a biodiesel producing plant for further treatment. After multiple treatments, bio-diesel is created and can be used as an alternative resource to fossil fuels. Bio-diesel will eventually get rid of the use for fossil fuels; it will provide the world with a cleaner, renewable source that will benefit the world and every one living in it.

1.3 Literature Survey
1.3.a. Waste Vegetable Oil Classification

Waste Vegetable Oil is classified into two different types, yellow grease and brown grease. Yellow grease is any WVO that has been recycled; it is basically cooking oil that can be reused. At times yellow grease can be used to make biodiesel as is, however it still contains small amounts of water as well as debris that if removed yields as better quality feedstock. Within plumbing systems, grease traps are placed, these devices are designed to capture any oil that passes through, and any WVO that is recovered using these traps is considered brown grease. Both yellow and brown grease are inexpensive, which is why biodiesel producing companies are shifting towards purchasing these greases, properly cleaning them and producing biodiesel from them rather than purchasing more expensive pure oils.

Figure 1. Yellow and Brown Grease [1]
1.3.b. Water Phases

Waste Vegetable Oil contains concentrations of water; within these the water phases can be divided into three different types. The first is free water and this is water that has not mixed with the oil, thus generally this water will sink to the bottom since water is naturally heavier than oil. Free water only occurs if the concentration of water within the oil exceeds a certain amount at which point it will no longer mix within the oil. Therefore if there are signs of free water within a specific WVO, which signals that it has a high overall water content. The second type is emulsified water; this occurs when the oil has exceeded its saturation point, this emulsified phase creates a milkiness or fog in the oil [2]. In the emulsified phase the water content exceeds 1500 parts per million (PPM). Finally the last phase is dissolved water, which is the hardest of all three to remove, in this phase the water is dispersed molecule to molecule throughout the oil. Depending on the water content of WVO as well as the different phases the water is in the WVO will either look clear, as oil does, or cloudy.

Water is not desired within the WVO because it affects the oil’s base stock, it supports oxidation, and increases the overall viscosity. There are various technologies that are successful at removing the different phases from oil; table 1 provides basic information about these technologies.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Phases of Water Removed</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity Separation</td>
<td>Free, Emulsified, Dissolved</td>
<td>Low cost.</td>
<td>Removes only free water.</td>
</tr>
<tr>
<td>Centrifuge</td>
<td>X</td>
<td>Effective at removing large volumes of free and emulsified water fairly quickly.</td>
<td>Does not remove dissolved moisture.</td>
</tr>
<tr>
<td>Polymer Absorption</td>
<td>X</td>
<td>Cost-effective on small systems, requiring polishing to remove moisture. Removes solid contaminants.</td>
<td>Limited volume capacity. Does not remove dissolved moisture.</td>
</tr>
<tr>
<td>Vacuum Dehydration</td>
<td>X, X, X</td>
<td>Capable of removing 80% – 90% of dissolved water.</td>
<td>High cost and comparatively low flow rates.</td>
</tr>
<tr>
<td>Air Stripping Dehydration</td>
<td>X, X, X</td>
<td>Removable dissolved water to less than 100 ppm. Removes gaseous contaminants.</td>
<td>High cost.</td>
</tr>
<tr>
<td>Heat</td>
<td>X</td>
<td>Portable units available. Low cost.</td>
<td>Heating may cause base oil degradation due to oxidation and thermal depletion of certain additives.</td>
</tr>
</tbody>
</table>

Table 1. Water Removal Technologies [2]
1.3.c. Biodiesel Characteristics

Biodiesel is a combination mixture of resources including: animal fat, vegetable oil, recycled cooking oil, agricultural oils with an alcohol product combined with esters [3]. Separating the glycerin from the vegetable oil or animal fat, which is called transesterification, makes bio-diesel. Strict specifications are implemented in ASTM (ASTM D6751) for production of bio-diesel (Biodiesel). Bio-diesel improves our environment; it is a form of renewable energy that cleans the burning diesel and as most green technologies reduces the dependence on importing diesel [3]. One can purchase bio-diesel from producers, distributors and several retailers. It is the only alternative fuel in the Clean Air Act Amendments that has passed all testing health requirements.

Biodiesel blends with conventional diesel type fuels. It delivers a lower emission compared to petroleum diesel and is produced using natural resources. Essentially, bio-fuel can decrease the dependence of oil from other countries; which in turn, helps the economy grow. One of the disadvantages of using bio-diesel is, you should not use more than 5 percent bio-diesel when the tank is outside, specifically during cold weather. The cost of biodiesel is comparable with normal heating oil. Biodiesel has absent impurities from sulfur and hydrocarbon. It acts as a cleaning agent and lubricant to help furnaces operate more effectively. The improvements of technology today, gives you the opportunity to purchase an oil furnace with the capability of setting your speed to maximize comfort, while minimizing the sound levels and energy costs and providing a long lasting performance on the equipment [3].

1.3.d. Water Content Test

Waste Vegetable oil is vegetable oil that has been used and now contains debris and concentrations of water. In order to produce biodiesel this water must be removed from the oil itself, in order to do this it is important to be able to calculate the water content within the oil. Prior to treating the WVO a water content test is conducted on the raw product. For this senior thesis the water test kit offered by Utah Biodiesel Supply was utilized.
Figure 2. Water Test Kit Contents [4]

Figure 1 illustrates the contents of the kit, the blue colored capsule is where the reaction takes place, by adding two different reagents to the unit as well as a predetermined amount of WVO and mixing, the gauge will show a reading. The kit includes various tables that allow the user to convert the obtained readings to a water content level. The utilization of this test kit prior to and after the cleaning process has taken place allows the user to determine exactly how much water was removed from the WVO.

1.3.e. Centrifuge

A centrifuge is a tool that is used to separate two liquids or solids within a liquid from one another. Within a centrifuge the rapid rotation causes the heavier liquid or particles to sink towards the bottom, allowing the lighter substances to remain at the top [5]. In this particular application the WVO will travel into the centrifuge as it begins to spin the heavier water will move towards the bottom along with any small solids, while the lighter oil will remain at the top and move on to the next phase within the system. A centrifuge operates behind the principal of centrifugal force that is the force that pulls an object away from the center of a rotating frame. Centrifuges play an important role in the separation of liquids, therefore they will be vital to the design of the pre-treatment station.

1.3.f. Water Polymer Absorption Removal

As stated under water content test, oil contains water after being used. A main focus of this project is to be able to remove as much water or debris from the oil. One possibility is adding a polymer that is considered to be a hydrophilic, or water-loving, polymer. These
polymers in shapes of small crystals are used for many external purposes to retain water. They are found from anywhere between diapers for babies to in landscaping for plants [6].

Figure 3. Water Absorbing Polymer Crystals [7]

In figure 3, towards the bottom of the cup, there are small crystals that absorb the water from the oil.

1.3.g. Water Polymer Absorption Filter

Water absorbing polymer crystals are used in multiple purposes. By using a filter with a water polymer filter cartridge, there is a higher opportunity to the removal of water from oil [6]. This cartridge will essentially be absorbing the water from the oil as it passes through the filtration system. Unfortunately, a disadvantage to this type of filter is the small capacity it has to filter water from the oil. For this reason, it is best to utilize this small filter towards the end of the pre-treatment system. Fortunately, this method is very cost effective and filters debris instead of just water [8]. It is a reasonable assurance and back up to the removal of water aside from using a heater.
Figure 4. Polymer Absorption Filter [9]

In figure 4, a small micron filter is shown. It is similar to the small filter towards the end in the pretreatment system. Once difference is the filter cartridge used. The filter cartridge contains the small crystals that absorb water making the filtering device much more efficient.

1.3.h. Magnetic Filtration

Research has been done to prove that magnetic removal of oil is possible. Small magnetically friendly particles are injected in the fluid. The particles are naturally attracted to the oil’s chemical structure, therefore allowing for the oil to be caught by the magnets found in the apparatus. The technique was originally designed because of the 2010 Deepwater Horizon oil spill [8]. It would be used to more efficiently filter the large amounts of oil that were found in the choppy waters of the Gulf of Mexico. The same technology can be applied in a fluid flow. Figure 5 shows a small sample of the technology. The apparatus used for testing by Massachusetts Institute of Technology (MIT) is slightly bigger with multiple magnets that collect the oil into a set of tubes [10].
1.3.i. Vacuum Dehydrators

Vacuum dehydrators decrease the partial pressure which allows for the water to boil at lower temperatures. With a lower pressure, it is possible to reduce the water’s boiling point to about 120° F. Therefore, by heating the oil to temperature of about 150°F, the water can be vaporized while still maintaining the full properties of the oil. This method also allows for the removal of low-boiling impurities such as solvents [10].
2. CONCEPTUAL DESIGN

2.1 Overview

The biodiesel pre-treatment system is an ongoing project under the direct supervision of Dr. Tremante. This team is beginning the design phase on an already existing prototype worked on by a previous senior design team. The stage in which the system currently is in does not meet the various requirements of biodiesel producing companies. The design will incorporate components of the already existing system; however go in a different direction in terms of how the system will eventually function.

The existing prototype’s functionality is limited. WVO contains not only a percentage of solids or “debris” however it more importantly contains varying contents of water. The current system is capable of removing most of the debris, however only after various run-throughs of the material. It fails to separate any of the water from the oil, thus obtaining a final product, which still has high contents of water and cannot be processed by the sponsor. Per the sponsor’s specifications, the system must yield a product that is no less than 90% oil, while doing so in a timely and efficient manner.

2.2 Design Specifications

In order to accommodate for the stated specifications the existing system must be re-engineered. The existing system is composed of a storage tank in which the WVO is initially placed. Within the tank there is a rough filter that captures any of the larger solids within the raw product. Furthermore a heating system is located inside the tank, its purpose is to decrease the WVO’s viscosity. A primary filtration device is placed close to the storage tank’s outlet followed by the pump. The oil is then pumped through a centrifuge or a micro filter before it exits the system into another tank.

2.3 Existing Prototype

The starting point for this project was the 2013 Biodiesel Feedstock Pre-Treatment Station. The design has six components that are necessary for the filtration of the waste vegetable oil. The first part of the system is an insulated black holding tank where the “dirty” vegetable oil is placed. The tank has a mesh filter that grabs the greater sized chunks of debris that may be found
in the WVO. The tank also includes an electrical heater that reduces the viscosity of the oil to allow for easier movement throughout the system.

A pump is necessary to move the fluid from one component to the next. The pump being used in its current state is the Oberdorfer Plastic Centrifugal Pump Model 144. It is a small electrical pump that runs of 1.25 amps and operates at 10,000 RPM. Another major component is the centrifuge found downstream of the pump in this system. This centrifuge is a passive system so the fluid flow alone allows for the proper function of this component. It allows for the separation of items of different densities without the use of external power. This allowed the team to keep the energy usage to a minimum.

There are two other filters installed in the system. The first is the “primary filter” that serves to ensure there are no big particles being introduced to the pump. It works similar to a centrifuge by using the separating the particles of different densities. The other filter is a membrane filter at the end of the team’s system. The membrane filter is a simple filter component, which cleans oil up to the 20 microns. According to the team, this component is crucial for the cleaning of brown grease.

The components in the system are connected using schedule 40-rubber hosing and schedule 40 PVC piping after the centrifuge. The valves vary in material depending on the temperature the valves will need to withstand. The ½-inch brass valves are attached at the sedimentation (holding) tank, while the ½-inch PVC fittings are placed after the pump where the temperatures are lower and not as crucial.

The components are supported by bent sheet metal in order to keep all components and valves at the same height level. These fixed supports are bolted into a plastic cart that has two levels. The top level of the system contains all filtering components, the pump, and the sedimentation tank. The lower level contains the residue tank and the final product tank.
2.4 Design Alternatives

Various design options have been considered, while utilizing the existing components. The design is divided into two portions: pre-pump and post-pump. Pre-pump refers to all components placed directly before the pump, these include: the storage tank, rough filter, heater, and primary filtration. Post-pump refers to components located after the pump, these include: the centrifuge, and micro filter. Some considered designs include adding an additional sedimentation tank directly after the storage tank, with its own heater; this would allow the water to further evaporate from the WVO. Allowing the product to settle in this sedimentation tank will also ensure that most of the heavier solids settle to the bottom. Post-pump the design will offer alternatives, which the WVO can take, depending on its original purity level. It will go through a centrifuge and or a micro filter, furthermore another centrifuge and filter will be placed towards the end of the prototype to ensure final processing. Finally a second sedimentation tank will be placed where the oil will settle and be heated once more in order to evaporate any last contents of water.
3. PROPOSED DESIGN

3.1 Overview

After careful consideration of all design alternatives a final design was agreed upon. The design was chosen taking into great consideration the fact that the content of water within WVO will vary depending on where the product was attained. For instance, one product can contain a 20% water concentration, whereas another might contain 35%. Taking this into account the team has developed a system that can be adjusted by the user in order to accommodate for the differing compositions of the WVO.

3.2 Final Design

Alongside the prototype a “menu” is easily visible. The menu displays a chart with different water concentrations and the appropriate procedure to follow in order to obtain a desired end product for each one. The prototype has a series of valves that can be opened or closed; determining the flow the WVO will follow throughout the system. For example, if the WVO feedstock contains a 15% water concentration the user would go to the chart and re-adjust the prototype to execute the process according to the product. By readjusting the prototype the user can dictate whether the WVO will flow through all portions of the system, or only designated ones. The flow is split post-pump where it can be directed towards the various components immediately following the pump. In addition to the already existing components, another micro filter has been supplemented, as well as another larger centrifuge. Finally once the product reaches the end destination of the pre-treatment station it will settle into a sedimentation tank in which the product will be further heated to evaporate any final concentrations of water.
Figure 9. Prototype Schematic
4. PROJECT OBJECTIVES

4.1 Timeline

Table 2. Gantt Chart

4.1 Breakdown of Responsibilities

Table 3. Responsibilities
5. ANALYTICAL ANALYSIS

Bernoulli’s principle states that an increase in an incompressible fluid’s velocity occurs as the fluid’s pressure decreases. Utilizing this principle the following calculations can be performed in order to analyze the system and all of its components. In the proposed design Bernoulli’s equation is implemented from the evaporation tank to the final product tank.

Bernoulli’s Equation:

\[
\frac{P_1}{\gamma} + \frac{v_1^2}{2g} + z_1g = \frac{P_2}{\gamma} + \frac{v_2^2}{2g} + z_2g + \sum H_f
\]

Where:
- \( P_1 \): Pressure at Point 1
- \( \gamma \): Specific Weight of Fluid
- \( v_1 \): Velocity at Point 1
- \( z_1 \): Height at Point 1
- \( g \): Gravity
- \( P_2 \): Pressure at Point 2
- \( v_2 \): Velocity at Point 2
- \( z_2 \): Height at Point 2
- \( H_f \): Loss of Head

The constraints that have been placed on the system state that the pressure at point 1 and the pressure at point 2 are both open to the atmosphere thus they are equal. This reduces Bernoulli’s Equation to:

Reduced Bernoulli’s Equation:

\[
\frac{v_1^2}{2g} + z_1g = \frac{v_2^2}{2g} + z_2g + \sum H_f
\]
An important aspect of the design is to maintain all components at a constant height relative to each other. Once the WVO exits the evaporation tank into the main piping system all pipes will be maintained at a constant height throughout the entire system. This further reduces Bernoulli’s Equation to:

Final Bernoulli’s Equation: 

\[ \frac{V_1^2}{2g} = \frac{V_2^2}{2g} + \sum H_f \]

Head loss can include major losses and minor losses. This involves the effects of friction and minor losses in the piping and fittings while also including energy loss due to the length of the pipes and tubes. Head loss can be analyzed using:

\[ \frac{fLV^2}{D_h2g} + \sum K \frac{V^2}{2g} \]

Where: 

\( f \): Friction coefficient 

\( L \): Length of Pipe 

\( V \): Average Velocity of Fluid 

\( D_h \): Hydraulic Diameter 

\( g \): Gravity (9.81 m/s² or 32.17 ft/s²) 

\( K \): Loss Coefficient for Piping and Fittings

In order to ensure proper flow through the system, the proper area is required for the tubing and piping used in the system. Proper analysis begins with the basic equation of Volumetric Flow Rate:

\[ Q = V \cdot A \]

This equation allows for the calculation of the proper area by allowing the area (A) to be isolated when the flow rate (Q) and the velocity (V) are known. When used in conjunction with the theory of Conservation of Mass:
\[
\frac{dM}{dt}_{\text{system}} = 0
\]

allows for the same flow rate equation to be used in the joints that may deal with a fluid going in two different directions. This equation, in a hypothetically ideal system, allows for the proper calculation of the amount of fluid that can be introduced and expelled at a given moment.

6. **MAJOR COMPONENTS**

6.1 **Heat and Settle Tank**

The heat and settle tank is where the raw product is first placed into; the WVO is poured through a small opening atop the tank prior to being processed through the prototype. Within the tank there are a series of filters, which are designed to capture any of the larger debris that may be contained in the WVO. The tank’s shape is cylindrical throughout, and will be placed vertically above the main platform of the prototype. Towards the bottom, the inside of the tank changes from cylindrical to cone shaped, this is done in order to capture most of the debris as well as free water by means of gravity, since the solids within the WVO are heavier than the oil itself they will sink to the bottom. Figure 10 illustrates the basic design and idea of a heat and settle tank.

![Figure 10. Illustration of Heat and Settle Tank [2]](image-url)
The tank has two outlets, one directly above the line where the tank begins to funnel, and the other placed directly at the bottom of the tank. The first outlet is strategically placed above where most of the debris would have settled. The second outlet is placed directly below where all the debris that has settled will be. Once the oil has been pumped through the rest of the prototype, the second outlet will be opened and the extracted debris can be removed into a residual container.

6.2 Evaporation Tank

The evaporation tank, is placed below the heat and settle tank, they are connected by a pipeline angled downwards 45 degrees and equipped with a valve. Post heat and settling the WVO flows into the evaporation tank, where it will be heated to around 150 °F. The diameter of this tank is larger than the first this is in order to increase the cross sectional area, which ultimately speeds up the evaporation process. The tank is equipped with a vent valve in order to allow the evaporated water to exit the system. Calculations are yet to be made on how long the WVO should stay in the evaporation tank, once it exits it will be pumped towards the main components of the system.

6.3 Pump

The WVO will be driven throughout the system by a pump; the pump’s pumping power is dependent of the actual piping system itself. Through the use of Bernoulli’s principle, and analysis of the system the adequate pumping power will be calculated and then a fitting pump will be selected. Within the proposed design the pump is placed post the primary filter and prior to the centrifuge, it is of great importance as well to have all elements at an equal height as to eliminate any additional losses.

6.4 Centrifuge

The centrifuge is the first component that will filter the WVO after it is pumped though by the pump. Centrifugal forces cause the heavier solids and or liquids to sink to the bottom, thus allowing the lighter oil in this case to stay on the top. Centrifuges are classified into two main types, passive and active. Passive types, work exclusively on how high the flow strength is. What actually produces the centrifugal process is the flow itself, forcing the heavier objects to sink.
Active centrifuges come with their own motor, this motor powers the sinning motion, therefore no matter the flow’s characteristics the active centrifuge will be able to filter the contents.

![Biodiesel Centrifuge](image)

Figure 11. Biodiesel Centrifuge [12]

7. STRUCTURAL DESIGN

7.1 Main Structure

The current system was constructed above a plastic rolling cart. Plans to utilize this already existing main frame are set, furthermore another mainframe will be attached to this in order to have the heat and settle tank above all other components within the system.

7.2 Insulation

All containers within the system are properly insulated for safety precautions, as well as for energy saving. The containers include the heat and settle tank, evaporation tank, debris and free water tank, and the final storage tank. Securing that insulation is present wherever components handling the hot WVO are is extremely important to prevent any accidents. Furthermore by placing a layer of insulation on the heat and settle tank as well as the evaporation tank, reduces the heat into the system via the electric heaters, as it helps to keep the heat in. The required thickness and overall type of insulation is yet to be determined.
7.3 Pump

The pump is one of the main components of the system; it is placed after the primary filter and before the centrifuge. The existing pump is an Oberdorfer Plastic Centrifugal Pump Model 144; the housing material is made of non-metallic glass reinforced nylon. The impeller is constructed from non-metallic glass reinforced PPS. Its rotational speed of 10,000 RPM utilizes 120-volt source and is of 1.25 amp current. The pump’s inlet and outlet diameters are 3/8 of an inch, and has an output flow rate of about 1 gallon per minute. Further calculations are to be made in order to adequately determine whether this pump may be used in the proposed design, reengineering the system while utilizing as many of the existing components as possible is a priority.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amperage</td>
<td>1.25 Amps</td>
</tr>
<tr>
<td>Pump Speed</td>
<td>10,000 RPM</td>
</tr>
<tr>
<td>Pump Electrical Feed</td>
<td>115 Volts</td>
</tr>
<tr>
<td>Pump Height</td>
<td>5 in.</td>
</tr>
<tr>
<td>Pump Length</td>
<td>9 in.</td>
</tr>
<tr>
<td>Pump Width</td>
<td>8 in.</td>
</tr>
<tr>
<td>Pumping Housing Material</td>
<td>Non-metallic Glass Reinforced Nylon</td>
</tr>
<tr>
<td>Impeller Material</td>
<td>Non-metallic Glass Reinforced PPS</td>
</tr>
</tbody>
</table>

Table 4. Pump Specifications [11]
7.4 Piping Systems

In order to transfer the WVO from one point of the system to the other, the appropriate piping system has to be chosen. One big challenge and specific goal is to have a piping system that is strictly horizontally parallel to the platform throughout the prototype. By not having any changes in height between all the components losses can be avoided, as the height difference within Bernoulli’s equation will be zero. The first instance of piping in the system is the connection between the heat and settle tank and the evaporation tank. This pipe will be angled downwards at around 45 degrees from the heat and settle tank, which is at a greater elevation. The current prototype utilized schedule 40 transparent rubber hoses. This hose can withstand pressures of up to 130 psi with temperatures as high as 150 degrees Fahrenheit. Other options for piping materials will be considered and further considered.

Figure 13. Pump [14]
## 8. COST ANALYSIS

### 8.1 Prototype Cost

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
<th>Cost Estimate ($)</th>
<th>Required Cost ($)</th>
<th>Total Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat and Settle Tank*</td>
<td>1</td>
<td>20</td>
<td>775.17</td>
<td>1677.06</td>
</tr>
<tr>
<td>Residue Tank*</td>
<td>1</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaporation Tank</td>
<td>1</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Product Tank*</td>
<td>1</td>
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<td></td>
</tr>
<tr>
<td>Component Supports</td>
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<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Primary Heater*</td>
<td>1</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary Heater</td>
<td>1</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pump*</td>
<td>1</td>
<td>267.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrifuge*</td>
<td>1</td>
<td>246.18</td>
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<td></td>
</tr>
<tr>
<td>Macro Filter</td>
<td>1</td>
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<td></td>
</tr>
<tr>
<td>Primary Filter*</td>
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<td></td>
</tr>
<tr>
<td>Micron Filter*</td>
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</tr>
<tr>
<td>Water Absorption Filter</td>
<td>1</td>
<td>134.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nozzle</td>
<td>1</td>
<td>56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulation</td>
<td>1 roll / 32ft</td>
<td></td>
<td>12.8</td>
<td></td>
</tr>
<tr>
<td>Pipes</td>
<td>2 pipes/10ft</td>
<td></td>
<td>7.84</td>
<td></td>
</tr>
<tr>
<td>Tubes</td>
<td>1 tube/ 10ft</td>
<td></td>
<td>3.93</td>
<td></td>
</tr>
<tr>
<td>Control Panel</td>
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<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Hardware</td>
<td>----</td>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Cart*</td>
<td>1</td>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Test Kit</td>
<td>1</td>
<td>210</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Prototype Cost Analysis

In the table shown below, an estimated cost analysis was created. This table will serve as a basis for the budget of the project. Costs will tend to fluctuate as time goes by, offering an opportunity to purchase a part under the estimated costs. Now, in the table, multiple parts are marked with an asterisk (*). The reason being is these parts were already obtained through donations from a previous group. This is beneficial because it decreases the amount of parts needed and costs. One column shows required cost; this calculated cost is the total cost of the remaining parts waiting to be purchased. The entire, total cost is stated in the table to give an understanding of what the estimated cost would be if all the parts were purchased.
8.2 Operational Cost

<table>
<thead>
<tr>
<th>Labor</th>
<th>Harrison</th>
<th>Rainer</th>
<th>Favyan</th>
<th>Hours Spent</th>
<th>Total Hours Spent</th>
<th>Cost Estimate ($)</th>
<th>Total Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research</td>
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<td>15</td>
<td>15</td>
<td>45</td>
<td>144</td>
<td>1350</td>
<td>4320</td>
</tr>
<tr>
<td>Prototype Design</td>
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<td>15</td>
<td>10</td>
<td>30</td>
<td></td>
<td>900</td>
<td></td>
</tr>
<tr>
<td>Report Preparation</td>
<td>10</td>
<td>25</td>
<td>7</td>
<td>42</td>
<td></td>
<td>1260</td>
<td></td>
</tr>
<tr>
<td>Presentation Preparation</td>
<td>2</td>
<td>4</td>
<td>9</td>
<td>15</td>
<td></td>
<td>450</td>
<td></td>
</tr>
<tr>
<td>Graphic Design and Analysis</td>
<td>4</td>
<td>1</td>
<td>7</td>
<td>12</td>
<td></td>
<td>360</td>
<td></td>
</tr>
<tr>
<td>Components Acquisition</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Manufacturing</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>System Assembly</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System Adjustments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Operational Costs

This table shows the amount of individual man-hours put into the project, as well as the total time between the team. Furthermore, to understand the total cost of the project, an estimated average salary of $60,000 was taken into consideration. The salary amount converted to an hourly wage was calculated to be roughly around $30 per hour. When multiplied the total hours with the estimated hourly wage, the total engineering cost came to be $4320.

9. PROTOTYPE SYSTEM DESCRIPTION

9.1 Containers

9.1.a. Heat and Settle Tank

In order to remove any free water as well as larger debris, a heat and settle tank is implemented. By combining the water separation techniques of gravity and heating separation, the overall effectiveness of the first step is increased. The heat and settle tank offers separation of water from oil by means of gravity. The density of water is greater than that of oil, therefore gravity will separate the two; the water will sink to the bottom of the tank, while the oil remains above it. Utilizing separation by means of gravity is very advantageous as it is inexpensive. The proposed tank design includes the 5 gallon tank in the existing prototype, it will be outfitted with an aluminum sheet rolled up and fitted into a cone shape, this sheet is meant to function like a funnel, refer to figure 10. The angle of the funnel is roughly 45 degrees in reference to the base of the tank. A small hole, of a diameter yet to be determined, will be cut at the tip of the funnel.
and fitted with a drain valve; this is to remove any debris contained within the funnel post the heating and sedimentation process. Another hole will be cut exactly above the line where the tank begins to funnel down; a piping line will be attached at this point, in order to pump the clean oil, which resides above the water and any debris.

9.1.b. Water Evaporation Tank

The water evaporation tank is where the WVO will be heated in order to evaporate the water. This tank is positioned at a height lower than the heat and settle tank, and both will be joined by a pipeline angled 45 degrees downward. The downward angle allows the transfer of WVO from the first tank to the second by means of gravity. It is a five gallon tank, however with a larger diameter, in order to create a larger surface area, which ultimately speeds up the evaporation process. In order to remove the water from the headspace a vent valve is attached to the top of the closed tank. The vent valve allows the headspace, which is saturated with water to exit the tank. Finally the main piping system will be attached to the bottom of the tank, functioning as an entry for the now pre-processed WVO to enter the main treatment section.

9.1.c. Debris and Free Water Tank

Positioned under the heat and settle tank, the debris and Free Water tank is connected to the funneled section. A pipeline with a valve leads directly into it and the debris and free water that settled is allowed to flow through and out of the main system. Once more the existing tank will be used for this purpose, however minor safety modifications will be made. In the current prototype it is just tank uncovered and unbolted, in order safely use it, it will be bolted down, sized with a closure and covered with insulation.

9.1.d. Final Product Tank

Once the WVO has been processed through the entire station, it will settle back into a final product tank. The current prototype’s holder tank is utilized for this, as it is of right size, and no further modifications must be made.

9.2 Heating Elements

9.2.a. Primary Heater

The primary heater is placed inside the heat and settle tank, the current heater is going to be reused as it serves its purpose. It is equipped with a variable thermostat, which can control the
actual temperature that it can heat to. It consumes 15 amps of current, utilizes a voltage source of 110 volts and has a power output of 1500 watts. The heater’s length is 9 inches; therefore since it is placed within the tank it will offer a better heat transfer rate, ultimately speeding the heating process.

<table>
<thead>
<tr>
<th>Scale Reading</th>
<th>Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>100-120</td>
</tr>
<tr>
<td>2</td>
<td>120-140</td>
</tr>
<tr>
<td>3</td>
<td>140-160</td>
</tr>
<tr>
<td>4</td>
<td>160-180</td>
</tr>
<tr>
<td>5</td>
<td>180-200</td>
</tr>
<tr>
<td>6</td>
<td>200-220</td>
</tr>
<tr>
<td>7</td>
<td>220-280</td>
</tr>
<tr>
<td>8</td>
<td>280-340</td>
</tr>
<tr>
<td>9</td>
<td>340-420</td>
</tr>
<tr>
<td>10</td>
<td>420-500</td>
</tr>
<tr>
<td>11</td>
<td>500-560</td>
</tr>
</tbody>
</table>

Table 7. Electric Heater Scale [11]

9.2.b. Secondary Heater

The secondary heater is submerged in the water evaporation tank, prior to tests performed on the primary heater; a second one identical to the first will be purchased and used. All specifications for this second heater are to be the same as the first.
9.3 Filtration Devices

9.3.a. Macro Filter

When the WVO is first introduced into the system it will contain debris from food as well as other miscellaneous objects. In order to reduce the amount of debris, which actually makes it into the Heat and Settle Tank, a macro filtration process has been employed. Utilizing the idea of the existing prototype’s strainer, the improved macro filter’s design consists of three meshed metal sheets, placed in half-inch increments at the top of the tank. The meshes within each individual sheet vary in sizes, and are placed in a way so that the larger mesh sheet is the highest one, then the medium one and finally the smallest. This arrangement’s purpose is so that the first filter can capture the larger debris, if any, and so on. The macro filter will reduce the amount of debris, which enters the tank itself, and ultimately keep the funnel section of the heat and settle tank cleaner, thus reducing the maintenance intervals.
9.3.b. Primary Filter

The purpose of this primary filtration device is to act a safety device for the pump. This filter is already present in the existing prototype, and it has a cleaning capacity of about 50 microns. By placing this filter between the outlet of the evaporation tank and the pump, it is ensured that any remaining larger debris, which might damage the pump is filtered prior to going through.

![Primary Filter](image)

Figure 16. Primary Filter [11]

9.3.c. Centrifuge

The existing centrifuge is a model BC-200 Centrifuge, it operates at 1135 Liters per hour, and needs a minimum operating pressure of 40 PSI. At normal operating conditions the rotor rotates at around 8000 RPM. It is mentioned that this small capacity centrifuge cannot clean the WVO in one single pass, however with the proposed design and the implementation of a heat and settle tank as well as an evaporation tank, the oil will reach the centrifuge much cleaner than before. However if once calculated it is still found that the existing centrifuge isn’t enough, a new centrifuge will be found. Replacing this BC-200 for 3 BC-50’s will not only decrease the total cost, but also increase the centrifugal force by 25%; this is an idea, which will be considered. [16]
9.3.d. Micron Filter

This micron filter is produced by Baldwin Filters, and it is a model B10-AL. It removes damaging particles and water from diesel fuels, and it is very user friendly and easy to install. It offers effective filtration at flow rates up to 25-gpm or gravity flow of 10-gpm with 30-inch head. It weighs 4 pounds, has a length of 9 25/32 inches and an outside diameter of 4 5/32 inches. The micron capacity of this specific filter is about 20 microns, and the filter’s characteristics make it adequate for processing brown grease. Within the prototype the micron filter is placed after the centrifuge, in order to capture any of the smaller scale debris still present in the WVO.
9.3.e. Water Absorption Filter

This filter is placed after the Micron Filter, the Water Absorption Filter is a water separation device. Its flow rate is about 150 liters per minute with a filtering capacity of 30 microns. It requires an operating pressure of 3.5 bars and a bursting pressure of 10 bars, which is a safety pressure that should never be exceeded. It is equipped with an inlet and outlet diameter of 1 inch. This fine filtration device is the last process the WVO goes through prior to entering the final product tank.

![Figure 19. Water Absorption Filter][18]

9.3.f. Dry Pro Nozzle

The final filtration device is placed within the final product tank. A dry pro nozzle supplied by Utah Biodiesel Supply Company adapted to all three main exits of the system serves as a final filtration device for any water that may still be present in the WVO. The nozzle sprays the oil into the final tank rather than pouring, this creates a larger surface area. This fanning effect creates a thin layer of oil in which any final water present will escape the final product.
10. PROTOTYPE TESTING PLANS

Upon prototype manufacturing completion, the team will begin to test the system immediately. The testing samples will be obtained through two different ways. Acquisition of actual WVO from local restaurants is the first and preferred option, as it will offer real world results. The second option is to purchase vegetable oil and contaminate it with miscellaneous debris and water, as to simulate actual yellow and brown grease scenarios. The prototype will be tested as intended, offering an initial “menu” of concentrations within the WVO. Depending on the water and debris concentrations the user will find their optimal range in which to operate the system. The appropriate valves will be closed and or opened in order to allow the WVO to flow through the specific elements it is intended to. The WVO will be water and debris tested prior to entering the prototype and it will be tested once more after it has gone through a full cycle within the system. The results will be recorded, and ideally if the desired results are not obtained, minor or major adjustments will be made, and the testing process will be repeated.

The WVO specimen are to be tested in a specific order, the oil will first be introduced into the heat and settle tank. As it is poured into the tank the macro filtration within it is designed to capture any of the larger debris entering the tank. Once the heat and settle period is over the oil is transferred into the evaporation tank, where most of the water is to be removed through the vent valve. The WVO is then pumped into the primary filter, which serves as a safety mechanism for the pump, certifying that no large debris enters the pump and cause any damage. Post pump
the WVO is introduced into the centrifuge, at this point depending on the initial concentration of the oil the WVO can either exit into the final product tank or move onto the membrane filter. From the membrane filter it can once more either exit the system or move onto the final filtration device. Once the WVO enters the final storage tank it will do so through a nozzle adapted to all three exits, this nozzle ensures any final water within the system exits.

11. CONCLUSIONS

Prior to the completion of the project the expected outcome was to create a system that successfully cleans Waste Vegetable Oil, removing all debris as well as water. The purpose of this Pre-treatment system is to obtain oil that is at least 99% pure, in order for it to be utilized to produce biodiesel. Upon completion of the prototype as well as extensive testing of the product, the proposed goal was achieved. After running the WVO through the prototype the water contents were significantly reduced. The miscellaneous solids within the WVO were furthermore completely removed. Upon completion of one cycle through the system the objective of obtaining oil that is 99% pure was met. Overall the intentions of this senior thesis were satisfied, creating a system that functioned as designed, doing so effectively and cost efficiently.
12. REFERENCES


13. APPENDICES
SEICHELLE’s Principle: Stated that an increase in the speed of the fluid occurs simultaneously with a decrease in pressure.

\[ \frac{P_1}{\gamma} + \frac{v_1^2}{2g} + z_1g = \frac{P_2}{\gamma} + \frac{v_2^2}{2g} + z_2g + z_{LF} \]

* Specific weight

\[ P_1 = P_2 = P_{ATM} \]

\[ \frac{v_1^2}{2g} + z_1g = \frac{v_2^2}{2g} + z_2g + z_{LF} \]

* All components will be placed at an equal height.

\[ z_1 = z_2 \]

\[ \frac{v_1^2}{2g} = \frac{v_2^2}{2g} + z_{LF} \]