EML 4905 Senior Design Project

A B.S. THESIS
PREPARED IN PARTIAL FULFILLMENT OF THE
REQUIREMENT FOR THE DEGREE OF
BACHELOR OF SCIENCE
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MECHANICAL ENGINEERING

BIODIESEL PRE-TREATMENT STATION

Final Report

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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, which is cooking oil that is contaminated with debris and water. WVO is fully renewable unlike diesel obtained from fossil fuels. 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 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 transport 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 acquirement in any area of the world. Biodiesel is a possible clean alternative that allows for a change in common combustible systems. 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 for 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. Bio-diesel 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. Motivation

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 1: Water Removal Technologies [2]

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

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

Figure 3: Water Absorbing Polymer Crystals [7]

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].

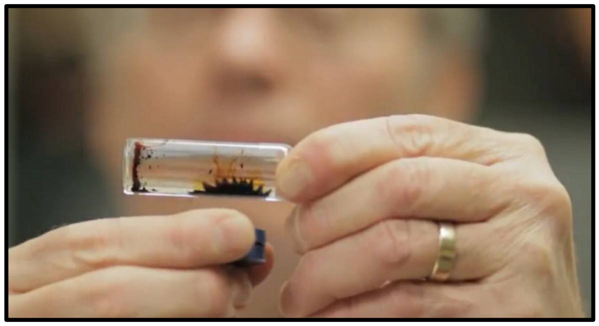


Figure 5: Sample of Magnetic Oil [10]

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].

Figure 6: Vacuum Dehydrator [8]

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.

Figure 7: Existing Prototype [11]

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.

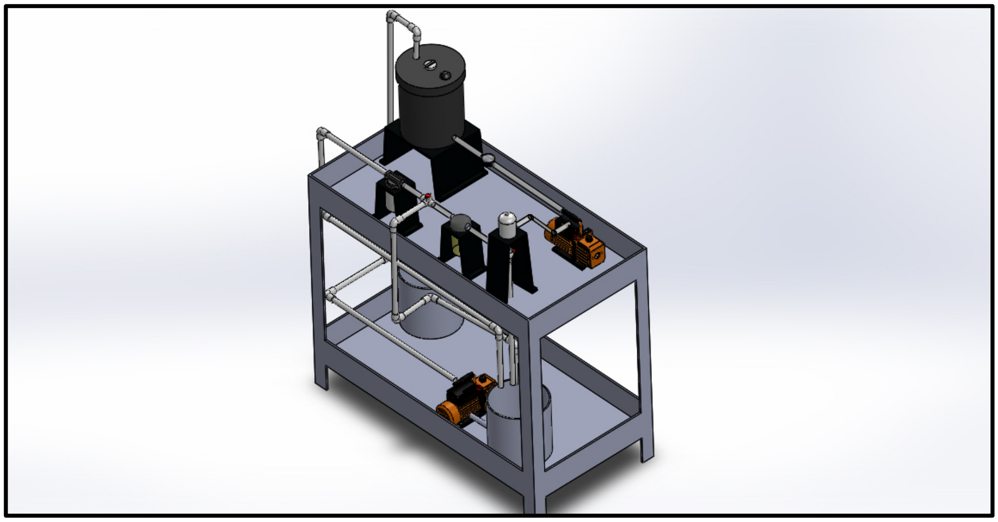


Figure 8: Prototype Assembly Model

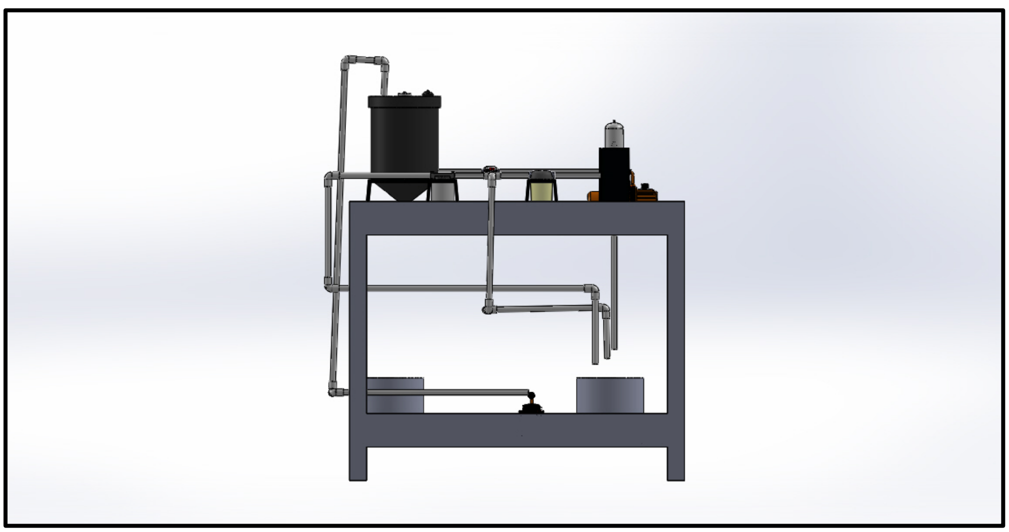


Figure 9: Prototype Assembly Side View

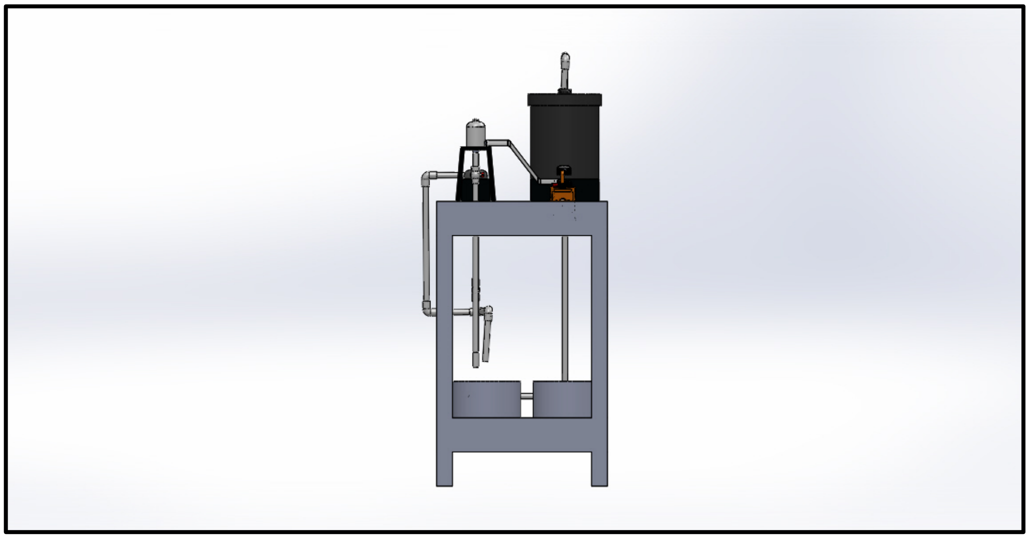


Figure 10: Prototype Assembly Front view

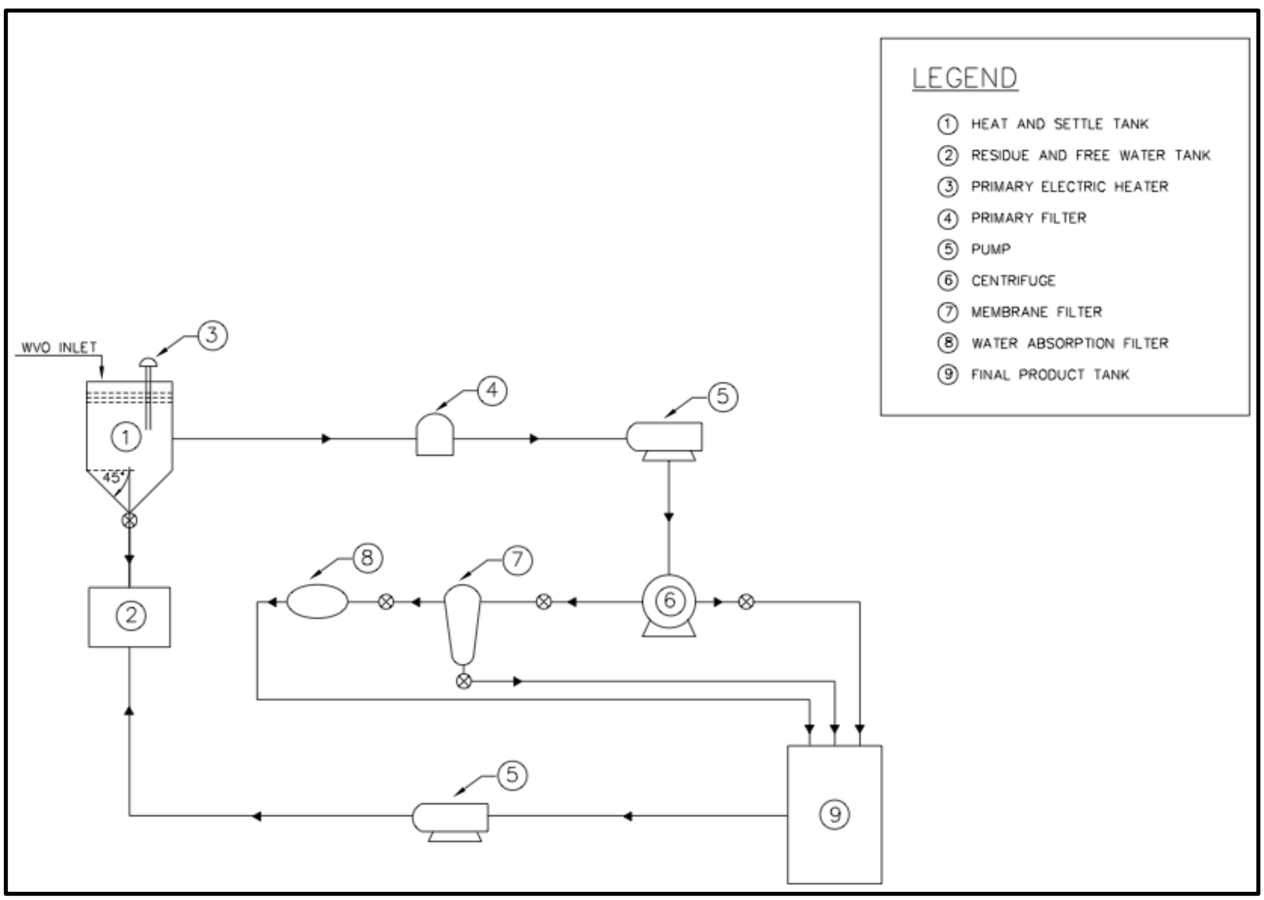


Figure 11: Prototype Schematic

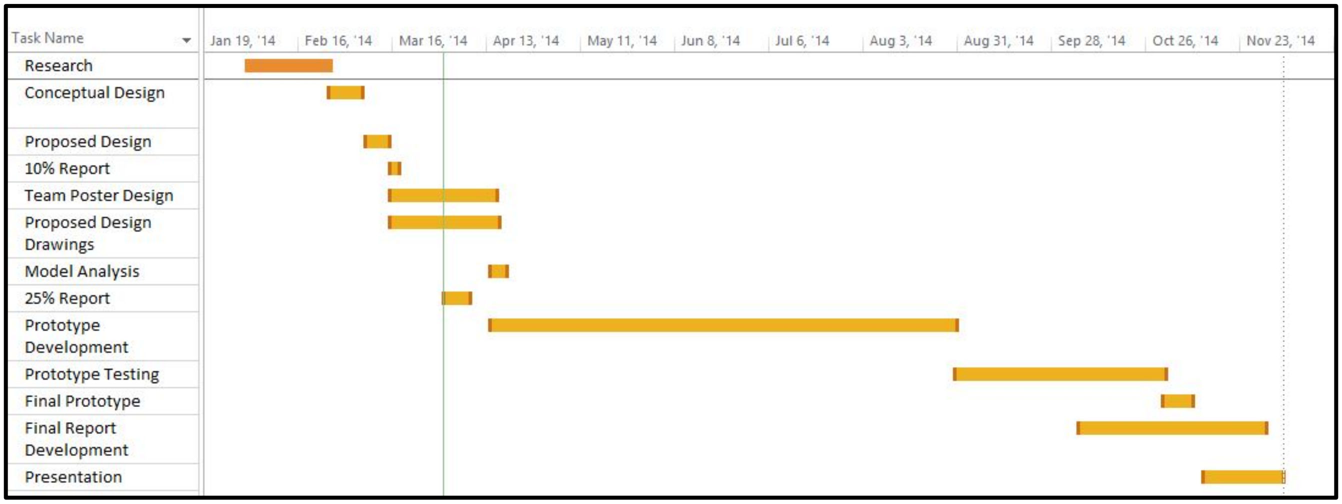
4. PROJECT OBJECTIVES

The project was broken down into 14 major tasks, all shown in table 2. The first step was to conduct extensive research; this ultimately becomes the stepping stones for the design, construction and testing of the prototype. Upon completion of the research phase, the team began creating conceptual designs for the prototype, utilizing the literature survey gathered a finalized design is agreed upon, and proposed. The 10% portion of the report began to be written, this included much of the research that was done, as well as the conceptual and chosen designs. The team poster was slowly created and information was added along the way, as the team began making larger decisions involving prototype design and objectives. The proposed design's drawings were drafted utilizing mostly SolidWorks 2014; the design was worked on and perfected. Analysis and required calculations were performed, changes were made to the prototype design and iterations were conducted until arriving at a finalized design. The 25% portion of the report was eventually created, although this was only 25%, it marked the halfway point, for the 1-year senior thesis.

Prototype development took up the majority of the schedule, this included disassembly of existing system, purchasing of parts, manufacturing, and prototype assembly. Testing was the phase that followed, testing procedures were created, idealized and perfected and results were gathered and analyzed. The finalized prototype was included within the preparation of the final report as well as the final presentation. Upon completion of the senior thesis, all tasks initially set were met, and a fully functioning prototype was delivered.

4.1. Timeline

Table 2: Gantt Chart



4.1. Breakdown of Responsibilities

Table 3: Team Member Responsibilities

Breakdown of Responsibilities			
Task	**Rainer**	**Harrison**	**Favyan**
Research			
Design			
Analysis			
Reports			
Presentations			
Manufacturing			
Testing			

Major Role	
Support Role	

5. ANALYTICAL ANALYSIS

5.1. Initial Calculations

In order to calculate the diameter of the pipes, equation (1) was utilized, the steps taken are described below.

$$d = \sqrt{\frac{4Q}{v\pi}} \qquad \text{Eq. (1)}$$

Where: $d = Pipe\ Diameter$

$Q = Volumetric\ Flow\ Rate$

$v = Velocity$

In order to properly calculate the appropriate diameter of the piping system, a few values must be known, including: the volumetric flow rate and the desired velocity of the fluid. The constraints obtained from the previous senior team, as specified by their sponsor are implemented for this project. Understanding that the desired values are standards for the industry. The values below were provided the sponsor, and have been confirmed.

Volumetric Flow Rate (Q): 1800 liters/hour

Common Industrial Velocity: 4 meters/ second

The results for the calculations of the pipe diameter are shown in table 4, a pipe diameter of ½ inch was obtained. In order to simplify the prototype construction the actual diameter used was ¾ inch due to the inlets and outlets of the system mostly being this size. Adjusting the diameter removed the need to utilize reducing bushings and sudden expansions. In addition I order to achieve a working prototype the volumetric flow rate utilized was 20% of the provided value, this was done in order to accommodate for the existing pump. In order to implement this prototype into an actual large-scale system, a pump whose allowable volumetric flow rate is 80% greater than this one must be chosen.

Table 4: Optimal Pipe Diameter Calculation

Optimal Pipe Diameter		
Propery	Value	Units
Volumetric Flow Rate	7.93	gpm
Volumetric Flow Rate	0.018	ft^3/s
Flow Velocity	13.12	ft/s
Pipe Diameter	0.0413	ft
Pipe Diameter	0.496	in

Obtaining information for certain waste vegetable oil characteristics was sometimes difficult. Since this project deals with very specific classifications of WVO. In order to obtain the viscosity of vegetable oil data was obtained from an online article “Viscosity and specific heat of vegetable oils as a function of temperature: 35°C to 180°C”, this article contained the necessary information required.

Table 5: Viscosity of vegetable oils at different temperatures [22]

	Sample temperature (°C)									
Oil Source	35	50	65	80	95	110	120	140	160	180
Almond	43.98	26.89	17.62	12.42	9.15	7.51	6.54	5.01	4.02	3.62
Canola	42.49	25.79	17.21	12.14	9.01	7.77	6.62	5.01	4.29	4.65
Corn	37.92	23.26	15.61	10.98	8.56	6.83	6.21	4.95	3.96	3.33
Grape Seed	41.46	25.27	16.87	11.98	9.00	10.37	9.18	7.50	6.10	4.78
Hazlenut	45.55	27.40	17.83	12.49	9.23	7.56	6.69	5.25	4.12	3.48
Olive	46.29	27.18	18.07	12.57	9.45	7.43	6.49	5.29	4.13	3.44
Peanut	45.59	27.45	17.93	12.66	9.40	7.47	6.47	5.14	3.75	3.26
Safflower	35.27	22.32	14.87	11.17	8.44	6.73	6.22	4.77	4.11	3.44
Sesame	41.14	24.83	16.80	11.91	8.91	7.19	6.25	4.95	4.16	3.43
Soybean	38.63	23.58	15.73	11.53	8.68	7.17	6.12	4.58	3.86	3.31
Sunflower	41.55	25.02	16.90	11.99	8.79	7.38	6.57	4.99	4.01	3.52
Walnut	33.72	21.20	14.59	10.51	8.21	6.71	5.76	4.80	3.99	3.46

The two most commonly used vegetable oils for cooking purposes, were olive and peanut oil, therefore the data was obtained from these two. The desired temperature was 140°F which is about 60°C, the data for this temperature had to be interpolated, the results for these values are shown below.

$$Olive\ Oil\ Viscosity = 21.11\ mPA * s$$

$$Peanut\ Oil\ Viscosity = 21.10\ mPA * s$$

The specific heat and viscosity were obtained through similar research; the values for these properties are shown below.

$$Olive\ Oil\ Specific\ Heat = 1.76 \frac{kj}{kg * k}$$

$$Peanut\ Oil\ Specific\ Heat = 2.01 \frac{kj}{kg * k}$$

$$Vegetable\ Oil\ Density = 920\frac{kg}{m^3}$$

5.2. Laminar vs. Turbulent Flow

In order to determine whether a flow is turbulent or laminar the Reynolds number for that specific flow must be calculated. Utilizing equation (2) the Reynolds number can be calculated.

$$Re = \frac{\rho \upsilon d}{\mu} = \frac{\upsilon d}{\nu} \text{ Eq. (2)}$$

Where: $\rho = Density$

$\upsilon = Velocity$

$d = Pipe\ Diameter$

$\mu = Dynamic\ Viscosity$

$\upsilon = Kinematic\ Viscosity$

$Re = Reynolds\ Number$

Table 6: Reynolds Number Calculation

Reynold's Number Calculation		
Density	57.408	lb/ft^3
Velocity	13.123	ft/s
Diameter	0.04167	ft
Dynamic Viscosity	0.0142	lb/ft*s
Reynold's Number	**2213**	No units

Any flow with a Reynolds number lower that 2100 is considered a laminar flow, any flow between 2100 and 2300 is considered a transitional flow, although these values slightly vary from book to book. Finally any Reynolds number above 2300 is considered turbulent. After performing the calculation the results shown above were obtained. This specific flow is in the transitional state therefore it is a laminar flow that is becoming turbulent.

5.3. Friction Factor

As mentioned above the flow obtained is transitional therefore in order to properly identify the friction factor, both the laminar and turbulent equations are implemented, and results are compared.

Friction Factor of a laminar flow:

$$f = \frac{64}{Re} \qquad \text{Eq. (3)}$$

Table 7: Friction Factor Calculation

Friction Factor for a Laminar Flow		
Friction Factor:	**0.0289**	No units

Friction Factor for turbulent flow:

In order to calculate the friction factor of a turbulent flow the Moody diagram is used. Utilizing this table allows the user to locate the specific friction factor of a flow by knowing the Reynolds number and the roughness over the diameter of the pipe. For this setup PVC is used as the piping system; PVC is smooth and therefore has a roughness of zero. Below a moody diagram is shown highlighting what the friction factor of the flow is for this case.

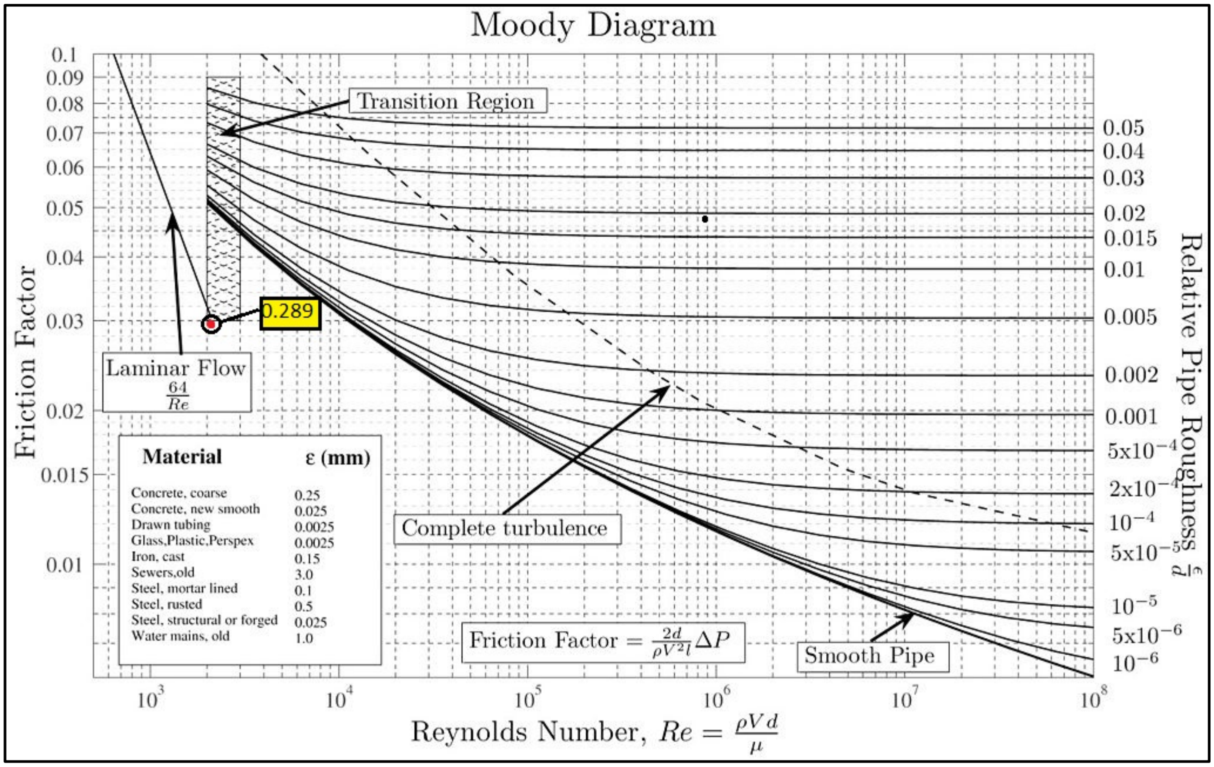


Figure 12: Moody Diagram

After analyzing the Moody diagram it is evident that both methods for obtaining the friction factor yield very similar, almost identical, answers. The friction factor is therefore used in further calculations throughout the thesis.

5.4. Pressure Difference

In order to choose a pump that is appropriate for the proposed system, the pressure losses throughout the system need to calculated. Normally this analysis is performed prior to ordering a pump, however for this specific project a pump has already been acquired from the previous senior team, therefore one of the challenges faced is to reengineer the system while staying within the constraints from the existing pump. The pressure losses are calculated depending on which path the flow will take. The proposed design offers different flow paths; therefore the pressure losses for each scenario are calculated separately keeping in mind that the flow path scenario with the most losses should be the longest path, which is the last scenario. Nonetheless all the scenarios are calculated and the pressure losses are shown.

The pressure losses of a fluid in a piping system are composed of major and minor losses, both these can be observed and analyzed within the expanded form of Bernoulli's equation, which is shown below.

$$\frac{P_1}{\rho g}+\frac{v_1^2}{2g}+z_1=\frac{P_2}{\rho g}+\frac{v_2^2}{2g}+z_2+\frac{fl}{d_h}*\frac{v^2}{2g}+\Sigma H_f*\frac{v^2}{2g} \qquad \text{Eq. (4)}$$

Where:

$P_1 = Pressure\ at\ Position\ 1$	$z_1 = Elevation\ at\ Position\ 1$
$P_2 = Pressure\ at\ Position\ 2$	$z_2 = Elevation\ at\ Position\ 2$
$\rho = Density$	$f = Friction\ Factor$
$g = Gravity$	$l = Pipe\ Length$
$v_1 = Velocity\ at\ Position\ 1$	$d_h = Pipe\ Diameter$
$v_2 = Velocity\ at\ Position\ 2$	$H_f = Minor\ Losses$

The major losses consist of the change in velocities within the system, the changes in elevation and the friction factor. The minor losses are the pressure losses fluids experience as they travel through valves, fittings, and additional components within the system.

Flow Path Scenario #1: (Including Primary Filter and Centrifuge).

Table 8: Major Losses for 1st Scenario

Major Losses		
Property	Value	Units
Gravity	32.17	ft/s^2
Friction Factor	0.0289	No units
Pipe Diameter	0.0625	ft
Velocity	13.12	ft/s
Pipe Length	2.5	ft
Total Head	3.10	ft

Table 9: Minor Losses for 1st Scenario

Minor Losses		
Component	K-Value	Quantity/Units
Inlet	0.5	1
Primary Filter	0.11	1
45° Elbow	0.35	2
Centrifuge	0.16	1
T-Joint (Branch Flow)	1.9	1
90° Elbow	1.4	1
Exit	1	1
Total Head	15.44	ft

Table 10: Pressure Difference for 1st Scenario

Pressure Difference		
Property	Value	Units
Gravity	32.17	ft/s^2
Density	57.41	lb/ft^3
Change in Height	0.5	ft
Pressure Difference	52331	Pa
Pressure Difference	7.59	psi

Flow Path Scenario #2: (Including Primary Filter, Centrifuge and Membrane Filter).

Table 11: Major losses for 2nd Scenario

Major Losses		
Property	Value	Units
Gravity	32.17	ft/s^2
Friction Factor	0.0289	No units
Pipe Diameter	0.0625	ft
Velocity	13.12	ft/s
Pipe Length	4.7	ft
Total Head	5.82	ft

Table 12: Minor Losses for 2nd Scenario

Minor Losses		
Component	K-Value	Quantity/Units
Inlet	0.5	1
Primary Filter	0.11	1
45° Elbow	0.35	2
Centrifuge	0.16	1
Membrane Filter	0.27	1
T-Joint (Branch Flow)	1.9	2
90° Elbow	1.4	2
Exit	1	1
Total Head	25.0	ft

Table 13: Pressure Difference for 2nd Scenario

Pressure Difference		
Property	Value	Units
Gravity	32.17	ft/s^2
Density	57.41	lb/ft^3
Change in Height	1.6	ft
Pressure Difference	89106	Pa
Pressure Difference	12.92	psi

Flow Path Scenario #3: (Including Primary Filter, Centrifuge, Membrane Filter and Water Captor Filter).

Table 14: Major Losses for 3rd Scenario

Major Losses		
Property	Value	Units
Gravity	32.17	ft/s^2
Friction Factor	0.0289	No units
Pipe Diameter	0.0625	ft
Velocity	13.12	ft/s
Pipe Length	5.4	ft
Total Head	6.69	ft

Table 15: Minor Losses 3rd Scenario

Minor Losses		
Component	K-Value	Quantity/Units
Inlet	0.5	1
Primary Filter	0.11	1
45° Elbow	0.35	2
Centrifuge	0.16	1
Membrane Filter	0.27	1
Water Capturer Filter	0.39	1
T-Joint (Branch Flow)	1.9	1
T-Joint (Line Flow)	0.9	1
90° Elbow	1.4	3
Exit	1	1
Total Head	27.1	ft

Table 16: Pressure for 3rd Scenario

Pressure Difference		
Property	Value	Units
Gravity	32.17	ft/s^2
Density	57.41	lb/ft^3
Change in Height	1.6	ft
Pressure Difference	97301	Pa
Pressure Difference	14.11	psi

A second pump has been added in order to pump the clean vegetable oil obtained from the final storage tank back to the heat and settle tank, this has been done for two main reasons. One, to facilitate moving the oil back to the starting point for further testing options and scenarios, and more importantly to allow for further cleansing of the dirtier oils. Calculations for the second pump's specifications are shown below.

Table 17: Major Losses for 2nd Pump

Major Losses		
Property	Value	Units
Density	57.41	lb/ft^3
Gravity	32.17	ft/s^2
Friction Factor	0.0289	No units
Pipe Diameter	0.0413	ft
Velocity	13.12	ft/s
Pipe Length	7.083	ft
Change in Height	3.75	ft
Total Head	25.31	ft
Change in Pressure	46747	Pa
Change in Pressure	6.78	psi

Table 18: Minor Losses for 2nd Pump

Minor Losses		
Component	K-Value	Quantity/Units
Inlet	0.5	1
90° Elbow	1.4	3
Exit	1	1
Total Head	0.0123	ft
Change in Pressure	23	Pa
Change in Pressure	0.00329	psi

5.5. Pump Selection

Whenever designing a piping system that includes a pump the calculations conducted above, in order to find the total head loss, and change in pressure, must be conducted. Normally the head loss is calculated and according to the desired flow rate a pump that meets the specifications would be chosen. For this specific prototype, the loss of head was calculated, however since a pump was already made available. It was important to compare the obtained calculations to the specs from the pump, and decide whether or not the pump was capable of pumping the oil through the system.

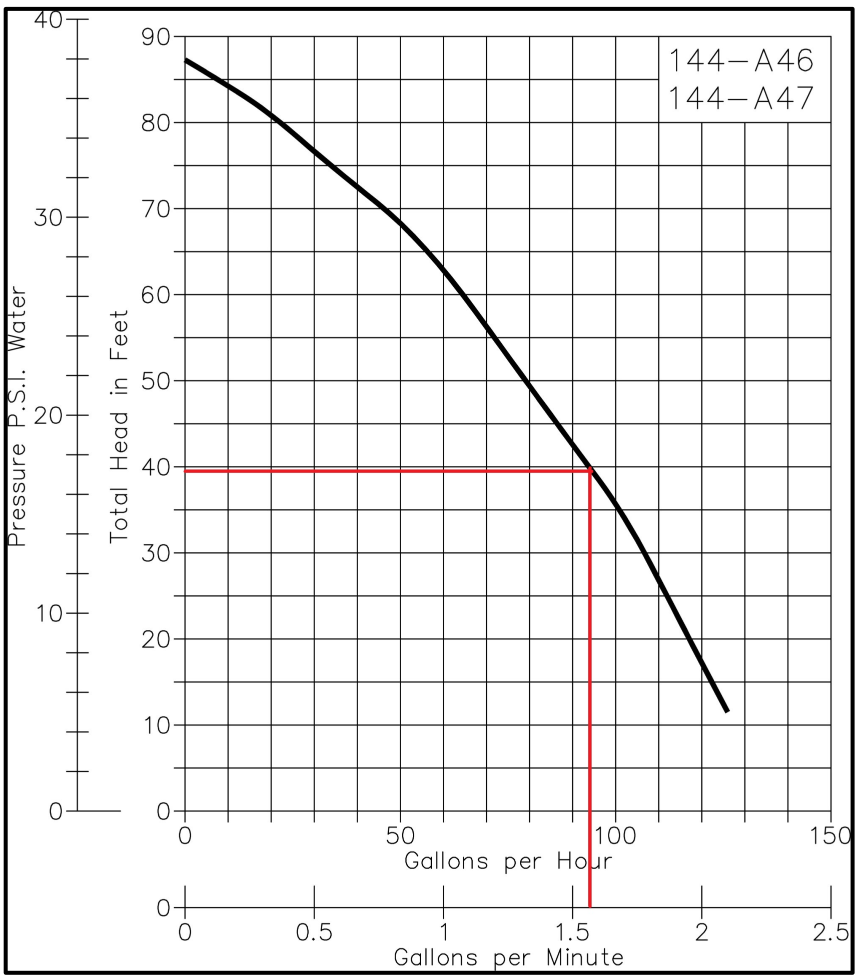
Upon completion of the calculations, the total head loss shown in the above calculations was obtained. It was important at this point to utilize the pump's performance curve in order to decide whether the available pump could handle the task at hand. The flow rate was taken down as a scaled version of the intended standard flow rate, as shown below.

$$Volumetric\ Flow\ Rate\ (Q) = 1800\,\frac{liters}{hour} = 7.93\,\frac{gal}{min}$$

$$20\%\ of\ Volumetric\ Flow\ Rate\ (Q) = 0.20 * 7.93\,\frac{gal}{min}$$

$$20\%\ of\ Volumetric\ Flow\ Rate\ (Q) = \mathbf{1.59}\,\frac{\boldsymbol{gal}}{\boldsymbol{min}}$$

Table 19: Pump Efficiency Curve



The maximum head loss for the pump running at the given volumetric flow rate is just under 40 ft. The flow scenario with the largest head loss is the third one, which includes the centrifuge, membrane filter, and the water absorption filter. The head loss for this scenario was 33.8 ft. which is less than the value obtained from the pump's performance curve. The available pump was therefore capable of handling the requirements; this pump was then chosen rather than having to look for other pumps. Had the calculations yielded different results and the pump was not capable of handling the job, a new pump would have been selected and purchased; utilizing the head loss calculations and knowing the desired flow rate would have been enough to have precisely chosen a different pump.

5.6. Piping Simulation

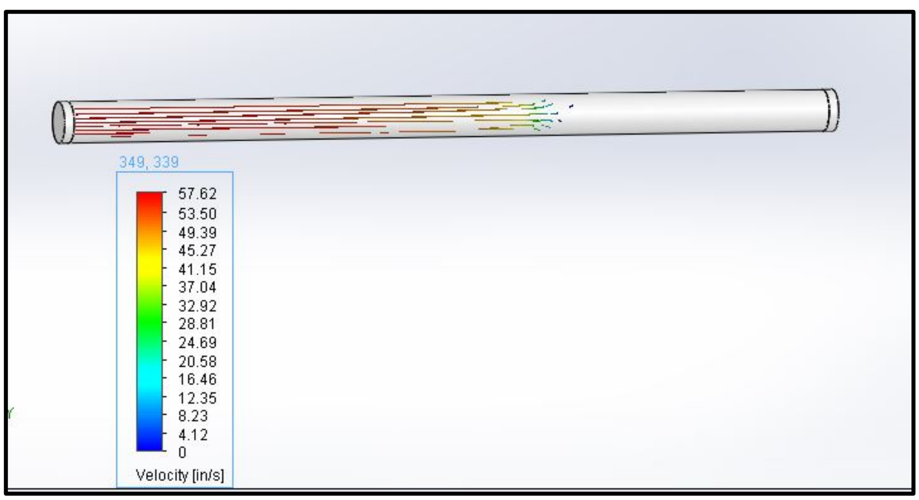


Figure 13: Pipe Simulation

The flow simulation above was produced using SolidWorks 2014's FloXpress feature. The pipe pictured above is a ¾"- Schedule 40 PVC pipe that measures 22" in length. This pipe was modeled and tested because it is the longest pipe in the recirculation system that was implemented. The simulation was done at 120° F (49°C) to simulate the possible temperature of the oil as it is being recirculated back to the heat and settle tank. The basic simulation shows that the flow is consistently laminar through the pipe. The volumetric flow rate under analysis is 28.9 in ^{3}/s so the initial velocity is claimed to be 57.62 in/s with a considered stabilizing flow at approximately 32.92 in/s.

A CFD analysis was performed on a ¾" 90° adapter made of PVC, attached to two 13" PVC pipes with an inner diameter of ¾". The analysis was performed using Solidworks 2014 FloXpress Analysis Wizard. The analysis was performed using water as the fluid to simulate the possible characteristics of the waste vegetable oil. The initial conditions were set at 49°C and an initial volumetric flow of about 312 in^3/s or 0.18 ft^3/s. The outlet pressure was set at about 15 psi. The flow is shown by the pipes of various colors.

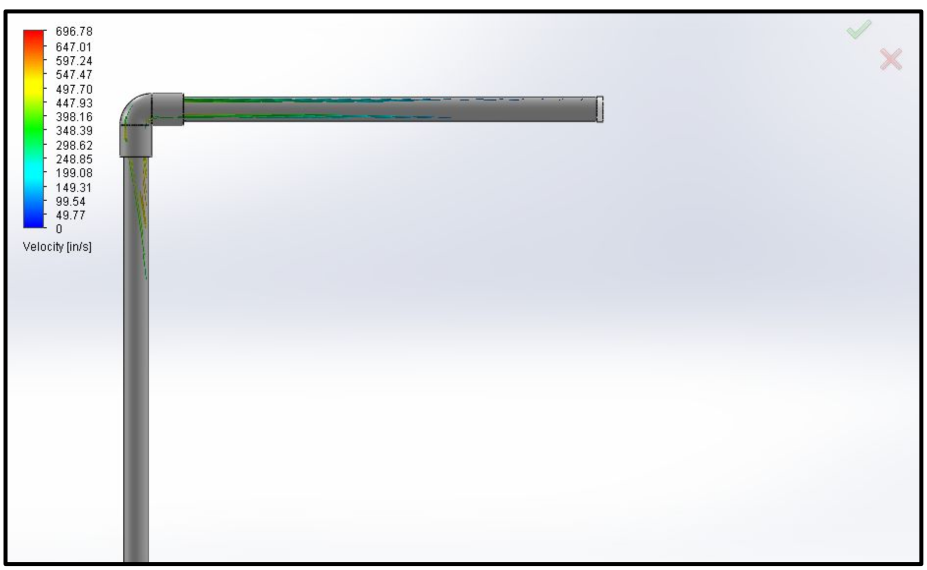


Figure 14: 90° Elbow CFD Analysis: Inlet

Figure 14 demonstrates the possible flow characteristics through the elbow from the input side, and its result after the bend. The fluid starts at 199.08 in/s and eventually the fluid flows into the bend at approximately 348.39 in/s and exits the bend at around 597.24 in/s. This is probably due to small constriction at the bend which would reduce the overall diameter, which when paired with the consistent volumetric flow rate, would cause an increase in speed.

Figure 15: 90° Elbow CFD Analysis: Outlet

Figure 15 demonstrates the return to a standard velocity of 199.08 in/s. After the 90° elbow, the speed slows down as the pipe returns back to the ¾" diameter. This simulation was used to determine the possible behavior of the oil after the fluid flows through either a bend or a valve.

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 11 illustrates the basic design and idea of a heat and settle tank.

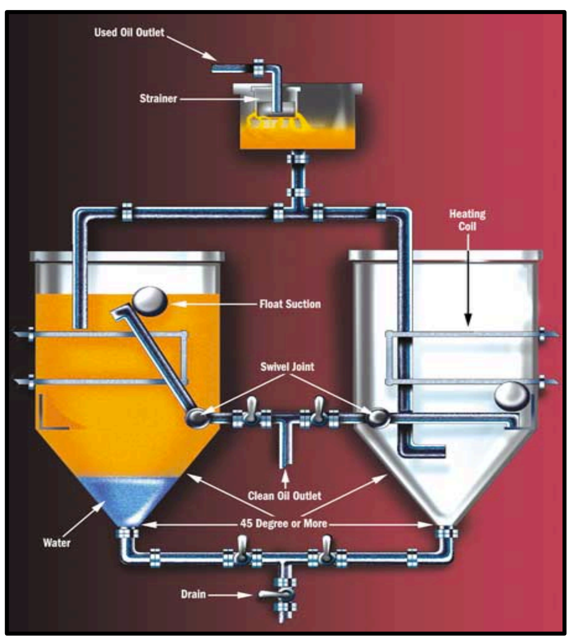


Figure 16: Illustration of Heat and Settle Tank

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. 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 actual 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.

6.3. 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.

Figure 17: 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.

Figure 18: Insulation [13]

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 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 20: Pump Specifications [11]

Characteristics	Value
Amperage	1.25 Amps
Pump Speed	10,000 RPM
Pump Electrical Feed	115 Volts
Pump Height	5 in.
Pump Length	9 in.
Pump Width	8 in.
Pumping Housing Material	Non-metallic Glass Reinforced Nylon
Impeller Material	Non-metallic Glass Reinforced PPS

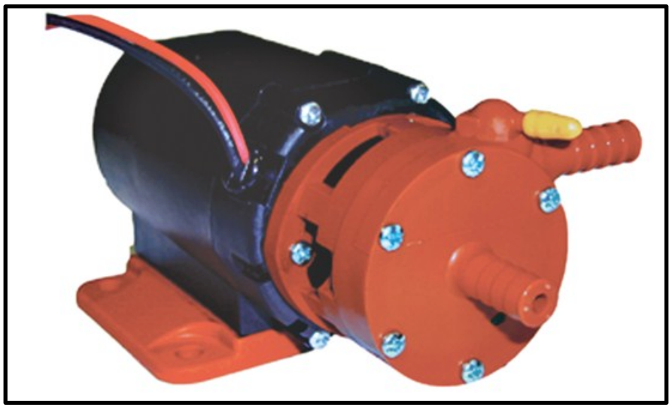


Figure 19: Pump [4]

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° 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°F. Other options for piping materials will be considered.

8. COST ANALYSIS

8.1. Prototype Cost

In table 12, 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.

Table 21: Prototype Cost Analysis

Component	Quantity	Cost Estimate ($)	Required Cost ($)
Heat and Settle Tank*	1	20	20
Residue Tank*	1	10	10
Final Product Tank*	1	20	20
Component Supports	6	100	80
Primary Heater*	1	50	50
Primary Pump*	1	267.85	267.85
Secondary Pump	1	50	40
Centrifuge*	1	246.18	246.18
Macro Filter	1	20	20
Primary Filter*	1	80	80
Micron Filter*	1	47.86	47.86
Water Absorption Filter	1	134.6	134.6
Insulation	1 roll / 32ft	20	18.75
Pipes	2 pipes/10ft	20	15.68
Tubes	1 tube/ 10ft	5	3.93
Control Panel	1	100	100
Hardware	----	100	100
Cart*	1	120	120
Water Test Kit	1	210	210
Brass 3- Way Ball Valves	2	100	82
PVC 3- Way Valve	3	90	102.3
		Total Cost ($)	1666.85

8.2. Operational Cost

Table 12 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.

Table 22: Operational Costs

Labor	Harrison	Rainer	Favyan	Hours Spent	Total Hours Spent	Cost Estimate ($)	Total Cost ($)
Research	15	15	15	45	419	1350	12570
Protoype Design	5	15	10	30		900	
Report Preparation	10	25	7	42		1260	
Presentation Preparation	2	4	9	15		450	
Graphic Design and Analysis	4	1	7	12		360	
Components Acquisition	10	11	9	30		900	
Manufacturing	15	10	14	39		1170	
System Assembly	16	20	18	54		1620	
Testing	30	35	33	98		2940	
System Adjustments	18	17	19	54		1620	

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° 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. 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.c. 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 23: Electric Heater Scale [11]

Scale Reading	Temperature (°F)
0	0
1	100-120
2	120-140
3	140-160
4	160-180
5	180-200
6	200-220
7	220-280
8	280-340
9	340-420
10	420-500
11	500-560

Figure 20: Electric Heater [11]

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 ½ 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.

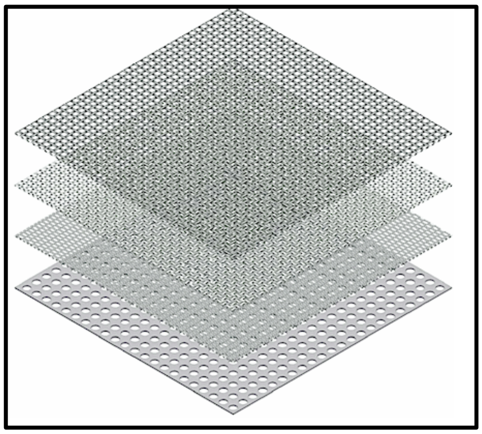


Figure 21: Macro Filter Illustration

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.

Figure 22: 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]

Figure 23: Centrifuge [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.

Figure 24: Micron Filter [17]

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 25: Water Absorption Filter [18]

10. PROTOTYPE MANUFACTURING

10.1. Prototype Description

The major goal of this prototype was to create a system, which offers an effective and reliable method for cleaning WVO. Understating that WVO is contaminated with waster and debris, and that it comes in different categories depending on the contamination level, the objective of creating a user-friendly system was also an important design constraint. In order to accomplish these goals a system in which the oil could take different flow paths was created. This enabled the user to be in control of the path the oil takes within the system depending on the initial classification of the WVO. A total of three different flow scenarios were implemented, each allowing the user to purify the WVO to a certain extent. Depending on the how "dirty" the oil is initially the user can choose to either have the WVO travel through the entire system or to deviate before entering all the components. This allows the system to furthermore be more efficient since it reduces the energy consumed when the user decides it is not necessary to run the WVO through the entire system.

The three major components that the WVO passes through are the centrifuge, the membrane filter and the water capturer filter. Between each of these components three way valves are implemented allowing the flow to either enter the following filter or exit the system prior to entering the filter.

10.2. Heat and Settle Tank

The prototype construction begins by taking apart the current prototype and performing analysis and visual inspection of all the existing components. One important factor and challenge to consider and overcome is to utilize as many of the existing components since they have all already been paid for. With that being said the first major step towards the construction of the prototype is to remove the storage tank, which will be utilized as a heat and settle tank. The bottom of the tank is cut out, cleaned and prepped for a hand-made funnel. A funnel shaped, metal sheet is to be welded to the bottom of the tank and a ball valve secured to the bottom to allow any debris to exit.

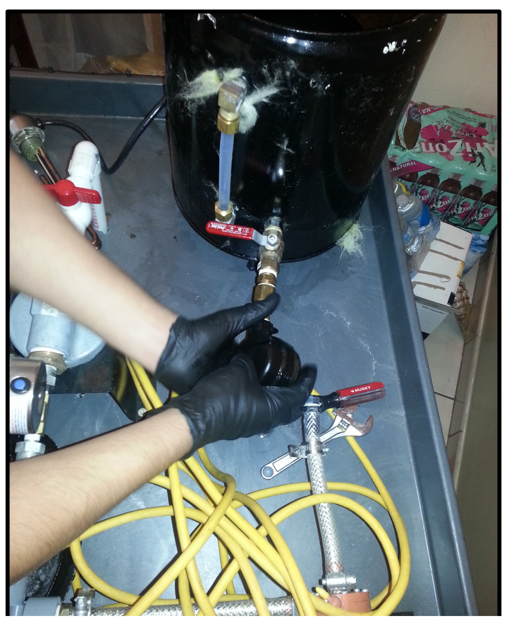


Figure 26: Disassembly of Existing Tank

Figure 25 is the 24-gauge 1080 steel. Once the material was shaped to the required diameter of 9 inches and a height of 5 inches, the funnel was then welded to the bottom of the tank. To prevent any oil from leaking, the funnel was sealed using 3M adhesive sealant as a safety precaution. A brass ball valve will be fitted to the end of the funnel to release any debris from the heat and settle tank.

Figure 27: Tank Inspection and Cleaning

Figure 28: Sheet Metal Funnel

10.3. Piping System

The prototype consists of two different types of piping. The main construction of the system consists of strictly ¾"-Schedule 40 PVC piping. The PVC piping will go from the outlet of the centrifuge to the multiple filters to the final product tank. The final product tank will then have a pipe going to the recirculation pump and back into the heat and settle tank.

Figure 29: Pipe Construction

Figure 26 depicts a mock up of the pipe work for the prototype. As shown in the image above, Figure 26, a different type of piping is used from the main tank to the primary pump. The primary has an outlet that is connected to the centrifuge. The material used for this portion is a clear plastic tubing that is ½" diameter.

Upon completion of measuring and assembling the piping system, regular clear PVC cement was used in order to properly attach and seal the piping system. Prior to assembling to prototype it was tested for leaks. All threaded fittings were outfitted with thread seal tape. Figure

27 shows the assembly of one the piping systems, and figure 28 portrays the piping system fully assembled onto the prototype.

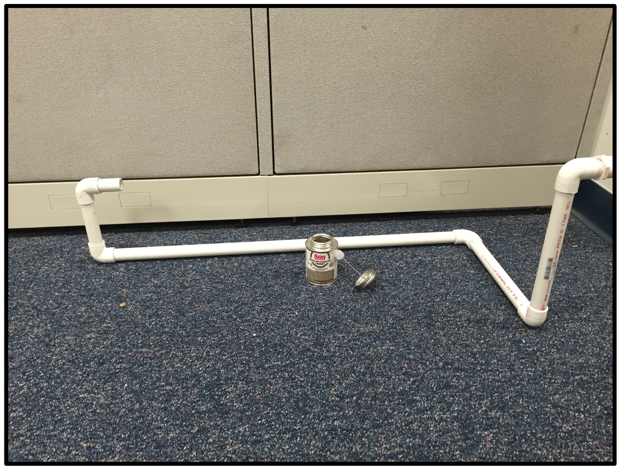


Figure 30: Piping System Assembly

Figure 31: Piping System Fully Assembled

Some of the fittings had to be adjusted in order for proper function within the system. Holes were drilled through the 2 brass three-way valves, this enabled the flow to be split into an in line flow and a perpendicular flow. The holes were drilled using a drill press with an initial pilot hole 1/8-inch; this size was slowly increased to an eventually size of 9/16-inch. The PVC three way valve underneath the centrifuge was marked in order to facilitate understanding of the flow's direction. The handle on this valve was cut as well in order to accommodate for space restrictions.

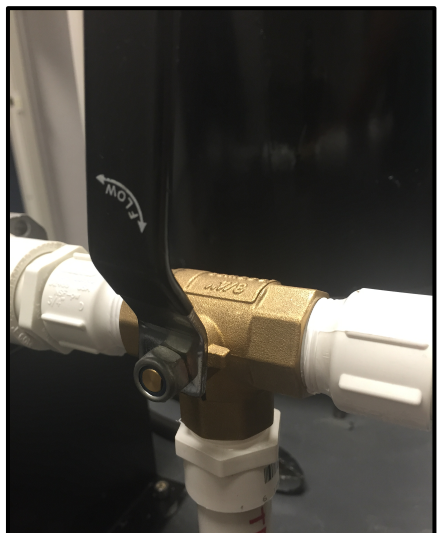


Figure 32: Three-Way Brass Valve

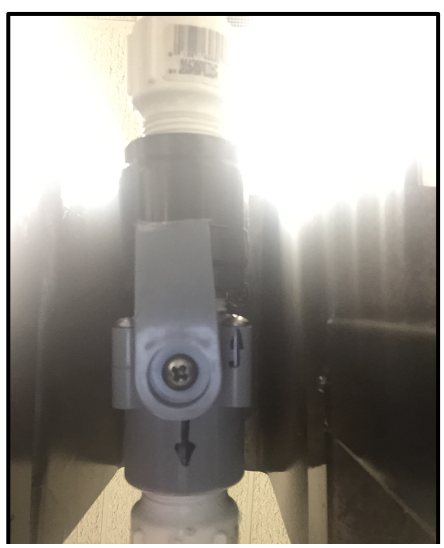


Figure 33: Labels on Three-Way Valve

10.4. Filter Brackets

Brackets were manufactured for the primary filter, the water capturer filter, and for the centrifuge. The brackets were produced out of 10-gage steel sheets, and were manufactured utilizing a sheet metal brake. A CNC machine was used for the large opening on the water capturer filter bracket. The brackets were then painted with a coat of paint for cosmetic reasons.

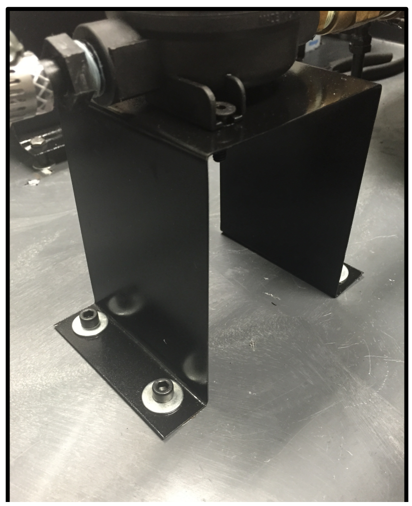


Figure 34: Bracket for Primary Filter

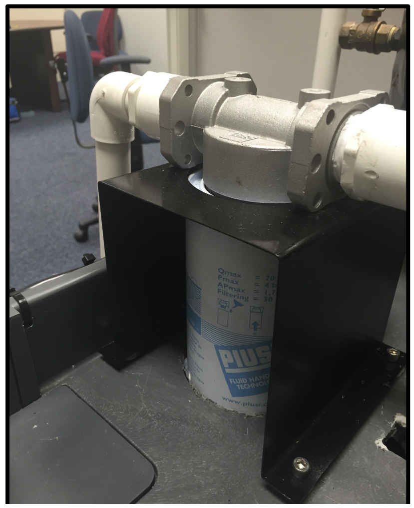


Figure 35: Bracket for Water Capturer Filter

The bracket for the centrifuge were raised and reinforced from the previous prototype. This was done primarily to allow the flow to exit under the centrifuge at which point it would go to the rest of the system. The previous prototype had the centrifuge in line with the outlet from the pump, this made it impossible to create a continuous flow onto the rest of the components within the system. In order to create the mounts 4130 steel square tubing was utilized and welded onto the final shape of an I-beam. Figure 33 shows the beams being welded. These mounts were then attached underneath the existing brackets and together lifted the centrifuge to the desired distance. Figures 34 and 35 show a before and after comparison, showing how the centrifuge was mounted before and how it is mounted now.

Figure 36: Centrifuge mounts being welded

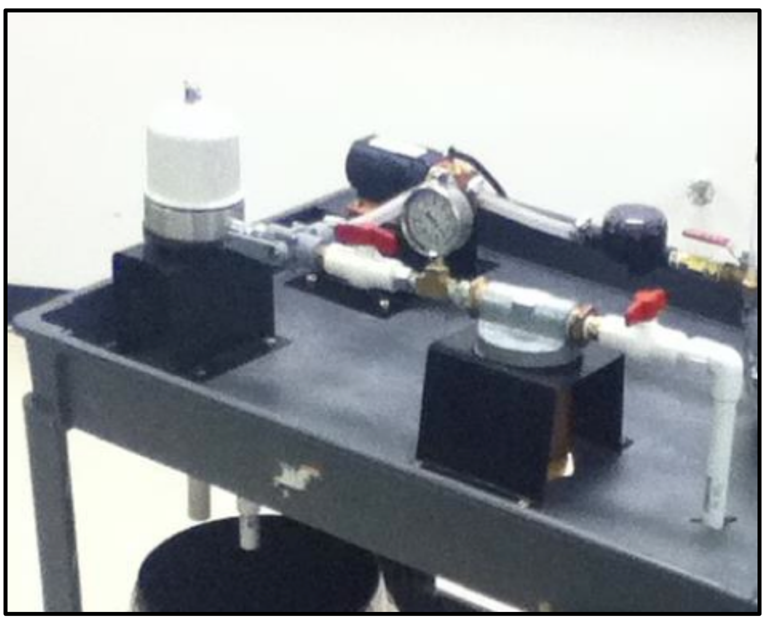


Figure 37: Centrifuge Mount for Old Prototype

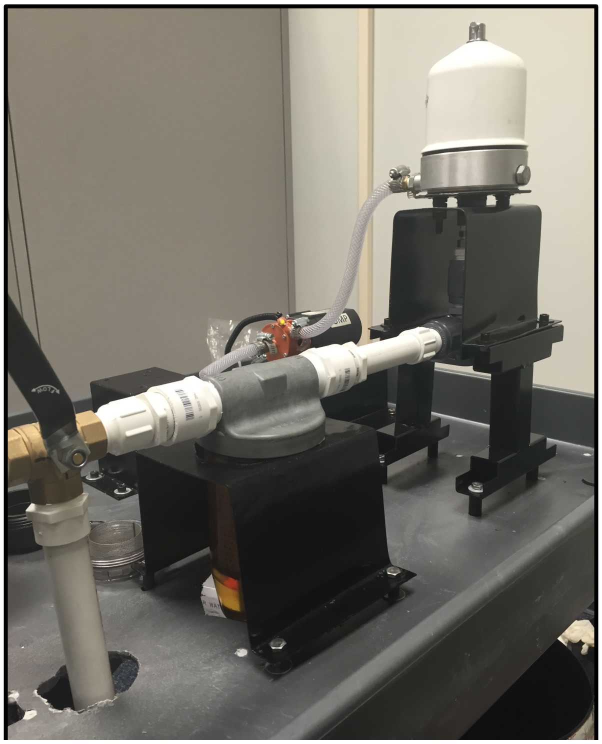


Figure 38: Centrifuge Mount for New Prototype

In the old prototype once the flow exited the pump the flow would be split, either it could go towards the centrifuge or towards the membrane filter. Once the flow went into the centrifuge it would exit into the final storage tank, this was because of the way it was originally mounted. The centrifuge has an inlet on its side and an outlet underneath it. The centrifuge was originally mounted in line with the pump therefore once the oil reached the centrifuge outlet it would be at a point, which was under the rest of the system. The new configuration, places the centrifuge above the pump, strategically placed at a height so that when it exits the centrifuge the outlet is in line with the pump's outlet. This allows the oil flow to continue throughout the system, rather than having to choose only one flow possibility, this new configuration allows for three different flow paths, without having to pour the oil back to the initial tank.

10.5. Insulation

All three tanks within the system were properly insulated for safety. The heat and settle tank was heated to about 140°F and therefore proper insulation was required.

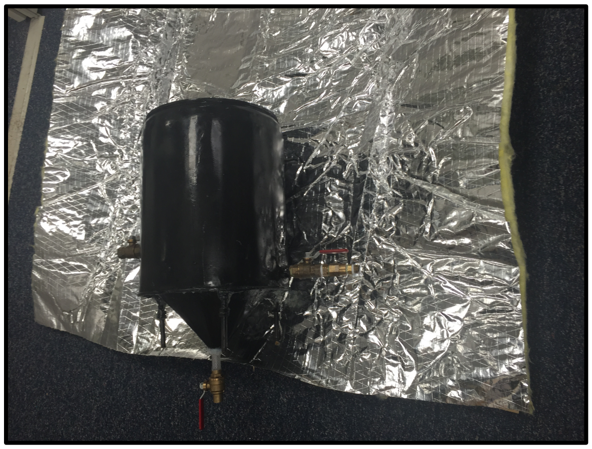


Figure 39: Prepping Insulation for Heat and Settle Tank

Figure 40: Insulation on Water and Debris Tank

10.6. Final Prototype

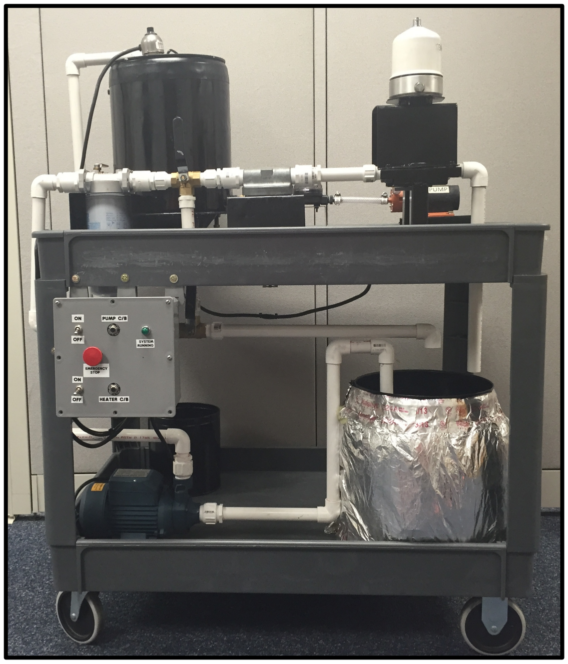


Figure 41: Final Prototype Front View

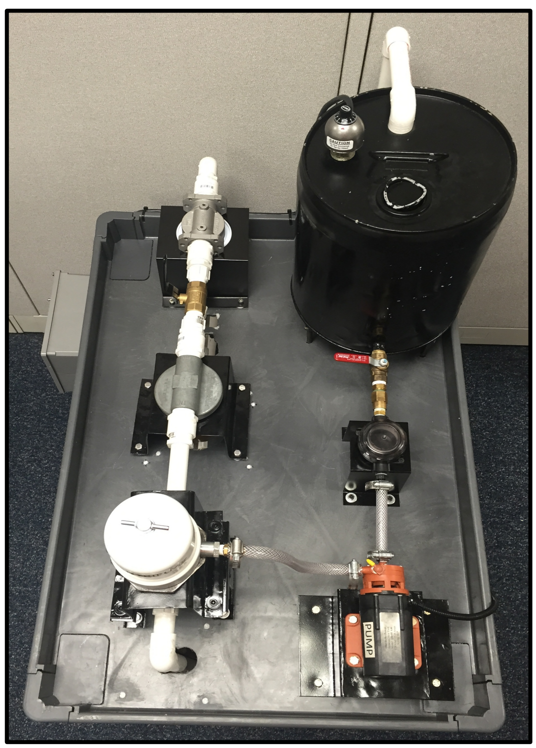


Figure 42: Final Prototype Top View

Figure 43: Final Prototype Bottom Section

Figure 44: Final Prototype Isometric View

Figure 45: Prototype Front View

Figure 46: Prototype Isometric View #2

11. DESIGN CONSIDERATIONS

11.1. Prototype Comparison: New vs. Old

The task of reengineering an existing system requires understanding of the system's present functionality as well as understanding of where the system needs to get. Analysis of the system's existing problems is required as well as a clear objective on how to address those problems. The existing prototype was designed and built to accomplish the same eventual results, which were to successfully purify waste vegetable oil. Below each of the differences from one prototype to the other are described.

The old initial tank had an angled piece of sheet metal within it, this allowed the heavier debris to drop towards that end, and the cleaner oil would enter into the system through a valve placed above the angled sheet metal. The new heat and settle tank is composed of a funnel angled at about 20° this allows for the heavier debris and water to settle towards the bottom. The valve is placed right above the funnel, this new design allows for the debris to fall all the way to the bottom of the funnel and allows more oil to be preserved for actual cleaning. The previous design had large losses of oil initially since the valve was placed higher up on the tank, leaving more oil behind.

The position of the centrifuge in the old prototype was in line with the pump, in the new design the centrifuge was raced above the pump, in order to allow the flow to exit the centrifuge and continue onto the membrane filter. The centrifuge's outlet is underneath it; a PVC three way valve was attached to this outlet. This valve allowed for the diversion of the flow to either the first flow scenario, which was the oil exiting the system to the final storage tank, or to the second scenario, which diverted the flow towards the membrane filter. Raising the centrifuge allowed for the continuation of the system, rather than the old setup which composed of the oil entering either the centrifuge or the membrane filter and exiting right after. This new prototype allows the flow to go through the entire system rather than just one component at a time. These changes can be observed on images 34 and 35, the old and new centrifuge designs respectively

A third filtering device was added to the prototype, a water absorption filter was placed after the membrane filter. This filter is capable of filtering any remaining water emulsified within the oil. The idea was that this last filter would be utilized in order to purify the oil to its finest level possible, removing any small amounts of water still remaining. After flowing through the membrane filter the oil flows through a brass three way valve, which when changed allows the oil to either exit the system to the final storage tank or flow into the water absorption filter. The final stage of the piping system that the oil travels through is underneath the top floor of the cart. This portion is joined a by a third and last three way valve which allows the flows exiting the water absorption system to take the same exit as the oil exiting the membrane filter. This was done in order to remove the amount of PVC being used, as well as for space considerations.

11.2. Maintenance of the system

To ensure proper maintenance of the prototype it is important to keep all filters clean, and to periodically exchange the filtering elements. The primary filter should be opened and cleaned after about 10 uses, or if it seems like it is becoming too clogged. The centrifuge's jets should be periodically unscrewed and cleaned out, using something thin enough to unclog the jets' outlets. The membrane filter should be exchanged after about 150 uses, as per the manufacturer's instructions. Always inspect the system for any leaks and use the PVC cement to seal them, whenever they may come up. Maintenance for this prototype mostly includes changing the filters in a timely manner, and inspecting that it is in working order.

11.3. Risk Assessment

When performing any tests utilizing the prototype it is important to take all safety measures into account. There are a number of risks associated with handling hot oil. It is important to carefully handle the hot WVO using safety equipment, such as: gloves, goggles, and aprons. Insulation of the heat and settle tank is beneficial to the system; it contains the heat from seeping out of the tank walls. Having insulation around all the reservoirs protects the user from the hot temperatures.

The pumps should be kept in working condition, this is done by priming the pumps; this is also a safety precaution. Unsuccessful priming of the pumps can cause problems and potentially damage the pumps, halting any further testing. The prototype is integrated on a movable cart; therefore precaution should be taken whenever moving the cart while oil is present in the system. In order to avoid any possible injuries regarding this it is advised to always empty out all tanks prior to transporting the prototype.

Further concerns regarding risk assessment can be found within the user manual in the appendix section; these manuals are also present on the prototype itself in both English and Spanish.

11.4. Environmental Impact

The utilization of biodiesel over fossil fuels to power our cars offers many advantages, including a reduction of emissions of harmful air pollutants. “Unlike conventional diesel, biodiesel is non-toxic, biodegradable and safer to ship. Spills do not require emergency response clean-up activities”[23]. Biodiesel, which is produced from vegetable oils as well as animal fats, these are all naturally occurring things, which unlike fossil fuels are fully renewable. Overall biodiesel is a much cleaner alternative to traditional fossil fuel usage.

11.5. Standards used in the project

The reliability of a piping system rests solely on the way it was constructed and the principles that were implemented during the design and manufacturing stages. A piping assembly is composed of pipe, fittings, brackets, valves, and joints; all of these components strictly follow set guidelines and standards, which have been respected throughout the creation of the prototype. The following standards and guidelines were implemented:

- American National Standards Institute (ANSI)
- American Society of Mechanical Engineers (ASME)
- International Organization for Standardization (IOS)
- American Society for Testing and Materials (ASTM)

These standards were implemented within the components of the system, for example the dimensions on the threads on SCH-40 pipe fittings, and the radius on 90° elbows [24]. The standards were also obeyed with all machinery that was utilized during the manufacturing process, as well as all materials used in order to construct the eventual prototype. Every machined part was manufactured within the student machine shop within FIU; all safety procedures were respected, eye safety, closed toe-shoes, no food, etc. All machines were examined prior to use and all were up to date with safety inspections.

In addition all values obtained when performing analysis were obtained from trusted, published sources. For instance all values for the minor loss coefficients for pipe fittings such as inlets, exits and elbows were obtained from the "Design of Fluid Thermal Systems, third edition" textbook [25].

12. PROTOTYPE TESTING

12.1. Overview

Upon prototype manufacturing completion, the team will begin to test the system immediately. The prototype as previously described is to be operated depending on the initial classification of the WVO, how much debris and water is initially present will determine the flow path of the oil. In order to precisely choose a path, extensive preliminary tests are to be conducted in order to determine the most effective ways to cleanse the oil with different impurities.

Waste vegetable oil was obtained from various restaurants in the area and were tested prior to and after running it through the system.. Different tests will be conducted in which the oil will have a certain % of debris as well as water. Ensuring that the initial WVO has a controlled percentage of contamination will allow for concrete results to be obtained. The WVO obtained will have miscellaneous debris and water and will be classified into yellow and brown grease. 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.

12.2. Testing Scenarios

The WVO specimen will flow through the system in different directions depending on its initial classification. 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 has ended 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 water capture filter. Finally a second pump can pump the oil back into the heat and settle tank should the final product still not be of the desired purity.

12.3. Solid Debris Testing

For the testing of our prototype, three samples of the WVO batch (pre-treatment) will be measured on a scale. The sample will be placed in a 1-liter container. The container's weight will be measured prior to the testing to ensure a strict standard is maintained when testing for debris and impurities. The weight of the sample will be measured and recorded. The measurement will be taken three times and averaged. This will allow for an accurate representation of the waste vegetable oil that is being tested and cleaned. After the samples have been initially weighed, the samples will be strained using the same meshed material found within the heat and settle tank. After straining the three samples, the specimens will be placed on the scale and reweighed. This will result in a reduction of weight, which signifies the amount of solid debris that is contained within that WVO sample. This can give an accurate representation of the total batch, which will allow for proper classification of the WVO batch.

12.4. Water Content Testing

For water content testing of our WVO batches, three samples will be taken from the batch in placed in a 1-liter flask. The sample will be weighed to measure the overall weight of the oil prior to testing. The oil will then be heated to approximately 130° C (approximately 265°F) to ensure for the boiling and release of water vapor by the specimen. The oil sample will then be weighed and the difference in weight, compared to the initial weight, will be the amount of water found in the batch of waste vegetable oil. The content can be directly related and a percentage, or proportion, can be established which will allow for classification and justification of sending the oil into the last filter.

12.5. Testing Procedures

Based on water and solid debris testing, a specific path will be selected in order to accommodate the sample being used. The Weigh Heat Weigh (WHW) method is the simplest method to find out the percentage of water the oil sample contains. Although the Sandy Brae Test is much more accurate compared to the WHW method, it is an expensive and time-consuming process. The WHW method provided the team with an appropriate figure that depicts the difference between before and after the heating.

Upon post testing the oil, the Sample A had the least amount of water after performing the WHW method. Sample A only needed to go through the centrifuge to remove the necessary left over water content. The oil was placed in the heat and settle tank and was heated for roughly 45 minutes. As previously stated, the purpose of heating the sample WVO in the heat and settle tank for an extended period of time is to remove high quantities of water, as well as, letting any remaining minute waste settle at the bottom of the funnel. At 45 minutes, the valve at the bottom was opened in order to remove any waste that had settled at the bottom. At this point, the oil has a low viscosity causing the sample to flow easily through the system. Sample A WVO proceeded to flow through the system and exit at the centrifuge. In order to prove the importance of the centrifuge, a small amount was collected at the exit and weighed. Compared to WHW data, there was a noticeable difference between the initial data testing and the final product. In order to understand the importance of the remaining membrane and water filter, a second and third trial was implemented. Each section saw notable decrease from water and debris. Although sample A, which had the least amount of water, only needed to go through the centrifuge; using the membrane filter and water filter provided with a more and better pure substance of oil as opposed to the centrifuge. Unfortunately, with the addition of the remaining filters, there was not a drastic difference from the centrifuge to the remaining filters. This did provide positive outputs.

The WHW method was used for the remaining two other samples. Sample B showed a high concentration of water and debris. The same procedure was done for sample B. The team used the same amount of WVO for WHW testing. To keep the testing procedure evenly matched, sample B was held to 45 minutes of heating and settling before going through the system. After initial heating, the settled waste was released into the residue and free water tank. This particular sample collected a good amount of waste in the primary filter. This filter, as stated, protects the pump from any remaining debris. To see the efficiency of each filter in the respective section with this particular sample, a series of trials were ran through each. Due to a high amount of debris and water, the centrifuge portion did not have much effect on sample B. Although somewhat positive results were reached from the centrifuge section, it was required to continue through the system to achieve a higher removal of water and debris content. Through the remaining filters, the results depicted a higher rate of removal content as opposed to the initial WHW testing. The water filter removed a substantial amount of remaining water. In biodiesel, it is important for the oil to have a very minuscule amount of water content.

Lastly, sample C depicted roughly the same initial WHW testing and water content. Fortunately, sample C has had higher debris content. The debris was separated using the heat and settle tank filter. Then proceeded to weigh the remains from the oil. For this particular sample the membrane filter seemed to be much more beneficial then the water filter. For this reason, there was a larger difference from the centrifuge to the membrane filter as opposed to the membrane to water filter.

Each sample tested saw notable losses with water and debris content. The last sample was used to test the recirculation system. The output oil was reinserted into the heat and settle tank. At this point, the period of heating was kept at 45 minutes. The parameters stayed the same for the recirculation process. During this portion, there were still notable gains. As previously, sample C still benefited from the membrane filter. The difference from the centrifuge to membrane filter was still higher compared to membrane to water filter. The recirculation process serves its purpose. The main reason for the recirculation process is to give the oil a second run. WVO comes with different water and debris content. Not all oil will be able to reach a refine pure substance of biodiesel after just one run. The recirculation procedure shows how there is progress after each round of the system.

12.6. Testing Observations

There are few noteworthy and evident observations that prove each section functions properly. First, as shown below in figure 45, the debris that settled at the bottom of the tank is being released to the residue and free water tank.

Figure 47: Settled Residue Release

Although not clearly shown, the oil being released in the figure is actually a somewhat thick substance from sample C. As a closer view of how this debris would look like, figure displays the waste escape the funnel and go through the system.

Figure 48: Captured Oil Debris

In figure 46, the water had either evaporated or settled at the bottom of the tank. The micron filter had collected dried oil from sample B. This problem arises when either the oil has not settled at the bottom or was not released to the residue tank. It is important to release the waste from the primary tank in order to avoid clogging in the system.

When WVO has been somewhat cleansed, there is a substantial difference visually. When cleaned, oil goes from dark and obscure to light and clear. The figure below displays the change in color after a simple WHW testing.

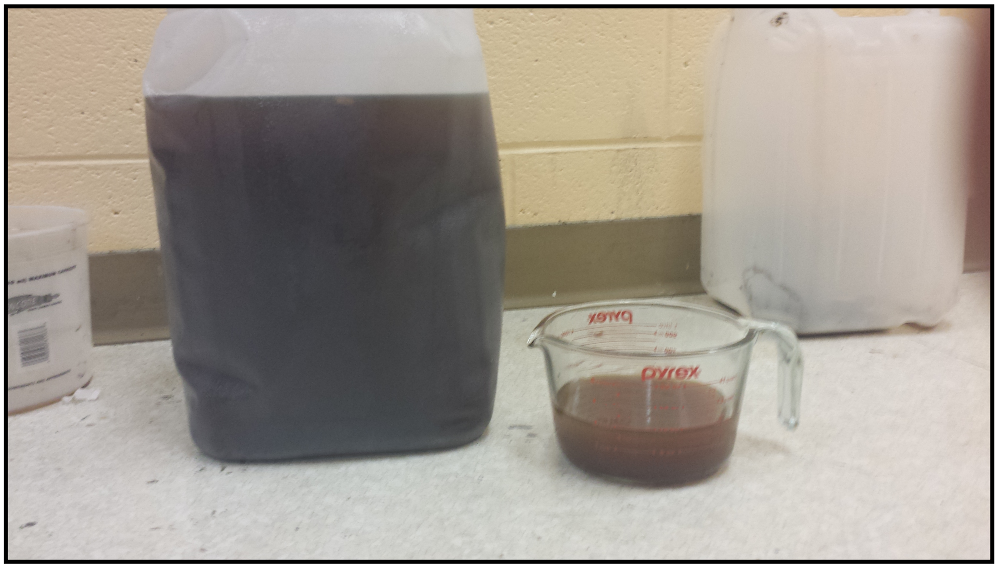


Figure 49: Before & After Filtration (Top View)

Figure 47 displays the drastic change after sample C went through each section in the system. As it can be seen from the clearer color the oil within the smaller container to the right is much cleaner than the initial oil.

Figure 50: Before & After Filtration (Top View)

The oil on the left is the initial WVO prior to the weigh-heat-weigh testing method. The oil on the right is the same oil as the left after just one pass through the system. Essentially, after numerous passes the oil can be cleansed and free from water and debris.

Figure 51: Debris Captured by Primary Filter

Figure 51 shows the weight of the captured oil debris after it was pulled from the primary filter. This shows that though the oil does not show signs of debris when it is heated, there is definitely still debris in the oil. When the oil is heated and stirred, the debris begins to thin. This definitely shows that time is required to let the debris settle at the bottom of the tank to ensure the pump does not pull the debris and clog the system.

12.7. Data and Results

The figures below show the results that were attained after testing for water and debris.

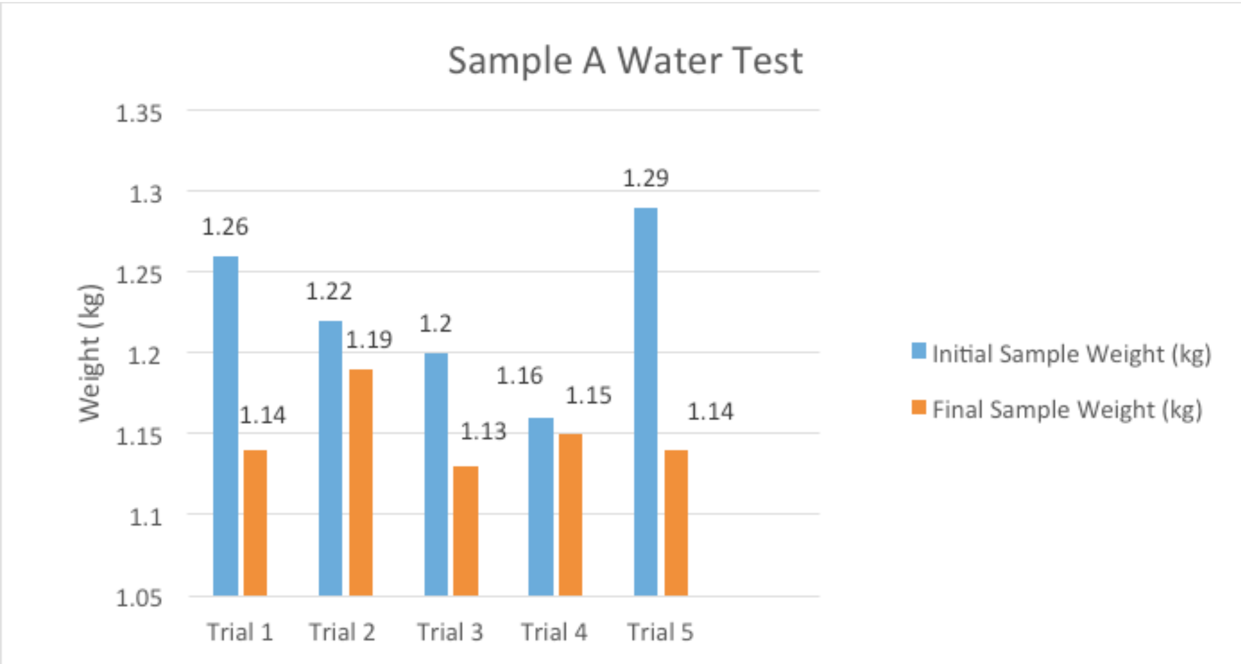


Figure 52: Sample A (Water Test)

Figure 52 demonstrates the total weight that was dropped simply by boiling the oil to remove water that could have been found in Sample A. The total amount of weight dropped varies as the numbers of trials increase. In the figure below, the debris test was performed on samples of the oil. From the figure, the oil was not very polluted.

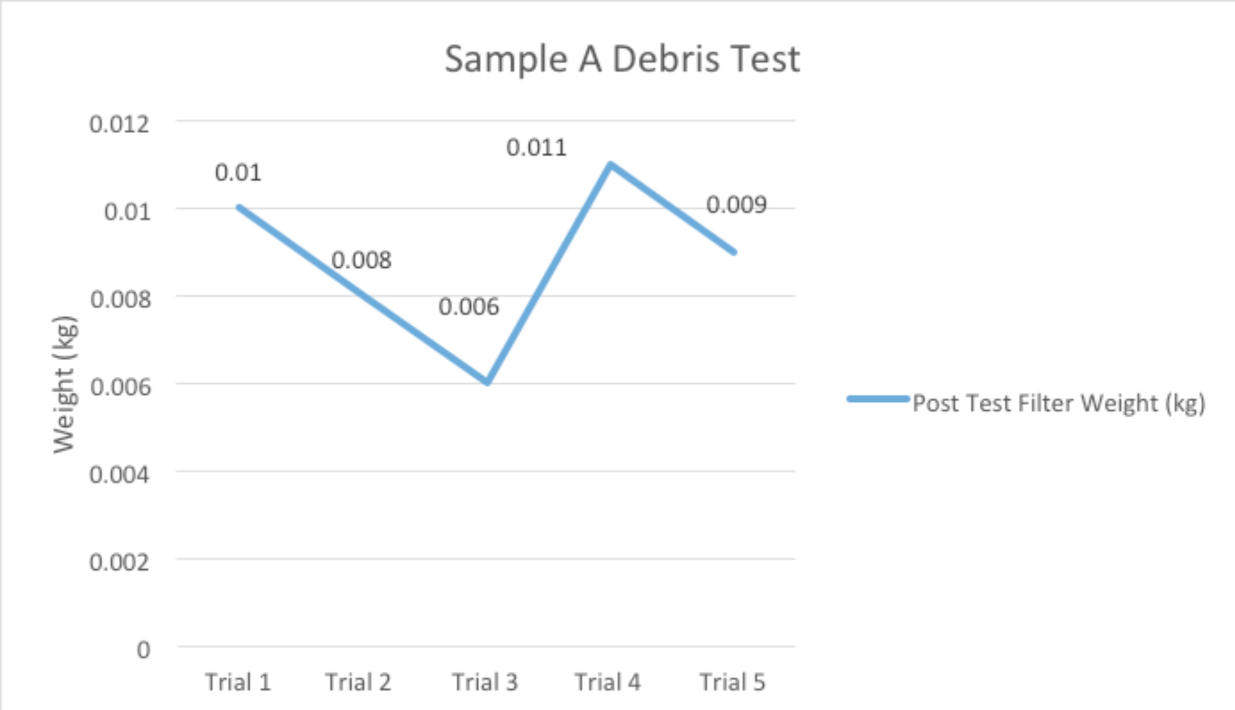


Figure 53: Sample A (Debris Test)

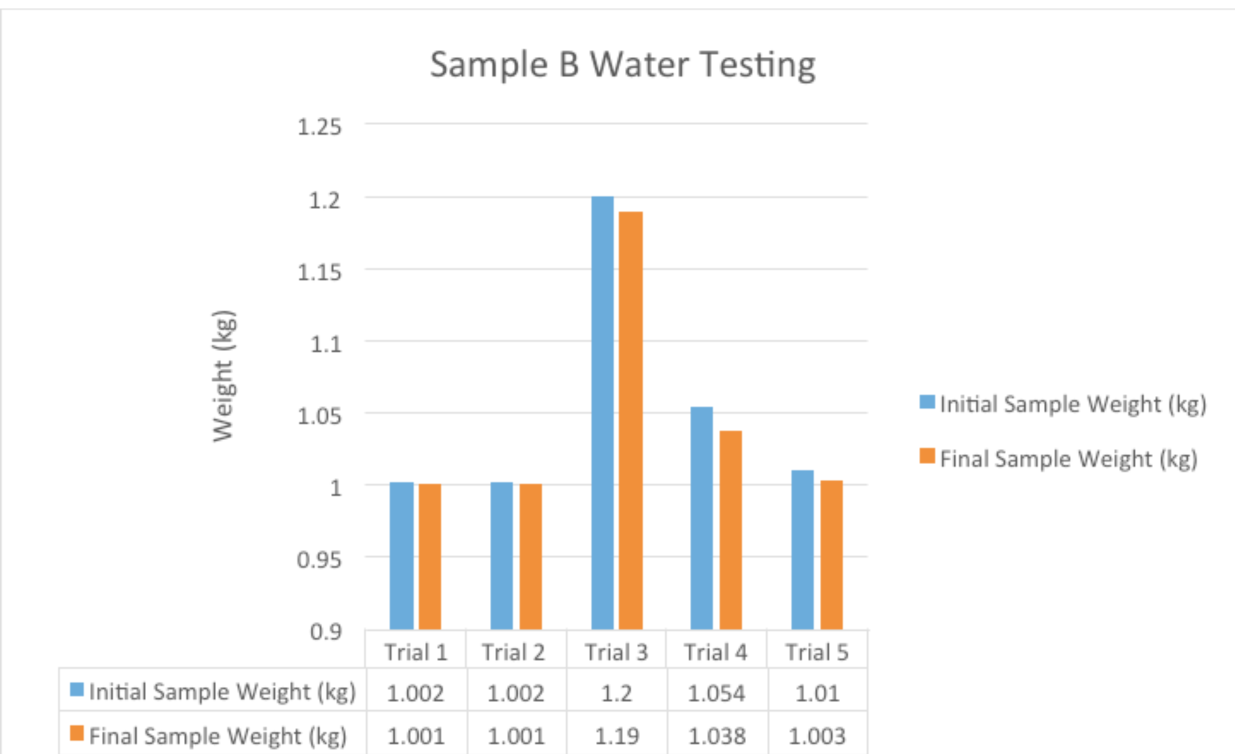


Figure 54: Sample B (Water Test)

Figure 54 is again, the weight that was dropped after boiling the oil. The graphs show that there was a lot of water removed because approximately 0.20 kg was dropped from the heating. The below graph shows the result of debris testing for Oil Sample B. The peak value was probably due to the movement from grabbing the sample from the previous trials which caused some of the debris to float.

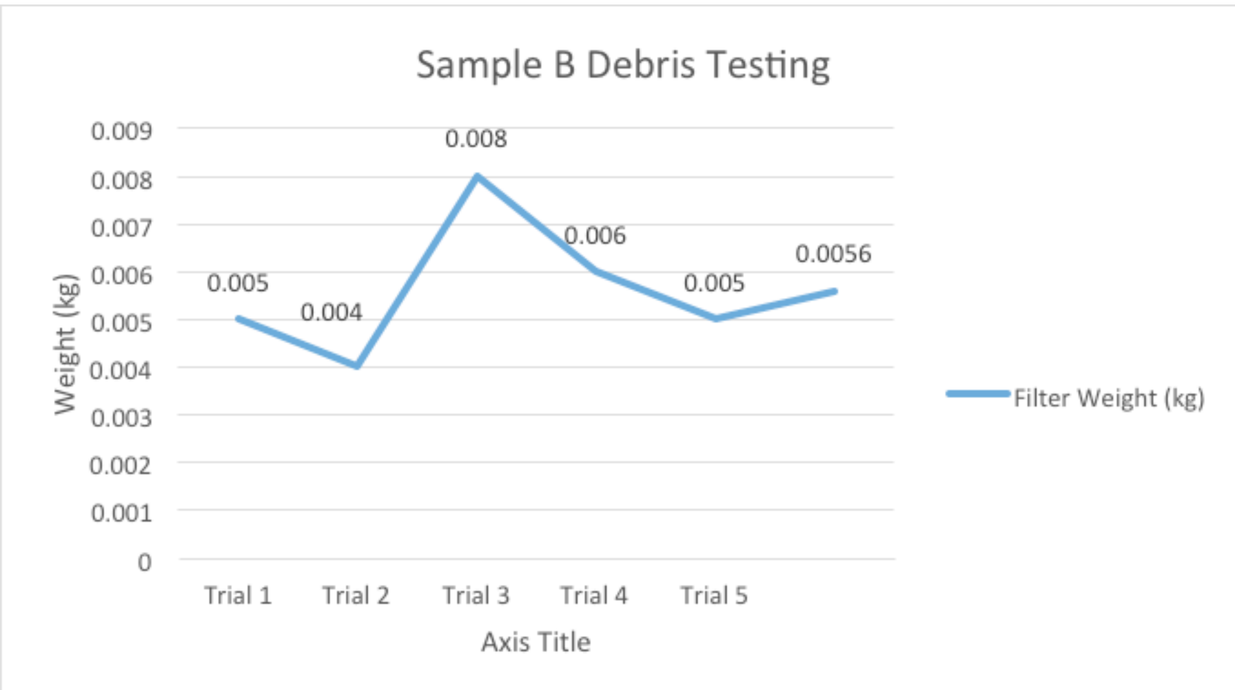


Figure 55: Sample B (Debris Test)

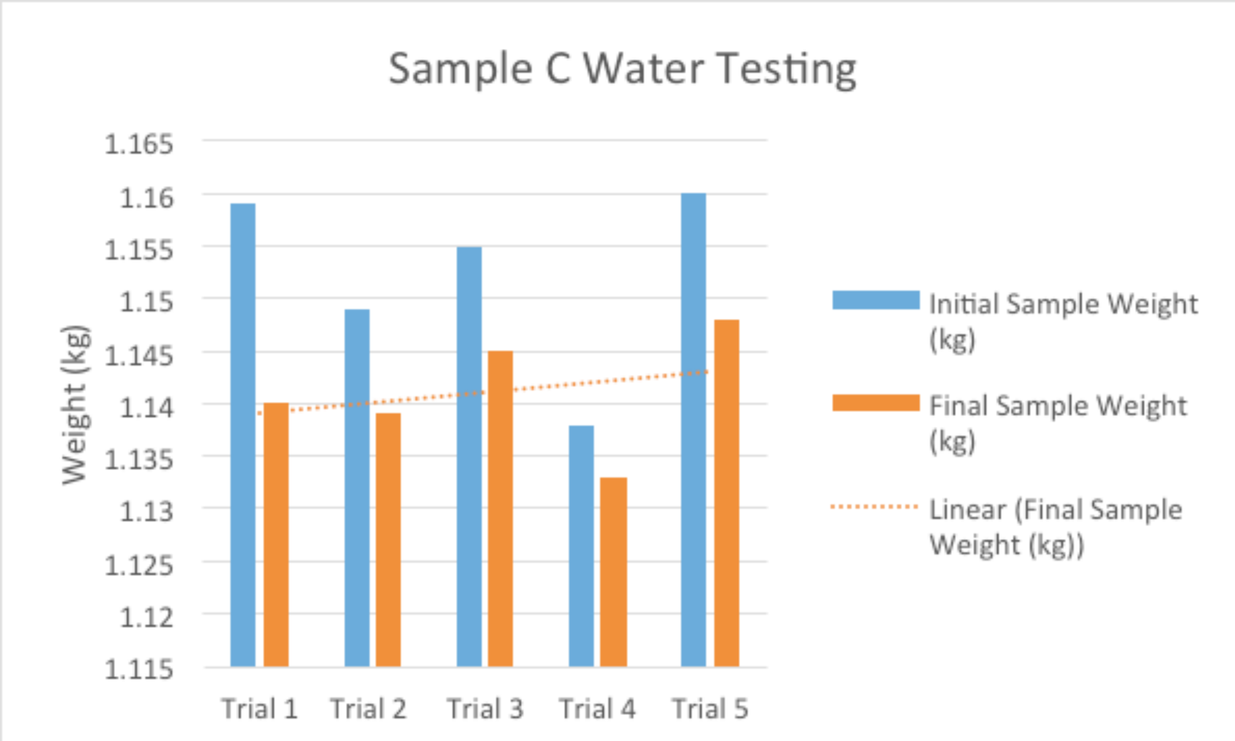


Figure 56: Sample C (Water Test)

Sample C's water and debris testing proved to be very effective because it fully demonstrated the need to run the oil through all filters. As the trials went on, the debris testing seemed to decrease which would mean that the majority of the debris was solid food particles.

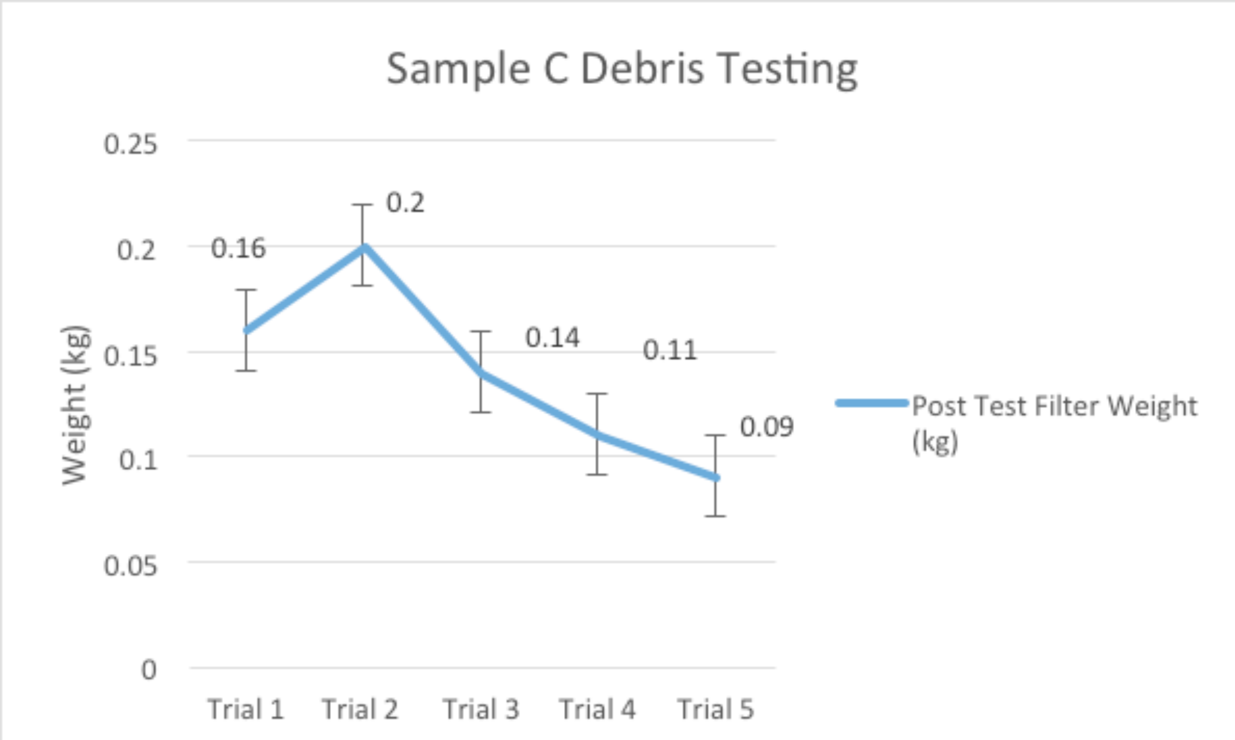


Figure 57: Sample C (Debris Test)

In order to see and understand if the prototype functions properly, initial and final testing sampling was required. One of the easiest methods to learn of the improvement is testing the water content in the waste vegetable oil. Using basic algebraic functions and the WHW method, a percentage of water removed was established. This percentage from the initial sampling will serve as a baseline for the prototype sampling.

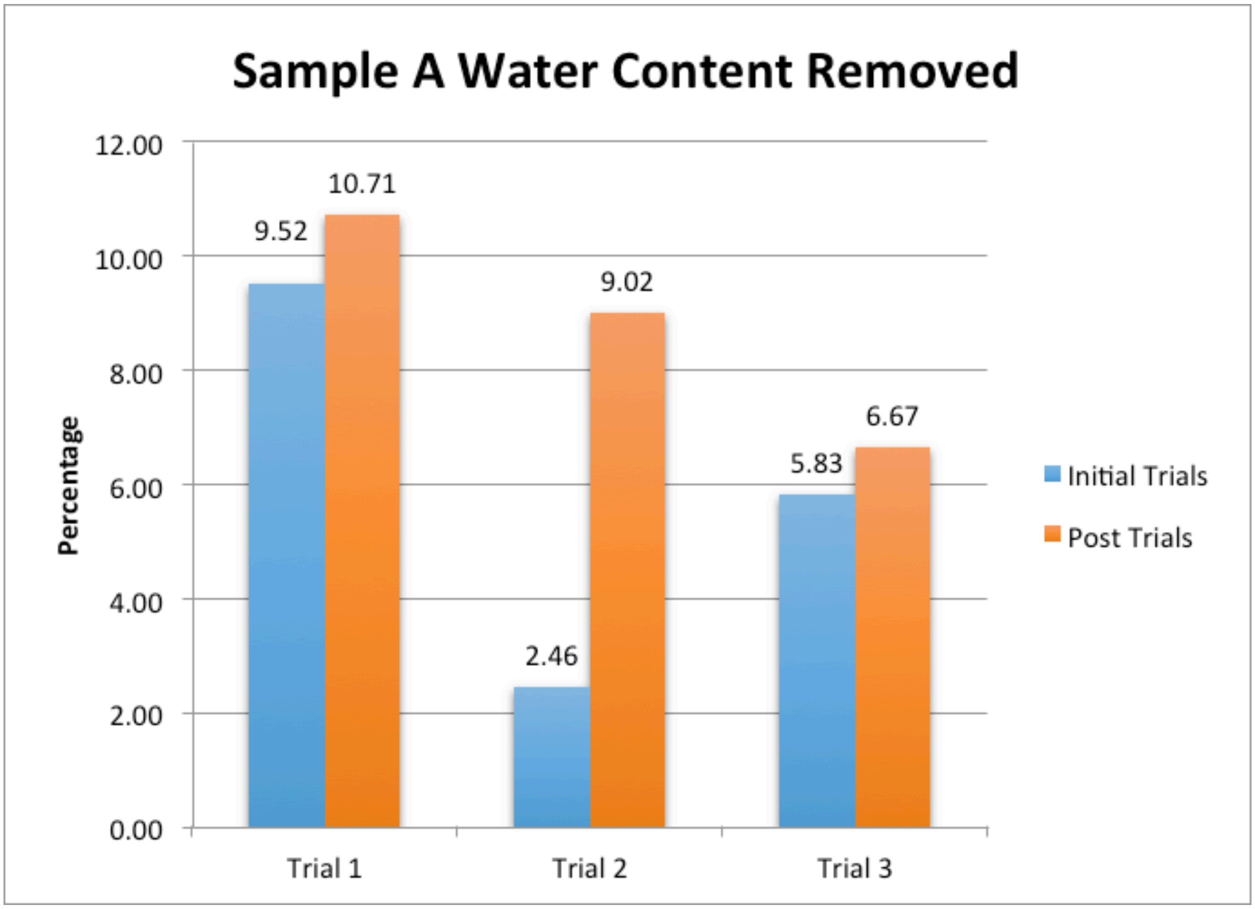


Figure 58: Sample A Water Content Removed

As shown in figure 58, the initial trials varied. The reason being is water has a different density compared to oil. The portion of water taken from trial 1 is different from trial 2 and 3. To begin, after prototype testing, the water content removed increased compared to initial testing. This is all a positive outcome. Unfortunately, sample A oil was constantly heated and used. In other words, the difference between the initial and final water content testing should not be vast. There was already a portion of water moved prior to any testing.

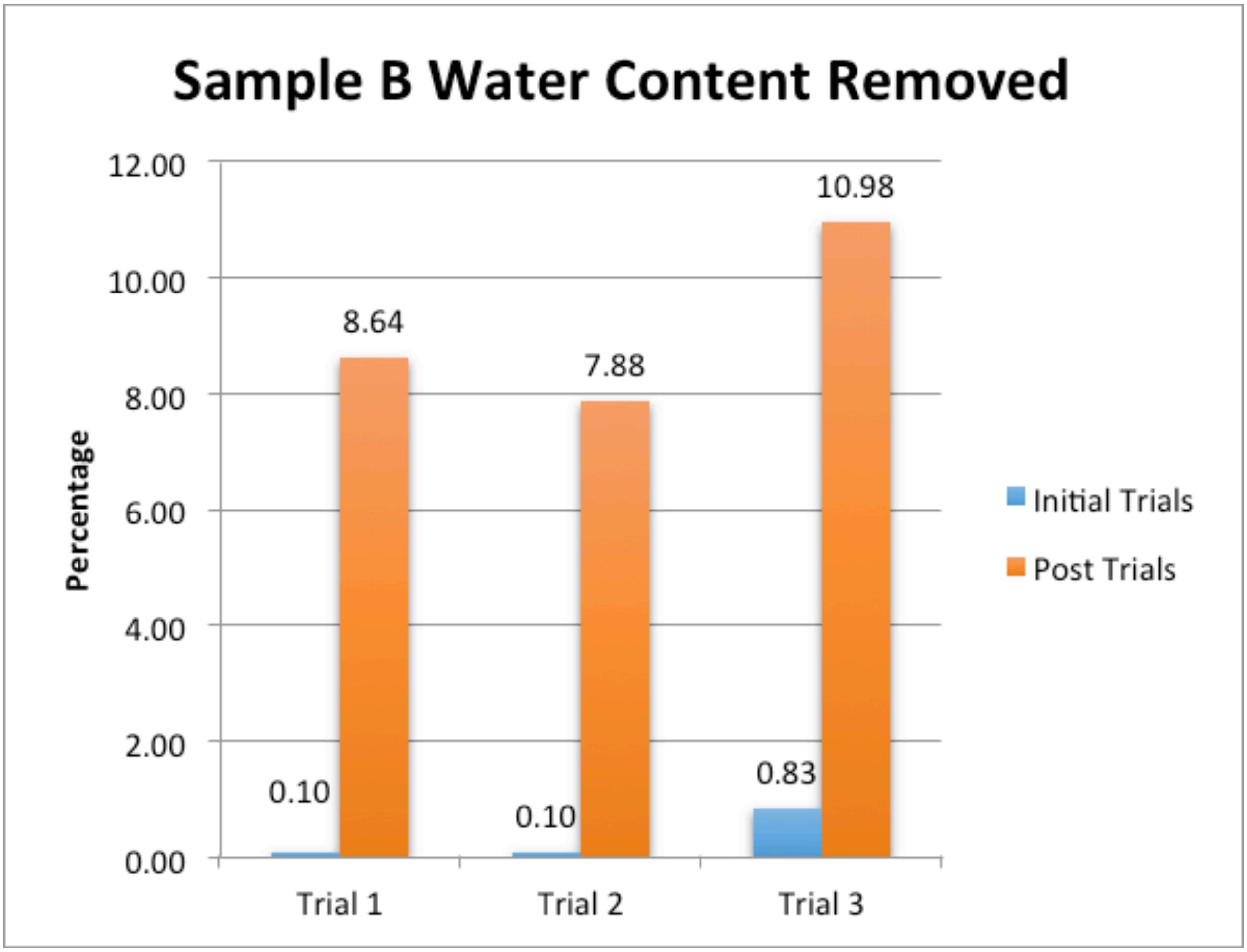


Figure 59: Sample B Water Removed

As opposed to sample A, sample B resulted in drastic increases in the percentage of water removed. Sample B contained much debris and water. Prior to testing, the oil had a murkiness look. The murkiness indicates that there is water mixed in with the oil. For this particular substance, the centrifuge and water filter helped the most. As shown in figure 46, the dried up oil is evidence that the oil contained much water.

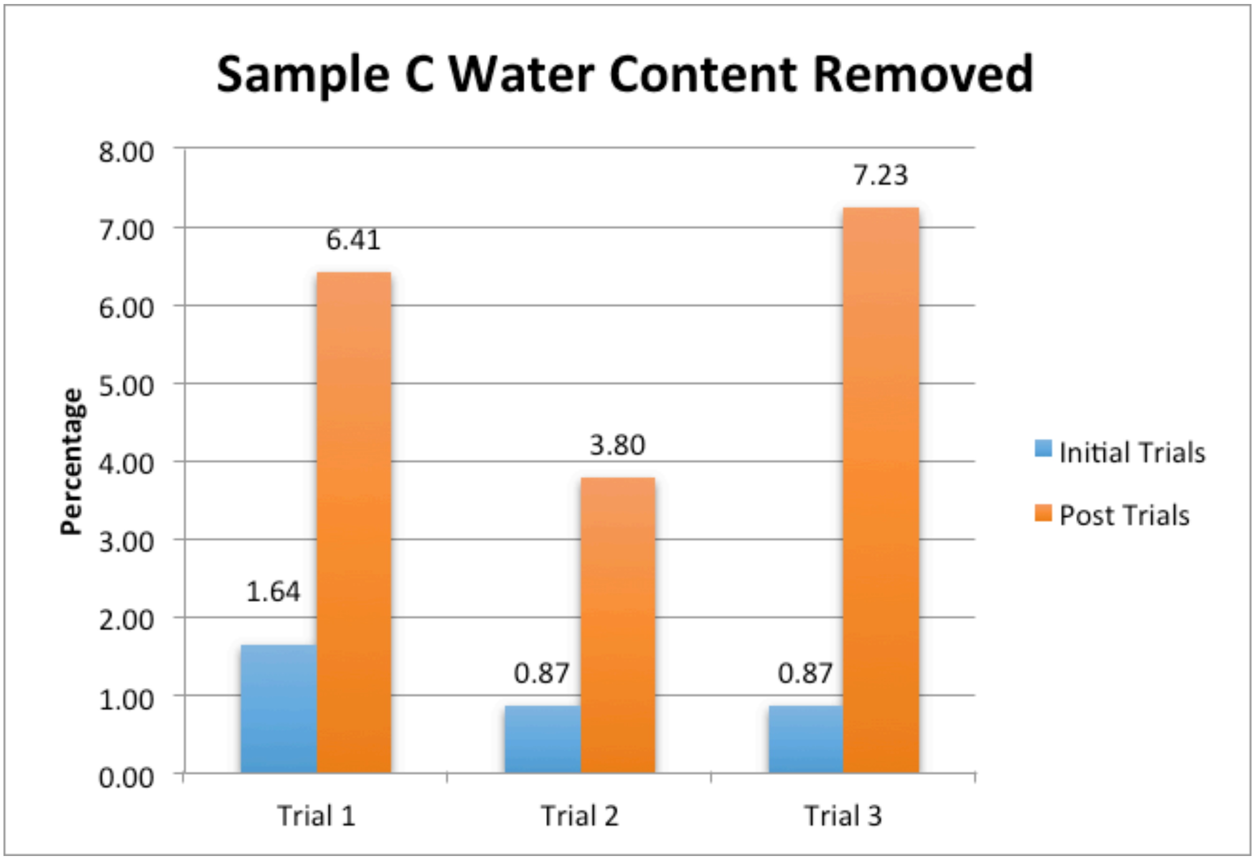


Figure 60: Sample C Water Content Removed

Sample C had similar results compared to sample B. The water content removed from sample C was a bit less due to the extra debris. Sample B was mainly water while sample C had about a 70/30 ratio of water and debris. In other words, this substance benefitted more from the membrane and water filter as opposed to the centrifuge. Because of this reason, sample C was chosen to be a recirculation candidate. The purpose was to continuously remove water and debris through multiple cycles.

The following figures are graphs that demonstrate the effectiveness of the prototype and its components.

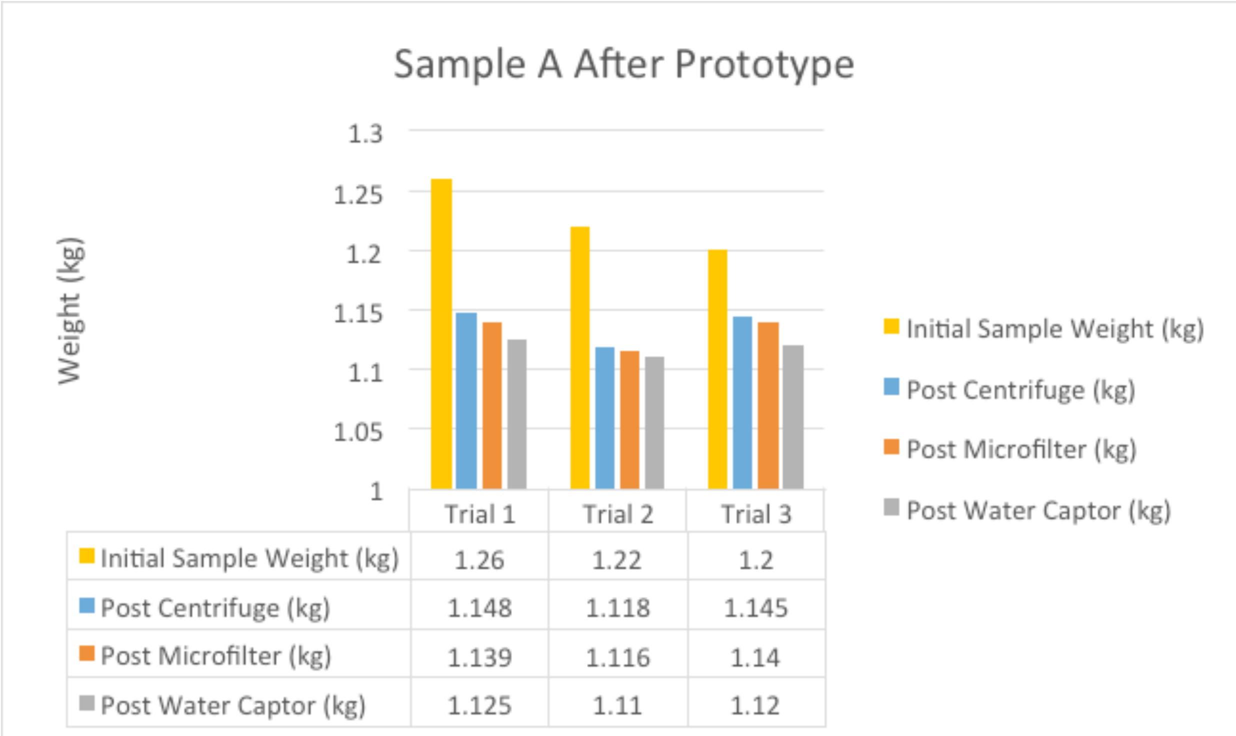


Figure 61: Sample A After Prototype

For Sample A, there is a clear understanding that a simple run through the centrifuge allows for thorough cleaning of the sample. The post water captor weight demonstrates a successful run through the entire system and the final weight of the oil. For Sample Oil A, a grand majority of the cleaning comes from the centrifuge.

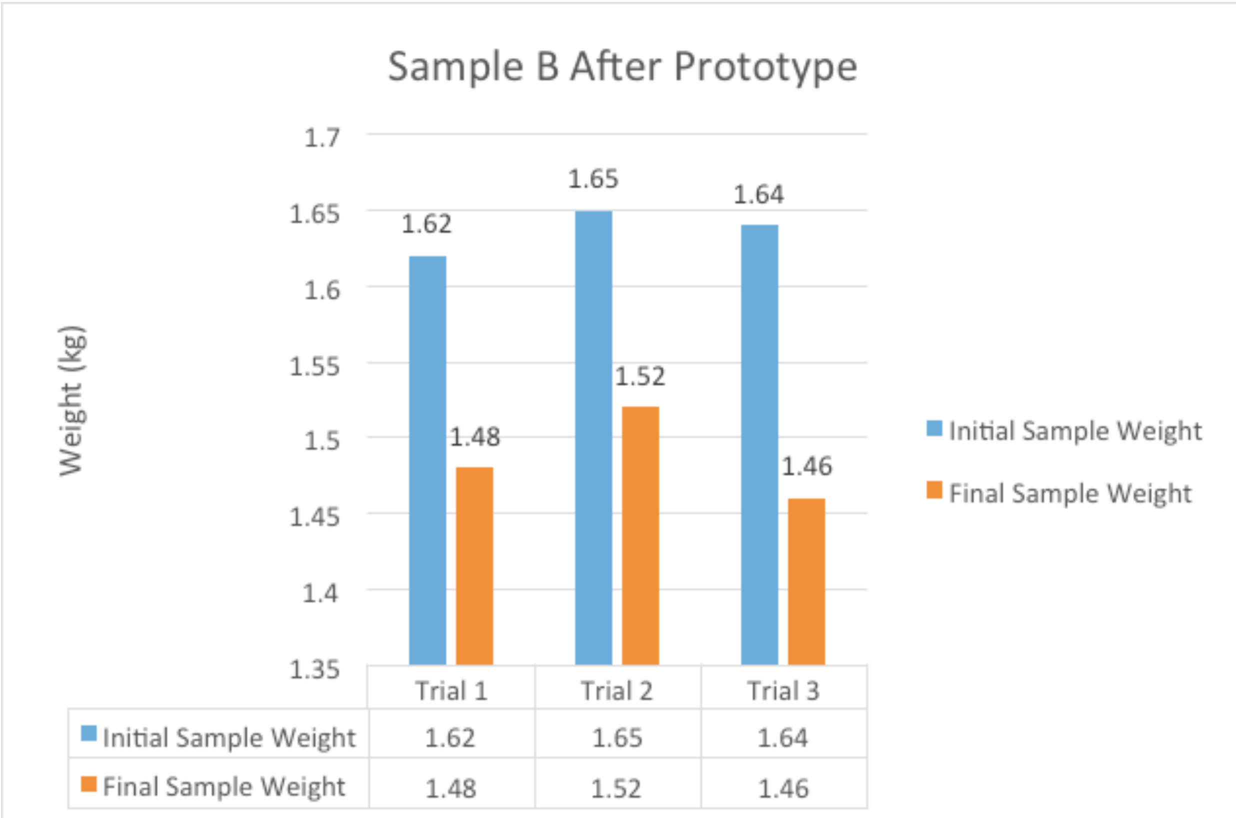
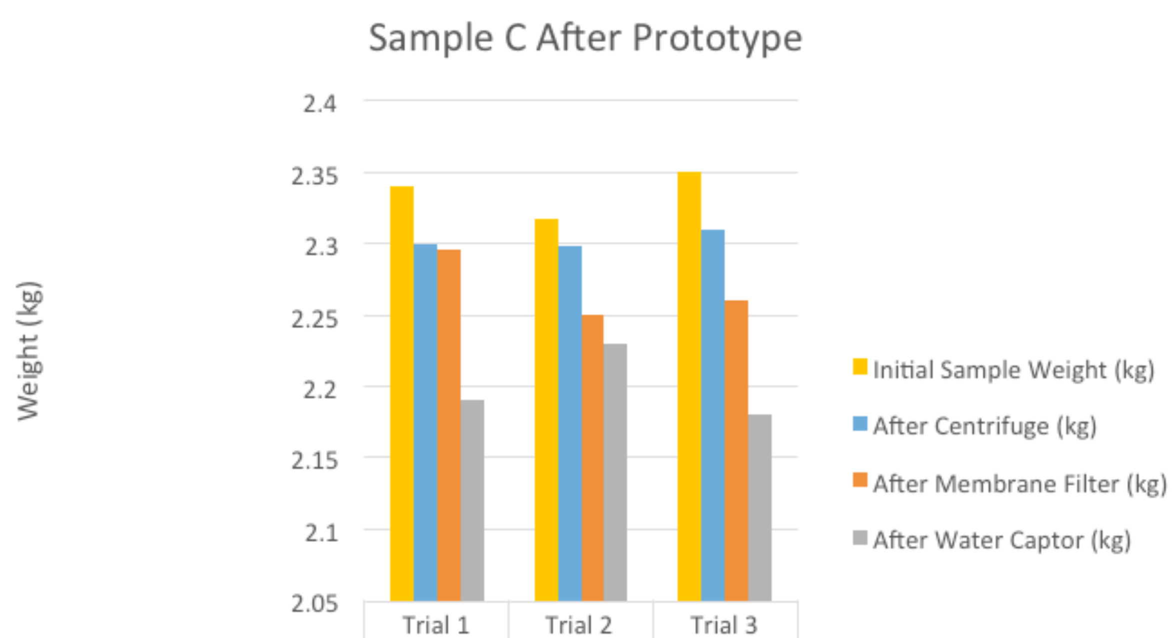


Figure 62: Sample B After Prototype

Sample B was the oil with the highest water content. Because the oil had a high water content, it was decided that the oil would be run through the entire system. Because there was a limited amount of Sample B, it was decided that only a few trials would be ran and it would be analyzed after a full run of the system. The samples show a general cleaning of the sample.



	Trial 1	Trial 2	Trial 3
Initial Sample Weight (kg)	2.34	2.318	2.35
After Centrifuge (kg)	2.3	2.298	2.31
After Membrane Filter (kg)	2.296	2.25	2.26
After Water Captor (kg)	2.19	2.23	2.18

Figure 63: Sample C After Prototype

Sample C showed the greatest variance in effectiveness of the different components within the system. Each component dropped the system's weight more and more as the oil progressed through the system. Sample C allowed for the testing of the recirculation process. After recirculation, there was a clear decrease in the total weight of the samples. The greatest weight reductions came from the water capturing filter which would tell that there was a high water content.

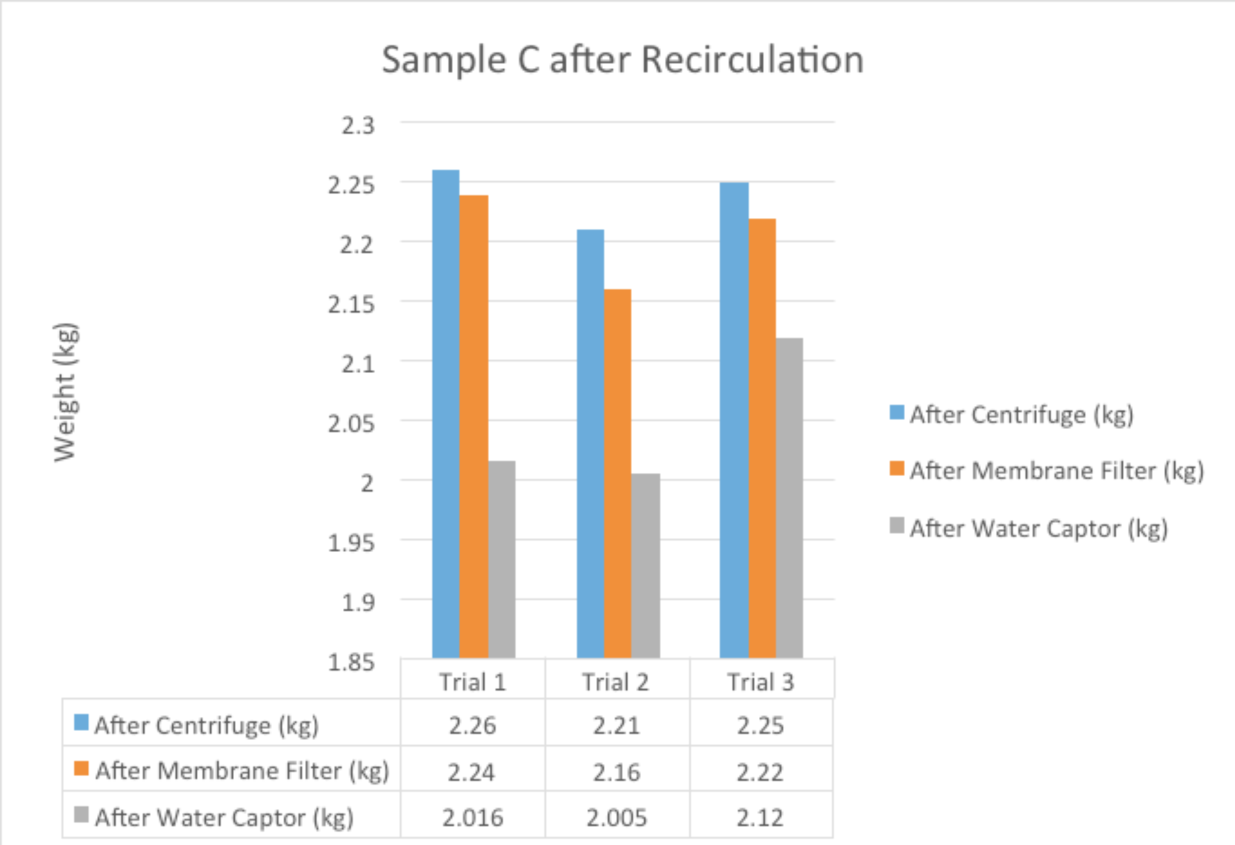


Figure 64: Sample C After Recirculation

13. CONCLUSIONS

13.1. Conclusion and Discussion

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 or more 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.

13.2. Evaluation of Global Aspects

The finalized prototype accounts for the feasibility of utilization in countries around the world, most specifically in Hispanic countries. A user manual has been included with the system, which highlights instructions for use, safety and major components. The manual has been translated to Spanish and included within the system as well. Incorporating different languages allows the amount of users to increase drastically. This prototype was intended to reach a wide audience, the issues with fossil fuel consumption and energy alternatives are topics discussed all around the world. This prototype portrays a perfect example of an alternative energy, allowing the user to purchase inexpensive WVO and to purify it to eventually produce biodiesel. Biodiesel's production and consumption is increasing exponentially and systems such as this one facilitate the transition from fossil fuel dependency to renewable resources.

13.3. Commercialization Prospects of Prototype

Upon completion of the prototype and successful testing, commercialization of the prototype is possible here in the United States as well as other countries. This prototype was designed and built to process small amounts of WVO, in order to commercialize it; some adjustments would have to be made. Rather than processing 5 gallons of WVO at a time, the system would be utilized to process much larger amounts than this.

A larger initial tank would be required as well as a more capable pump; the piping system would also be of a larger diameter. The biggest adjustments would deal with the membrane filter as well as the water capturer filer, as these would have to be much larger and much more capable of handling a larger flow rate. Once a new system is designed, following the specs obtained from the prototype, the new system will yield similar results to those obtained from the prototype.

As biodiesel's production and consumptions continues to increase, so will the demand for systems such as this one. Companies will look to purchase WVO rather than clean oil in order to produce biodiesel. As fossil fuels become more and more scarce, various studies show that biodiesel is believed to be one of the leading contenders in renewable energy alternatives. A prototype like this one would be a sought after one, by companies interested in exploiting the up and coming field of renewable energy.

13.4. Recommendations for Future Work

Filtration systems fully depend on whether or not the filters are in working order. In order to determine whether a filter is working, the pressure drop across the filter can be used as an indicator. In order to accomplish this, pressure gages are used, placing one directly before the filter and one right after it can display the loss in pressure across the filter. Unfortunately due to space restriction, doing this was impossible. The standard distance to place the pressure gages are 5 times the filter's inlet diameter for the gage that goes before the filter, and 2 times the diameter for the gage that goes after the filter. For future work, it would be recommended to add these gages to the prototype, placing one before the membrane filter, one after it, and one after the water absorption filter.

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15. APPENDICES

15.1. Pressure Loss Calculations

Flow Scenario #1 (Flow through centrifuge, exit to final product tank):

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2 + \frac{fl}{d_h} * \frac{v^2}{2g} + \Sigma H_f * \frac{v^2}{2g}$$

Major Losses Calculation:

$$H_{major} = \frac{fl}{d_h} * \frac{v^2}{2g}$$

$$H_{major} = \frac{0.0289 * 2.5ft}{0.0625ft} * \frac{13.12^2 ft^2/s^2}{2 * 32.17ft/s^2}$$

$$\boldsymbol{H_{major} = 3.093\ ft}$$

Minor Losses Calculation:

$$H_{minor} = \Sigma H_f * \frac{v^2}{2g}$$

$$H_{minor} = 5.77 * \frac{13.12^2 ft^2/s^2}{2 * 32.17ft/s^2}$$

$$\boldsymbol{H_{minor} = 15.44\ ft}$$

Loss Coefficient Calculation:

$$\Sigma H_f = K_{in} + K_{filter} + 2K_{45^\circ\, elbow} + K_{centrifuge} + K_{3-way\, ball\, valve} + K_{90^\circ\, elbow} + K_{out}$$

$$\Sigma H_f = (0.5 + (2\%\, of\ loss) + 0.7 + (3\%\, of\ loss) + 1.9 + 1.4 + 1)$$

$$\Sigma H_f = 5.5 + 0.11 + 0.16$$

$$\boldsymbol{\Sigma H_f = 5.77}$$

Pressure difference:

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2 + H_{major} + H_{minor}$$

$$\frac{P_1}{\rho g} - \frac{P_2}{\rho g} = z_2 - z_1 + H_{major} + H_{minor}$$

$$P_1 - P_2 = \left(z_2 - z_1 + H_{major} + H_{minor}\right) * \rho g$$

$$P_1 - P_2 = (0.5 + 3.093 + 15.45)ft * \frac{57.41lb}{ft^3} * 32.17ft/s^2$$

$$\boldsymbol{P_1 - P_2 = 52339\ Pa}$$

$$\boldsymbol{P_1 - P_2 = 7.59\ psi}$$

Flow Scenario #2 (Flow through centrifuge and membrane filter exit to final product tank):

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2 + \frac{fl}{d_h} * \frac{v^2}{2g} + \Sigma H_f * \frac{v^2}{2g}$$

Major Losses Calculation:

$$H_{major} = \frac{fl}{d_h} * \frac{v^2}{2g}$$

$$H_{major} = \frac{0.0289 * 4.7ft}{0.0625ft} * \frac{13.12^2 ft^2/s^2}{2 * 32.17ft/s^2}$$

$$\boldsymbol{H_{major} = 5.82\ ft}$$

Minor Losses Calculation:

$$H_{minor} = \Sigma H_f * \frac{v^2}{2g}$$

$$H_{minor} = 9.34 * \frac{13.12^2 ft^2/s^2}{2 * 32.17ft/s^2}$$

$$\boldsymbol{H_{minor} = 25\ ft}$$

Loss Coefficient Calculation:

$$\Sigma H_f = K_{in} + K_{filter} + 2K_{45^\circ\, elbow} + K_{centrifuge} + K_{membrane\ Filter} + 2K_{3-way\ ball\ valve}$$

$$+2K_{90^\circ\, elbow} + K_{out}$$

$\Sigma H_f = (0.5 + 0.11 + 0.7 + 0.16 + (3\%\ of\ loss) + 3.8 + 2.8 + 1)$

$\Sigma H_f = 9.07 + 0.27$

$\boldsymbol{\Sigma H_f = 9.34}$

Pressure difference:

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2 + H_{major} + H_{minor}$$

$$\frac{P_1}{\rho g} - \frac{P_2}{\rho g} = z_2 - z_1 + H_{major} + H_{minor}$$

$$P_1 - P_2 = \left(z_2 - z_1 + H_{major} + H_{minor}\right) * \rho g$$

$$P_1 - P_2 = (1.6 + 5.82 + 25)ft * \frac{57.41 lb}{ft^3} * 32.17 ft/s^2$$

$$\boldsymbol{P_1 - P_2 = 89106\ Pa}$$

$$\boldsymbol{P_1 - P_2 = 12.92\ psi}$$

Flow Scenario #3 (Flow through centrifuge, membrane filter and water capturer filter, exit to final product tank):

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2 + \frac{fl}{d_h} * \frac{v^2}{2g} + \Sigma H_f * \frac{v^2}{2g}$$

Major Losses Calculation:

$$H_{major} = \frac{fl}{d_h} * \frac{v^2}{2g}$$

$$H_{major} = \frac{0.0289 * 5.4ft}{0.0625ft} * \frac{13.12^2 ft^2/s^2}{2 * 32.17ft/s^2}$$

$$\boldsymbol{H_{major} = 6.69\, ft}$$

Minor Losses Calculation:

$$H_{minor} = \Sigma H_f * \frac{v^2}{2g}$$

$$H_{minor} = 10.13 * \frac{13.12^2 ft^2/s^2}{2 * 32.17ft/s^2}$$

$$\boldsymbol{H_{minor} = 27.1\, ft}$$

Loss Coefficient Calculation:

$$\Sigma H_f = K_{in} + K_{filter} + 2K_{45^\circ\, elbow} + K_{centrifuge} + K_{membrane\ Filter} + K_{water\ filter}$$

$$+K_{3-way\ ball\ valve\ branch} + K_{3-way\ ball\ valve\ line} + 3K_{90^\circ\, elbow} + K_{out}$$

$$\Sigma H_f = (0.5 + 0.11 + 0.7 + 0.16 + 0.27 + (4\%\ of\ loss) + 1.9 + 0.9 + 4.2 + 1)$$

$$\Sigma H_f = 9.74 + 0.39$$

$\boldsymbol{\Sigma H_f = 10.13}$

Pressure difference:

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2 + H_{major} + H_{minor}$$

$$\frac{P_1}{\rho g} - \frac{P_2}{\rho g} = z_2 - z_1 + H_{major} + H_{minor}$$

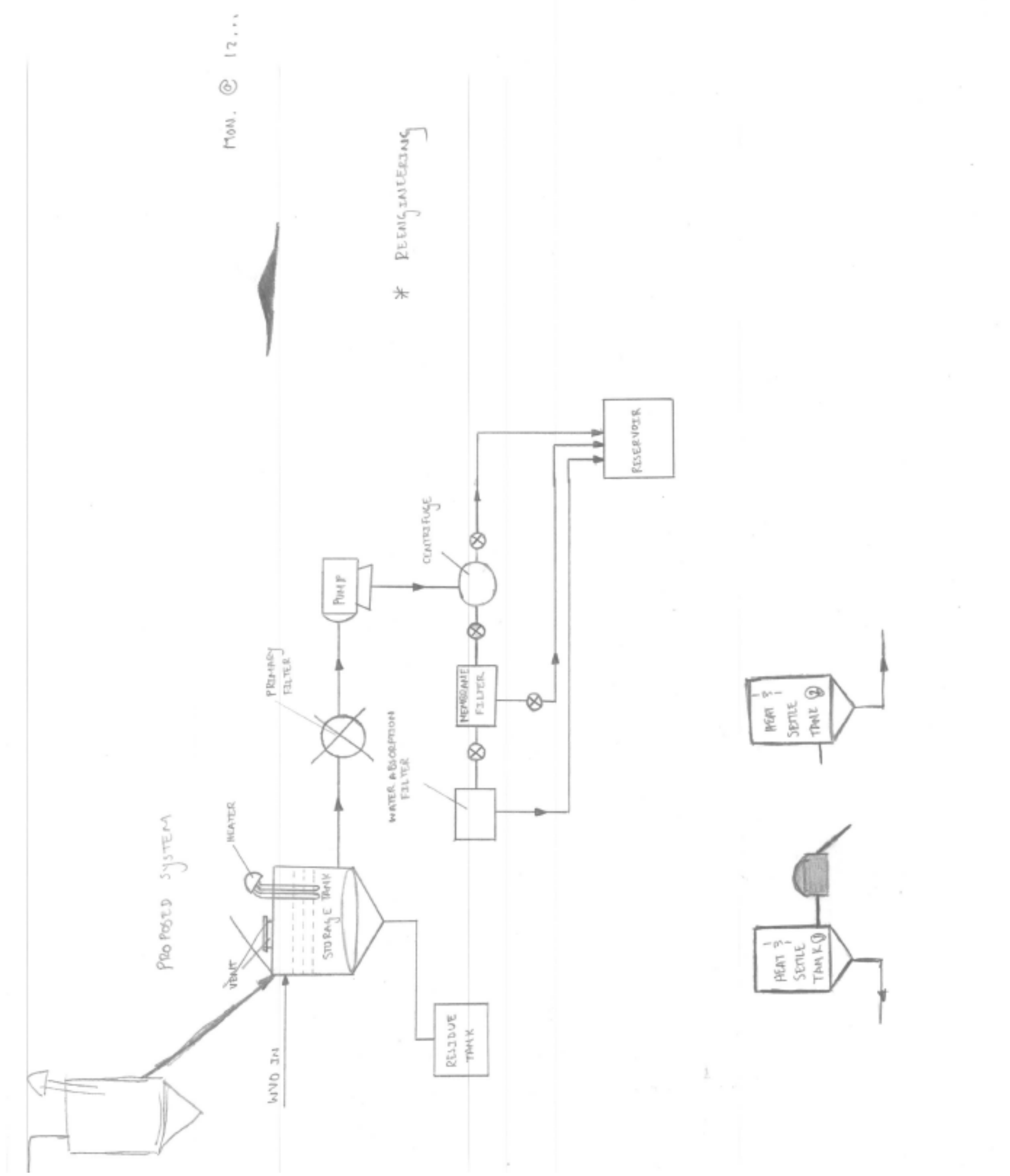
$$P_1 - P_2 = \left(z_2 - z_1 + H_{major} + H_{minor}\right) * \rho g$$

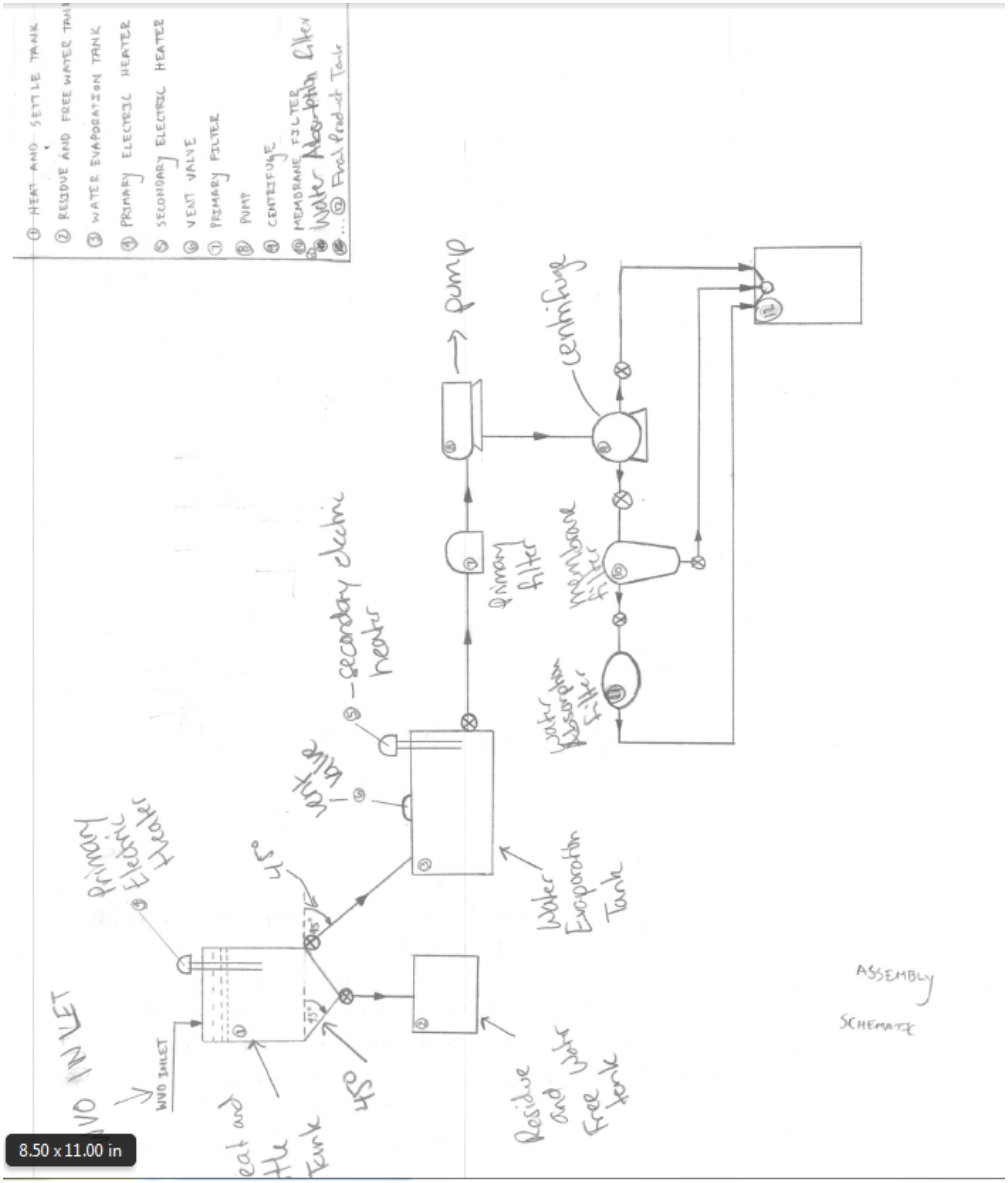
$$P_1 - P_2 = (1.6 + 6.69 + 27.1)ft * \frac{57.41lb}{ft^3} * 32.17ft/s^2$$

$$\boldsymbol{P_1 - P_2 = 97301\ Pa}$$

$$\boldsymbol{P_1 - P_2 = 14.11\ psi}$$

15.2. Initial Designs and Formulations




① HEAT AND SETTLE TANK
② RESIDUE AND FREE WATER TANK
③ WATER EVAPORATION TANK
④ PRIMARY ELECTRIC HEATER
⑤ SECONDARY ELECTRIC HEATER
⑥ VENT VALVE
⑦ PRIMARY FILTER
⑧ PUMP
⑨ CENTRIFUGE
⑩ MEMBRANE FILTER
⑪ Water Absorption filter
⑫ Final Product Tank
WVO INLET
Primary Electric Heater
45°
vent valve
secondary electric heater
Primary filter
pump
centrifuge
membrane filter
Water Absorption Filter
Water Evaporation Tank
Residue and Water Free tank
ASSEMBLY SCHEMATIC
8.50 x 11.00 in

BERNOLLI'S PRINCIPLE: STATES THAT AN INCREASE IN THE SPEED OF THE FLUID OCCURS SIMULTANOUSLY WITH A DECREASE IN PRESSURE.

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 g = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 g + \Sigma H_F$$

γ > SPECIFIC WEIGHT

$$P_1 = P_2 = P_{ATM}$$

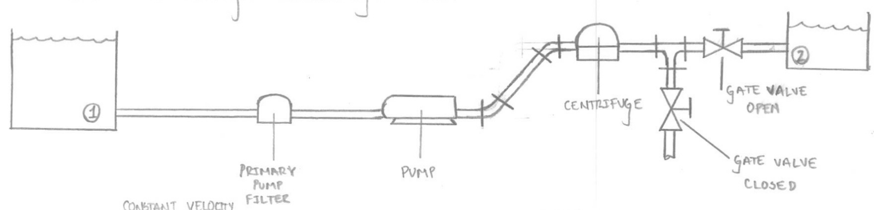
$$\frac{V_1^2}{2g} + z_1 g = \frac{V_2^2}{2g} + z_2 g + \Sigma H_F$$

- ALL COMPONENTS WILL BE PLACED AT AN EQUAL HEIGHT.

$$z_1 = z_2$$

$$\boxed{\frac{V_1^2}{2g} = \frac{V_2^2}{2g} + \Sigma H_F}$$

↳ SCENARIO #1 : FLOW THROUGH CENTRIFUGE ONLY



$5 \times 10^{-4}\ m^3/s$

CONSTANT VELOCITY THROUGHOUT SYSTEM

0.029

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + \frac{fL}{D_H}\cdot\frac{V^2}{2g} + \left[K_{INLET} + K_{PRIMARY\ FILTER} + 2K_{45^\circ ELBOW} + K_{T\text{-}JOINT} + K_{VALVE} + K_{EXIT}\right]\frac{V^2}{2g}$$

$+ K_{CENT.}$ — OR NOZZLE

$$\frac{P_1}{\rho g} + z_1 = \frac{P_2}{\rho g} + z_2 + K_{TOTAL}\cdot\frac{V^2}{2g}$$

4 m/s

$$\frac{P_1}{\rho g} - \frac{P_2}{\rho g} = z_2 - z_1 + K_{TOTAL}\cdot\frac{V^2}{2g}$$

$$P_1 - P_2 = z_2\cdot\rho g - z_1\cdot\rho g + K_{TOTAL}\cdot\frac{V^2\rho}{2}$$

$$\boxed{P_1 - P_2 = (z_2 - z_1)\rho g + K_{TOTAL}\cdot\frac{V^2\rho}{2}}$$

$\dot{Q} = 0.132\ gal/s$

$V = 13.123\ ft/s$

$D = 0.4956\ in \sim 0.5\ in$

DENSITY : OLIVE OIL @ 20°C
800–920 kg/m^3

DENSITY : 920 kg/m^3

↳ TEMPERATURE @ 140°F ≈ 60°C

	SPECIFIC HEAT	VISCOSITY
OLIVE OIL :	1.756 kJ/kg·K	21.11 mPa·s
PEANUT OIL :	2.095 kJ/kg·K	21.10 mPa·s

$$P_1 - P_2 = (z_2 - z_1)\cdot 57.408\ lb/ft^3\,(32.17\ ft/s^2) + \frac{K_{TOTAL}\cdot(13.123\ ft/s^2)\rho}{2}$$

$$P_1 - P_2 = (z_2 - z_1)\,1{,}846.82\ lb/ft^2\cdot s^2 + \frac{9886.41}{2}\ lb/ft\cdot s^2$$

$$P_1 - P_2 = (z_2 - z_1)\,1{,}846.82\ lb/ft\cdot s^2 + 4{,}943.205\ lb/ft\cdot s^2\cdot K_{TOTAL}$$

↳ INTERPOLATION :

• OLIVE OIL

50	27.18
60	x
65	18.07

$$\frac{65-60}{65-50} = \frac{18.07 - x}{18.07 - 27.18}$$

$x = 21.11$

• PEANUT OIL

50	27.45
60	x
65	17.93

$$\frac{65-60}{65-50} = \frac{17.93 - x}{17.93 - 27.45}$$

$x = 21.10$

K_{TOTAL}

K_{INLET} : SQUARE-EDGED INLET : $K = 0.5$

$K_{PRIMARY\ FILTER}$: 1-2% OF TOTAL PRESSURE

$\boxed{1.488164394\ \text{PASCAL} \Rightarrow lb/ft\cdot s^2}$

$K_{45^\circ ELBOW}$: REGULAR : $K = 0.35$

$K_{T\text{-}JOINT}$: LINE FLOW : $K = 0.9$
BRANCH FLOW : $K = 1.9$

K-GATE VALVE : FULLY OPENED : $K = 0.15$

K-EXIT : $K = 1.0$

LAMINAR OR TURBULENT :

$$\boxed{Re = \frac{\rho V D}{\mu} = \frac{VD}{\nu} < 2100 \quad (\text{LAMINAR})}$$

CIRCULAR PIPING :

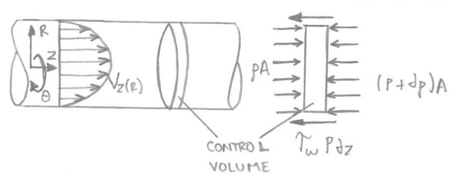
NOMINAL DIAMETER : SPECIFY THE DIAMETER (ROUNDED OFF NUMBER)

SCHEDULE NUMBER : SPECIFIES THE WALL THICKNESS.

Ex: "2 - NOMINAL SCHEDULE 40"

REFER TO APPENDIX TABLE D.1

- EQUATION OF MOTION FOR FLOW IN A DUCT:



LAMINAR FLOW

$$\boxed{\underbrace{pA - \tau_w}_{\text{WALL SHEAR STRESS}} \underbrace{P dz}_{\text{PERIMETER TIMES AXIAL DISTANCE}} - (p+dp)A = 0}$$

- FRICTION FACTOR :

$$\boxed{f = \frac{4\tau_w}{\rho V^2/2}} \rightarrow \text{DARCY - WEISBACH FRICTION FACTOR}$$

- ENERGY BALANCE (BERNOULLI'S EQUATION):

$$\boxed{\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + \frac{fL}{D_H}\cdot\frac{V^2}{2g}} \rightarrow \left[\begin{matrix}\text{PRESSURE}\\ \text{HEAD}\end{matrix} + KE + PE\right]_1 = \left[\begin{matrix}\text{PRESSURE}\\ \text{HEAD}\end{matrix} + KE + PE\right]_2 + \left[\begin{matrix}\text{ENERGY LOSS}\\ \text{DUE TO FRICTION}\end{matrix}\right]$$

- LAMINAR FLOW OF A NEWTONIAN FLUID IN A CIRCULAR DUCT:

$$\boxed{\underbrace{V}_{\text{VELOCITY}} = \frac{\overbrace{Q}^{\text{VOLUMETRIC FLOW RATE}}}{\underbrace{A}_{\text{AREA}}}}$$

$$\boxed{f = \frac{64}{Re}} \rightarrow \text{LAMINAR FLOW CIRCULAR DUCT}$$

- TURBULENT FLOW IN A CIRCULAR DUCT:

$$\boxed{f = f(Re, \varepsilon/D)}$$

* USES THE MOODY DIAGRAM* PG. 94-96!

- REFER TO: THE CHEN EQUATION, THE CHURCHILL EQUATION, THE HAALAND EQUATION, THE SWAMEE-JAIN EQUATION } SOLVE FOR f WITHOUT USING MOODY DIAGRAM

*TABLE 3.1 (PG. 92) HAS ROUGHNESS FACTORS FOR VARIOUS MATERIALS.

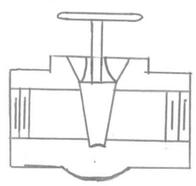
- MINOR LOSSES:

↳ PRESSURE LOSSES ENCOUNTERED BY A FLUID AS IT FLOWS THROUGH A FITTING OR A VALVE IN A PIPING SYSTEM.

$$\boxed{\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + \frac{fL}{D_H} \cdot \frac{V^2}{2g} + \sum K \frac{V^2}{2g}}$$ → MODIFIED BERNOULLI EQUATION

* TABLE 3.2: LOSS COEFFICIENTS FOR PIPE FITTINGS: INLETS, EXITS, & ELBOWS.

GATE VALVE



↳ THREADED:

FULLY OPEN: $K = 0.15$

$K = 0.0525\,(ID)^{-0.47}$

ID FROM 7.6-101 MM

↳ FLANGED, WELDED, GLUED, BELL & SPIGOT:

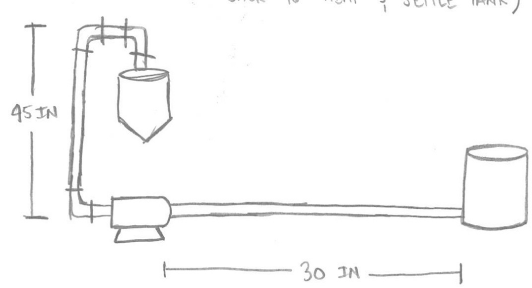
FULLY OPEN: $K = 0.15$

$K = 0.02\,(ID)^{-1.14}$

ID FROM 25-500 MM

$\dot{Q}$ = 1800 L/HR → 475 G/H

▸ SECOND PUMP: (PUMP OIL BACK TO HEAT & SETTLE TANK)



85 IN. TOTAL => 7.083 FT

ΔZ = 45 IN. => 3.75 FT

1.65 PSI

PASCAL TO PSI => 1 PA = 0.000145037738 PSI

$1 \, Pa = 0.671968975 14 \, LB/FT \cdot S$

Reynold's Number Calculation:

$$R_e = \frac{\rho V D}{\mu} \Rightarrow \frac{[57.408 \, \cancel{LB/FT^3}] \cdot [13.123 \, \cancel{FT/S}] \cdot [0.04167 \, \cancel{FT}]}{[0.014185265 \, \cancel{LB/FT \cdot S}]}$$

$$\boxed{R_e = 2{,}213.05} \longrightarrow \text{TRANSITIONAL}$$

$$f = \frac{64}{R_e} \rightarrow \frac{64}{2{,}213.05} \rightarrow 0.0289 \checkmark$$

USING MOODY DIAGRAM WITH: $R_e = 2{,}213.05$, ε/D = SMOOTH $\Big\}$ $0.029 \checkmark$

$$\boxed{f = 0.029}$$

Senior Values

Company Provided Values

1800 L/hr (volumetric flow rate)

common industrial velocity 4m/s

$$D = \sqrt{\frac{4Q}{V\pi}} = \sqrt{\frac{4(0.132\ gal/s)}{13.123\ ft/s\ \pi}}$$

$$1800\ \frac{L}{hr} = 475.2\ \frac{gal}{hr} = 0.132\ \frac{gal}{s}$$

$$\left(\frac{1\ hr}{3600\ s}\right)$$

$1\ ft^3 = 7.48$ gallons

$$V = 4\ m/s = 13.123\ ft/s$$

$$= \sqrt{\frac{4(0.0176\ ft^3/s)}{13.123\ ft/s\ \pi}}$$

$$0.132\ gal\left(\frac{1\ ft^3}{7.48\ gal}\right) = 0.0176\ ft^3$$

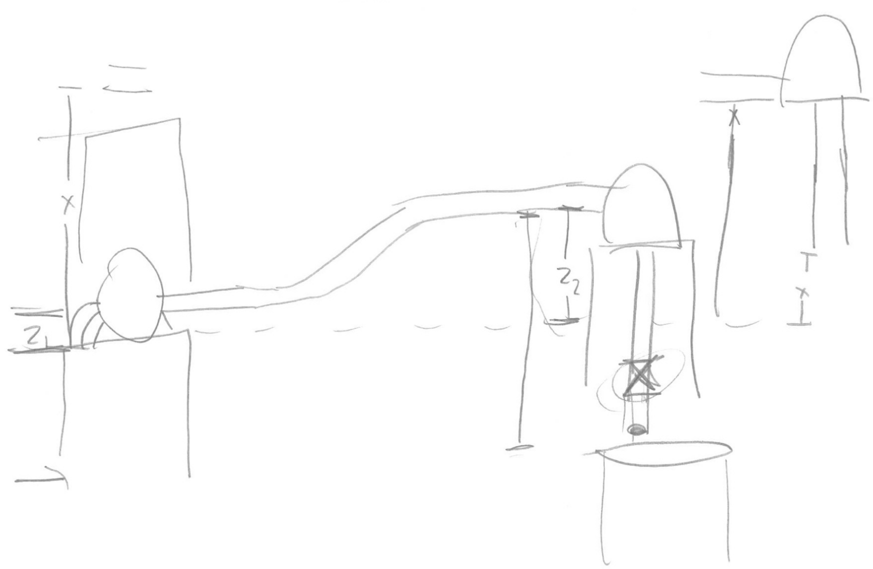
$$0.0413\ ft\left(\frac{12\ in}{1\ ft}\right) = 0.4956$$

Optimal diameter is $\boxed{0.4956 \text{ inches}}$

previous team acquired 0.0157 inches

2.9 Pa·S

$1\ CP = 4.848 \times 10^{-9}\ P_A$



15.3. Experimental Data

Sample A:

Water Test					
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Sample Size (liters)	0.354	0.354	0.354	0.354	0.354
Initial Sample Weight (kg)	1.26	1.22	1.2	1.16	1.29
Heating Time (100 C) (min)	10.58	10.6	10.41	10.52	10.59
Total Heating Time (min)	17.67	17.34	17.25	17.65	17.7
Final Sample Weight (kg)	1.14	1.19	1.13	1.15	1.14

Prototype Test			
	Trial 1	Trial 2	Trial 3
Sample Size (liters)	0.35	0.354	0.345
Initial Sample Weight (kg)	1.26	1.22	1.2
Post Centrifuge (kg)	1.148	1.118	1.145
Post Microfilter (kg)	1.139	1.116	1.14
Post Water Captor (kg)	1.125	1.11	1.12

Debris Test					
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Sample Size (liters)	0.235	0.25	0.235	0.23	0.24
Post Test Filter Weight (kg)	0.01	0.008	0.006	0.011	0.009

Sample B:

Water Test					
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Sample Size (liters)	0.231	0.231	0.473	0.372	0.256
Initial Sample Weight (kg)	1.002	1.002	1.2	1.054	1.01
Heating Time (100 C) (min)	10.95	10.95	10.35	10.1	9.56
Total Heating Time (min)	21.9	20	20.7	20.2	19.12
Final Sample Weight (kg)	1.001	1.001	1.19	1.038	1.003

Debris Testing						
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
Sample Size (liters)	0.25	0.25	0.5	0.3	0.3	0.32
Filter Weight (kg)	0.005	0.004	0.008	0.006	0.005	0.0056

Prototype Test			
	Trial 1	Trial 2	Trial 3
Sample Size (liters)	0.71	0.7	0.71
Initial Sample Weight	1.62	1.65	1.64
Final Sample Weight	1.48	1.52	1.46

Sample C:

Water Test					
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Sample Size (liters)	0.354	0.354	0.354	0.354	0.354
Initial Sample Weight (kg)	1.159	1.149	1.155	1.138	1.16
Heating Time (100 C) (min)	13.5	13	13.24	13.94	13.52
Total Heating Time (min)	23	21.42	22.56	21.15	23.14
Final Sample Weight (kg)	1.14	1.139	1.145	1.133	1.148

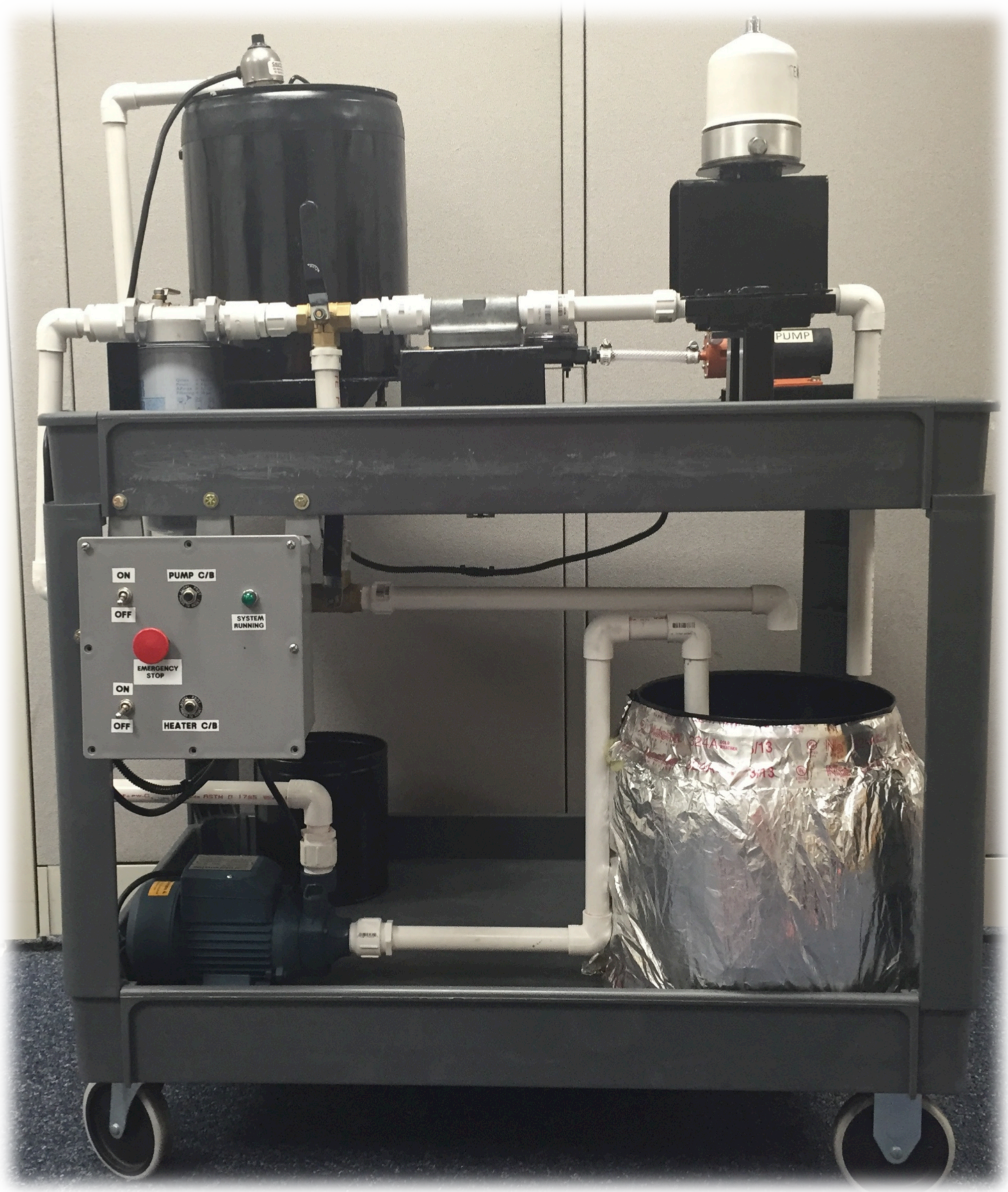
Debris Test						
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	
Sample Size (liters)	0.235	0.235	0.235	0.23	0.24	
Post Test Filter Weight (kg)	0.16	0.2	0.14	0.11	0.09	

15.4. User Manual (English Version)

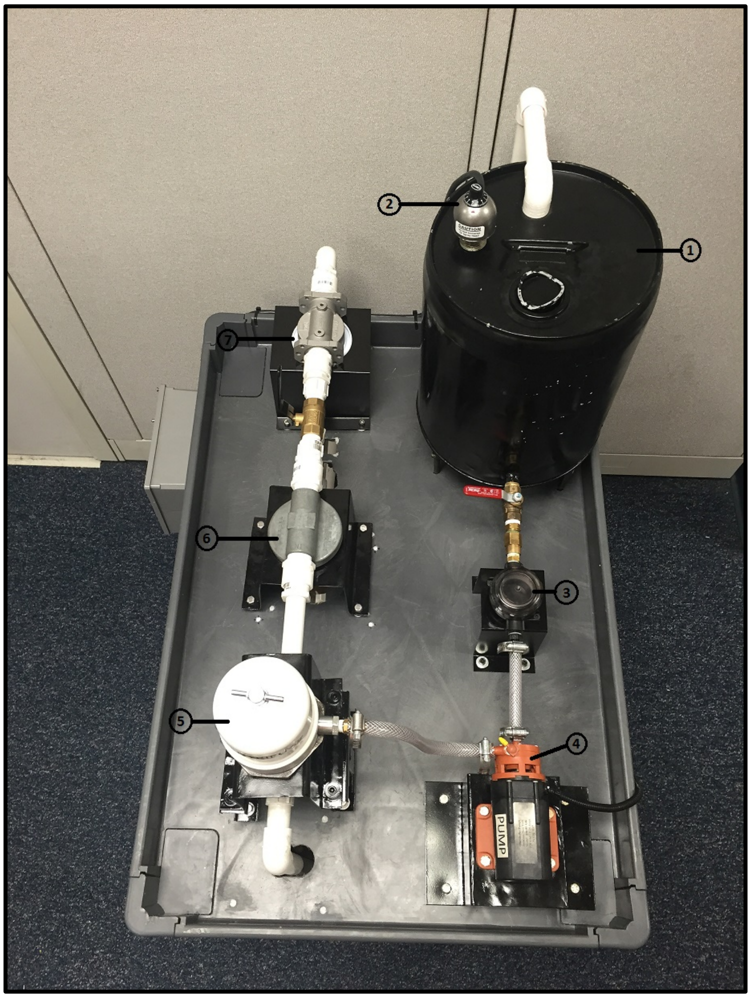
This user manual has been included within the prototype, in English and Spanish, with this the user should be able to properly run the system, as well as identify any problems.

USER MANUAL

BIODIESEL PRE-TREATMENT SYSTEM



Components:



1. Heat and Settle Tank (Initial Storage Tank)
2. Heater
3. Primary Filter
4. Pump #1
5. Centrifuge
6. Membrane Filter
7. Water Absorption Filter

Testing Instructions:

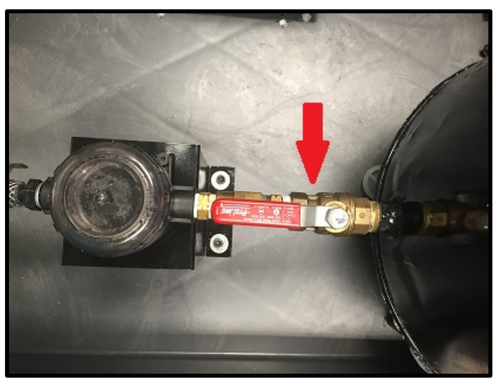
1. Make sure all three valves on heat and settle tank are closed prior to pouring in the Waste Vegetable Oil (WVO).

2. Slowly pour the WVO into the inlet on the top of the tank, this ensures that the oil goes through the initial filter, which is placed within the tank itself.

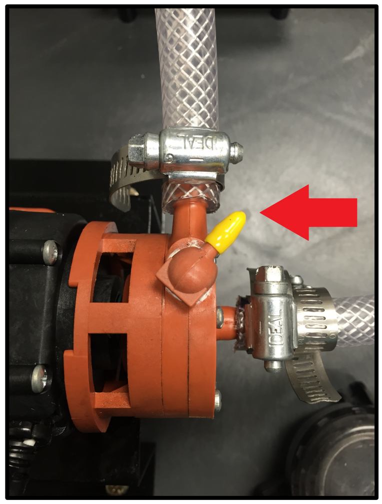
3. Turn the switch for the heater to the ON position and select the appropriate temperature setting. Do not select a setting greater than “8” to prevent damaging the heater.

4. Once the heating period has ended turn the switch for the heater to the OFF position.

5. Once the settling period has ended, open the valve leading to the primary safety filter, leave valve open until instructed to close.



6. Remove the small yellow cap from the pump's priming outlet; ensure that a steady stream of oil exits the pump prior to continuing. Once this is done, slide the cap back onto the pump.



7. Using the classification "menu" provided, close and/or open the 3 three-way valves within the system accordingly. (Refer to Classification Menu)

8. Turn the switch for pump #1 to the ON position.

9. Once the level of oil within the tank is just above the outlet, close the valve leading to the primary filter, and immediately after turn the pump OFF.

10. Open the valve on the bottom of the heat and settle tank in order to allow the debris and water contaminated oil to exit onto the debris tank. Close once tank is empty.

11. If further cycles are required turn Pump #2 to the ON position and allow the oil to be pumped back into the heat and settle tank. Repeat the above steps for any subsequent cycles.

Pump Priming Instructions:

Pump #1:

This is the pump above the cart; in order to properly prime this pump, open the valve leading to the primary filter and allow the fluid to enter the piping system. If the tank is filled above the valve then gravity should be enough to push the oil into the system. Once the oil has reached the pump inlet, remove the yellow vent cap. At this point a steam of oil should exit from the air vent fitting. If the stream isn't steady turn the pump ON, while leaving the air vent open. It is suggested to have a container readily available in order to capture the oil; this ensures the oil does not splash everywhere. Once a steady stream is achieved, place the cap back on the air vent. The pump has now been successfully primed.

Pump #2:

This is the pump that is on the bottom portion of the cart. In order to prime this pump use a flat head screwdriver to unscrew the screw on the top portion of the pump. Once the screw is open pour some clean oil until pump has been filled. Screw the bolt back in. The pump has now been successfully primed.

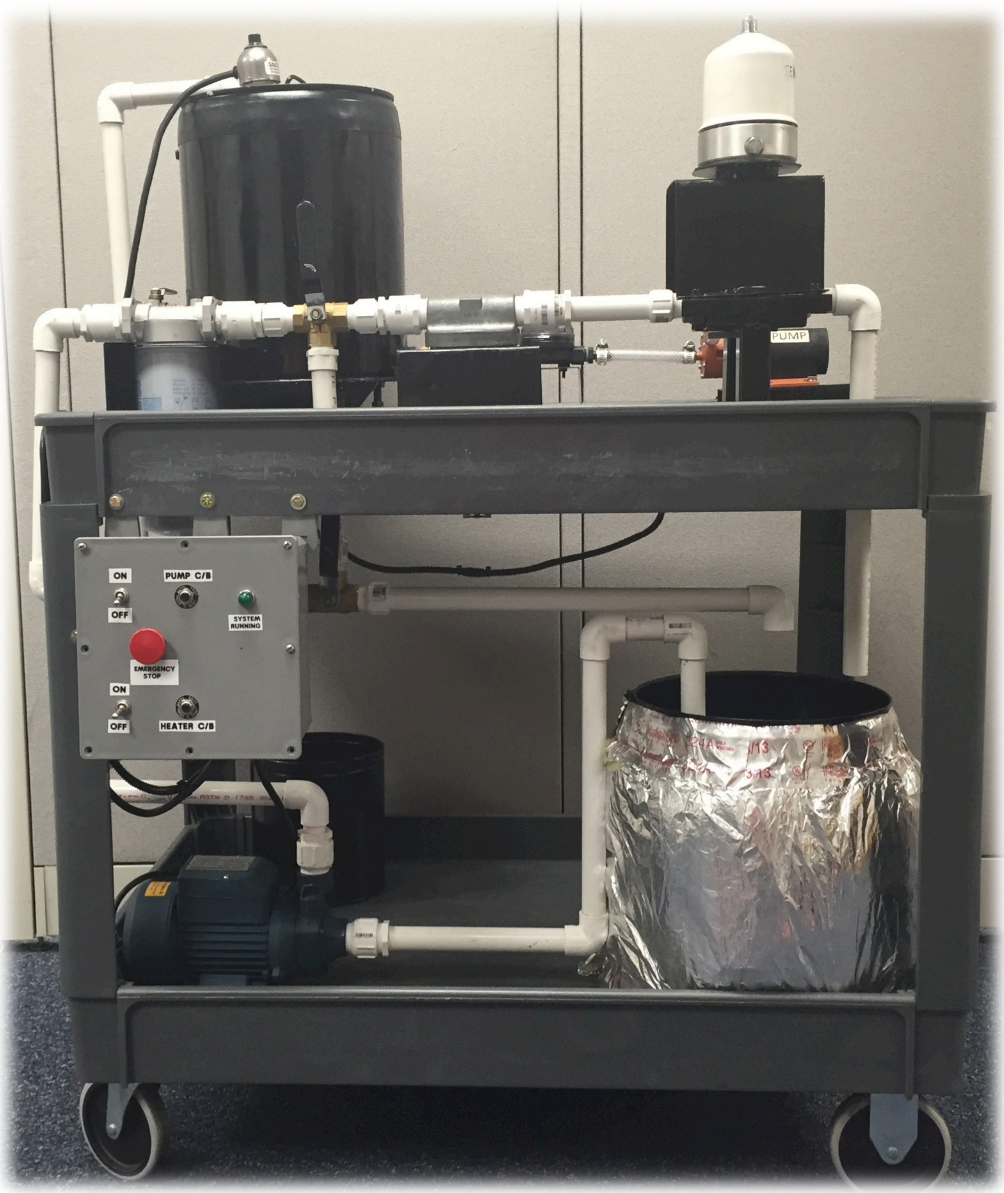
Safety Instructions:

1. Avoid removing the insulation from any of the tanks, especially if the system has been recently used.
2. If the system has not been utilized in a while, make certain that the bottom pump is properly primed. Refer to priming section.
3. Prior to connecting the system to an electrical outlet, be certain that all switches are in the off position.

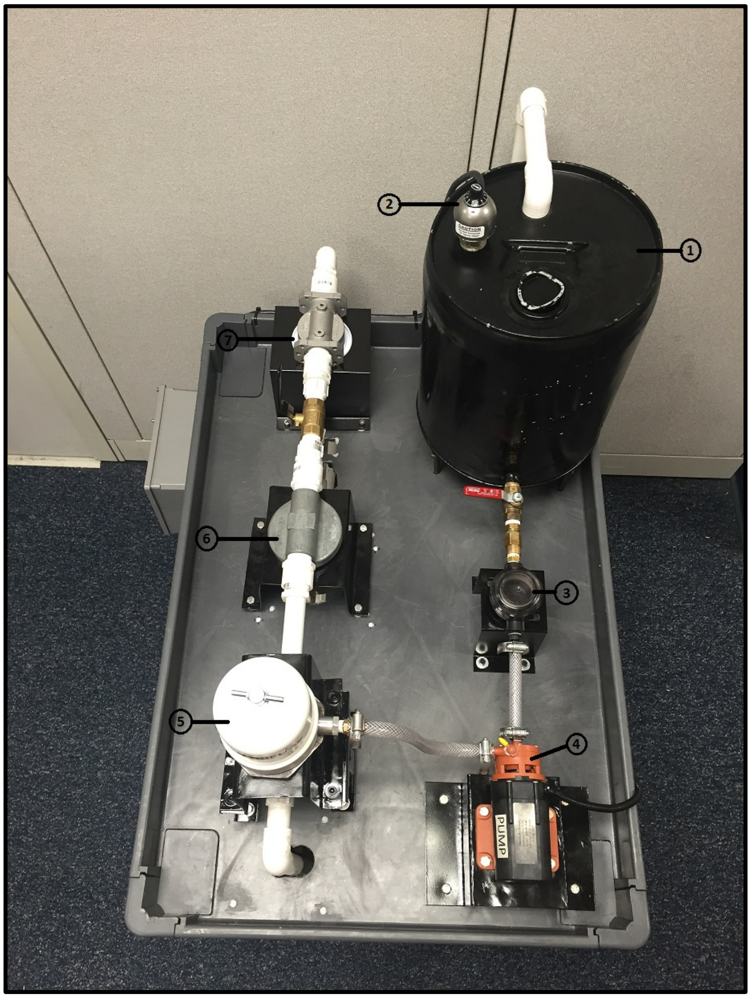
15.5. User Manual (Spanish Version)

MANUAL DE USUARIO

SISTEMA DE PRE-TRATAMIENTO PARA BIODIESEL



Componentes:



8. Tanque de calor y estacionamiento (Tanque de almacenamiento inicial)

9. Calentador

3. Filtro primario

4. Bomba # 1

5. Centrifugadora

6. Filtro de membrana

7. Filtro de absorción de agua

Instrucciones de Prueba:

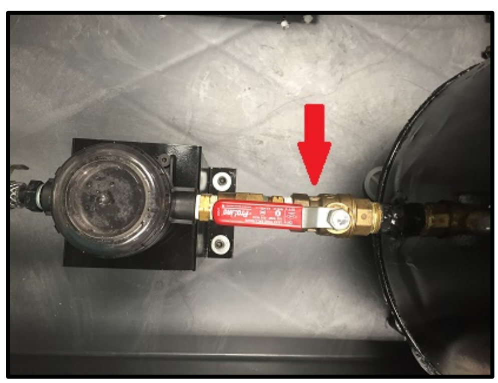
1. Asegúrese de que las tres válvulas localizadas en el primer tanque esten cerradas antes de derramar el Aceite Vegetal Usado (AVU).

2. Derrame lentamente el AVU en la entrada en la parte superior del tanque, esto asegura que el aceite pasa a través del filtro inicial, cual esta localizado dentro del propio tanque.

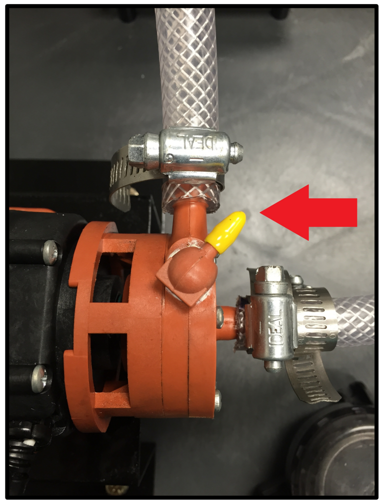
3. Gire el interruptor del calentador hacia posición ON y seleccione el ajuste de temperatura apropiado. No seleccione un ajuste superior a "8" para evitar daños en el calentador.

4. Una vez que el periodo de calentamiento ha terminado gire el interruptor para el calentador hacia posición OFF.

5. Una vez que el período de asentamiento ha terminado, abra la válvula dirijida al filtro principal de seguridad, deje la válvula abierta hasta que sea instruido para cerrarla.



6. Retire la pequeña tapa amarilla de la bomba; asegurar que un flujo constante de aceite sale de la bomba antes de continuar. Una vez hecho esto, deslice la tapa en la bomba denuevo.



7. Utilizando el "menú" de clasificación prevista, cerrar y / o abrir las 3 válvulas de tres vías en el sistema en consecuencia. (Consulte el menú de Clasificación).

8. Gire el interruptor de la bomba # 1 en la posición ON.

9. Una vez que el nivel de aceite en el tanque está justo por encima de la salida, cierre la válvula hacia el filtro principal, e inmediatamente después apague la bomba.

10. Abra la válvula de la parte de abajo de el tanque , esto permite que los escombros y el agua escapen el tanque. Cerrar una vez que el tanque está vacío.

11. Si se necesitan más ciclos de la bomba gire el interruptor de la bomba # 2 en la posición ON, esto permite que el aceite se bombee de nuevo por el sistema. Repita los pasos anteriores para cualquier ciclos posteriores.

Instrucciones para preparer las bombas:

Bomba #1:

Esta es la bomba por encima del carro; con el fin de preparer esta bomba correctamente, abra la válvula principal del filtro principal, y permite que el fluido entre en el sistema de tuberías. Si el tanque se llena por encima de la válvula entonces la gravedad debería ser suficiente para empujar el aceite en el sistema. Una vez que el aceite ha llegado a la entrada de la bomba, retire la tapa de ventilación de color amarillo. En este punto, una corriente de aceite debe salir de la salida de aire apropiado. Si la corriente no es constante enciende la bomba, dejando que el aire de ventilación escape el sistema.. Una vez que se logra un flujo constante, coloque la tapa en la rejilla de ventilación de aire. La bomba ha sido preparada con éxito.

Bomba #2:

Esta es la bomba que está en la parte de abajo de el carro. Para preparar la bomba utilice un destornillador de cabeza plana para aflojar el tornillo de la parte superior de la bomba. Una vez que el tornillo está abierto derrame un poco de aceite limpio hasta que la bomba se ha llenado. Atornille el tornillo de nuevo. La bomba se ha preparado con éxito.

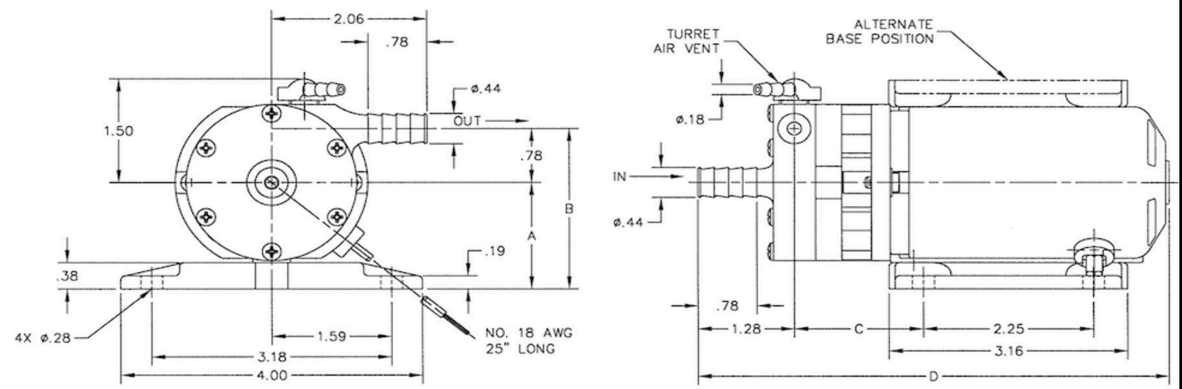
Instrucciones de seguridad:

4. Evitar quitar el aislamiento de cualquiera de los tanques, especialmente si el sistema ha sido utilizado recientemente.

5. Si el sistema no se ha utilizado desde hace tiempo, asegurarse de que la bomba inferior este preparada correctamente. Consulte la sección de preparacion de las bombas.

6. Antes de conectar el sistema a una toma de corriente, asegúrese de que todos los interruptores están en la posición OFF.

15.6. Copies of Used Commercial Machine Element Catalogs



PUMP	DIMENSIONS A	B	C	D
144–01A44	1.54	2.32	1.71	6.25
144–01A46	1.67	2.45	2.74	7.16
144–01A47	1.67	2.45	2.74	7.16
144–01A91	1.67	2.45	2.74	7.16

Figure 65: Pump Dimensions

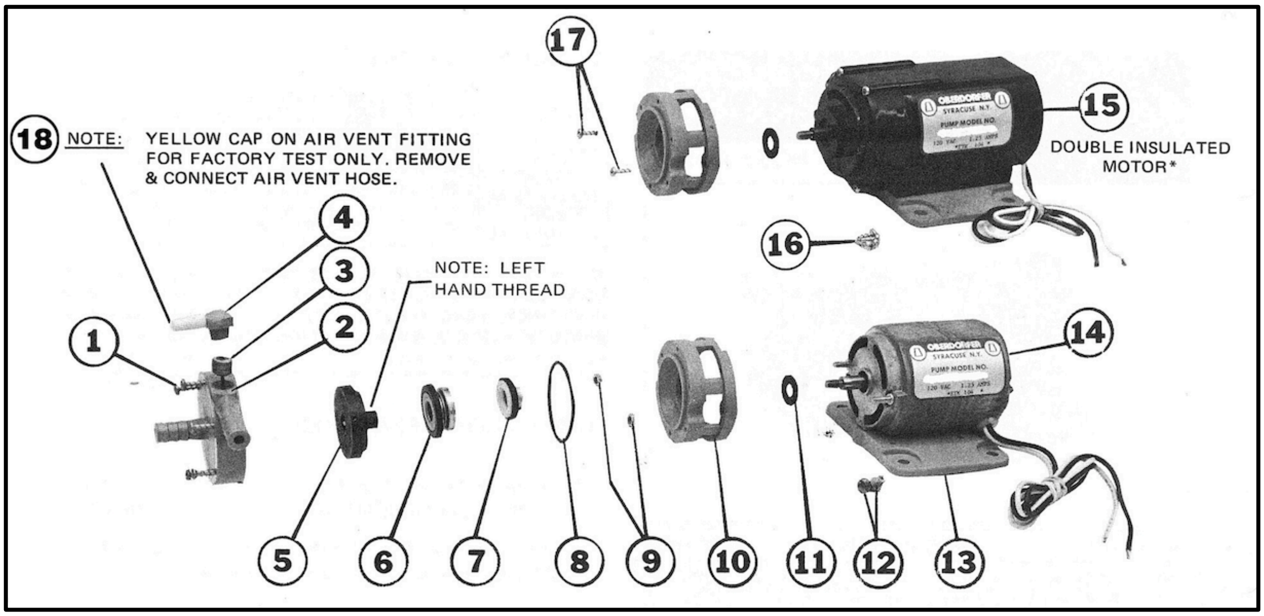


Figure 66: Pump Exploded View

PLASTIC CENTRIFUGAL PUMP

PIPE SIZE: 3/8 HOSE CONNECTION IN
3/8 HOSE CONNECTION OUT
1/8 AIR VENT HOSE CONNECTION

MODEL 144-01A46 SHOWN

PUMP & MOTOR FEATURES

- Chemical resistant construction
  - Body and Adapter made of non-metallic glass reinforced Nylon 6/6
  - Impeller made of non-metallic glass reinforced PPS
- Mechanical Seal - carbon / ceramic faces, silicone rubber elastomer
  - Tolerates intermittent dry running
- Barbed -Hose Connections
- Static Buna O-Ring body/adapter seal
- Integrated Air Vent - prevents loss of prime
- Compact and Lightweight
- Installation/Mounting Versatility - port orientation
- Universal - Open Drip Proof Motors with internal fan cooling, UL listed
  - No 18 Wire leads - 25" long
  - Low amperage
  - 120VAC, 240VAC (Optional: double insulation) and 12VDC versions.

GENERAL

These compact high speed centrifugal pumps are suited for a variety of applications including condensate removal. They are particularly well suited for handling soap solutions in extraction type carpet cleaning equipment.

The design's symmetry provides a wide range of configuration possibilities allowing ready customization of discharge port position and optional air vent orientation relative to the motor base. (see below)

INSTALLATION

Maximum fluid temperature is 180° F (82.2° C). Fluids must be compatible with silicone rubber seal elastomer. To promote long product life, assure that ambient air can circulate around the unit to prevent over-heating.

Ground metal frame motors. There is a #6-32 tapped hole ground connection provided on the end of metal framed motors.

Prevent air trapping in plumbing lines by avoiding loops. Use air vent fitting connection to purge air. Though capable of pulling slight vacuum, the pump performs best under flooded suction conditions when located for gravity feed.

AC Motors (10,000 RPM)

							Optimum Efficiency Range				
HEAD	PSI		0	5	10	15	20	25	30	35	40
	FT.HD.		0	11.5	23	34.6	46.2	57.7	69.3	80.8	92.4
FLOW	GPM	Plugged Vent	2.2	2.1	1.9	1.7	1.4	1.1	0.7	0.4	0.1
	GPM	With Bypass thru Vent	2.0	2.0	1.7	1.5	1.2	1.0	0.6	0.2	-
CURRENT	AMPS	@ 120V	1.35	1.34	1.33	1.31	1.29	1.26	1.23	1.20	1.18
	AMPS	@ 240V	0.70	0.69	0.68	0.67	0.65	0.64	0.62	0.58	0.59

12 VDC Motor (7,000 RPM)

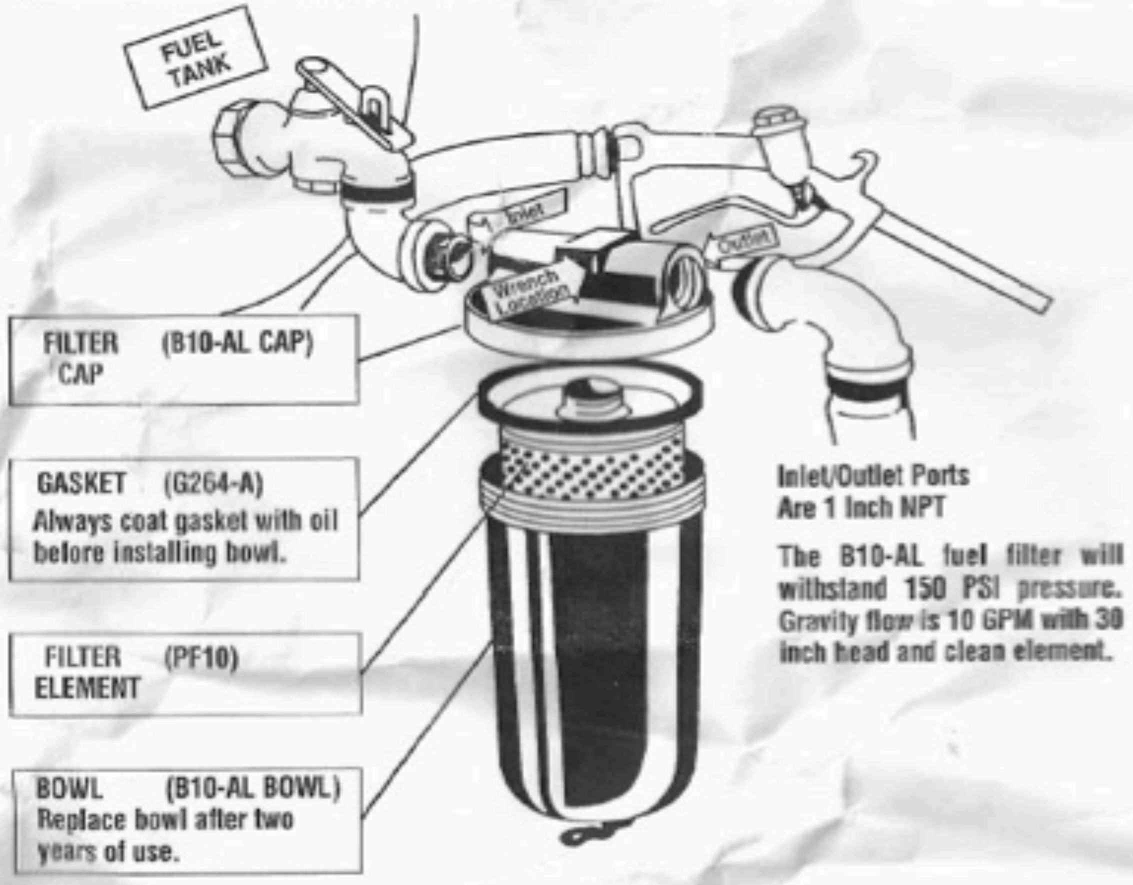
HEAD	PSI		0	5	10	15	20
	FT.HD.		0	11.5	23	34.6	46.2
FLOW	GPM	Plugged Vent	1.9	1.7	1.4	1.1	0.5
CURRENT	AMPS	@ 12V	1.35	1.34	1.33	1.31	1.29

www.oberdorfer-pumps.com PHONE (800) 448-1668; (315) 437-0361 FAX (315) 463-9561

Figure 67: Pump Specs

B10-AL FUEL TANK FILTER

IMPORTANT: Always mount shut-off valve between filter and tank.
Close shut-off valve when not delivering fuel.



INSTALLATION INSTRUCTIONS
(See other side for service instructions)

1. Remove bowl and element from cap.
2. Attach filter cap to storage tank valve on opening marked "IN." (Be sure shut-off valve is between filter and tank.)
3. Attach discharge hose and nozzle to filter opening marked "OUT."
4. Tighten filter cap with wrench at flat surface of cap. (See illustration.) <u>NEVER USE BOWL AS A LEVER</u> for tightening or removing cap.
5. Replace element. Coat gasket with oil and replace bowl.
6. Close bowl drain valve. Open storage tank valve.

Figure 68: Membrane Filter Installation Instructions

TO DRAIN WATER FROM FILTER

1. Close storage tank valve.
2. Open filter bowl drain valve.
3. Open discharge hose nozzle.

CHANGE ELEMENT WHEN FLOW IS RESTRICTED

1. Close storage tank valve.
2. Drain filter bowl.
3. Unscrew filter bowl and element.
4. Wipe filter bowl and cap clean.
5. Install new element.
6. Coat new bowl gasket with oil and install in bowl groove.
7. Replace bowl. Hand tighten only.
8. Close bowl drain valve. Open storage tank valve.

NOTE: This filter is rated for 150 PSI pressure. If the fuel system is prone to violent pressure surges (water hammers, etc.), a pressure cushion device should be installed. A vertical capped pipe installed in the line near the filter (so that it traps a pocket of air) will serve this function. This is not necessary unless pressure surges above 150 PSI occur.

BALDWIN FILTERS® BALDWIN
a CLARCOR company

4400 East Highway 30 • P.O. Box 6010
Kearney, Nebraska 68848-6010
Phone: (308) 234-1951 • Toll Free: (800) 822-5394
Fax: (800) 828-4453 • Int'l Fax: (308) 237-9769
Internet: www.baldwinfilter.com

200140 (R 11/02) Printed in U.S.A.

Figure 69: Membrane Filter Removal Instructions

USE AND MAINTENANCE INSTRUCTIONS

PK.CPM SERIES PERIPHERAL ELECTRIC PUMPS
JSW SERIES SELE-PRIMING ELECTRIC PUMPS

Carefully follow the instructions below to obtain the best performance and a long service life from your pump. Contact your local agent or **Technical Office** if you have any problem.

OPERATING CONDITIONS: These pumps have been designed to pump neutral clean liquids in which no abrasive solids are suspended at temperatures of no more than 80°C (60°C for electric pumps with plastic impellers or diffusers).

INSTALLATION: The pumps must be installed in a dry well-ventilated place with an ambient temperature of no more than 40°C (Fig. A).Fix the pump in place on a solid flat surface using suitable bolts to avoid vibration. The pump must be installed in a horizontal position to ensl: that the bearings operate corretly. The diameter of the intake pipe must not be smaller than that of the intake month. If the intake height exceeds 4 mtres,use a pipe witha latger diameter. The diameter of thedelivery pipe must be chosen to suit the flowrate and pressure required at the takeoff points.The intake pipe must be slightly- angled up towards the intake mouth to avoid the formation of air locks (Fig. B). Make sure that the intake pipe is completely airtight and immersed in the water by at least half a metre to avoid the formation of vortexes. Always fit a foot valve at the end of the intake pipe. It is advisable to fit a non-return valve between the delivery mouth and flow rate adjustment gate valve to avoid dangerous water hammering in the event of the pump suddenly stopping. This measure is compulsory if the delivery water column is over 20 metres.

The pipes mustalways be fitted using the related brackets(Fig.C)to avoid transmitting stress to the pump body. Take care not to damage any part by overtightening the pipes when fitting them.

ELECTRICAL CONNECTIONS: The installer is responsible for making the electrical connections to the mains supply in compliance with the relevant gulations in force;

- note that Italian and international regulations demand that fixed installations incorporate a device ensuring omnipolar disconnection from the mains supply;
- make sure that the specifications on the pump rating plate and the rated line values are the same(Fig.D);
- connect the pump to an effective earth circuit and then connect up the phases following the diagram on the terminal block cover rating plate;
- our single-phase motors are protected against overloads using a thermal device (overload cutout)fitted in the winding. Users are responsible for fitting a suitable protaction device for three-phase motors;
- check that three-phase pumps rotate clockwise when looking at the pump from the motor fan side, swapping over two of the phase connections if they do not (Fig. E).

PRIMING: Fill the pump completely with clean water before switching it on. The water should be poured in through the priming plug (Fig. F). When you have compteted the operation, screw the plug back in again and start the pump. The pump should be primed again whenever it has not been used for a long period of time or when air has made its way into the system.-

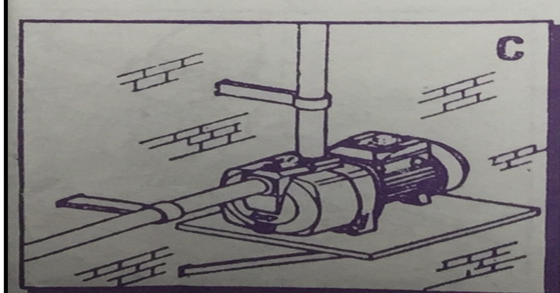
IMPORTANT: Never run the pump empty. If this happens by mistake, switch the pump off, wait for it to cool down and then prime it using clean water.

MAINTENANCE: Our pumps do not require any maintenance provided one takes the following precautions: When thereis a risk of freezing,empty the pump through the drain plug on the bottom of the pump boby, making sure you prime it when subsequently starting it again; check that the foot valve is clean at regular intervals:if the pump is to remain unused for a long period of time (e.g. in the Winter) (Fig. G). it is advisable to empty it compiotoly,rinse it withclcan water and storoe it in a dry placo;if the shaft does not tutn freely, roloaso it uoing a screwdriver inserting it in the special slot (Fig. H);if this is not sufficient to solve the problem,remove the pump body, undoing the relevant mounting bolts, and clean it thoroughly to remove any encrustation.

Never carry out any work on the pump without having first disconnected it from the mains supply.

PROBLEM	CAUSE	SOLUTION
Motor won't start	• No power • Impeller stuck	• Check connections and voltage values • See section on maintenance
Motor turns without pumping water	• Clogged filter • Excessive intake height • Air in intake	• Clean filter • Move pump closer to water outlet level • Check intake pipe is airtight • Make sure foot valve is immersed by at least 50 cm • Pump needs to be primed again.
Flow rate insufficient	• Intake height at limit • Filter partially clogged • Impeller blocked	• Check intake height • Clean foot valve and,if necessary, whole intake pipe • Disassemble pump and carefully clean pump body and impeller
Tripped motor overtoad cutout	• Overheater motor • Impeller stuck	• Check voltage and ventilation • Release impeller (see section on maintenance)

Failure to take the above precautions could damage your pump and invalidate the guarantee.



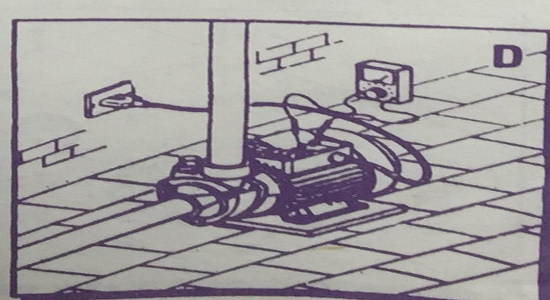


Figure 70: Second Pump Use and Maintenance Instructions

15.7. Receipts and Documentation

More saving.
More doing.

FLAGLER HOME DEPOT STORE #786-388-9108

6343 00057 61218 10/21/14 01:01 PM
CASHIER SELF CHECK OUT - SCOT57

611942038183 1 PVC BUSH <A>
1"X3/4" PVC BUSHING SPGXS
3@0.81 2.43
611942038350 1" M ADAPTER <A>
1" PVC MALE ADAPTER SXMPT
4@0.68 2.72
611942038923 3/4 TEE SSS <A> 0.48
3/4" PVC TEE SXSXS
032888110359 1/2FPBVSWT <A> 8.86
1/2" FP BALL VALVE SWT 600PSI LF

SUBTOTAL 14.49
SALES TAX 1.02
TOTAL $15.51
[redacted] 15.51
AUTH CODE 330568

6343 57 61218 10/21/2014 9983

More saving.
More doing.

FLAGLER HOME DEPOT STORE #786-388-9108

6343 00058 85207 10/21/14 01:00 PM
CASHIER SELF CHECK OUT - SCOT58

078864177329 PTFE TAPE <A> 1.47
1/2"X520" PTFE THRD SEAL TAPE
611942135127 10PK PVC EL <A> 2.68
3/4" PVC EL 90D SXS 10 PACK
051135052204 ADHE 5200302 <A> 8.97
3M 5200 FAST CURE MARINE SEALANT 3OZ

SUBTOTAL 13.12
SALES TAX 0.92
TOTAL $14.04
[redacted] 14.04
AUTH CODE 731594

6343 58 85207 10/21/2014 7609

RETURN POLICY DEFINITIONS

More saving.
More doing.

12700 SW [illegible] ST [illegible]
MIAMI, FL [illegible]

0210 [illegible] 10/13/14 [illegible] PM
CASHIER SELF CHECK OUT - [illegible]

611942066612 PVC40 PEPIPE <A> 2.50
3/4" X 10' PVC40 PE PIPE
098268038477 10' BR VINYL <A> 7.99
5/8ODX3/8IDX10' BR VINYL TUBE
042805445983 ADAPTER <A> 2.80
3/8X1/4 BRASS ADAPTER BARB X MIP LF
611942038183 1 PVC BUSH <A>
1"X3/4" PVC BUSHING SPGXS
2@0.81 1.62
012871626050 1" M ADAPTER <A>
1" PVC MALE ADAPTER SXMPT
2@0.68 1.36
611942[illegible] 3/4 PVC EL-45 <A> 0.90
3/4" PVC EL 45D SXS
611942038633 3/4 PVC 90EL <A> 0.48
3/4" PVC EL 90D SXS
611942038343 3/4 M ADAPTR <A> 0.48
3/4" PVC MALE ADAPTER SXMPT
000-858-260 PVC ELBOW <A> 1.[illegible]
3/4" PVC-LOCK ELBOW

SUBTOTAL 19.72
SALES TAX 1.39
TOTAL $21.11
CASH 10.00
CASH 5.00
[redacted] 6.11
AUTH CODE [illegible]
TA

0210 [illegible] 10/13/2014 3677

More saving.
More doing.

FLAGLER HOME DEPOT STORE #786-388-9108

6343 00056 74023 10/21/14 09:39 PM
CASHIER SELF CHECK OUT - SCOT56

012871626036 3/4 M ADAPTR <A> 0.48
3/4" PVC MALE ADAPTER SXMPT
611942066612 PVC40 PEPIPE <A> 2.58
3/4" X 10' PVC40 PE PIPE
887480164381 1/4GR8HXNTZN <A>
HEX NUT GR-8 1/4 ZINC
4@0.60 2.40
887480070781 1/4 LCK WSHR <A>
1/4 LOCK WASHER ZINC
2@0.80 1.60

SUBTOTAL 7.06
SALES TAX 0.49
TOTAL $7.55
[redacted] 7.55
AUTH CODE 930224

Save money. Live better.

(305) 470 - 4510
MANAGER KEVIN PERRY
8651 NW 13TH TER
DORAL FL 33126
ST# 2091 OP# 00007167 TE# 17 TR# 06781
MARKET SCALE 692222710138 14.97 X
SUBTOTAL 14.97
TAX 1 7.000 % 1.05
TOTAL 16.02
VISA TEND 16.02

ACCOUNT # [redacted] S
APPROVAL # 04263B
REF # 431900625966
TRANS ID - 0684319163010619
VALIDATION - 652P
PAYMENT SERVICE - E
TERMINAL # 168061800

11/14/14 23:31:38

CHANGE DUE 0.00

ITEMS SOLD 1

More saving. More doing.

FLAGLER HOME DEPOT STORE #786-388-9108

6343 00012 69190 10/31/14 02:26 PM
CASHIER ALVARO - AXC5162

012871626036 3/4 M ADAPTR <A>
3/4" PVC MALE ADAPTER SXMPT
3@0.48 1.44
020066187569 2X MDWGRN <A> 3.87
PAINTERS TOUCH 2X MEADOW GREEN

SUBTOTAL 5.31
SALES TAX 0.38
TOTAL $5.69
[redacted] 5.69
AUTH CODE 560077

Share Your Opinion With Us! Complete
... store visit

FLAGLER HOME DEPOT STORE #786-388-9108

6343 00057 24141 11/08/14 02:47 PM
CASHIER SELF CHECK OUT - SCOT57

045686045426 HS RNG 16 <A>
HS RING TERMINAL, 16-22, STD 8-10, 5 4.28
098268038675 PRECUT VNYL <A> 6.67
3/40DX1/2IDX10' VINYL TUBE

SUBTOTAL 10.95
SALES TAX 0.77
TOTAL $11.72
CASH 10.00
CASH 1.00

More saving. More doing.

FLAGLER HOME DEPOT STORE #786-388-9108

6343 00012 69182 10/31/14 02:25 PM
CASHIER ALVARO - AXC5162

887480022643 WASHERS <A> 2.70
1/4" CUT WASHERS HDG - 25 PC
887480022247 HEX NUTS <A> 3.15
1/4" HEX NUTS HDG-25 PC
887480150433 SPACER NYLON <A>
SPACERS NYLON 1X1/2
4@0.40 1.60
BAH HEX BOLT <A>
1/4-20"X1-1/2" HEX BOLT S/S(BAH)
4@0.47 1.88
BKE HEX BOLT <A>
1/4-20"X2-1/2" HEX BOLT S/S (BKE)
4@0.67 2.68

SUBTOTAL 12.01
SALES TAX 0.84
TOTAL $12.85
[redacted] 12.85
AUTH CODE 230428

More saving. More doing.

FLAGLER HOME DEPOT STORE #786-388-9108

6343 00023 22428 11/10/14 02:35 PM
CASHIER KEVIN - KXI6832

098268038682 10' VINYL <A> 16.64
10DX3/4IDX10' VINYL TUBE
077578052168 W HTR JACKET <A> 19.97
WATER HEATER JACKET-R3.5
0000-320-285 12 STR WH FT <A>
12 STRANDED THHN WHITE - 1 FT
2@0.39 0.78
032076890148 SWITCH <A> 5.69
20/10A ON/OFF SP RPLCMT TGGL SWITCH

SUBTOTAL 43.08
SALES TAX 3.01
TOTAL $46.09
[redacted] 46.09
AUTH CODE 010508/5235134 TA

Invoice

Page: 2 of 2

C & R Metals, Inc.
2991 N.W. North River Drive
Miami, FL. 33142

C&R METALS INC.
2991 N.W. NORTH RIVER DRIVE
MIAMI, FL 33142
(305) 634-2111 P
(305) 634-9067 F
WWW.CRMETALS.NET
M-F 7:30AM- 5PM SAT 8AM-1PM

Ticket #: T-7854
Ticket date: 10/20/14
Station: ST2

Sold to:
[redacted]

Ship to:

Customer #: C-1002317
Sls rep: JOSE
Ship date:
Location: LOC1
Ship-via code:
Terms:

Item #	Description	Quantity	Price	Selling unit	Ext prc
STS24GA	STEEL SHEET 24ga X 4' X 10'	5.33		FEET	8.10
CUT-STEEL500	CUT	1.00	5.00	EACH	5.00

User: JOSE
Total line items: 2
Sale subtotal: 13.10
Tax: 0.92
Total: 14.02

Tender:
Visa 14.02
Net tender: 14.02

CUSTOMER SIGNATURE

Shipping Document

PIUSI

PIUSI USA Inc.
5553 Anglers Avenue Suite 104 - FORT LAUDERDALE, FL 33312 USA
Telephone 954 584 1552 - Fax. 954 584 1554
e-mail: piusiusa@piusiusa.com
www.piusiusa.com

S.D. DATE	S.D. NUMBER
09/30/2014	3002852

CUSTOMER **COD: 3000524**
SOLARES FLORIDA CORP
P.O. BOX 520458
MIAMI, FL FL 33152
USA

DELIVERY ADDRESS **COD: 3000524**
SOLARES FLORIDA CORP
P.O. BOX 520458
MIAMI, FL FL 33152
USA

FROM STORAGE LOCATION 3011
PIUSI USA INC.
5553 ANGLERS AVENUE SUITE 104 33312
FORT LAUDERDALE FL - USA

REASON OF SHIPPING	OUR REFERENCE	CARRIAGE
Sale	80185385	EXW Ex Works FORT LAUDERDALE

NOTES

Item Code	Description	UM	Qty
	Customer's PO no./item 606401		
F00611A00	*WATER CAPTOR FILTER 70L\MIN \ 2 CART*	*PC*	*1*
	SHIPLABEL, SHIPPING LABEL, PC 1		

SHIPPED BY	OUTWARD GOODS APPEARANCE	N. OF	GROSS WEIGHT	DATE/TIME	DRIVER SIGNATURE
By Truck	See details above	00001	2.175		

1st FORWARDER - AGENT / ADDRESS	DATE / TIME	MOTOR VEHICLE N. PLATE	FORWARDER SIGNATURE
UPS PO BOX 650580 - 75265-0580 DALLAS TX Tel. 8008111648 - Fax Vat N.			

2nd FORWARDER - AGENT / ADDRESS	DATE / TIME	MOTOR VEHICLE N. PLATE	FORWARDER SIGNATURE
			CONSIGNEE SIGNATURE

RECEIVER COPY