Waste Cooking Oil to Biodiesel Automated Fuel Pump Project

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ABSTRACT

Biodiesel has potential to reduce our dependence on petroleum, but is not widely used due to its high cost. Traditionally, biodiesel comes from virgin vegetable oil, but it is possible to convert waste cooking oil into biodiesel. Using waste cooking oil offsets the need for virgin crops and recycles what would be discarded. Applying the results of past senior design projects on the chemical reaction and separation process; we will package the entire system into an automated, usable prototype. Our focus is on producing a safe, clean, easy to operate system, and estimating its cost of mass production and distribution.

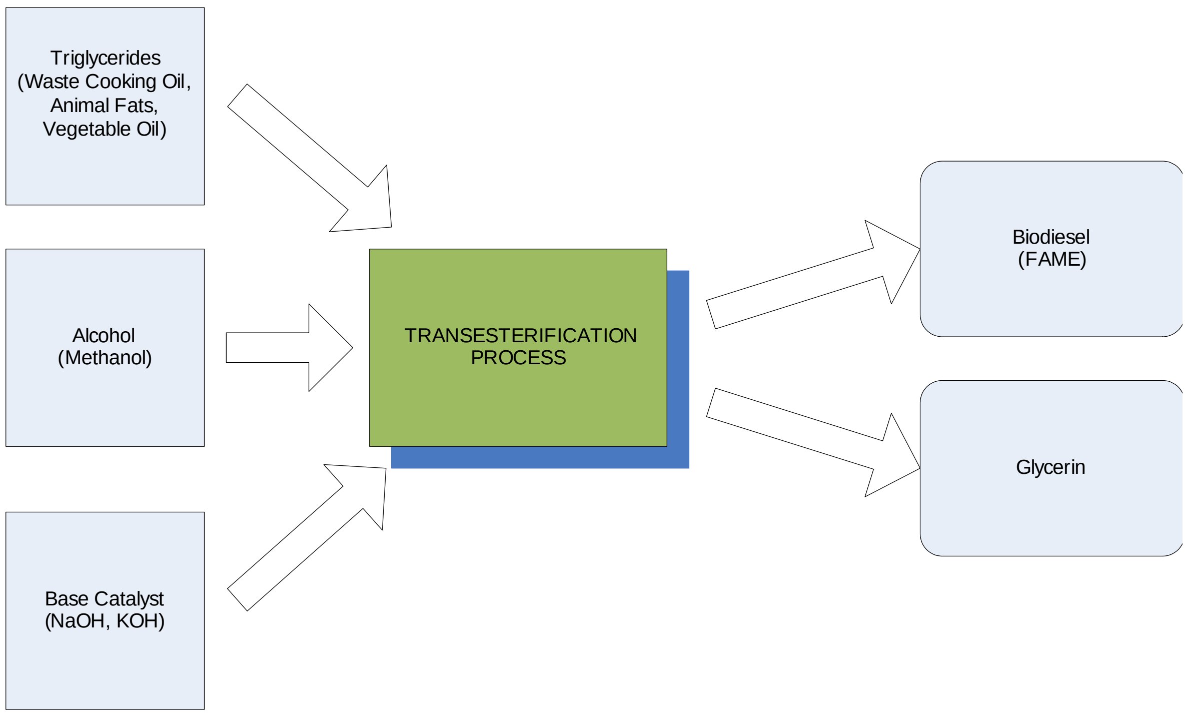
INTRODUCTION

The U.S. Department of Energy estimates that biodiesel accounts for approximately 0.07% of the nation's total diesel consumption [1]; this hampered commercial viability arises primarily from the fuel's high cost at $2-3/gallon [2]. Factors contributing most to this price include feedstock and production costs [2]. Current U.S. biodiesel production uses primarily soybean oil, a feedstock about twice as expensive as the cleanest grease, "yellow grease" [3]. Contaminated waste grease, like that produced by restaurants, is essentially free but obviously requires purification before fuel production [4]. A system designed specifically for this restaurant grease alleviates the primary factor in biodiesel cost, feedstock price [5]. In cooperation with our sponsor John Deere, we are researching and constructing a system engineered specifically for this restaurant grease scenario.

A potential customer for our product is the University of Michigan grounds crew, which could use the system to fuel some or possibly all of their diesel vehicles. The university residence hall cafeterias would be the primary source of waste grease. Using waste grease from the residence hall would eliminate the cost the university faces for the removal of the cooking oil; in addition to the savings associated with producing fuel in-house makes our product desirable for both the U of M grounds crew and the residence hall cafeterias. Another possible use for biodiesel produced from waste grease is heating University buildings. The biodiesel could be used to heat the buildings in which the waste grease is produced. Previous University of Michigan Senior Design project results on this project has supplied us the chemical reaction requirements and procedures necessary for grease-to-fuel conversion, so we may focus on the system packaging, function, and automation. Our biodiesel production prototype will safely and quickly convert waste grease to biodiesel in an enclosed system while requiring very little manual labor.

INFORMATION SEARCH

The U.S. uses 178 million tons of petroleum-based diesel fuel annually, creating a major source of greenhouse gases [5]. Using fuels from renewable biomass sources, such as biodiesel, will reduce the release of CO_2, particulates, and greenhouse gases into the atmosphere [5]. Unlike petroleum fuels, carbon dioxide produced by combustion of biodiesel will be recycled by photosynthesis [7]. Biodiesel, chemically described as a fatty acid methyl ester (FAME), can be produced from a variety of animal or vegetable fats (triglycerides) through a chemical process known as transesterification [3]. Using raw vegetable oils in diesel engines can cause problems such as injector coking, deposits, and piston ring sticking. Transesterification, as shown in Figure 1, is used to reduce and sometimes eliminate these effects [6].



$$NaOH + CH_3OH + \text{Waste Cooking Oil} \rightarrow \text{Biodiesel} + \text{Crude Glycerin}$$

Figure 1. Transesterification process inputs and outputs

The triglyceride consists of three fatty acids attached to a glycerin molecule [3]. An alcohol (usually methanol), in the presence of a catalyst, is then added to react with the fatty acid to produce biodiesel and crude glycerin [3]. The resulting biodiesel can be used as fuel in diesel engines with little or no modification [6]. In addition, biodiesel is less volatile and safer to handle than petroleum diesel and its lubricating properties can reduce engine wear [7].

Semi-refined and refined vegetable oils are the most common feedstock for biodiesel production [9]. In the United States soybean oil is the predominant feedstock, whereas in Europe rapeseed oil is commonly used [9]. In Brazil, where biodiesel production has been a focus for over 20 years, production also relies mainly on soybean oil [14]. Crude soybean oil in the U.S. has been priced in the range of $0.40 - $0.48 for the oil used to create 1 liter of biodiesel [9]. U.S. prices for petroleum diesel have recently been in the range of $0.21 - $0.24 per liter, about half the price of the biodiesel feedstock [9]. Noordam and Wither found that raw material is one of the most crucial variables that affect the cost of biodiesel [5]; biodiesel produced with virgin oils cannot compete economically with petroleum based diesel, a fact that contributes to the lack of production in the U.S.

To make biodiesel an economically viable alternative fuel, the feedstock used for production must be relatively cheap. Waste cooking oils have the potential to reduce the raw material cost considerably. Yellow grease, which has a free fatty acid content of less than 15% and is the most expensive, ranges in price from about $0.14 – $0.32 per liter [3, 5]. Therefore, both yellow and brown (FFA >15%) grease both have the potential to provide a biodiesel feedstock that is less expensive than the finished petroleum product. From 1995 to 2000, the USDA estimates that the U.S. produced an average of 2.6 billion pounds of yellow grease per year [3]. 350 million gallons of biodiesel could be produced per year from this grease. In addition, using waste oil eliminates the need for disposal [7]. The glycerin byproduct can also be sold for $0.50 - $1.00 per pound (1999-2002), increasing the economic viability of biodiesel [3]. However, producing high quality biodiesel from used oils provides an engineering challenge in part because of the variability in the feedstock quality. The resulting biodiesel must meet the requirements established in ASTM Standard D-6751, "Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels" [3].

Many researchers have developed processes for converting waste oils into usable biodiesel fuel. The basic process consists of a reaction between an alcohol and the long chain fatty acids in the oil. For an effective reaction, the oil must be properly filtered to remove all contaminants. In the work of Zhang et al., an acid-catalyzed system was used to pre-treat the waste oil. Methanol is the most commonly used alcohol because of its relatively low cost [7]. The reaction produces fatty acid methyl esters (biodiesel) and a glycerin byproduct. These products can then be separated from each other using a variety of techniques. Zhang et al. used pumps to provide the mixing in the reaction chamber and then used a water washing column to separate the mixture [7]. Figure 2 below shows the general conversion process used by both previous research teams. We plan to utilize their work by using the same basic setup.

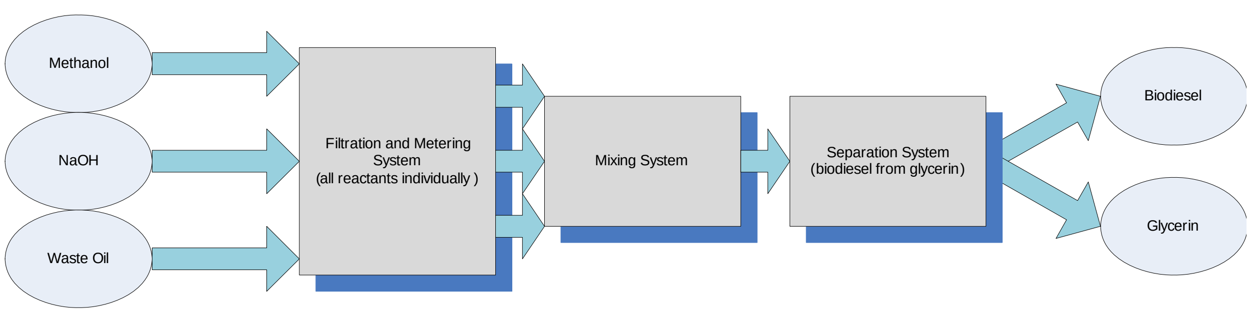


Figure 2. General waste cooking oil conversion process

The main reaction between the triglyceride and the alcohol are catalyzed either with an alkali or an acid [7]. We will ignore the enzyme-catalyzed solution since it requires a much longer reaction time [7]. Freedman et al. found that using an alkali catalyst was less damaging to process equipment than the acid catalyst [7]. The ME 450 group from Winter 2005 designed an alkali-catalyzed process using sodium hydroxide, which has been used extensively in research on the transesterification of waste oil in the past [5]. One of the limitations of the alkali system is its sensitivity to water and the free fatty acid content of the waste oil [7]. According to Jeromin et al., the oil must have less than 0.5 wt.% free fatty acid content to be a viable commercial solution [7]. In most waste cooking oil, the level of free fatty acids is above 2 wt.% [7]. In the work of Zhang et al. they pretreated the waste oil to obtain an acceptable acid level [7], but the ME 450 Fall 2006 group did not address this concern. We also will not address this concern because we are focusing on the automation and safety of the process. We realize that future work will be needed to optimize the quality of the biodiesel product.

In our process reaction, we will continue using the chemical formulation developed by the original ME 450 Winter 2005 team. The results of Felizardo et al. suggest that a methanol/oil ratio of 4.8 and a catalyst/oil weight ratio of 0.6% give the highest yield of methyl esters [8]. The proportion used by ME 450 Fall 2006 was quite close to these values. They used a methanol/oil ratio of 5 and a catalyst/oil weight ratio of 0.4% [10].

There are a number of systems currently on the market for converting waste cooking oil to biodiesel. We will now discuss three of the competitive systems.

The Freedom Fueler, shown to the left, costs approximately $2,200 and produces 40 gallon batches in 24 hours. It is available with either hose or steel plumbing. The user must be present at different times during the process, as all valves and pumps must be manually actuated; however, they claim that a 40 gallon batch will only require 30 total minutes of manual labor. It has cone-shaped containers to ensure complete fluid transfers. It also features an explosion-proof methanol pump. There are many available add-ons for the system ranging from an oil barrel heater to a fueling nozzle.

The FuelMeister II has many of the same features as the Freedom Fueler. However, it produces the same batch size in half the time (12 hours). This unit is quite compact, having a footprint of only 6.25 ft^2. The FuelMeister costs $3,000 for the domestic 110 volt version. The design consists of a single tank in which the reaction processes occur. Its relatively simple design only uses three steel valves. This system uses a pump to mix the reactants in the main chamber by recycling the fluid.

The Deepthort 100B, designed by a Professor in Thailand, was produced for less than $2,000. It is capable of batch sizes up to about 26 gallons. Since palm-oil is abundant in Thailand, the system was designed to use this it as the feedstock. It is capable of performing other tasks besides basic biodiesel production, such as pre-washing the oil, drying the oil, and recovering methanol.

CUSTOMER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

We spoke with our sponsor and customers to develop a set of customer requirements that are weighted according to importance to the customers [12, 13]. We used those desired attributes to formulate a set of engineering specifications by which to design our product. Using a Quality Function Deployment (QFD) diagram, we determined the engineering specifications that were most important to achieving the customer requirements.

CUSTOMER REQUIREMENTS The customer requirements are centered on three major areas: safety of operation, efficiency of process, and automation of system. The method of inputting the reactants, the system operation, and the method of dispensing the products must all be safe for the user. The customer would like the prototype to be safe during a power loss, when left unused, on a "dry run," and able to be shut down in an emergency. These customer requirements are represented in the QFD diagram in Appendix A. The production of biodiesel should be as fast as possible. The process should be automated as much as possible to ensure consistent results, increase the cleanliness of the process, and require as little operator involvement as possible. Specifically, our design will minimize the need for manually changing filters or cleaning components.

The customer gave us the requirements with numerical values assigned to denote their importance. These values range from one to ten and are shown in the QFD diagram in Appendix A. We assigned values based on the major focuses of the previous paragraph.

ENGINEERING SPECIFICATIONS From the customer requirements, we developed a set of engineering specifications. We assessed the relationship between each engineering specification and each customer requirement and assigned values in the relationship matrix in the QFD diagram. We used the values one, three, and nine in the relationship matrix to increase the impact of the stronger relationships. For example, the temperature of the grease will greatly impact user safety (9), yet it will help the speed of the filtration/reactant input process (3). We multiplied the customer importance weight by the relationship matrix value and summed those values for each engineering specification to determine the total point value. With these values we decided on appropriate engineering targets which would best suit the customer's needs. These targets are shown in Table 1 below.

Table 1. Engineering Targets

Parameters	Prototype Target Value	Full-Scale Target Value
Batch Size	5 gal	25 gal
Batch Time	4 hrs	4 hrs
Number of Uncontained Elements	0	0
Filtration Quality	25-50 micron	25-50 micron
Filtration Speed	5.5 GPM	25 GPM
Level of Automation	1 user action/batch	1 user action/batch
Mixing Time	1 hr	1 hr
Separation Motor Decibel Level	60 dB	60 dB
Overall Unit Size	20 ft^3	35 ft^3
Power Consumption	900 W	4100 W
Pump Power	420 W	2000 W
NaOH, CH_3OH Resistance	PVC, steel, stainless steel	Stainless steel
Separation Time	3 hrs	3 hrs
Strength of Mixing/Separation	E = 200 GPa	E = 200 GPa
Container Material	wall thickness ≥ 1/8”	wall thickness ≥ 1/8”
Grease Temperature	25°C	25°C
System Weight	200 lbs	1000 lbs

We decided that a 1/5th scale volume prototype would adequately demonstrate functionality of its full-scale 25 gal counterpart, and thus chose a 5 gal batch size. Our 4 hr total batch time is very competitive with current designs and was the smallest time achievable based upon our metering, mixing, and separation time estimates. Literature searches gave appropriate choices for grease filtration (10-25 micron) and reactant-resistant materials (stainless steel). Mass, inertia, and torque calculations yielded a necessary strength value for that steel, as well as a target system weight. Our primary automation goal—as close to user-independent as possible—involves a single action, simply pressing a “start” button to begin conversion. Upon research into typical grease pumps, we decided that a 350 W, 5.5 GPM model (420 W consumption) would quickly supply grease to the mixing container and also consumes an acceptable amount of power. From this, solenoid valves, the separation motor, and LabVIEW software necessary for automation, we arrived at an appropriate total system power consumption. For user comfort working in the vicinity of the system, 60 dB was deemed the maximum volume allowed to the separation motor and pumps (slightly quieter than a busy intersection). Lastly, grease temperature was regulated to 25°C (room temperature) in light of user safety issues and the added energy and monetary cost of a barrel heater. If testing shows the grease is too viscous for proper flow rates and filtering, this decision will be reconsidered. We also analyzed the interaction among the engineering specifications. In the correlation matrix above the relationship matrix, we used a system of pluses and minuses to denote a positive or negative interaction among the engineering specifications. If optimizing one specification aids in optimizing another, those two have a positive relationship and vice versa.

For example, increasing the level of automation of the system will greatly reduce the time required for producing a batch of biodiesel (++). However, this introduces increased weight and size (-).

DESIGNING A REDUCED SCALE PROTOTYPE

Given cost and time restrictions, manufacturing a full-scale biodiesel system is impossible and we have thus decided on the previously mentioned 1/5th scale version. We will address the targets in Table 1 at the conclusion of our full report and give our findings from prototype testing. Our 1/5th scale system is large enough such that we cannot neglect the large masses, moments of inertia, and stresses inherent to a 5 gal batch size, similar to a 25 gal setup which will require similar engineering. The prototype should be large enough that we see problems which would likely be even worse in a large system. From this point forward in concept generation, evaluation, selection, design, and manufacturing, we will focus on the prototype. Upon conclusion of reduced-scale testing, formal recommendations can be made for a full scale system.

CONCEPT GENERATION

The Functional Analysis System Technique (FAST) Diagram (see Figure 3) breaks up the basic and secondary functions of the overall system design. The FAST starts with the overall system and the task of converting waste cooking oil into biodiesel fuel and then breaks off into branches for each subsystem. The subsystems are methods of input of products, filtration of cooking oil, mixing, separation, and the output of the reactants. Each of these smaller categories breaks up into the functions that need to be performed before the next subsystem.

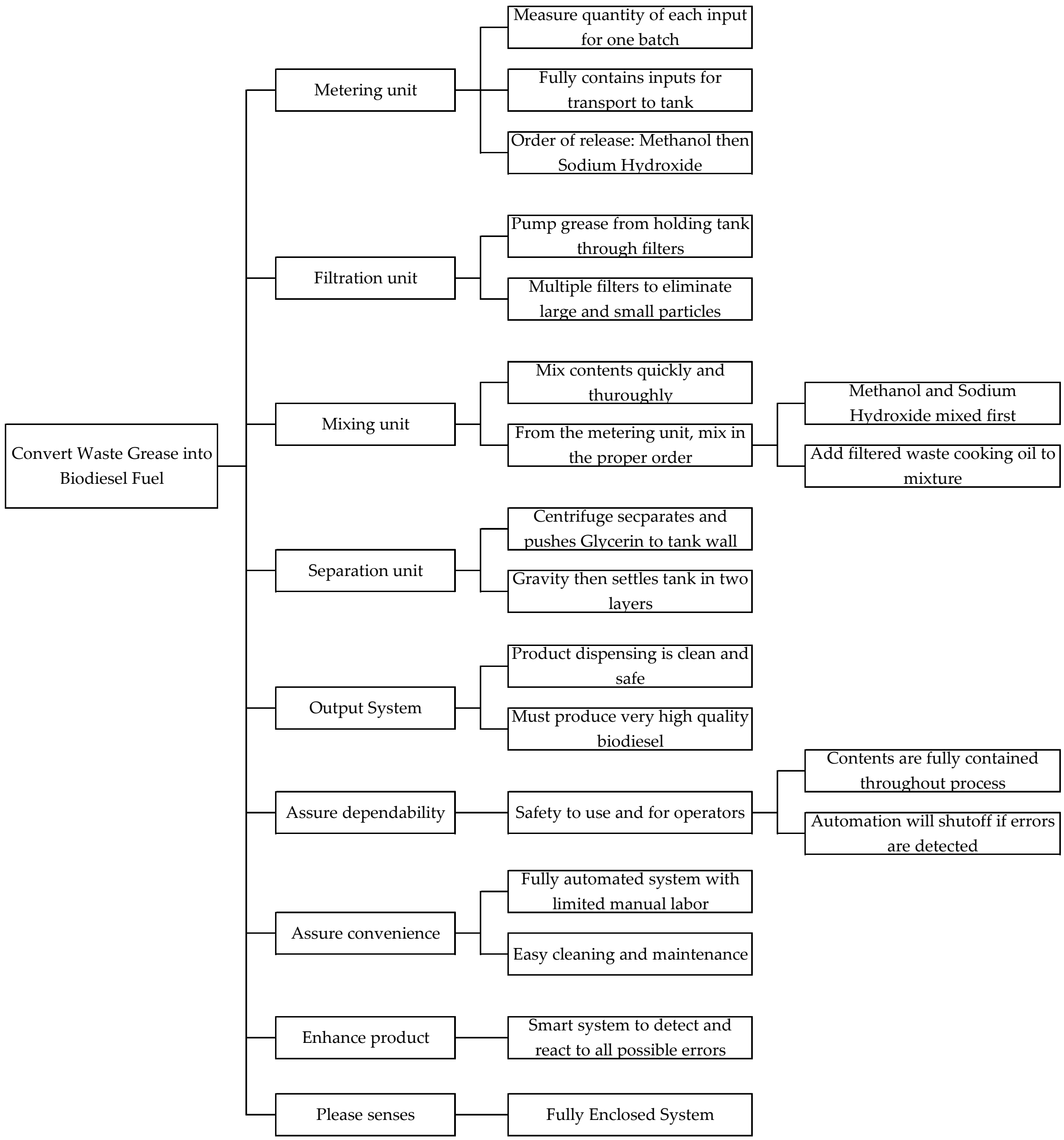


Figure 3. FAST diagram

INPUT OF REACTANTS The reactants are loaded into initial holding tanks by the operator. Once the system is started the process begins by using a method to transport the liquids from the holding tanks into the mixing unit. The correct proportions of each reactant, methanol, sodium hydroxide, and waste cooking oil must be transported into the mixing tank. Designing a completely automated system requires the system to have sensors to determine when the correct amount has entered the system. Methanol and sodium hydroxide will be dispensed into the mixing unit in the proper order to generate the correct products. The input process chosen for the waste grease will incorporate the filtration unit to clean the oil before the waste oil enters the mixing unit.

Gravity Transportation From the initial holding tanks gravity will be used to draw the contents from the holding tanks and into the mixing/separation tank. The amount of each reactant transported from the tank will be the exact amount required to complete the reaction. Using gravity for transportation is inexpensive but it also creates some design challenges. The holding tanks for all three liquids, grease, methanol, and sodium hydroxide would need to be higher than the mixing tank. The grease comes in 50 gallon barrels so this barrel would need to be higher than the mixing tank in order to use gravity as the feeding into the system. The amount of required methanol and sodium hydroxide is not as large so gravity seems to be a practical way to input both liquids.

Pump Transportation A pump can be used to transport the reactants from the initial tanks into the mixing tank. Once the desired amount of liquid is inside the tank, the pump can be turned off. Although this is not very practical for the methanol and sodium hydroxide tanks because of the small amounts required per batch, using a pump for the waste grease would be very beneficial. The waste grease barrel, sitting on the ground next to the system, employs a pump to carry the grease up and into the mixing tank. The difficulty with using a pump for the waste grease is to achieve the appropriate amount in the mixing chamber. The waste grease used in the system would be of variable properties including temperature and particle content. For an automated system, a sensor would need to be used to shut the pump off after the correct amount of grease is measured out. The sensors used in this case could be a time sensor, level sensor, or flow meter.

Time Sensor for Grease Input Every time the system was to run a single batch the pump would operate for a set length of time before shutting off. The length of time would be based on how long it takes to get the grease pumped through a filter and the desired amount into the mixing chamber. The main problems for using a time sensor is that the grease from batch to batch will have a varying number of particles to be removed with the filtration system. The time required to get the amount of grease into the system would vary per batch because very clean grease would move through the filters quicker than the dirtier grease with large particles. The use of a time sensor would not be a very accurate way of getting the correct amount of grease into the tank.

Level Sensor A level sensor is a piece of equipment that would be located at a certain height inside the mixing tank. The sensor works by detecting changes in the density from its initial state. In our system, the sensor would be surrounded by air initially but as the tank filled up the liquid level would reach the point of the level sensor. At this detection of the change in density from air to a liquid, the sensor would send a signal to inform the system that the grease had reached the desired level inside the mixing chamber, and the pump would be turned off. The level sensor must be located inside the mixing chamber which must be considered in the mixing design.

Flow Meter Sensor A flow meter sensor works by measuring the amount of flow through a given pipe. A flow meter could be used to determine how much liquid has passed through a pipe. The amount of desired waste grease can be calculated to determine how much grease needs to flow through the desired tube. After the calculated amount of fluid has been detected by the flow meter the system can be programmed to stop the pump.

FILTRATION METHODS The waste cooking oil obtained from the cafeterias is pre-filtered to remove the extra large particles from the grease. A better filtration system is required to produce pure products without particles floating inside. The filtration system will be coordinated with the input system to filter the waste cooking oil before it reaches the mixing chamber. A design challenge of creating a fully automated system is challenged by creating a filtration system that requires little to no changing of the filter. The goal is to ensure that filter maintenance does not become a nuisance. The filtration unit could include an automated cleaning system to reduce the amount of manual work or it could be a manual cleaning set of filters.

Screen Filter A screen filter is a wire screen that is placed in a tube to collect large particles located inside the waste oil. The particles are collected as the liquid passes through the pipe because they are not small enough to pass through the holes on the screen. This is a simple filter but if it becomes blocked because the particles buildup because they cannot pass through and then the liquid flow is stopped the system will not function. It could cause a safety hazard as well as a maintenance issue to unclog the blocked pipe.

Cartridge Filter The liquid enters through an inlet tube and is force fed through the chamber, which collects the particles, and then the filtered liquid exits through an outlet tube. Cartridge filters work very well with a strong force feed like one generated from a pump. They also come in many different sizes and filtration ranges allowing a large variety to be used in the system.

Bag Filter A bag filter is made of a synthetic material that allows the liquid to enter through an open end and then continue through the material and can be used with gravity feed. The particles are caught in the material because they are too large to make it between the fibers. Bag filters are beneficial to use in such a system because as the particles build up the bag gets filled but the sides are also made of the synthetic material. The entire bag would have to fill up before the filter would become blocked and liquid could not pass through. The bag filters come in different materials which allow for different sized particles to be caught in the bags. It is unclear how well the material would hold up when paired with a pump and a strong flow passing through the filter.

Strainer A strainer is a combination of a screen filter and a bag filter. The strainer uses the design of a bag filter where the particles are allowed to build up in a portion of the filter and the liquid can still pass through the sides. Although rather than being made of material the strainer is made out of metal like the screen filter. The metal is woven to allow a pattern that only liquid and particles smaller than the holes are allowed to pass through. The strainer gives the strength of the screen filter but in the shape of a bag filter. This allows the strainer to be used with a pump system.

MIXING METHODS The input system dispenses methanol, sodium hydroxide, and the waste cooking oil in the correct proportions into the mixing unit. The mixing unit must first mix the methanol and the sodium hydroxide to produce sodium methoxide. Then the waste oil is added into the mixing unit and mixed thoroughly to create a homogenous mixture. The method of mixing the liquids must be reliable and fast to reduce the amount of time required for the batch to be complete. Once the mixture is complete the liquid can begin the separation process. The design challenge is to create a mixing unit that will be compatible with the separation unit to occur in the same tank to reduce the size of the overall system.

Mixing Unit Inside Tank A motor with a belt system or gear system could be used to design a mixing system inside the tank. This mixing unit could incorporate individual paddles or a central rotating shaft with blades that force motion of the fluid. This unit must be compatible with the separation unit chosen.

Pump Recirculation A pump would take the mixture from the bottom of the tank and re-circulate the liquid back into the mixing chamber. The motion of the liquid being sucked from the bottom and back to the top and having the liquid fall back into the mixing tank would provide proper mixing of the reactants.

SEPARATION METHODS The mixing process forms a completely homogenous mixture. This mixture is then separated into two products, glycerin and biodiesel, which is a fatty acid methyl ester (FAME). Once the separation process is completed the bottom layer will be glycerin and the top will be FAME. The bottom will be drained out into a waste container and the FAME will be drained into a container to be used as biodiesel.

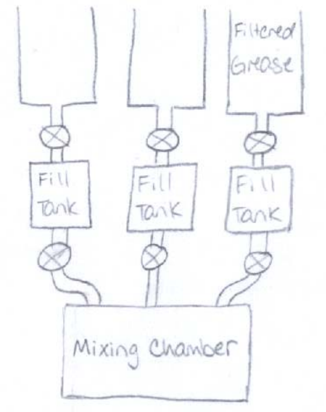
Gravity Separation can occur by allowing the mixture to set in a tank for an extended period of time. Unfortunately, this is a very time consuming process. Using gravity does not require any moving parts to reduce possible problems with the system and the resulting products can be achieved at low cost.

Centrifuge Applying centrifugal forces to the fluid decreases the amount of time required for the separation process to occur. A gear system and motor is used to spin the entire separation tank to create the centrifugal forces on the liquid. The liquid is spun at high speeds and creates two distinct layers in the separation unit. The centrifuge separation unit is costly because it requires a motor and gears to spin the entire separation tank. The centrifuge also needs to be designed so that it is safe for the large container to be spun at high speeds.

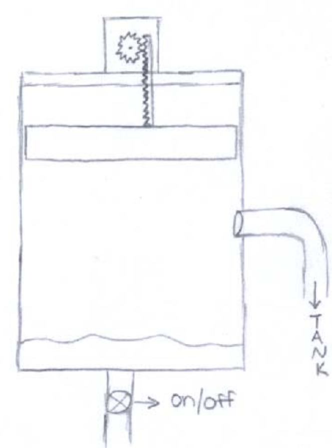
CONCEPT EVALUATION

For each of the main subsystems (reactant input, filtration, mixing, separation) we evaluated the concepts based on our major design objectives. Many of the designs outlined in this section were created under the assumption that the mixing and separation tanks were two separate units. For our final design we incorporated these two functions into one container, which greatly influenced the design and selection process. The following section describes our evaluation of each concept and the reasons behind our final selection.

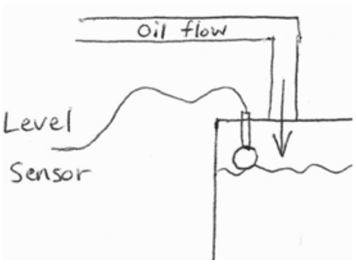
REACTANT INPUT CONCEPTS The first goal of our system is to transfer specific amounts of the three reactants to a common location, where they will be mixed. Our concepts for achieving this goal are shown below.



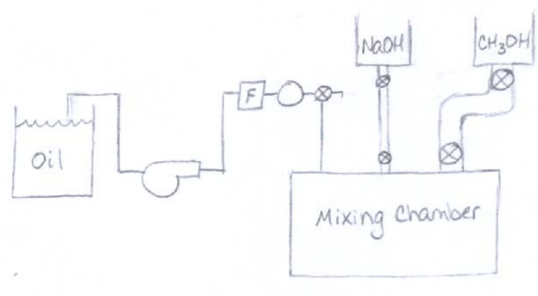
Gravity-fed Intermediate Tanks Our first concept for reactant input involved suspending open containers of waste oil, methanol, and sodium hydroxide above intermediate tanks, which in turn are suspended above the mixing chamber. With both valves in each line closed, the user would fill the reactant containers and then open the upper valves. Gravity would force the fluids into the intermediate tanks, which could only hold the amount of respective reactant needed for one batch. When the filling is complete, the lower valves open and release the reactants into the mixing chamber. If necessary, the timing could also be modified to release the methanol and sodium hydroxide to be mixed before the oil enters. While this design does not require a pump or any type of sensor, the suspended oil tank presents a large safety hazard. The technical feasibility of suspending such a large tank would also be questionable, not to mention the nearly impossible user task of filling the initial container.



Piston-operated Vacuum Cylinders We considered using a vacuum as a method for introducing the reactants into the mixing chamber. As shown in the drawing, the concept consists of a piston inside of a cylinder connected both to the source tank (side connection assumed to be at 1 atm) for each reactant and to the mixing tank (bottom). The piston is connected to a rack and pinion gear system, which is powered by an electric motor. At the appropriate time, the motor will turn the pinion, thereby lifting the piston inside the cylinder. As the volume of the cylinder increases the pressure of the air will decrease, thereby creating a differential pressure between the cylinder and the atmospheric pressure on the source tank. When the correct amount of fluid has entered, the valve to the mixing tank will open and release the contents. This design eliminates the need for pumps or the supply tanks placed above the mixing tank for a gravity feed. However, this concept would create other design problems. The cylinder, as well as the piston/cylinder interface, would need to be airtight to function. To obtain the necessary pressure to move the fluids, this concept may require a large volumetric expansion of the air, which would necessitate a large volume container. Although we eliminate the need for pumps, the motor necessary to drive this system would likely be more expensive than a pump.



Oil Pumped to Set Level This concept uses the gravity feed process for the methanol and sodium hydroxide assuming that the system height is still reasonable with these tanks. After opening the valves for these tanks, the oil would then be pumped into the mixing tank until the total fluid level achieves the correct volume of oil measured by when it reaches the correct height in the tank. A level sensor would provide the feedback to the control unit to shut down the pump and possibly close a valve. This design allows the user to simply insert the oil input hose into the barrel of waste oil and start the process. Since the method of measurement is relatively simple, this concept would allow for accurate proportions of reactant input. Although level sensors are fairly cheap, this design does introduce extra cost. In our later system designs, we incorporate the mixing and separation processes into a single tank, so any attached apparatus must be compatible with the tank rotation for the separation process. With a spinning tank, s level sensor presents many engineering challenges, such as what to do with the signal cable attached to the sensor. The cable will become wrapped around the tank and if the tank spins for several minutes at 500 rotations per minute, this introduces a large amount of cable to control.



Oil Pumped through Flow Meter A flow meter located in the oil line can be used to determine the velocity of the fluid. The velocity of the fluid multiplied by the cross-sectional area of the pipe results in the volume flow rate. By performing a time integration of the volume flow rate in our control software, we will shut the pump off when one batch's worth of oil enters the tank. This solution eliminates the need for any sensor attachments on the mixing/separation tank and the engineering challenges that presents. However, flow meters are more expensive than level sensors and will increase the cost of the design. The control method and software program may be more complicated as well.

Selection: Reactant Input For our design, the methanol and sodium hydroxide will enter from intermediate tanks fed by gravity. The cooking oil will be pumped from the storage container into the mixing tank with a flow sensor inside the oil line to achieve the correct volume for a single batch. A schematic of our basic reactant delivery method is shown in Figure 4, below.

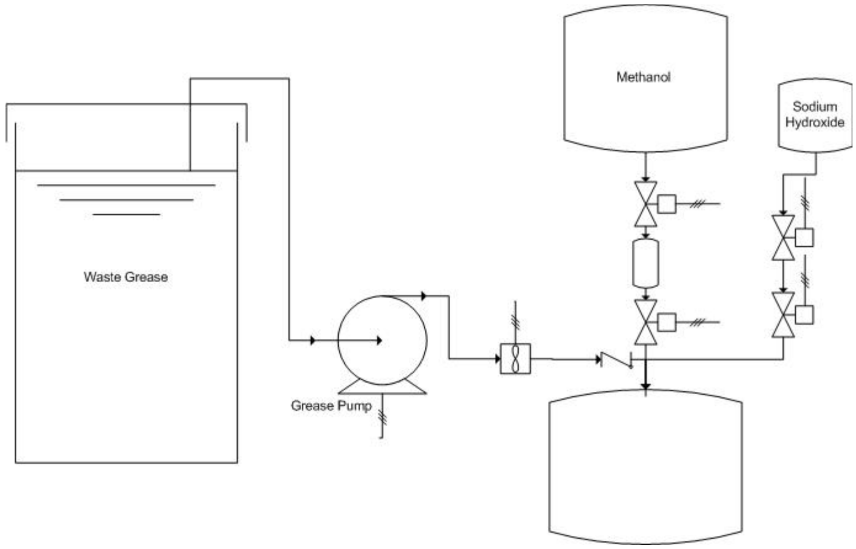
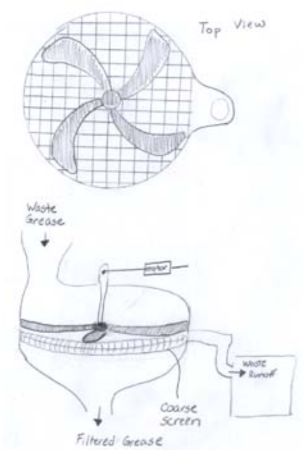
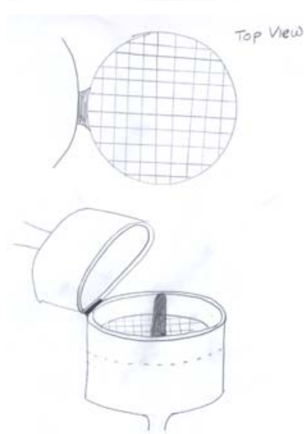


Figure 4. Reactant input concept selection (not showing other components)

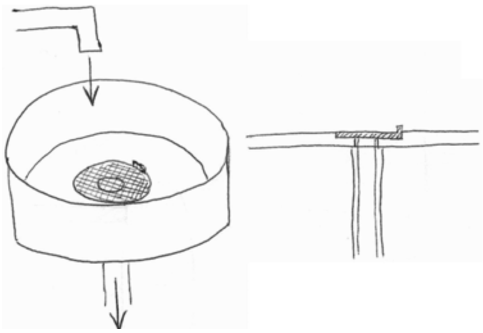
FILTRATION CONCEPTS The waste cooking oil most likely contains unknown particulate materials that may affect the quality of the reaction process. To reduce this risk, we have developed the following filtration concepts designed to provide a homogeneous, pure supply of oil. Work by previous groups has shown that filtration is most effective by using a coarse filter and a finer filter in series. We will use this same approach.



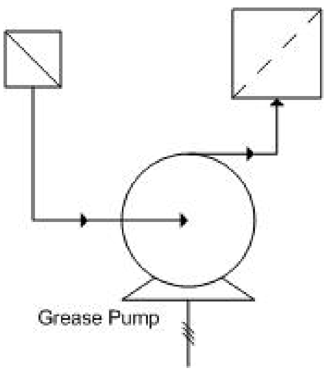
Self-cleaning Coarse Screen Filter To reduce the amount of manual maintenance, we developed an idea for a self-cleaning coarse filtration unit. The waste grease enters and flows through a metal screen, which catches the large particles. A blade system, attached by a shaft to a low-cost motor, barely scrapes the surface of the screen. The blades are shaped in a way that pushes the accumulating particulate matter into a waste outlet line. This design would not require the user to change the filter by hand. The user would only periodically empty the waste receptacle. While this does cut down on user effort, it inceases the complexity of the design and adds equipment and manufacturing costs.



Removable Coarse Screen Filter A coarse filter that requires manual cleaning is composed of two cylinders joined by a hinge on one side. The lips of each cylinder are covered in rubber to obtain a tight seal. The input line is a flexible hose to allow the upper cylinder to move freely on the hinge. The screen is supported on tabs inside the bottom cylinder and it has a handle for easy removal. This design would allow for relatively easy cleaning and removal of the screen, although it may be messy to remove the screen from the cylinder.



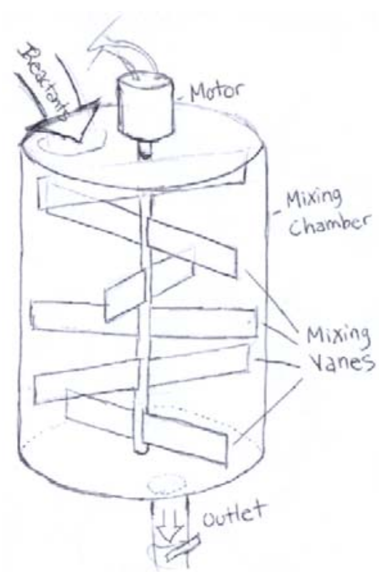
Open Coarse Screen Filter Another idea was a coarse screen filter that is open to the atmosphere. The fluid enters a tank and flows out through a screened drain in the bottom. The screen has either a tab or a handle attached for easy removal and cleaning. This design would violate our objective of enclosing all system components for safety and cleanliness. A picture of the concept from the top and also directly from the side are shown to the right.



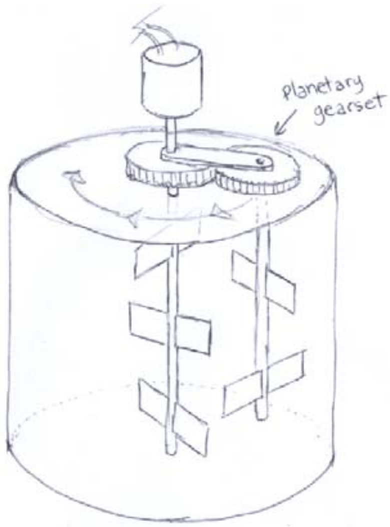
Coarse Strainer & Fine Cartridge Filter We were concerned that filtering downstream of the pump may damage or clog the pump. However, we were worried that filtering upstream of the pump may make priming difficult and possibly prevent proper flow. To alleviate both of these concerns we decided to include a coarse filter upstream and a fine filter downstream. This way we'll greatly reduce the particulates through the pump without creating too large a flow restriction on the inlet of the pump. We will incorporate an automotive oil filter or an equivalent cartridge filter as the fine particle filter following the pump.

Selection: Filtration We will use a two-stage filtration method with a coarse strainer upstream of the pump and a finer cartridge filter downstream. This will protect the pump from large debris without creating an excessively large flow restriction in the pump inlet line.

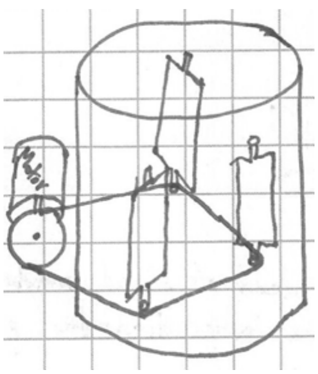
MIXING CONCEPTS Once the reactants have entered a common tank, they must then be mixed thoroughly to ensure the best possible reaction efficiency. Our concepts for mixing are described and evaluated in the following section.



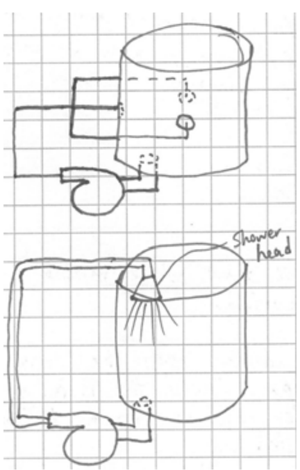
Motor-powered Shaft with Mixing Vanes The basis for our initial concept for mixing was inspired by the work of the Fall 2006 group. The design consists of rotating shaft powered by a motor. Mixing vanes are rigidly attached to the central shaft and physically mix the reactants. We had various concepts on the manufacturing of the shaft/vane assembly and the vane geometry. The most feasible solution we discussed was to mill slots into the shaft and to insert strips of sheet metal to serve as vanes. We would then just bolt the vanes to the shaft with two bolts. One drawback to this design is that some fluid at the bottom of the tank and in the outlet tube would not be mixed. We could place the outlet valve as close as possible to the bottom of the tank, but there will always be some unmixed fluid that enters the separation tank.



Motor-powered Planetary Gear System, Dual Shafts with Vanes Our next concept is very similar to the one just discussed, but we believe it would provide more effective mixing. In this design, we attach a sun gear to the drive shaft which mates with a planet gear connected to its own drive shaft. Mixing vanes are attached to both shafts. The drive shaft rotates in place and the secondary shaft rotates around its axis and circles around the drive shaft. This added rotary motion would likely speed up the mixing process by introducing added turbulence into the fluid. Along with the same disadvantages discussed for the single shaft design above, this design also requires another cutout in the top of the container for the secondary shaft. This may pose a safety hazard if the mixing process sends reactants or products out of the cutout.



Belt-driven Paddles We also considered a design which relies on belt-driven paddles for mixing. The ends of the paddles, attached to belt sheaves, would protrude out of the sides of the tank. A motor would drive a belt connected to the ends of either two or three paddles. The rotation of the paddles would move the fluid. The paddle could contain any number of holes or slots to help introduce extra turbulence. This design would require very good seals where the paddle ends protrude from the container. It may be difficult to keep these four to six load-bearing seals from leaking.

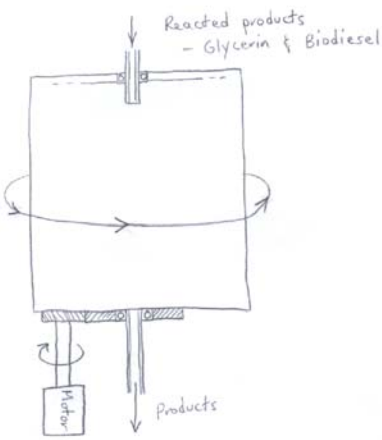


Pump Recirculation Our group developed a concept for mixing which relies on re-circulating the reactant fluids using a pump. The reactants will enter the tank, exit out the bottom of the tank, enter the tube and be pumped back in through the top of the tank. The entrance into the top of the tank could be through a sprayer or through multiple entry points to help mix the fluid. Our group anticipates that sending the fluid through this centrifugal pump will also greatly aid in the mixing process. This design approach is used in a number of the competitive products currently on the market, such as the FuelMeister II.

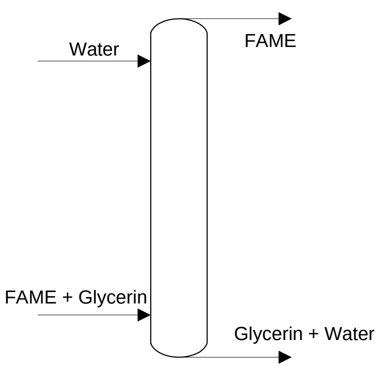
Selection: Mixing We will use a pump to re-circulate and mix the fluid in the tank because this will be sufficient for mixing and is the easiest design concept to pair with the separation methods.

SEPARATION CONCEPTS The waste oil, methanol, and sodium hydroxide react in the mixing chamber, forming glycerin and biodiesel as products. These products must then be separated from each other. Most comparable systems simply rely on gravity to separate the products, which can take up to 24 hours. Time effectiveness is one of our major design concerns so we developed the following concepts to decrease the separation time.

Centrifuge with Rotating Valves Much of the work of the previous ME 450 design teams was focused on separation by applying centrifugal forces to the fluid. Since we wish to utilize the applicable past research as much as possible, the majority of our focus has been on this method. The prototype from Fall 2006 used a centrifuge with two outlet valves, one on the bottom drain line and one on the side of the tank to drain the glycerin that is forced to the outer walls during spinning. While this provided adequate functionality for manually operated valves, solenoid valves present a problem because of their electrical cables. If we allow the valves to rotate the cables will tangle and twist. Therefore, our design must keep the valves stationary.



Centrifuge with Stationary Valve In order to keep the valves stationary we decided that the separation tank inlet and outlet lines will be on the axis of the tank. We will drill holes in the top and bottom of the tank and attach bearings to guide the fluid transfer lines. Both bearings and pipes will be reinforced by additional structural supports. This design allows the valves to be placed on the stationary pipelines. Since the outlet pipe is on the central axis, we need a way to offset the motor axis while still providing torque to the tank. We considered both a gear and belt system for perform this task. A belt system may provide a cheap way of transmitting the energy, but the high torque required may necessitate more costly V-belts (as well as appropriate sheaves). A belt would also require a tensioning system, which may introduce extra maintenance effort in the event that the belt slips off the sheave. Using a gear system will allow us to transmit high torque without worrying about tensioning or slipping.



Water-washing Column As in the research of Zhang et al., we considered using a water washing column to separate the reaction products. Water is piped into the column from above and biodiesel and glycerin from below. Biodiesel is less dense than both water and glycerin so it rises to the top of the cylinder. The glycerin and water are then removed out the lower drain. The biodiesel that produced by this process is not completely pure. Zhang et al. found that the biodiesel (FAME) contained less than 6% unconverted oil, methanol, and water. This stream must undergo an expensive and complicated purification process to remove the contaminants. This added expense is not feasible for our prototype or our recommended system design.

Selection: Separation We will separate the biodiesel from the glycerin using centrifugal forces and a stationary valve system. The tank containing the products will be rotated by a gear system connected to a motor. The valves for the input and output lines will be on the top and bottom of the tank and remain stationary during rotation to allow for cable connections. Figure 5, below, shows a more detailed sketch of the bearing, gear, and support system.

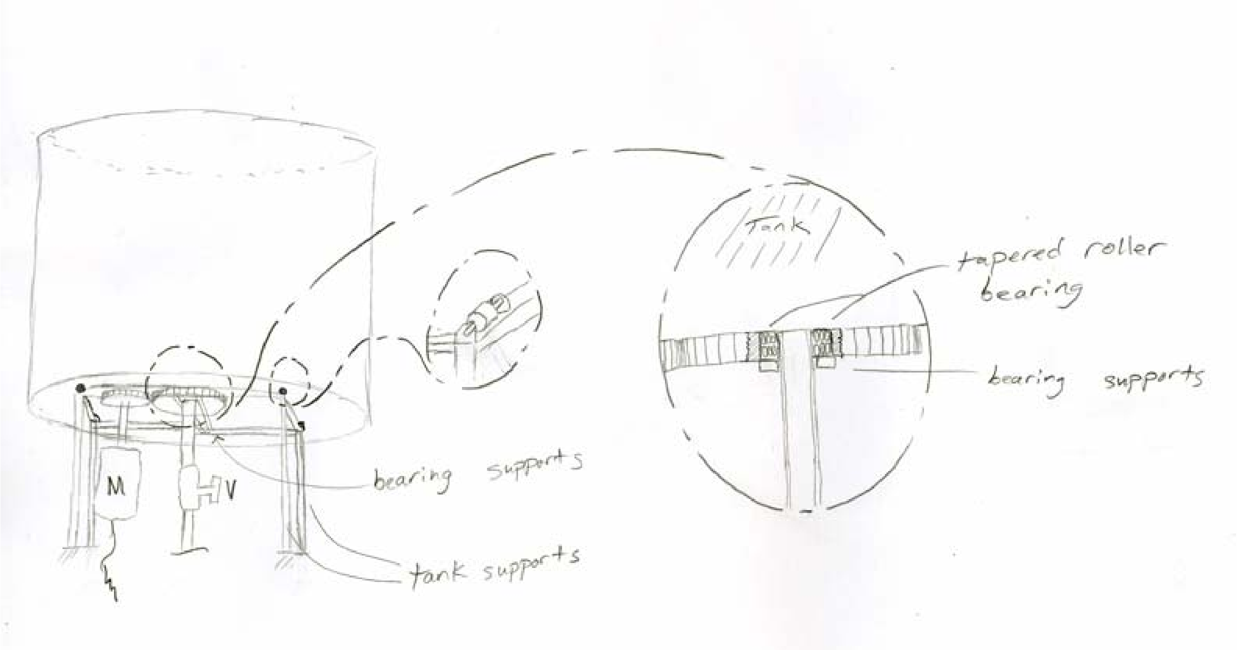


Figure 5. Detailed view of main separation tank support and bearing system

OVERALL SYSTEM CONCEPTS For the mixing unit we originally planned on using the vane/motor assembly, but soon realized that using two tanks would necessitate a pump between them to reduce the overall height of the unit. We then realized that a pump could be used for both transferring between tanks and for re-circulating flow for mixing purposes. With this design in mind, we decided to simply combine the mixing and separation processes into the same tank. This allows us to eliminate the costly motor required for the original mixing solution and to greatly reduce the manufacturing costs of the system. The total system schematic diagram is shown on the next page as Figure 6. All of our final design choices are supported by the Pugh charts in Appendix C. These allowed us to roughly quantify the advantages and disadvantages of each concept and select accordingly.

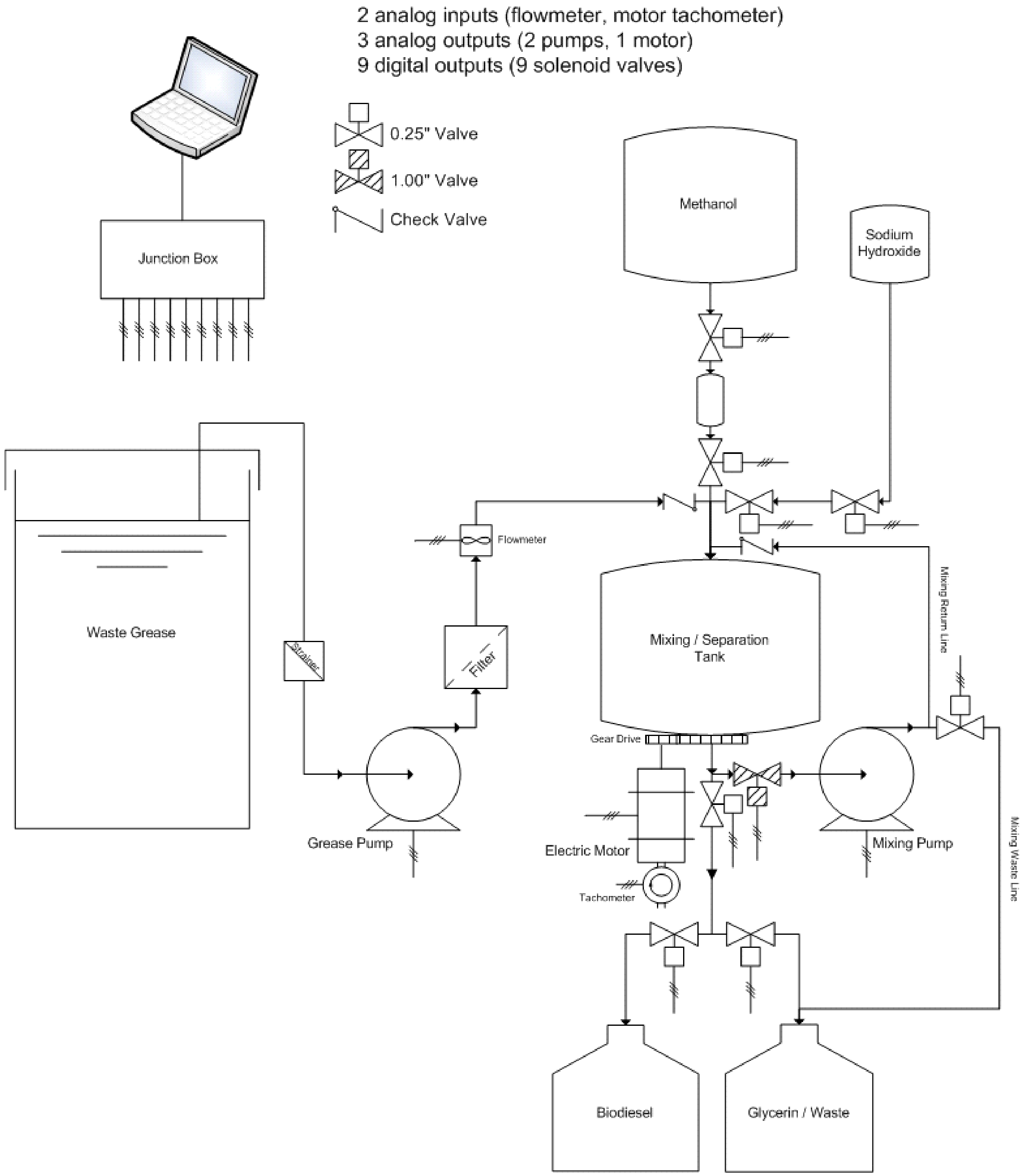


Figure 6. Waste cooking oil conversion system schematic diagram

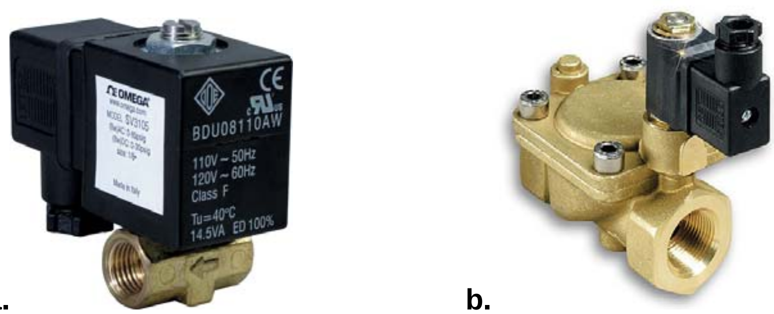
CONCEPT SELECTION

Our one-tank system can be divided into three functional component subsystems: automation and control; filtration, transport, mixing, and separation; and containment and piping. The following sections will discuss their characteristics and our reasons for choosing them.

AUTOMATION AND CONTROL The heart of our control scheme would be a computer running LabVIEW in conjunction with a USB box which sends signals to solenoid valves, the two pumps, and the separation motor, as well as receive signals from a flow meter and several shutdown sensors.

Digital Input/Output Box This interface possesses multiple digital inputs and outputs, is capable of interfacing with LabVIEW, and serves as the link between computer commands and mechanical function. This box, as well as LabVIEW, will be supplied to us by the University of Michigan so we are not sure of its exact specifications at the present time. Setups like this are the common solution for the relatively simple automation we require.

Solenoid Valves Electrically-actuated valves were seen as the most economical, feasible, and accurate method for controlling liquid movement. Their simple design easily incorporates them into our automation plan. Two diameters of electrically-actuated valves will be used, 0.25 in and 1.00 in (see Figure 7, below). To save cost, only one large diameter valve will be used in the entire system, as seen in Figure 6. Though using smaller valves elsewhere in the system will slow down the process, we estimate that our process time start to finish will still fall below that of competitive products.



a. **b.**

Figure 7. (a) 0.25"Ø and (b) 1.00"Ø solenoid valves

Check Valves At two times in the system process, pumps are shut off and further flow from their outlet pipes is not desired. Additionally, these outlet pipes must be sectioned off from other pipes later in the process to prevent batch contamination. Check valves suited these objectives, as positive pressure downstream of the valve during pumping ensures they stay open, but close upon pump shutoff. Specifically, there is time between the pump's electrical shutoff and the time its impeller stops spinning; check valves prevent the pressure buildup a typical actuated valve would cause, staying open until fluid stops flowing. We will utilize two 1.00"Ø PVC check valves in the system (see Figure 6), one after the grease pump and the other following the mixing pump. PVC is a good prototype choice, as it is a cheaper but less durable alternative to stainless steel, with the same NaOH resistance.

Flowmeter Summing individual output values with LabVIEW, a flowmeter gives us an accurate way of measuring how much grease has been pumped into the mixing tank. Paddlewheel flowmeters are useful for viscous fluids where extreme accuracy is not required, and are less expensive than ultrasonic or positive displacement meters. Our flowmeter will snap-fit into a PVC fitting, as seen to the left. This may be supplied by the University, so we are not sure of its exact specifications at the present time.

FILTRATION, TRANSPORT, MIXING, AND SEPARATION Filtration was designed with pumping in mind, as significant pressure drops upstream of centrifugal pumps hurts their performance significantly. Also, combining mixing and separation required space considerations with the electric motor working in close proximity to the mixing pump.

Strainer and Cartridge Filter Though the waste grease is pre-filtered, we decided to use a coarse strainer to ensure that no large particles enter the pump. The 400 micron strainer (shown in Figure 8(a), below) has 0.75" NPT fittings, is designed for room temperature grease, and will function well with a pump unlike conventional bag filters. Based on the viscosity of our grease, common automobile oil filters will work well with our pump, as they are a cartridge style and range from 15-50 micron filtration quality. Additionally, our choice of a synthetic media oil filter (Figure 8(b)) improves filtration and flow. We will likely remove the outer shell as shown in the figure and fabricate our own interface system between the filter and piping.

a. 

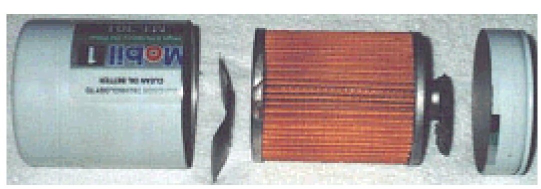
b. 

Figure 8. (a) Pre-pump strainer and (b) Cartridge oil filter

Grease Transportation Pump Based on our target times for transportation of the cooking oil, we chose an 11 GPM pump. This flow rate fills the mixing tank in about a minute with the correct volume necessary for a five gallon batch. The pump (shown in Figure 9(a) below) is cast iron and possesses mountable feet for permanent applications like our system.

Mixing Recirculation Pump The initial mixing process is just of methanol and sodium hydroxide to produce sodium methoxide. This requires the proper materials so that the chemicals don't eat through the pump material. The mixing procedure also needs to recirculate the entire five gallon batch at least 10 times, so a higher GPM than the grease transportation pump is desired. The stainless steel pump we chose operates at 11 GPM.

a.

b.

Figure 9. (a) Grease Transport Pump (b) Mixing Recirculation Pump

Separation Motor To size the electric motor that will turn the mixing/separation tank, we calculated the necessary torque requirements for a five gallon batch size and an angular speed of 500 rpm. These calculations are shown in the engineering analysis section. The Bison 32 frame permanent magnet 12 V DC motor, shown in Figure 10(a), will be used in our prototype.

Offset Gear Drive Rotation of the mixing/separation tank requires that all inlet and outlet piping be on its central axis, but a motor driving this axis directly from the bottom interferes with any co-axial outlet tube. An offset gear system, as shown in Figure 10(b), solves this problem, allowing the transfer of rotation between from the motor to tank axis. Along with the motor calculations in the engineering analysis section, are the calculations for the necessary gears required. The gears will be a 1 5/8 inch gear and a 6 ½ inch gear. The tank gear will employ a tapered roller bearing around the outlet tube, necessary because both radial and thrust loads will act upon it.

a.

b.

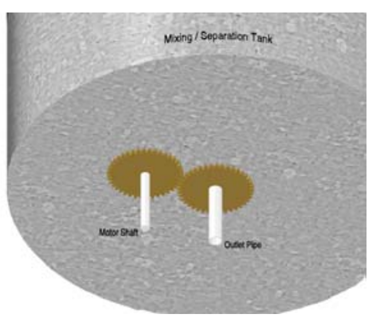


Figure 10. (a) separation motor (b) Offset gear drive illustration

CONTAINMENT AND PIPING The materials selected for the containment and piping cannot be reactive with sodium hydroxide, methanol, or waste grease; ideally, all components would be stainless steel. However, cost dictates that we compromise with PVC and steel. PVC is cheap and non-reactive with methanol and sodium hydroxide; steel is also non-reactive with sodium hydroxide but does corrode in contact with methanol. All of the piping will be made of PVC pieces and from the pumps we will use a clear vinyl thick-walled hose. The methanol and sodium hydroxide metering tanks were constructed of PVC tubing enclosed by valves. The size of these tanks is calculated in the engineering analysis below.

ENGINEERING ANALYSIS

METERING The metering system measures out the exact amount of sodium hydroxide and methanol to add to the batch to make a complete reaction. The reactants will be held in a large container and using a pipe with valves on both ends, the correct amount will be measured into the pipe to make a single batch. Ratios found from the previous senior design projects, were used to determine how much of each reactant was needed per batch. The results are shown in Table 2.

Table 2. Reactant ratios for a single batch

Variables	Value	Units
Total Liquid Volume of tank	5.00	gal
Cooking Oil	4.08	gal
Methanol	0.82	gal
Sodium Hydroxide	0.10	gal

Using the volume of each reactant necessary to complete the reaction, the metering system containers made from different sizes and attachments of PVC could be designed. The volume of liquid located in each pipe connecting the valves and in the endcaps or fittings for the tank were calculated first. Then subtracting this volume from the total volume of the reactant required gives the amount of liquid that has to be located in the metering container. The volume to be enclosed in the tank was divided by the area of the tank using the area of a circle and the diameter of the pipe to be used for each container. This left us with the length of the metering tank necessary to enclose the correct amount of volume, as shown in Table 3. Finding the lengths of each tube is necessary for purchasing the correct amount of PVC and also for designing the metering system. See Appendix F.2 for a full detailed drawing of the methanol metering tank.

Table 3. Metering container calculations

Methanol Metering Container

Variables	Value	Units
Volume of Methanol	0.82	gal
Diameter of pipe	4.00	in
Radius of endcaps	2.00	in
Length of inlet valve pipe	1.50	in
Length of exit valve pipe	1.50	in
Diameter of 1" valve pipe	1.00	in
Total Volume of Methanol	188.57	in^3
Volume of Fluid in Endcaps (x2)	33.51	in^3
Volume of Fluid in Valve pipes (x2)	2.36	in^3
Volume of Fluid in Pipe	152.70	in^3
Length of Methanol Pipe	**12.15**	**in**

Sodium Hydroxide Metering Container

Variables	Value	Units
Volume of Sodium Hydroxide	0.10	gal
Diameter of pipe	2.00	in
Length of fitting	1.00	in
Length of inlet valve pipe	1.50	in
Length of exit valve pipe	1.50	in
Diameter of 1" valve pipe	1.00	in
Total Volume of Sodium Hydroxide	23.57	in^3
Volume of Fluid in Fittings(x2)	1.13	in^3
Volume of Fluid in Valve pipes (x2)	2.36	in^3
Volume of Fluid in Pipe	20.09	in^3
Length of Sodium Hydroxide Pipe	**6.39**	**in**

MOTOR ANALYSIS To determine the correct motor, calculations for speed and torque had to be performed. The analysis started by finding the average angular acceleration, α, calculated from the target angular speed of 500 RPM. Using geometric properties and material properties the inertia, I, for both the tank and the liquid inside the tank were found and added to get the total inertia.

$$\tau = I_{total}\,\alpha \qquad \text{Eq. 1}$$

Using Eq. 1, the amount of desired torque, τ, was calculated. As shown in Table 4, the torque needed was around 252 oz-in. The motor selected for the operation is the Bison32 model. Using the specifications of the motor the speed was used to find the gear ratio. Once the gear ratio was found the amount of torque generated from the motor through the gears was calculated to ensure that enough torque would be produced to spin the large separation tank. Using the gear ratio the size of the gear located on the motor shaft and the gear mounted to the bottom of the tank could be determined. Of course we will have to buy standard size gears, but this analysis will at least give us a reference point so we know what approximate ratio we'd like to use. The spin-up time of the tank is not too important to our selection, since the motor will be spinning for approximately 30 minutes in total and we are only concerned with the steady state speed.

Table 4. Motor Specifications Required and Motor Selected Properties

Motor Calculations

Characteristics	Value	Units
Angular Speed (500 rpm)	52.3599	rad/sec
Average Acceleration	3.4907	rad/s^2
Moment of Inertia of Liquid	0.1625	kg/m^2
Moment of Inertia of Container	0.3479	kg/m^2
Total Moment of Inertia	0.5104	kg/m^2
Average Torque Needed	1.7817	Nm
Average Torque Needed	252.3136	oz-in

Bison 32 Motor Selected

Characteristics	Value	Units
Motor Speed	1948	rpm
Motor Torque	93.4	in-oz
Gear Ratio (motor speed/500 rpm)	3.896	----
Gear on Tank (set by design specs)	6	in
Gear for Motor	1.54	in
Torque on Tank (motor torque*gear ratio)	363.886	in-oz

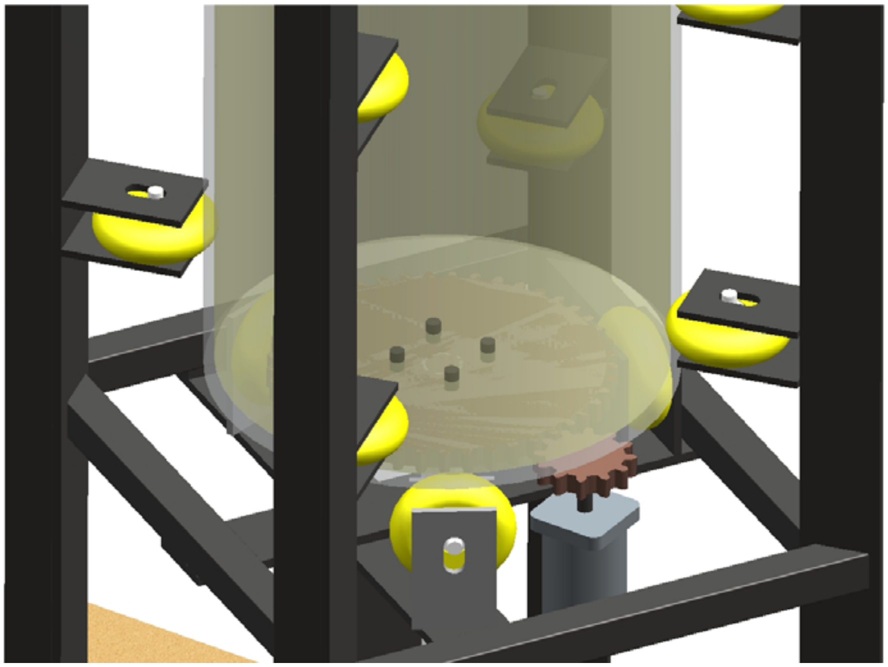


Figure 11. Tank Support Structure

TANK FRAME STRUCTURE Prior to construction, we needed to check support structure mechanics and ensure its integrity under the tank and fluid loads. Stress calculations were performed for the crossing members that directly support the tank, as well the square pieces that support those members. Buckling calculations were performed for the four main corner supports (see Figure 12 for illustration of these pieces). Orthographic drawings with overall structure dimensions are in Appendix F.4.

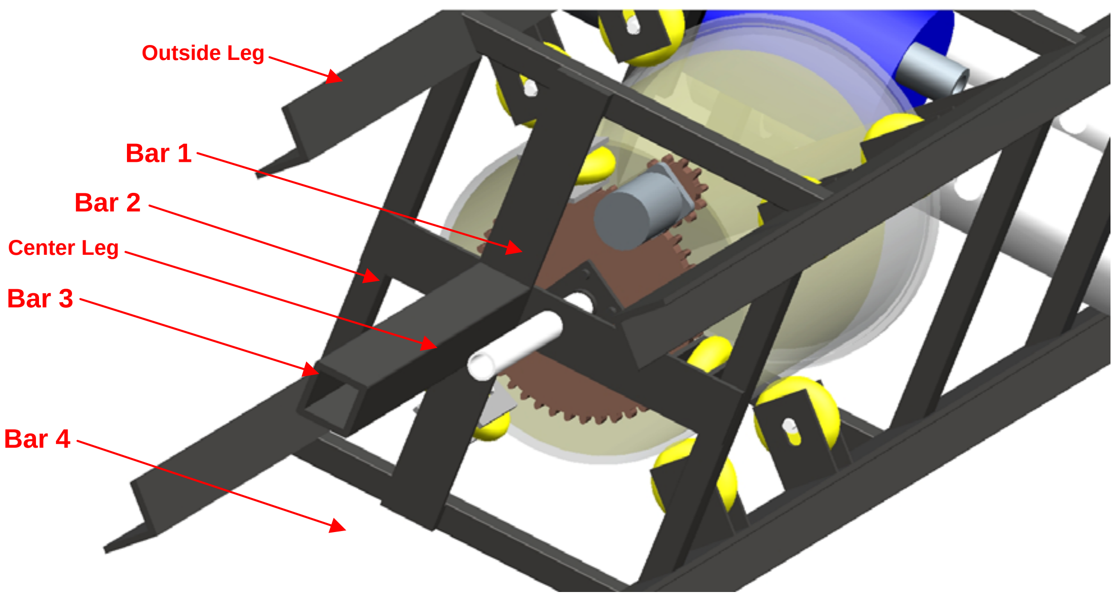


Figure 12. Tank support structure

Support Bars Stress Analysis Basic free body diagrams can be drawn for the principle crossing members (labeled in Figure 12), as shown below in Figure 13. Calculation assumptions and process are shown in Table 5; Table 6 gives material parameters and results.

Table 5. Stress calculation approach

Assumption/Process Step	Algebraic Result
1. Force/Moment balance	1 additional equation required to determine forces
2. Moment-Deflection relation	$\frac{d^2 v}{dx^2} = \frac{M}{EI}$
3. Isotropic steel	E = constant
4. Zero deflection at support forces	Bar 1 example: $v(0) = v(\delta_1) = v(2\delta_1) = 0$
5. Additional equation from deflection analysis	Solve for support forces
6. Bending moment diagram	Point of largest moment visible
7. Evaluate stress at x	$\sigma(x, y) = -\frac{M(x)y}{I}$

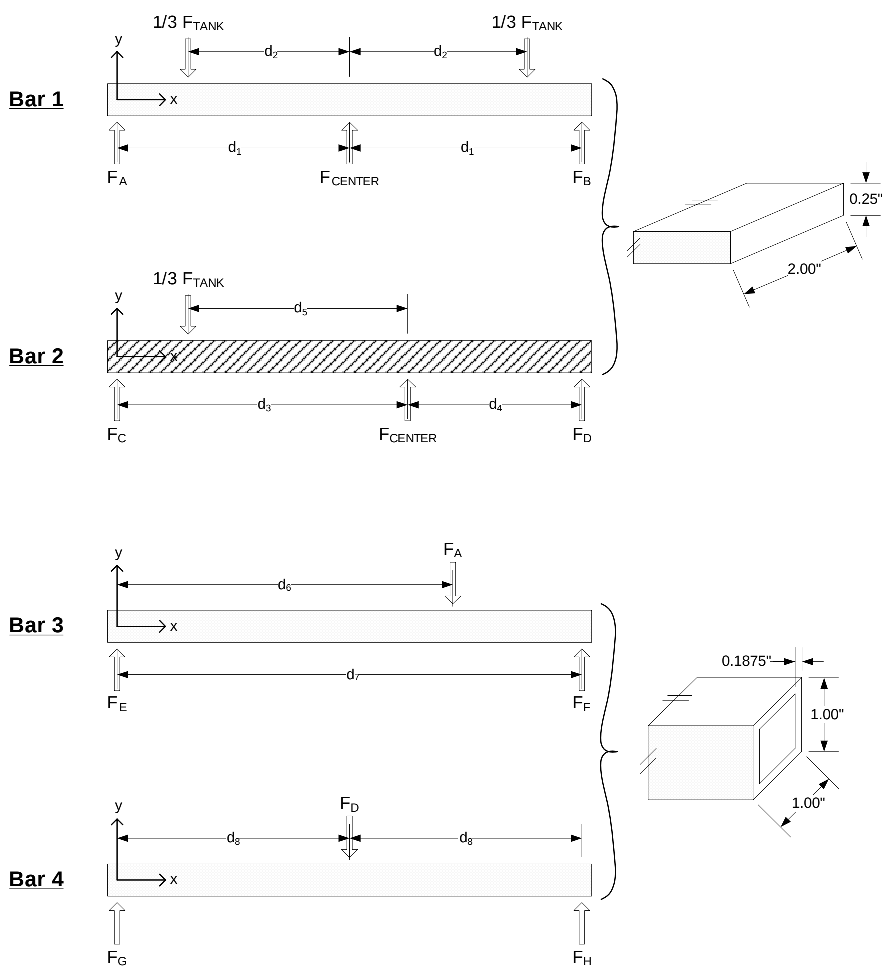


Figure 13. Support beam free body diagrams

Table 6. Maximum stress in bars 1, 2, 3, and 4

Bar	Maximum Stress
1	819 psi
2	5494 psi
3	136 psi
4	70 psi
ASTM A36 Steel Properties	*Note: max compressive and tensile stresses equal due to centrally located neutral axis
σ_{YIELD} = 36260 psi	
E = $30\text{x}10^6$ lbf/in^2	

Bar 2 experiences the largest stress and, as expected, the square support bars 3 and 4 experience the smallest stresses. All four calculated stresses fall well below steel's yield strength, so we can conclude that the support bars for the tank structure are a mechanically sound design and will withstand their respective loads. We realize that any deflection of the beams may introduce some misalignment of the tank's rotational axis. However, the resulting deflection will be miniscule compared with the uncertainty introduced by the manufacturing processes used to align the tank. For this reason, we are not concerned about these small displacements.

Vertical Legs Buckling Analysis Buckling analysis was performed one of the four outside vertical legs as well as the center square leg, according to the process given by Table 7. Results are shown in Table 8.

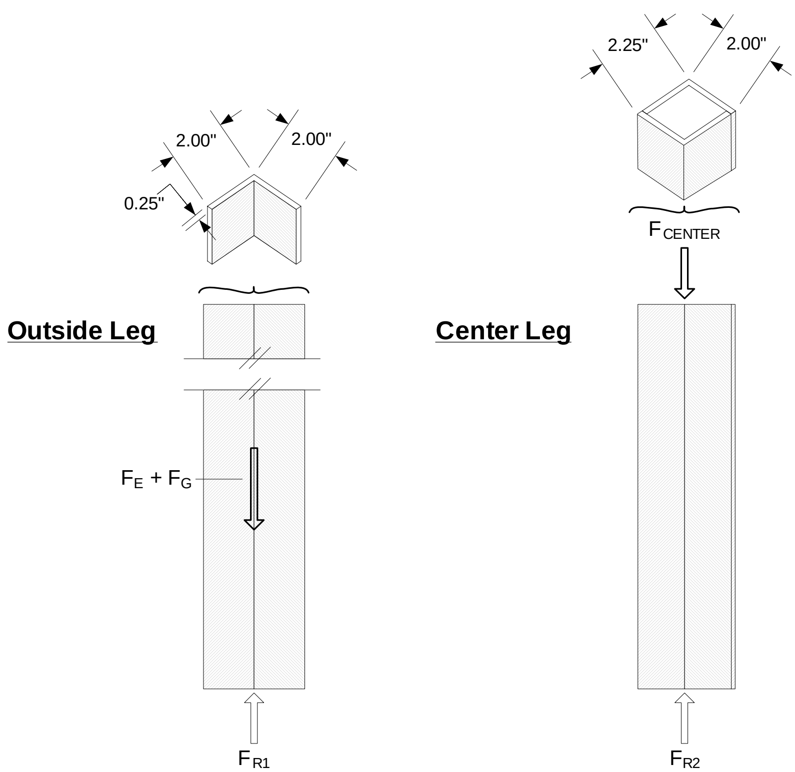


Figure 14. Vertical beams for support structure

Table 7. Buckling calculation approach

Assumption/ Process Step	Algebraic results
1. Force Balance	example: F_E and F_G from previous stress calculations
2. Euler Buckling Load	$P_{MAX} = \sigma_{YIELD} A$
3. Isotropic Steel	E = constant

Table 8. Force present in outside and center legs

Leg	Force	Buckling Force
Outside	6.39 lbf	3.4×10^4 lbf
Inside	23.14 lbf	6.8×10^4 lbf

ASTM A36 Steel Properties σ_{YIELD} = 36260 psi

As both center and outside leg loads are far less than their respective buckling loads, the outside and center supports are in no danger of failure.

MECHANICAL ANALYSIS OF MAIN TANK Using the same calculation methods as used for the prototype the two possible failure modes for the mixing tank are calculated as bending failure and circumferential stress. To ensure that the scaling methods are acceptable the calculations are very important to ensure that a system 5 times bigger. For the stationary tank supporting around 150 lbs of weight from the fluid, the bending failure stress is found. We first considered the possibility for bending failure in the bottom of the tank when the full five gallons of fluid is stationary. We then considered the possibility for excessive circumferential stress in the walls of the tank during rotation. For both of these cases we made sure that the design has a significant margin against failure.

Bending Failure Due to Static Fluid Pressure Before and after the separation process the tank will need to support roughly 40 lbs of stationary fluid. The most likely failure mode will be the bending of the bottom layer of material. Assuming that the tank is only supported by the rollers on the bottom, the diagram of this situation is shown below in Figure 15.

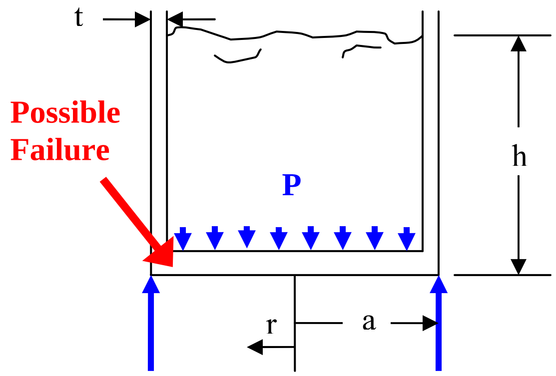


Figure 15. Free body diagram of the tank supporting 40 lbs. of fluid.

The pressure at the bottom of the tank is equal to ρgh, which equals 3.4 kPa. We treat the bottom part of the tank as a circular plate which is subject to a uniform pressure. Since the ends are simply supported from below and attached to the cylindrical portion of the tank, we consider the edge of the circular plate to be built-in (no deflection or change in angle). In this situation the bending moment is equal to the following:

$$M_{rr}(r) = -\frac{\omega_0\left((1+v)\cdot a^2-(3+v)\cdot r^2\right)}{16} \qquad \text{Eq. 2}$$

The maximum bending moment occurs at the outside of the plate (r = a) and is equal to 8.8 Nm. The resulting stress in the plate is described below.

$$\sigma_{\max} = \frac{6\left|M_{\max}\right|}{t^2} \qquad \text{Eq. 3}$$

The maximum stress (tensile and compressive) in the tank is 8.3 kPa. The yield strength of medium density polyethylene is 19.3 MPa and the fracture toughness is 3.8 MPa $\sqrt{m}$. This design doesn't come close to failing in this mode. Table 9 below shows the relevant parameters used in calculations.

Table 9. Values used for calculations

Parameter	Value
ρ	1000 kg/m^3
h	0.35 m
v	0.44
a	0.143 m
t	0.00635 m

Circumferential Stress When Rotating While the tank is rotating during the separation process the centrifugal forces from the fluid will put pressure on the side walls of the tank. A diagram of this situation is shown below in Figure 16.

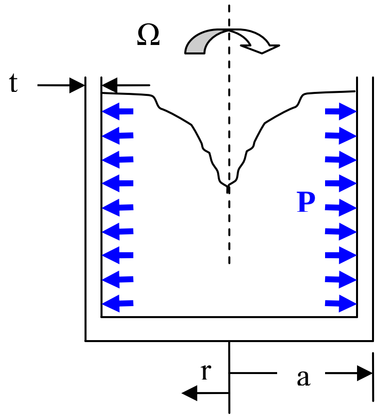


Figure 16: Free body diagram of the tank walls retaining rotating fluid.

To calculate the pressure the water exerts on the tank walls, we treat the water as an elastic-plastic material which yields at zero shear stress. We also assume that the tank is completely full of water when in fact it is only be 5/6ths full. The pressure distribution in the water will be:

$$P(r) = \rho \cdot \Omega^2 \left(r^2 - \frac{a^2}{2} \right) \qquad \text{Eq. 4}$$

The pressure at the inner surface of the tank wall will be 27.6 kPa. Assuming that the tank can be treated as a thin-walled cylinder, the circumferential stress will be:

$$\sigma_{\theta\theta} = \frac{P \cdot a}{t} \qquad \text{Eq. 5}$$

The stress will be 0.62 MPa in the tank wall. Since the yield strength of MDPE is 19.3 MPa, there is a safety factor of over 30 against yield. In addition, the critical flaw size needed to initiate a crack (mode-I conditions) will be extremely large. Table 10 below shows the values of the parameters used in calculations.

Table 10. Values used for calculations

Parameter	Value
ρ	1000 kg/m^3
Ω	52 rad/s
a	0.143 m
t	0.00635 m

CENTER OF MASS AND TIPPING ANALYSIS The full system was reduced into major components as seen in Figure 16, each with its respective x_{CM} and y_{CM} location and mass. Due to near perfect z-axis symmetry through the base centerline, z_{CM} was assumed to be zero. The x and y centers of mass were then calculated using Eq. 6, below.

$$x_{CM} = \frac{m_1 x_1 + m_2 x_2 + \ldots + m_n x_n}{m_1 + m_2 + \ldots + m_n} \qquad \text{Eq. 6}$$

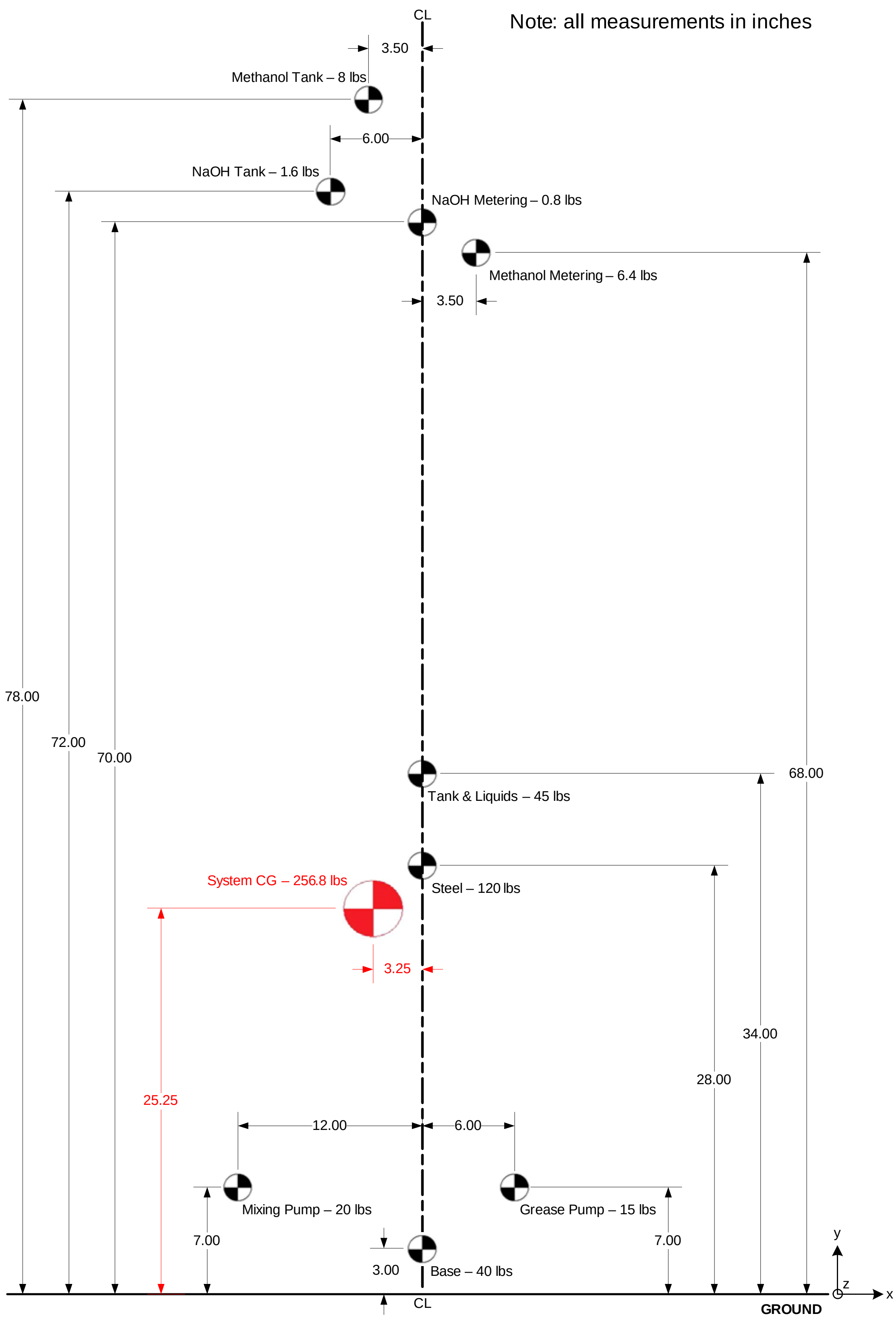


Figure 16: Center of masses for individual components and final COM for system

Because the base is 5 ft long and y_{CM} is slightly over 2 ft, tipping is highly unlikely. One would need to apply a force at the top of the structure while simultaneously keeping the casters locked against rolling, thereby pushing the system to an angle of 49.9°, as seen in Figure 17. This extreme angle yields very minimal danger of tipping in the x-y plane.

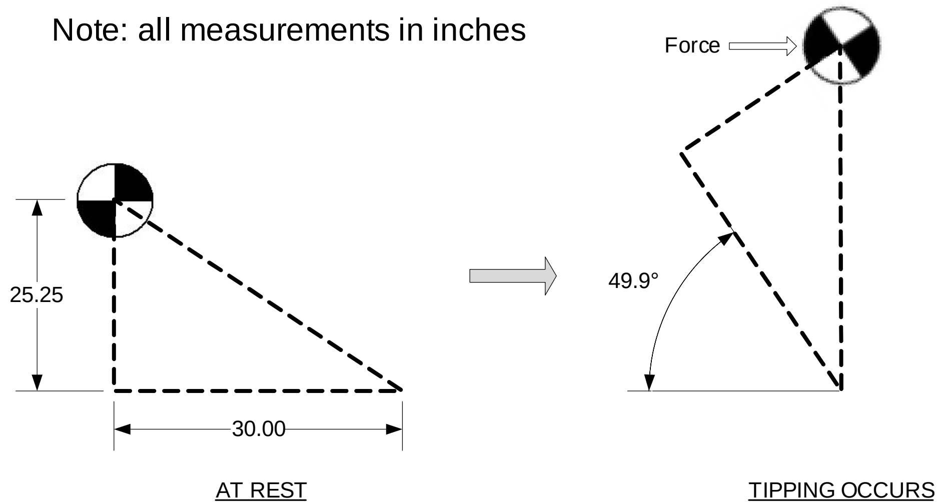


Figure 17: Tipping in x-y plane

The base is significantly narrower than it is long at 2.5 ft wide, so tipping was investigated further in the y-z plane. Figure 18 shows the smaller tipping angle in comparison to the x-y plane case.

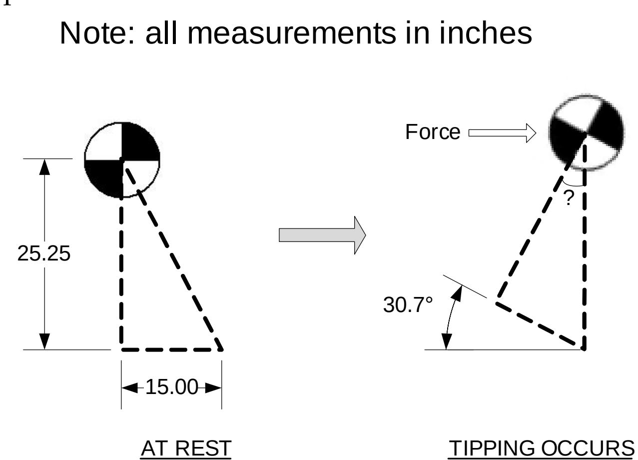


Figure 18: Tipping in y-z plane

To calculate the force necessary to achieve this tipping angle, a moment balance is first used to find the moment acting to keep the COM at its tipping point. Though the picture shows a force acting on the COM, we assume the largest moment arm available to the user (thus minimizing the force required for tipping), so the force is actually applied at the top of the structure, 80" from the ground. With the calculated tipping moment, one can determine the user-applied force required for tipping. This process is summarized in Eqs. 7 and 8.

$$M_{TIP} = mg\cos\theta \cdot 15 \qquad \text{Eq. 7}$$

$$Force = \frac{M_{TIP}}{80} \qquad \text{Eq. 8}$$

This process yields a user force of 41.42 lbf. The only likely scenario for tipping involves suddenly hitting a bump that stops the casters, and this involves an impulse force, not the constant force just calculated. Ultimately, the likelihood of a user *maintaining* a force greater than 41.42 lbf to the top of the structure for the time necessary to tip the base 30.7° is extremely small. The full system is thus determined to be stable in both planes of interest.

FAILURE MODE EFFECTS AND ANALYSIS Once we determined the general layout of our design we created a failure mode effects and analysis to identify the greatest failure risks and ways to mitigate them. For each of the main components of the system we determined the most likely possibilities for failure and determined the effect on the process as a whole. We used a scaling from one to ten to quantify the relative severity, cause, and subtlety of each mode of failure. The multiplication of these three parameters gives the Risk Priority Number (RPN), which quantifies the relative detriment to the system. For those failures with either a large RPN or a cheap or simple solution, we determined possible corrective actions to help mitigate the risk. We then re-calculated the RPN considering that the changes had been implemented and also calculated the percent reduction in RPN to quantify the effectiveness. From our analysis we found a need for fluid sensors downstream of the reactant valves, downstream of the biodiesel outlet valve, and after the mixing pump. We also determined that a flowmeter on the input oil line and a tachometer on the motor would help decrease the subtlety and severity of possible failures. These features are incorporated into the final design, but due to budget considerations we are unable to include them in the prototype. The full FMEA spreadsheet is shown in Appendix D.

DESIGN FOR MANUFACTURING AND ASSEMBLY We designed our prototype with ease of manufacturing and assembly in mind. We took several guidelines into account which are explained next along with how we applied them to our design.

Permit Assembly in Open Spaces Our design provides adequate space for assembly. All four sides of the support structure are open so there isn't any space where tools cannot reach. The mounting brackets for the support wheels are easily accessible and therefore allow the wheels to be attached. Also, the support bars on the top and bottom of the tank are bolted onto the side bars in areas with adequate clearance all around.

Standardize to Reduce Part Variety All bolts used for a given set of attachments are the same size. This includes the bolts for mounting the support structure to the base, mounting the support wheels in the brackets, and attaching the tank support beams to the side support beams. However, these sets of bolts are not the same size because each application requires a different length bolt.

Maximize Part Symmetry All of the steel parts used in our prototype are symmetric, which simplifies assembly procedures because orientation is not a factor. This includes the support legs and all support beams and support wheel brackets, the brackets used to attach the support legs to the baseboard are symmetric since no matter which way they are oriented the holes line up the same way.

Eliminate Fasteners We eliminated a lot of fasteners by allowing most of the support structure to be welded together. There are not any superfluous fasteners used in our prototype and some parts, including the mixing pump, were not attached because it was unnecessary.

Allow Access of Tools Going along with permitting assembly in open spaces, we made sure there was adequate room for the tools needed for assembly. For fasteners that incorporate a nut and a bolt we ensured there was access for tools at both ends.

DESIGN FOR THE ENVIRONMENT There were several guidelines which we considered in our prototype design. Although we were able to meet most of the guidelines, some were not possible to meet due to budget constraints.

Optimize Material Use We made a support structure to house all of our components rather than using a large board, thus reducing the amount of material used. However, due to budget constraints we were unable to avoid using PVC in our final prototype. Usually this is a material to avoid so we would have used stainless steel instead had it been feasible.

Optimize Production Techniques When considering production techniques we determined our product can either be assembled by hand or using robotics. An automated assembly plant would result in much larger production waste, but would also greatly increase the speed and volume of production.

Optimize Distribution Our entire product can be separated from the baseboard, thus reducing the size of container needed to transport it. This allows our product to be by a wider range of transports, including by air.

Reduce Impact During Use Our product runs off a typical wall outlet, requiring a maximum of 15 amps of current. No other energy sources are required during use. The inputs to the system are easily acquired – sodium hydroxide and methanol and by using waste cooking grease our product takes already wasted materials and makes them usable. Nothing harmful is produced from the operation of this product, and in addition to biodiesel, glycerin is produced, which can be used to make soap.

Optimize End-of-Life Systems The four main materials used in our prototype are recyclable, which includes steel, PVC, Polyethylene, and wood. Unfortunately our design required that much of the steel be welded together which results in greater difficulty in disassembly. The other recyclable materials can be easily removed and processed.

FINAL PROTOTYPE DESIGN

The final prototype design is shown in Figure 19. We use six manual PVC valves to replace the solenoid valves we initially planned on using. Once we realized that cost considerations would limit us from using a large number of solenoid valves, we then redesigned the system to use only two solenoid valves. We would have implemented a stainless steel 2-way valve and a brass 3-way, in addition to the four manual valves for the reactant metering. Even after working extensively with Kundinger Controls, a local process control distributor, we were unable to find solenoid valves that would fit within our budget.

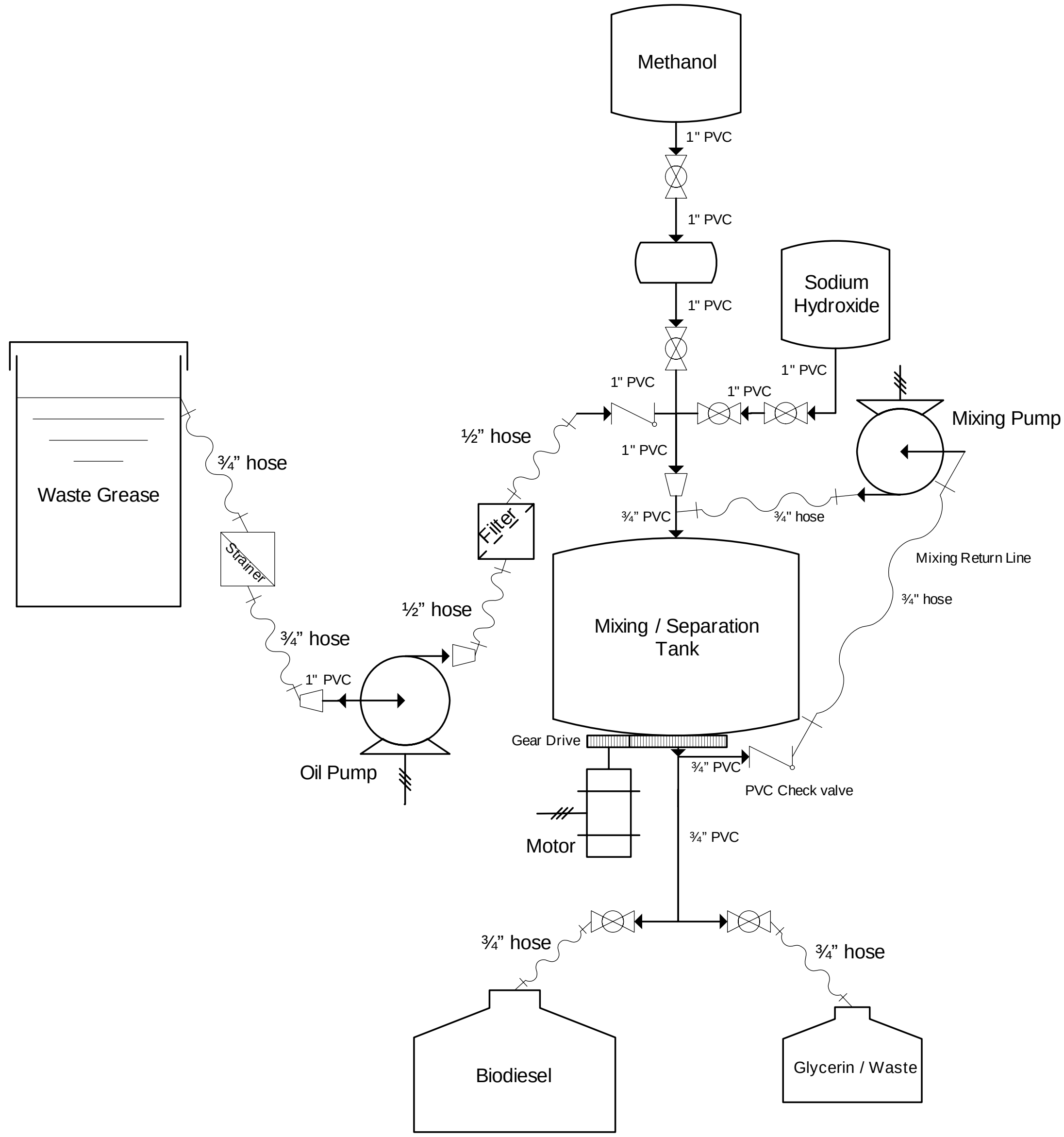
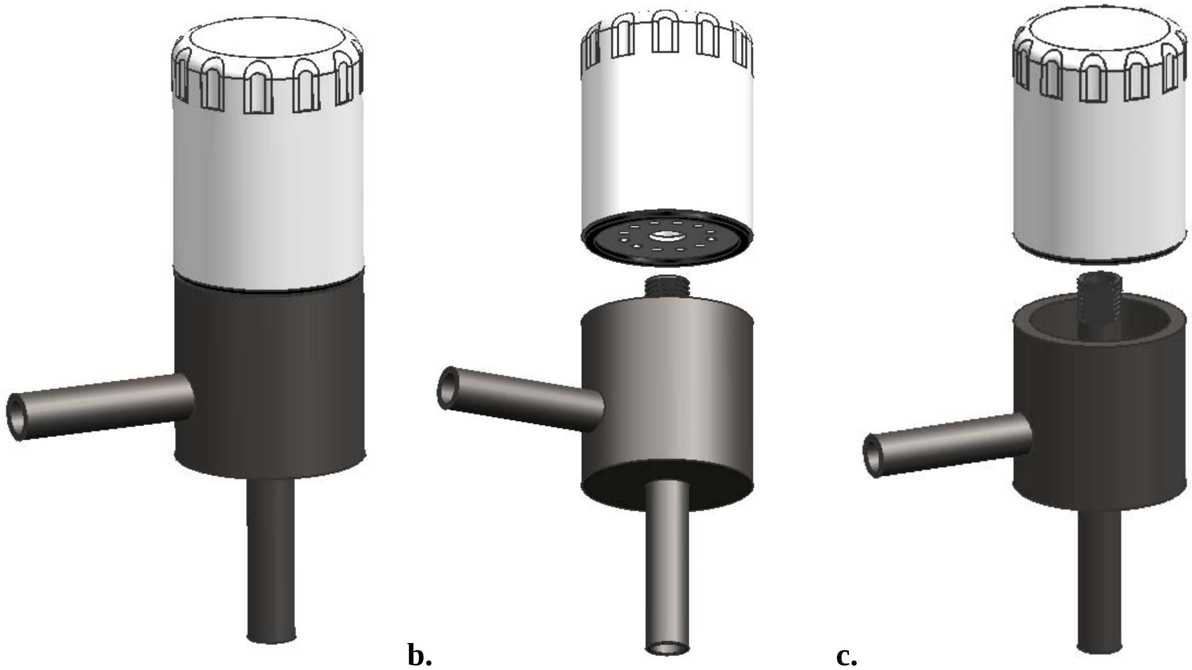


Figure 19. Final prototype design schematic

We chose to use mainly 1" PVC pipes to allow the fluids to move quickly through the system. Both on the inlet and outlet of both pumps we used flexible vinyl hose. We used ¾" on all connections except for the outlet of the oil pump, which was ½".

FILTERING A 400 micron strainer (Figure 8) will be incorporated before the oil pump and a Wix 57251 automotive oil filter will be located after the pump. The strainer is a self-contained unit which will be purchased from www.biodieselwarehouse.com. Locating the strainer in the oil line before the pump will stop large particles from entering the pump, preventing possible damage to the pump.

The WIX oil filter has a 19 micron rating which is sufficient for the waste oil entering the system. This unit is located after the pump and has a maximum flow rate of 12-15 GPM, which is larger than the flow rate of the pump so it will not cause a backup. The coupling (Figure 20) allows the filter to be connected in the inlet oil line and can be changed easily. See Appendix F1 for the engineering drawing.



a. **b.** **c.**

Figure 20. Oil filter with coupling (a) connected together (b,c) exploded to show connection

METERING We designed specific methods for metering in order to achieve the proper proportions of each of the three reactants. For the waste grease the oil pump will be timed to determine how long it takes to pump 4 gallons into the mixing/separation tank. For methanol metering an intermediate one gallon tank will be incorporated below the methanol storage tank with valves on the top and bottom (Figure 21 (a)).

This tank will be made with a four-inch diameter length of PVC pipe with end caps. A one-inch inlet tube is connected to the top and a similar tube for exiting out the bottom. Manual valves will control the flow of methanol in and out of the tank. The bottom valve starts out closed and the top valve opens until the tank is full. Then the top valve is closed and the bottom valve is opened until the tank empties.

The 0.102 gallons of NaOH needed is small enough so the two-inch PVC piping can be used to meter it with valves located a specific distance apart, as shown in Figure 21 (b). This will operate in the same way as the methanol metering tank, only on a much smaller scale.

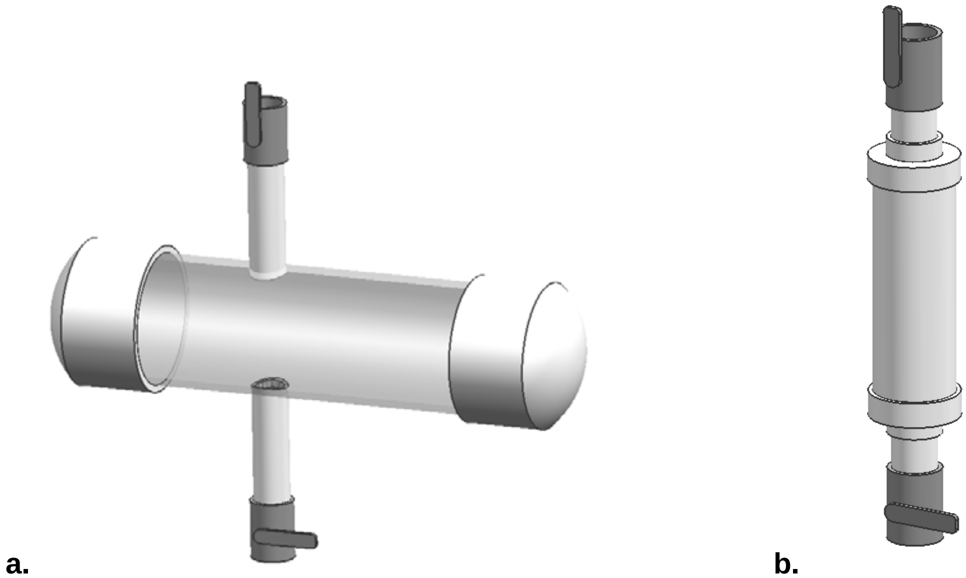


Figure 21. (a) Methanol intermediate metering tank and (b) NaOH metering pipe

MIXING We have decided on a pump to circulate the reactants in the mixing tank to achieve the desired level of mixing. Figure 22(a) shows the setup for the mixing pump and tank. The pump we will use for this is an 11 GPM stainless steel unit purchased from Biodiesel Warehouse. The stainless steel construction will ensure that the internal materials will not corrode when exposed to the reactants. The 11 GPM pump will completely re-circulate the reactants once about every 30 seconds and we feel that this will offer sufficient mixing. The mixing will rely on the level of turbulent flow and relative motion of the fluid. The pump will take the reactants from the bottom of the tank through the tank outlet tube and will pump them back to the inlet tube at the top of the tank. This process continues until the desired level of mixing is achieved.

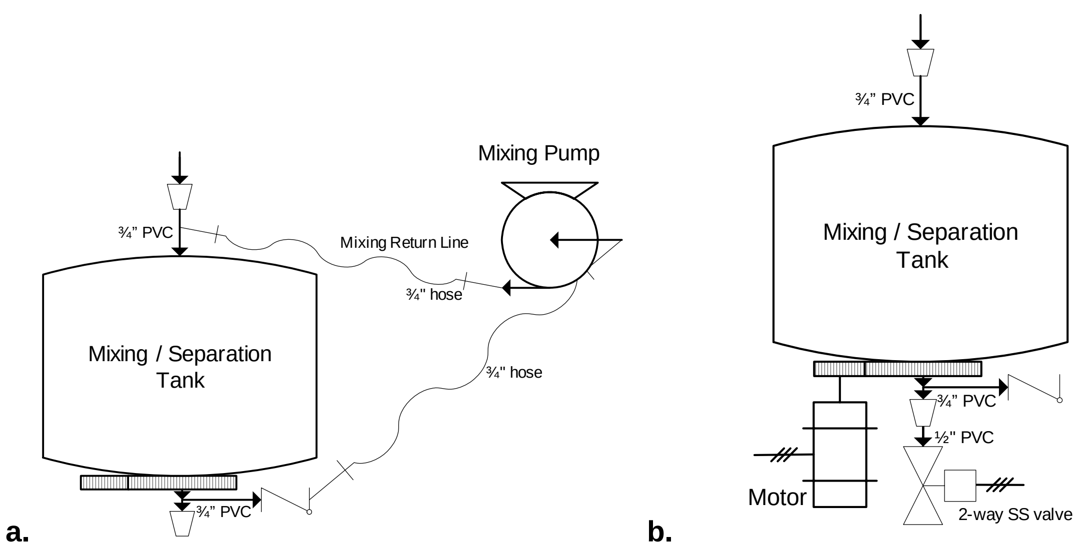
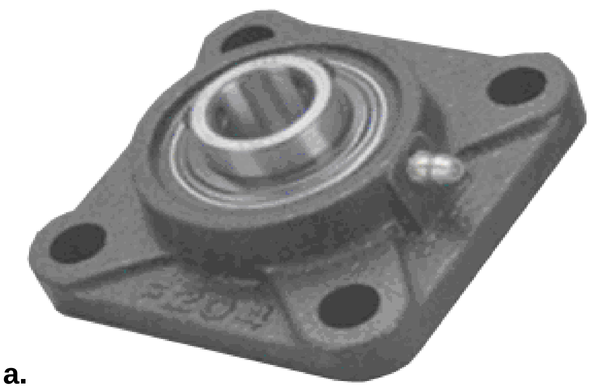


Figure 22. (a) Mixing pump setup and (b) Separation setup

SEPARATION The separation tank is the same tank which is used in the mixing step. For mixing the entire tank will spin on its axis at approximately 500 rpm. We used the work of previous groups by taking their recommendation for rotational speed. To accomplish this we chose a motor and will translate the torque using gears. Figure 20(b) shows the separation setup.

A 6.5” diameter gear will be attached to the tank and a 1.625” diameter gear will be attached to the motor shaft. This will decrease the rotational speed but increase the torque. The VXB ball bearing kit 7358 (Figure 23(a)) will be used at both the top and bottom of the tank to make sure the tank spins smoothly. The bearings will be attached to the inlet and outlet pipes, which will not spin. The motor to be used is a Bison32 DC motor (Figure 23(b)).



a.

b.

Figure 23 (a) Ball bearing kit and (b) Separation motor

To further support the tank while spinning, rubber wheels on ball bearing axis will be located around the tank both on the bottom and the sides.

SUPPORT STRUCTURE The mixing/separation, methanol, and sodium hydroxide tanks are each held in place by the primary support structure, as seen in Figure 24. The structure uses 2” L-type steel stock at its four corners, braced with 1” square-type steel between each leg. Attached to these braces are two crossing members that collectively support the mixing/separation tank at three points with medium hardness rollerblade wheels. Because of the significant load on these two crossing members, a large 2”x2” center support was added at their intersection. This type of wheel is also used around the sides of the tank to keep it spinning symmetrically; based on possible inaccuracies during construction, we made these wheels adjustable to enable the proper centering of the tank. The two methanol tanks combine for substantial weight to one side of the support structure, so the mixing pump was placed opposite them for counterbalancing. Based on observed stability during testing, additional structure bracing at the ground may or may not be required.

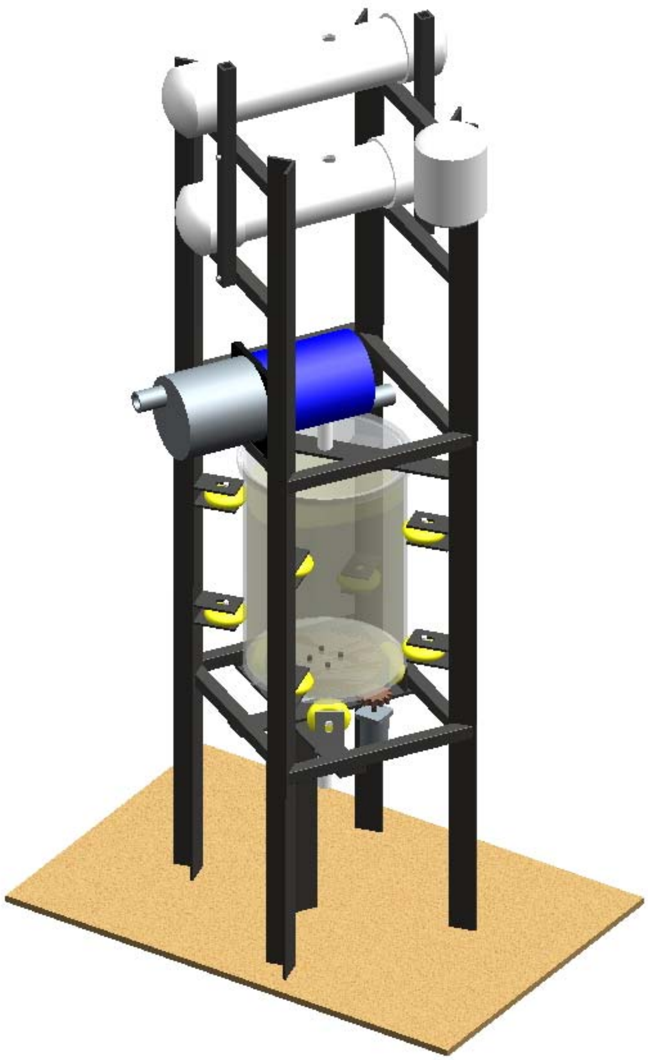


Figure 24. Support Structure

FULL SCALE TO PROTOTYPE COMPARISON We will not manufacture the full scale model of the system because the cost of all the components would exceed our budget, and because we have a limited manufacturing schedule that would not accommodate a larger system. The prototype represents a scaled model of the full scale design with a ratio of 1:5, or 5 gallon batch size to the full scale 25 gallon batch size.

System Layout The full scale model will be oriented horizontally to ensure safety and convenience for the operator. The fluid flow through the system will be achieved mainly through the use of pumps. Due to budget limitations, the prototype does not utilize as many pumps, but uses gravity to move the fluids through the system. The full scale model will have inlet pumps for the methanol and sodium hydroxide as well the waste grease.

Automation Cost limitations forced us to eliminate automation in the prototype; the full scale design will be entirely automated from start to finish. LabVIEW software will be used to turn each system component on and off, without additional user input. The three reactants can be metered using flow meters or by timing the inlet pumps. Due to the constant viscosity of the methanol and sodium hydroxide, timing the pumps for these two reactants would be equally accurate and less expensive than flow sensors. Using pumps to input the reactants decreases the number of valves required in the design, because it eliminates the metering tanks. Each remaining valve will be a solenoid valve that can be timed precisely to the reaction. The outlet valves will be timed based on the mixing and separation times and the predicted volumes of the products. The boundary layer will be included with the waste layer of glycerin to ensure the purity of the biodiesel.

Prototype Scaling Justification The scaling factor of 5:1 is small enough to allow for accurate comparisons to be made from the prototype to the full scale design in engineering calculations as well as practical application. By decreasing the batch size the group could save money by purchasing less methanol and sodium hydroxide, Table 10. The amount of reactants needed for the 5 gallon batch are 4.08 gallons of cooking oil, 0.82 gallons of methanol, and also 0.10 gallons of NaOH, per batch. The full scale model would require 16.33 gallons of cooking oil, 3.27 gallons of methanol, and 0.41 gallons of NaOH, for each batch. It also reduces the overall prototype construction costs because less material is needed to assemble the prototype system. The size of the required tank is reduced from a 30 gallon tank to a 6 gallon tank. The amount of required material for the support structure is less for a much smaller tank, although the exact same design will be used for the full system.

Table 11. Comparisons for reactant ratios for prototype and full scale model

Variables	Prototype	Full-scale	Units
Total Liquid Volume of tank	5.00	25.00	gal
Cooking Oil	4.08	20.41	gal
Methanol	0.82	4.08	gal
Sodium Hydroxide	0.10	0.51	gal

Table 12. Comparison of methanol and sodium hydroxide containers for prototype and full scale model

Methanol Metering Container

Variables	Prototype	Full-scale	Units
Volume of Methanol	0.82	4.08	gal
Diameter of pipe	4.00	8.00	in
Radius of endcaps	2.00	4.00	in
Length of inlet valve pipe	1.50	1.50	in
Length of exit valve pipe	1.50	1.50	in
Diameter of 1" valve pipe	1.00	1.00	in
Total Volume of Methanol	188.57	942.86	in^3
Volume of Fluid in Endcaps (x2)	33.51	268.08	in^3
Volume of Fluid in Valve pipes (x2)	2.36	2.36	in^3
Volume of Fluid in Pipe	152.70	672.42	in^3
Length of Methanol Pipe	**12.15**	**13.38**	**in**

Sodium Hydroxide Metering Container

Variables	Prototype	Full-scale	Units
Volume of Sodium Hydroxide	0.10	0.51	gal
Diameter of pipe	2.00	4.00	in
Length of fitting	1.00	1.00	in
Length of inlet valve pipe	1.50	1.50	in
Length of exit valve pipe	1.50	1.50	in
Diameter of 1" valve pipe	1.00	1.00	in
Total Volume of Sodium Hydroxide	23.57	117.86	in^3
Volume of Fluid in Fittings(x2)	1.13	3.13	in^3
Volume of Fluid in Valve pipes (x2)	2.36	2.36	in^3
Volume of Fluid in Pipe	20.09	112.38	in^3
Length of Sodium Hydroxide Pipe	**6.39**	**8.94**	**in**

The prototype will not be using a flow meter like the design of the full scale model. Instead the prototype will have a line marked on the outside of the tank at the correct volume for the grease input. The flow meter sensor is very expensive and using a length of time to automate the pump does not change the functionality of the system. Having an automated sensor would be a more accurate way of measuring the amount of cooking oil in the tank, but letting the user turn off the grease pump when the correct volume is reached will be sufficient for the prototype. The number of solenoid valves was also decreased in the prototype to cut the costs and these valves will be replaced with manual valves. Although the prototype is not automated, the design can be automated simply by substituting the automated components for the manual ones.

Mass Production Many cost factors need to be considered when planning to mass produce the full scale model. Table 13 below shows the cost of all the pieces for the full scale model when purchasing them from third party suppliers. The total cost for producing one system is around $1400. This estimate does not include the materials for the support structure, labor, or other small costs in tubing and PVC connectors. The estimate for the items shown is high because these products are not all discounted for purchasing large quantities and also they are not from a wholesale market. When taking into account the costs not included in the table it is expected that the overall cost will be around $2000 per system. When compared to other biodiesel conversion systems, this is a very competitive price for a fully automated system that will work quickly by using centrifugal separation

Table 13. Mass production for full scale design

Items	Price	Per 1000 Units	Price	Discount
Length of methanol metering 8" pipe	$14.60 /ft	1166.67 ft	$14,478.37	15% for 120 ft+
Length of methanol metering 8" pipe	$14.60 /ft	1500 ft	$18,615.00	15% for 120 ft+
Length of sodium hydroxide metering PVC	$6.18 /ft	750 ft	$3,939.75	15% for 600 ft+
Mixing/Separation container- 30 gal, polyethelene	$79.10	1000	$67,235.00	15% for 12+
Mixing pump- 11GPM, Stainless Steel	$159.00	1000	$159,000.00	
Oil Pump- 12 GPM	$49.00	1000	$49,000.00	
Methanol Pump- 12 GPM	$49.00	1000	$49,000.00	
Sodium Hydroxide Pump- 11 GPM Stainless Steel	$159.00	1000	$159,000.00	
Motor	$169.00	1000	$169,000.00	
Autofilter	$26.40	1000	$26,400.00	
Strainer	$29.00	1000	$29,000.00	
Solenoid valves (2 for system)	$400.00	1000	$400,000.00	
Flowmeter	$150.00	1000	$120,000.00	20%
Tachometer	$150.00	1000	$150,000.00	
		Total Cost	$1,414,668.12	
		Cost per System	**$1,414.67**	

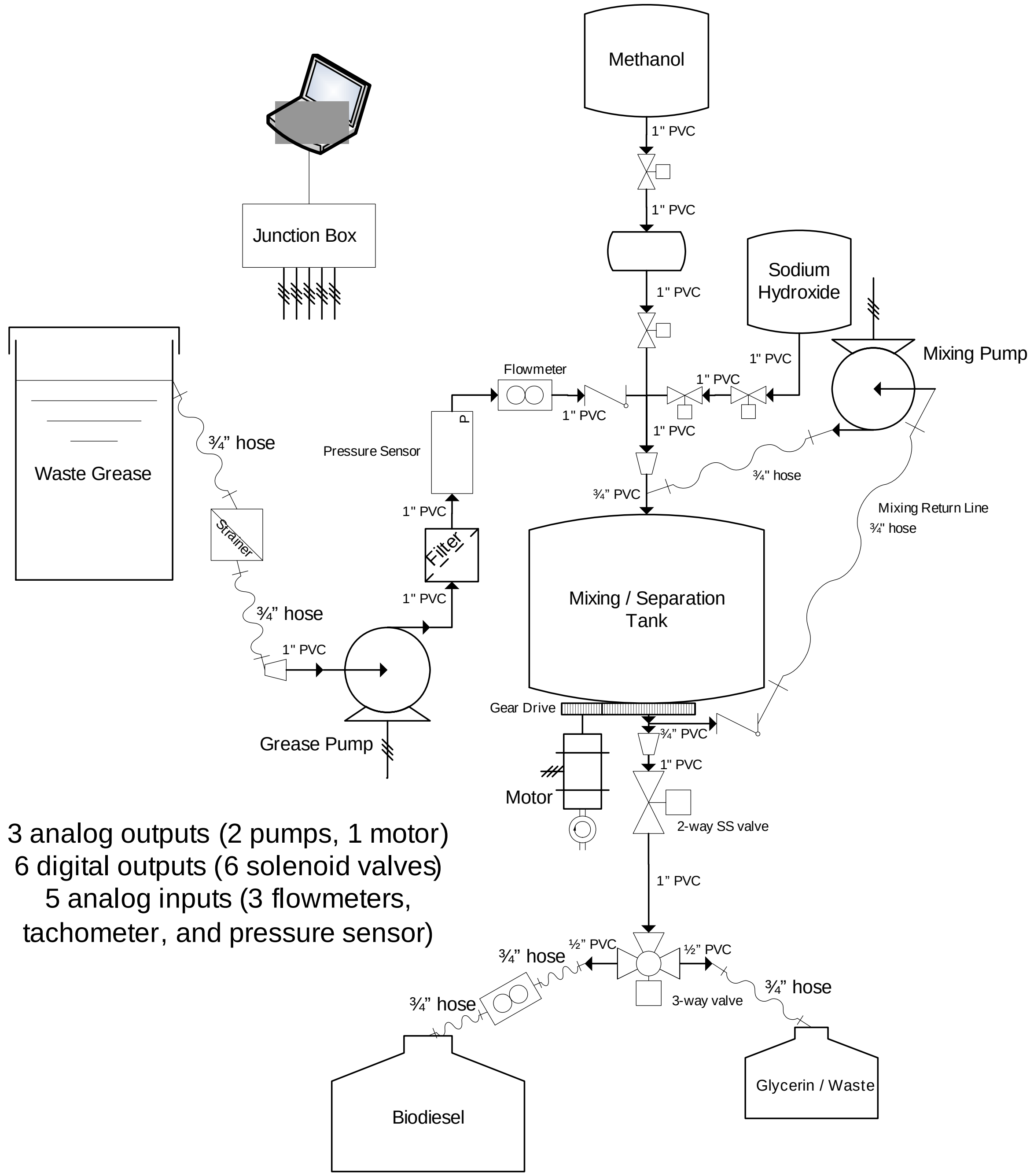


Figure 25. Final full-scale design schematic

PROTOTYPE MANUFACTURING AND TESTING PLAN

MANUFACTURING PLAN The prototype will be built from a combination of purchased and manufactured components. The purchased components can be seen in Table 14. The components that need to be manufactured in-house are described in Table 15. The mixing/separation tank is purchased; however, it will be modified to fit our design. Detailed manufacturing and assembly plans for each component are shown in Appendix E.

Table 14. Bill of Materials

Quantity	Part Description	Purchased From	Part Number	Price (each)
1	Waste Oil Pump	BioDiesel Warehouse	12 GPM Pump	$49.00
1	Mixing Pump	BioDiesel Warehouse	11 GPM SS Pump	$159.00
1	AutoFilter	Napa Autoparts	51515	$6.00
1	Strainer 400 microns	BioDiesel Warehouse	strainer	$29.00
1	piping/tubing/elbows	Home Depot	assorted	$300.00
1	Tank	United States Plastic Corp.	10105	$50.73
2	Bearing	VXB ball bearings	kit7344	$9.95
1	Separation Motor	Bisongear	Bison32	$169.00
1	Motor and tank gears	Martin Sprocket and Gear	S1624, S16104	$123.00
1	Oil filter relocation kit	Summit Racing	10695	$34.00
1	Rollerblades	MCSports	2529499	$63.00
Total				**$1,002.63**

Table 15. Manufactured Components

Quantity	Part Description	Raw Materials
1	NaOH Metering Tank	2 inch PVC pipe, 2" to 1" adapters
1	NaOH Holding Tank	4 inch PVC pipe, endcap, threaded top
1	Support Structure	1 inch square steel stock
		2 inch L-shaped steel stock
		2 inch square steel stock
1	Methanol Holding Tank	4 inch PVC pipe, 2 endcaps

Separation Tank We will use a third-party six gallon polyethylene tank for use as the separation tank. Prior to assembly and manufacture of the tank, we will obtain the parts shown below in Table 16.

Table 16. Separation Tank Hardware

Quantity	Hardware
2	VXB Flanged bearings
2	10”x10”x1/16” Sheets of stainless steel
2	3/8” Hex Bolts 1” long
2	1/4” Stainless Hex Bolts ½” long
2	1/4” Stainless Hex Bolts 1 ½” long
12	Washers (at least 3/8” inner)
1	Spur Gear
1	MDPE 6-gallon tank

The first step in the process will be to drill ½″ holes into both pieces of sheet metal at the locations of the bearing flange holes. In one of the sheets, we will also drill a ¾″ hole in the center. In the other sheet, we will drill four additional 3/8″ holes towards the corners. In the lid of the polyethylene container we will drill four matching holes. Then we will bolt one of the bearings to the sheet metal with the 3/8″ inch bolts. Afterwards, we will bolt the bearing-sheet assembly to the tank lid with the ¼″ stainless bolts (1/2″ long). Using the same pattern used on the pieces of sheet metal, we will drill four 3/8″ holes into the spur gear. The central hole of the gear will be drilled to 1.25″. The same four-hole pattern will be drilled in the bottom of the tank as well. We will then place the metal sheet into the bottom of the tank and attach the gear and bearing to the bottom by fastening all 4 parts with the 1 ½″ long stainless hexagonal head bolts. Once this is completed we will line up the bearings with the steel guides built into the structure and feed the PVC pipe into the bearings. The outer diameter of the pipe is 1.05″ and the inner bore of the bearing is 1.00″ so we will need to sand the ends of the pipe to allow for enough clearance for insertion. The engineering drawing for the tank assembly is shown in Appendix G.

ASSEMBLY The assembly instructions for the entire system are shown in Appendix G. The instructions assume the subassemblies (mixing/separation tank, filter housing, support structure, methanol holding tank) are complete. Assembly begins with the support structure. The separation tank, the methanol, and sodium hydroxide holding tanks are attached to the support structure. The motor and pumps are attached to the support structure, and all the components are connected physically with PVC pipe and hose. See Appendix G for detailed assembly instructions. The prototype system will be controlled through the LabVIEW software provided by the University.

TESTING PLAN In order to prove our prototype will meet the desired engineering specifications a series of tests will need to be performed. We will also measure the total weight of our prototype against the target weight of 200 pounds. We will confirm our engineering analysis with physical trials, and in some cases, obtain data that we could not obtain through calculations. Our testing is designed to minimize cost. The methanol and sodium hydroxide are the most expensive components of the testing process, so we will use alternate substances and reuse reactants whenever possible.

Other specifications which we know our prototype already meets are the filtration quality, reactant resistance, and batch size. The oil filter filtration level of 23 microns easily meets the 25-50 micron target and our planned batch size of five gallons is the target size. Also, we chose materials carefully in order to ensure no reactions will take place with the reactants.

Fill Time for Grease We have a rough estimate of how long it will take to pump the required amount of waste grease into the mixing tank based on flow rates. Due to the strainer and filter, the exact time to fill the tank with grease is an unknown. To time this process, we will pump the required volume of waste grease into the mixing tank, record the time, and recollect the reusable waste grease from the outlet. We will repeat this procedure multiple times and take an average of the values as our fill time. The filtration speed will be tested against the target speed of 5.5 gpm by timing how long a specified volume of waste grease passes through the pump and filtration system. The fill time will be programmed into the LabVIEW software, so that the grease pump turns on and off without much user input.

Fill Time for Methanol and Sodium Hydroxide In the prototype, the metering for the methanol and sodium hydroxide is controlled by manual valves. To obtain a realistic estimate of the time required to fill the metering containers, we will use a substance of similar viscosity (water) to time the process. The conservative time estimates will be included with the operating instructions.

Mixing and Separation Time To confirm the calculated appropriate mixing and separation times, we must run the system with the actual reactants, since separation and mixing cannot be visualized using water. We will ensure that the mixing pump runs for a sufficient time to mix the grease and sodium methoxide. We will then spin the tank until the products have separated and record the time. We will program conservative time intervals into the LabVIEW software for the mixing pump and separation motor run times. Our target times for mixing and separation are one hour and three hours, respectively.

Timed Solenoid Valves The only automated valves in the design are the solenoid valves below the separation tank. To determine the appropriate time to open each valve, we have to run the system with the actual reactants. We can estimate the relative volumes of the products based on our knowledge of the chemical reaction, and we can estimate the flow rates based on the valve diameter. We need to confirm that the engineering analysis is correct and allow for variations in proportions of the products. We will time the valves such that the boundary layer between the biodiesel and glycerin is let out into the waste container. This will waste a small volume of biodiesel, but preserve the quality of the end product.

PROJECT PLAN

In order to stay on task we made a plan to encompass all work that will be necessary to complete our project. There are four design reviews and a final design expo scheduled over a three month period of time. For the first design review we reviewed material from previous related projects, researched customer requirements, and developed engineering specifications. For the second design review we decided on a preliminary prototype and chose materials and parts to be used in the prototype. We spoke to Kelly Weaver [15], the head cook at South Quadrangle, who gave us an estimate of how much waste grease is produced in their kitchen. From this information we determined a rough estimate of 1200 pounds or 150 gallons of waste cooking grease produced each week across the entire campus, which could provide all of the fuel necessary for the vehicles used by the grounds crew. We also developed a by-component cost estimate to give our sponsor, John Deere, an idea of how much additional funding would be required. By the third design review we decided upon a final design while taking available funding into account, and modeled the project components using Unigraphics NX 4.0 and AutoCAD 2007. We also ordered necessary materials and began acquiring parts to be borrowed. A new prototype cost estimate was produced, based on new developments in component costs and necessary changes in our prototype design. The construction of our prototype was near completion by the fourth design review. We still had not obtained some vital components which were necessary to finish assembling the prototype. A manufacturing cost estimate was also produced. Before the final design expo we completed the assembly of our prototype and performed individual tests of the various components to ensure they worked properly, followed by the complete testing of our prototype. We also created a poster to summarize the project and what our prototype is capable of. A summary of our project schedule showing who will work on each task can be seen in the Gantt chart in Appendix B.

Building the prototype required welding, so our team attended a training session provided by Bob Coury, the mechanical engineering machine shop manager at the University of Michigan. Use of a testing lab was also necessary and was made available to us by Andres Clarens and Steven Skerlos. We did not encounter any other logistical problems.

TESTING

Our prototype met the majority of the engineering targets we initially required of our system. One of our main goals was that the system would only require one user action to create a batch of biodiesel. We were unfortunately unable to meet this target because of cost constraints. The prototype itself doesn't expose any of the reactants or products to an open environment. The only time the user will interact with an open container will occur when first priming the oil pump. We also ensured that all the materials used in the prototype are compatible with both the reactants and the products. We were able to achieve a quick oil filtration speed of approximately 5 GPM, which is very near our target. Although we have not performed any testing to determine the actual filtered quality of the waste oil, we are using a filter with a rated maximum particle size of 19 microns. This is much better than our goal of 25-50 microns. The cartridge filter used in our prototype is shown below in Figure 26.

Figure 26. Cartridge filter used in prototype.

The overall footprint area of our system is below the target of 20 ft^2. It can fit through most doorways and only requires one person for transport. Although we never weighed the full unit, we did determine that it was possible to lift with two people. Based on rough center of mass analysis, the overall system weighs approximately 250 lbs, 25% above our target value of 200 lbs. We determined this weight to be acceptable because of the maintained transportability. The system will never draw more than 200 W of electrical power if it is used appropriately, well below the limit of 900 W.

Our team performed four small scale experiments to determine the effect of varying the amount of sodium hydroxide in the reaction. We used four clean water bottles as containers for our experiments. We prepared 60 mL of a 5M (0.2 grams NaOH / mL H_2O) solution of sodium hydroxide by dissolving the solid crystals into de-ionized water. We poured 59 mL of methanol into each of the four bottles, then added 8.85 mL, 9.2 mL, 9.6 mL, and 11.1 mL of the sodium hydroxide solution to each respective bottle. These volumes will introduce 1.77 g, 1.84 g, 1.92 g, and 2.21 g of NaOH, respectively, into the reaction. We chose to test these amounts of base because used waste grease most commonly requires 6 to 7 grams of NaOH per liter of waste vegetable oil [16]. We then shook the bottles for approximately one minute to create sodium methoxide. We added 295 mL of waste grease to each of the bottles for a total volume of approximately 364 mL. The mixture was again shaken vigorously for one minute. After allowing the test reactions to settle for about 12 hours the glycerin and the fatty acid methyl esters had separated from each other and formed two distinct layers, as shown in Figure 27. All four trials were successful and produced biodiesel with identical visual properties. Upon further inspection, we noticed that the glycerin layer was a slightly larger proportion of the total volume for the trials with a larger amount of sodium hydroxide. For this reason, and to avoid wasting a costly chemical such as sodium hydroxide, we recommend the use of 6 grams of NaOH per liter of waste oil. To introduce this amount of base into our prototype the user should use a solution with a molarity of 6 (0.24 grams/mL). The large scale 5 gallon batch will require 92.5 grams of sodium hydroxide dissolved in 386 mL of water.

Figure 27. Four small scale biodiesel reaction experiments.

By performing a trial run of the system functionality we were able to validate the success of our metering, filtration, and mixing subsystems. After preparing a 6M solution of sodium hydroxide and procuring methanol, we poured these chemicals into their respective holding tanks. They were then released into the main holding tank and re-circulated with the mixing pump for approximately 1 minute. This re-circulates the entire volume about 11 times. At this time we turned on the oil delivery pump and began the filtration process. The oil pump produces sufficient flow to filter all the oil for one batch (4.08 gallons) in about one minute. As planned, the larger particles are caught in the strainer before they reach the pump. Once all three reactants enter the main holding tank we turned the mixing pump on for 5 minutes. This mixing time is significantly lower than our original target of 60 minutes. We then turned on the motor and began to spin the centrifuge. After the first 30 seconds of rotation we noticed that the mixture was leaking from the sealed area between the lid and the body of the tank. The increased pressure that the centrifugal force created at this interface forced openings in the silicone sealant. While we replaced this sealing material with one with better mechanical properties, we did not have sufficient time to validate the performance of the centrifuge. However, after allowing the mixture to settle for 48 hours we found that we had successfully produced about 4 gallons of biodiesel. This biodiesel had the characteristic amber color which was similar to the small scale results. However, this larger batch was slightly more cloudy, as shown in Figure 28 below. We believe that this is most likely the result of residue from the glycerin layer adhering to the outlet piping and slowly exiting with the biodiesel layer. The success of the large scale reaction validates the functionality of our metering, filtration, and mixing subsystems. The mixing process is especially efficient, achieving a mixture in one twelfth of our target time.

Figure 28. Comparison of full reaction results to small scale results.

The only aspect of our prototype which we were unable to validate was the centrifuge. Based on the work of previous design teams we feel that 30 minutes of centrifuge operation should be sufficient to separate 5 gallons of the product mixture. Previous groups have shown that the centrifugal design concept is an effective separation mechanism. The Fall 2006 design team validated a centrifuge design that is similarly shaped to our design. We were unable to test our prototype because of a leakage problem but it is otherwise fully functional. Assuming that our centrifuge is capable of achieving separation in 30 minutes, it will take approximately 55 minutes to produce one 5 gallon batch of biodiesel. This is more than four times better than our initial target of 4 hours.

FUTURE IMPROVEMENTS

STRENGTHS The overall design for our prototype does not need any major changes. It's greatest strengths are that the main functions operate as expected and perform the desired tasks. The grease pump quickly fills the tank with the necessary amount of grease, the mixing pump operates quickly, smoothly, and quietly, and the motor and gear design for spinning the tank works seamlessly. In addition, since our prototype produces a relatively large batch of biodiesel it could be used in a practical application. One of the major design improvements for our team was using only one tank for both the mixing and the separation processes. This drastically reduces the overall system volume, weight, and cost while making larger batch sizes much more economical. Although we were unable to incorporate a timing system (we bought timers from Home Depot but were forced to return them due to cost constraints), our system is user friendly. We wired switches between the power strip and the pumps and motor and placed them in a central location for easy access. We also positioned the power strip close to the switches to all the user to quickly cut all system power in the event of an emergency. The button panel is shown below in Figure 29.

Figure 29. Comparison of full reaction results to small scale results

WEAKNESSES Although the prototype produces the desired results, there are several improvements that could be made. These are not overall design changes, but minor alterations to the current design.

Tank and Lid The polyethylene tank and lid that were used in our prototype could be improved upon. The top did not fit adequately and even after several sealing attempts the tank still leaked between the tank and its lid. Also, the tank was not perfectly round and its bottom was not flat. This resulted in problems with the support wheels not making constant contact on both the bottom and sides of the tank. Using a stainless steel tank with a securely fitting top would eliminate these problems

Tank Ventilation Our design does not incorporate any way for air to escape. In our prototype air managed to escape through seals we put on the inlet tube and bearing, which then allowed fluids to leak through during separation. A ventilation system needs to be incorporated into the top of the tank to allow air to freely pass in and out of the tank. However, it could not allow fluids to pass through it since the tank would be spinning and the contents would most likely touch the venting system.

Tank Rotation Spinning the tank resulted in oscillations in the outlet piping despite our best efforts. This is because the bottom bearing was not mounted at the precise center of the tank. The holes drilled into the gear were very precise, but the screws used to mount the bearing into the tank were smaller in diameter than the screw holes on the bearing for mounting. These smaller screws allowed the bearing to be slightly off-center by shifting slightly with the larger screw holes, and the tube leading out of the bottom of the tank then oscillated when the tank spun. This off-center tube also connected the dispensing unit which created oscillations at the tip of the dispensing unit. The oscillations will cause excessive wear over time on the tank outlet pipes. To fix this problem extra care is required when mounting the bearing and gear concentrically with the tank.

Mixing Pump Line Drainage When the mixing procedure is complete, the mixing pump inlet and outlet hoses still contain fluid. This fluid remains in the hoses and is mixed with the methanol and sodium hydroxide of the next batch. The methanol and sodium hydroxide are supposed to be mixed together, before the addition of grease to the system, to achieve sodium methoxide. A possible solution is to add a T-fitting with a valve which could be opened to drain the fluid.

Grease Pump Inlet Line The grease pump requires a completely air free inlet line in order for it to function properly. We were able to achieve this by filling the line with grease using a funnel, which is a dirty and slow process. A method of keeping this inlet line air free is desired so the user does not have to fill it manually. Possible solutions are to use a pump that produces sufficient head so grease is still pumped in when air is encountered, or a check valve could be incorporated at the end of the inlet tube to prevent air from getting in and grease from getting out.

Power Supply Specifications The power supply we bought to use for the motor was rated to be used at up to 15 amps. This seemed sufficient because the motor was rated to operate at a maximum of 14.4 amps. This power supply did not work for the motor however, and a different power supply was used that could operate at higher than 15 amps and also could be ramped up and down accordingly. The motor should be tested to determine the exact power specifications required for operation.

Oil Titration In the future we would recommend performing a titration to find out the minimum amount of sodium hydroxide that will neutralize the FFAs for a given type of oil. We determined that the process will succeed with more than 6 grams of NaOH per liter of waste oil, but it would be useful to know the minimum amount that produce a high yield of biodiesel. This will allow the user to minimize the overall cost of the fuel because it will conserve the costly sodium hydroxide.

CONCLUSIONS

We have designed a prototype that safely and quickly converts waste grease to biodiesel in an enclosed system with little user input. Fuels from renewable biomass sources reduce greenhouse gas emissions. The use of virgin crops is responsible for the current high cost of biodiesel production and decreases the commercial feasibility of biodiesel as an alternate energy source, and using waste grease will greatly reduce this feedstock cost. We used previous University of Michigan research on the catalyst and alcohol specifics necessary for the biodiesel chemical reaction. Customer requirements focused on safety of operation, process efficiency, and system automation; engineering specifications were thus determined by a QFD diagram of these requirements. Our project plan equally distributes tasks among group members and insures appropriate amounts of time are devoted to certain tasks. Based on research and a thorough understanding of our motivation and customer need, the design process was efficient and yielded an innovative, user-friendly prototype.

We have narrowed many concept ideas down to those designed in further detail. Cartridge filtration, pumps for transport and mixing, separation and mixing in the same tank, an offset gear system for the separation motor, and a system of LabView-operated solenoid valves comprise the most fundamental results of funneling many concepts into their respective optimal solutions. Automation has proven to be too costly, however, and solenoid valves as well as precise pump and motor timing have been removed from the prototype. Original brainstorming did yield many valuable concepts for full-scale production, the most important among them being automation.

Though the centrifuge lacked sufficient testing due to faulty lid sealing, the bearing and offset gear setup proved to a valuable advancement in the overall progress of University of Michigan biodiesel systems. We built a system capable of producing larger, more practical batch sizes and in less time than any commercially available system, and with one less tank than typically employed in biodiesel systems.

ACKNOWLEDGEMENTS

We would like to thank the many people who assisted us throughout the design and construction of this project. Our project sponsor, Jim Phelan of John Deere made it possible for us to even be working on such a wonderful project. Thanks to our section leader for ME450 class, Professor Kazuhiro Saitou who gave us the valuable feedback on our progress and future steps to take throughout the project. To Professor Brent Gillespie for assistance with the electrical guidance, Professor Katsuo Kurabayashi for feedback of the manufactured system, and also the other ME450 Professors, Professor Shorya Awtar and Professor Suman Das. Thanks to the class GSI Mohammed Shalaby for the help printing the poster used at expo.

Very special thanks to the Machine Shop facilitators, especially Marv Cressey and Bob Courey, for all their assistance and welding expertise. Without their help in the shop along with the many other machine shop faculty we would not have a completed project. Thanks to Andres Clarens and Steven Skerlos for the use and assistance in the EASTlab for testing our prototype.

Thanks go out to Kristin Smak, dining services director for the Martha Cook dormitory. She generously donated fryer grease to our project in convenient 5-gal buckets—we were very fortunate for this size as they were easily transported.

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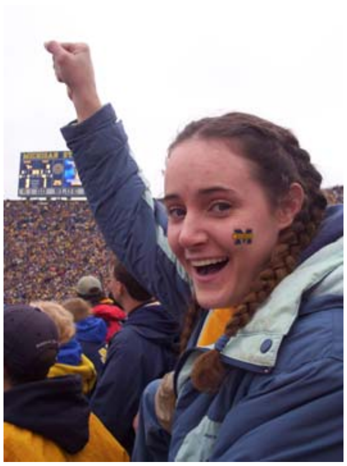
TEAM MEMBER BIOGRAPHIES

Abbey Gire



From the time I was a little girl I wanted to continue the family tradition of attending the University of Michigan. My grandfather and my father both received Mechanical Engineering degrees from the University of Michigan. My favorite things to do as a kid were to work puzzles, do logic problems, and beat my opponents in strategic games, so I was an engineer from the start. Both of my siblings are also wolverines, although neither of them are in the engineering school.

I grew up with my family in the small town of Coloma, Michigan. The 3 streetlight and 2 gas station filled town is one of the larger towns in the area. In high school I was a tri-athlete playing basketball, volleyball, and softball and following many other sports football, hockey, and golf. I spent most of my free-time outdoors at the local beaches, on the lake fishing, tubing, or skiing, and in my ten acre backyard.

After graduation I hope to move to Texas and work as an engineer while getting my masters degree in business. After a few years I want to move more to a management role and continue my way up through the company ladder. Besides having a family and spending extra time volunteering in my community, I also want to breed Labradors and start a program to train the dogs to become Guide Dogs.

Nate Jeffery

I am from Kalamazoo, which is about 90 minutes west of Ann Arbor. In my free time I enjoy creating music, watching films, and various outdoor activities.

My first introduction to the world of engineering was through technical drafting. From my affinity for drawing, I eventually realized that I wanted to be a part of the process of designing objects for use in engineering applications. Solid mechanics is the technical discipline that interests me most.

I have work experience in both utilities and aerospace engineering. I worked for Pfizer for two summers and at Parker Aerospace this past summer. At Parker, I worked on developing and testing the hydraulic pump for a new Boeing aircraft.

I plan to continue my education at U of M by pursuing an MSE in ME in the SGUS program. I will focus on design/manufacturing and solid mechanics. I hope to one day become the technical leader of a design team. I would like to work in aerospace (commercial aircraft / space travel) or the automotive industry.

Jessica Schulte

I grew up in southeast Michigan, but I finished my high school career in Grand Rapids, MI. My family still resides there. My family has moved about every seven years, so I've become used to adapting to new experiences and making new friends. I'm from a family of six, and I am second in the line of four kids. I love being home with my family, and there is never a dull moment with my older brother and two younger sisters.

I decided to study engineering because I was good at math and science in high school and because of my love for problem solving. I came to college thinking I wanted to study biomedical engineering, but within my first year, I decided to broaden the scope of my degree. I chose mechanical engineering because I love being able to see and touch the results of my work. I enjoy being able to see what is happening in a mechanical system. I'm excited to see where my passions take me in the future.

I am currently undecided in my plans immediately following graduation in April. I know that I want to pursue something nontraditional, but how that will materialize is still a fluid concept. Right now, I'm pursuing an internship to work abroad for up to a year. Hopefully I will be placed in Spain. Whatever I do, I know that I will continue to pursue my joys of running, Spanish, and finding creative solutions to the problems around me.

Jared Snow

I was born in Kalamazoo, Michigan, from which I moved away for much of grade school but eventually returned for high school.

My interest in mechanical engineering stems from an early interest in Lego's and later from tearing apart automobiles with one of my best friends. The interaction of each mechanical piece and the amazing tolerances to which they were machined always fascinated me. In the future, I plan to gain several years experience with a BSE degree and go back to school later for an MSE or possibly MBA, depending on my interest in and the industry demand for each option.

I thoroughly enjoy traveling, especially to places where I can use my SCUBA certification to see tropical animal and plant life. I hope to dive shipwrecks after graduation, preferably in freshwater like the Great Lakes where they have been nearly perfectly preserved.

Ross VanDyk

I was born and raised in Grand Rapids, MI, and that is currently where my parents live. I developed a liking for cars at a young age. Since then I've been interested in cars and how they work, as well as how other mechanical devices work. Mechanical Engineering seemed like a good match for these interests, hopefully being a field which will allow me to exercise my mechanical mind.

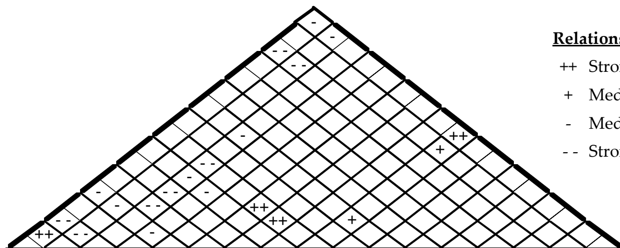
After graduating at the end of this term I hope to have a full time job related to mechanical engineering, and more specifically, to automobiles. On August 10 of this year my girlfriend of six years and I will be married and I will put her through her last year of college next year. My goals in regards to my career are based on supporting a family and enjoying what I do.

I enjoy building model cars – something that gives my great satisfaction upon completion. I have also done extensive work on my own car (the red car in the picture) and friends' cars. The transmissions in the picture were the new and old from replacing the transmission in my fiancée's car. And I enjoy surfing immensely.

APPENDICES

APPENDIX A: QFD DIAGRAM

Quality Function Development (QFD)



Relationships

- ++ Strong Positive
- \+ Medium Positive
- \- Medium Negative
- \- - Strong Negative

Engineering Specifications

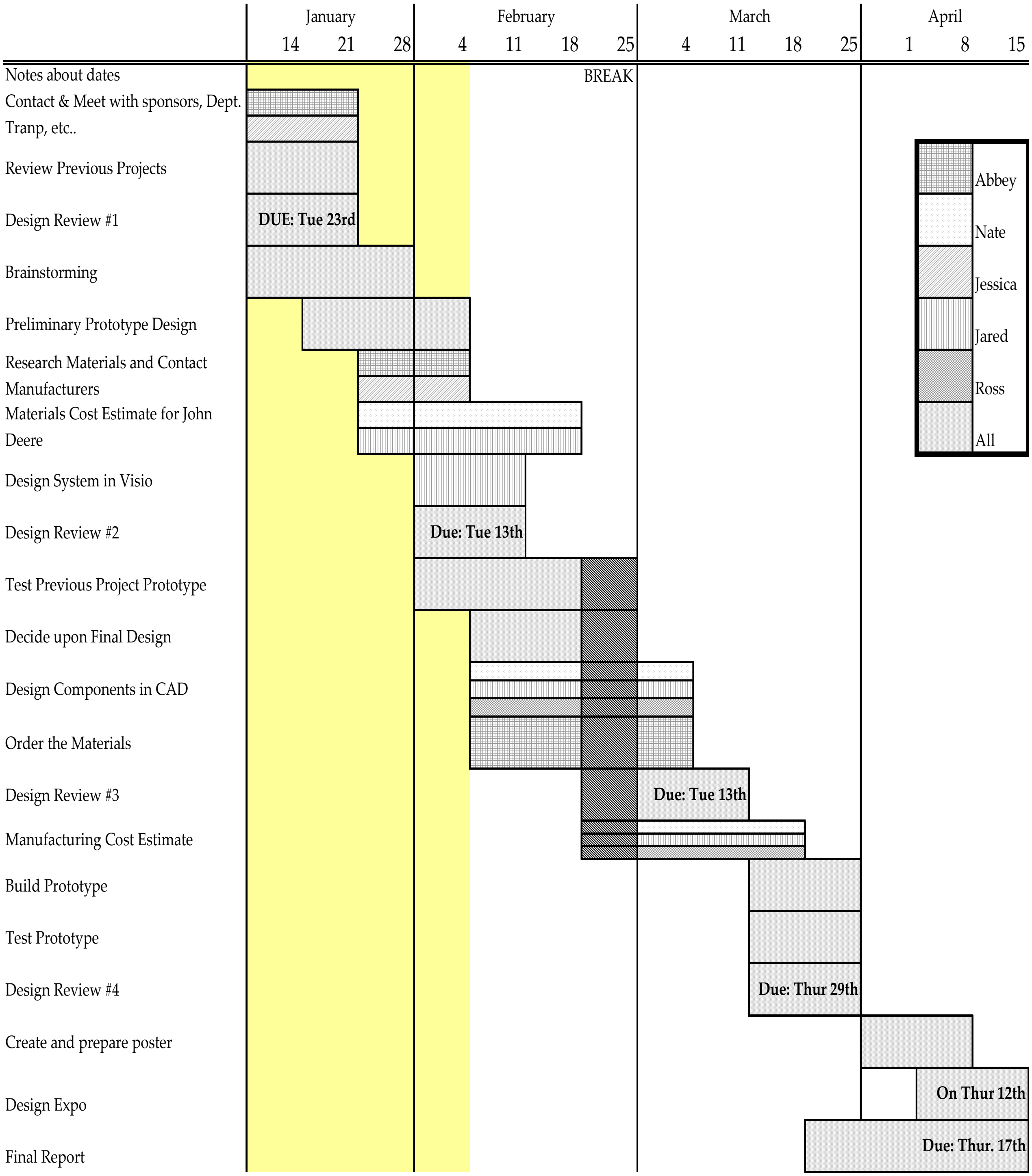
Benchmarks

Customer Requirements	**Weight***	Overall Unit Size	Weight of System	Batch Size	Temp. of Grease	Pump Power	Mixing Time	Separation Time	Power Consumption	Batch Time	Filtration Quality	Filtration Speed	Resistance to NaOH	Resistance to CH3OH	Strength of Container Mat'ls	Containment of Elements	Motor Decibel Level	Level of Automation	Deepthroat 100B	Freedom Fueler	FuelMeister II
Safe to operate	10		3	3	9	3			3		1	1	9	9	9	3		9	1	3	2
Enclosed system components	10	3		1							1					9			1	3	3
Limited manual labor	10							9	3	3		3				3		9	1	3	3
Easy to supply inputs/receive outputs	8	1		3							3								1	2	1
Small amount of time required per batch	8		3	9	3	3	9	9	3	9		9						3	2	3	3
Easy to clean and maintain	6	3		1	1						9		3	3	3	9			2	3	3
Quick to start/shutdown	4			1		1	1		3	1									2	3	2
Small unit size	4	9	9	9		1	3	3								9			2	1	3
Easy to relocate	4	9	9	3					1							3			1	1	3
Low cost	3	3	3	3	9	9				1	3		1	1	3		3	9	4	1	2
Low operating noise	1			1		9			3								9		3	2	2
Good visual appeal	1	3													3	9			2	2	3

	Overall Unit Size	Weight of System	Batch Size	Temp. of Grease	Pump Power	Mixing Time	Separation Time	Power Consumption	Batch Time	Filtration Quality	Filtration Speed	Resistance to NaOH	Resistance to CH3OH	Strength of Container Mat'ls	Containment of Elements	Motor Decibel Level	Level of Automation
Measurement Unit	ft^3	lbs	Gal	°C	gph	min	min	W	hr	%	s	N/A	N/A	Pa	N/A	dB	N/A
Target Value	20	100	30	25		60	120		4			yes	yes	high	yes		high
Importance Rating	**5**	**5**	**3**	**5**	**15**	**15**	**4**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**1**	**17**	**2**
Total	140	135	204	147	98	88	174	103	109	107	112	111	111	120	261	18	231
Normalized	0.06	0.06	0.09	0.06	0.04	0.04	0.08	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.12	0.01	0.10
Deepthort 100B	10		26	-	-	40	-	-	-	-	-	yes	yes	high	no	-	low
Freedom Fueler	41.3	100	40	-	720		-	-	24	-	-	yes	yes	med	yes	-	low
FuelMeister II	16.6	98	43.5	-	-	10	-	-	12	-	-	yes	yes	med	yes	-	low

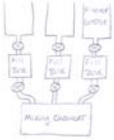
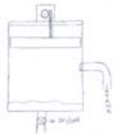
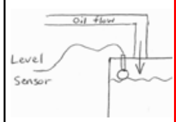
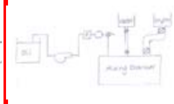
Key:
9 => Strong Relationship
3 => Medium Relationship
1 => Small Relationship
(blank) => Not Related

APPENDIX B: GANTT CHART



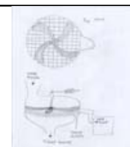
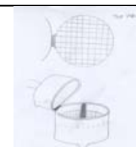
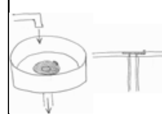
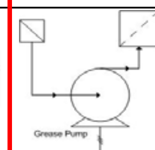
APPENDIX C.1: PUGH CHART - METERING

Impact	
+	Positive
-	Negative

Customer Requirement	Weight	Previous group	Idea 1	Idea 2	Idea 3	Idea 4
Component		Metering	Metering	Metering	Metering	Metering
Description		Input by hand into intermediate tanks	Intermediate tanks for all reactants.	Piston operated vacuum cylinders.	Pumping the oil into the mixing chamber, level sensor	Pumping the oil into the mixing chamber, flowmeter
Sketches						
Safe to operate	10	-	-		+	+
Enclosed system components	10	-	-	-	+	+
Limited manual labor	10	-	-		+	+
Easy to supply inputs/receive outputs	8	-	-			+
Small amount of time required per batch	8		+	-	+	+
Easy to clean and maintain	6		-	-	-	-
Quick to start/shutdown	4		+	-		+
Small unit size	4		-	-	-	+
Easy to relocate	4	-				
Low cost	3		-	-	+	-
Low operating noise	1		+			-
Good visual appeal	1	-	-		+	+
	Total +	0	3	0	6	8
	Total -	6	8	6	2	3
	Total	-6	-5	-6	4	5
	Weighted Total	-43	-39	-35	32	45

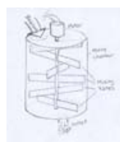
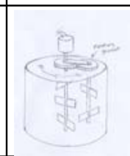
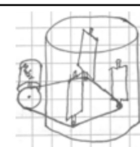
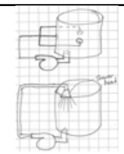
APPENDIX C.2: PUGH CHART - FILTRATION

Impact	
+	Positive
-	Negative

Customer Requirement	Weight	Previous group	Idea 1	Idea 2	Idea 3	Idea 4
Component		Filtration	Filtration	Filtration	Filtration	Filtration
Description		Bag Filters : Course and fine.	Self-cleaning coarse screen filter.	Removable coarse screen filter.	Open coarse screen filter.	Coarse strainer and fine cartridge filter.
Sketches						
Safe to operate	10		+	+	-	+
Enclosed system components	10		+	+	-	+
Limited manual labor	10	-	+	-		+
Easy to supply inputs/receive outputs	8				+	
Small amount of time required per batch	8		+	+		+
Easy to clean and maintain	6	-		+	+	
Quick to start/shutdown	4					+
Small unit size	4		-	+	-	+
Easy to relocate	4					
Low cost	3	+		+	+	
Low operating noise	1		-			
Good visual appeal	1	-	+	+	-	+
	Total +	1	5	7	3	7
	Total -	3	2	1	4	0
	Total	-2	3	6	-1	7
	Weighted Total	-14	34	32	-8	47

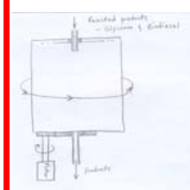
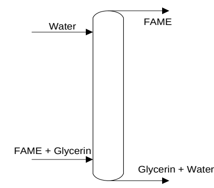
APPENDIX C.3: PUGH CHART - MIXING

Impact	
+	Positive
-	Negative

Customer Requirement	Weight	Previous group	Idea 1	Idea 2	Idea 3	Idea 4
Component		Mixing	Mixing	Mixing	Mixing	Mixing
Description		Paint stirrer.	Motor powered shaft with mixing vanes.	Motor powered planetary gear system, dual shafts with vanes.	Belt-driven paddles.	Pump re-circulation.
Sketches						
Safe to operate	10		+	+		+
Enclosed system components	10	-	+	-	-	+
Limited manual labor	10	-	+	+	-	+
Easy to supply inputs/receive outputs	8	-	+	+		
Small amount of time required per batch	8		+	+		+
Easy to clean and maintain	6	+	-	-	-	+
Quick to start/shutdown	4		+	+		
Small unit size	4					+
Easy to relocate	4					
Low cost	3	+	-	-	+	+
Low operating noise	1		-	-		
Good visual appeal	1	-	+	+		
	Total +	2	7	6	1	7
	Total -	4	3	4	3	0
	Total	-2	4	2	-2	7
	Weighted Total	-20	41	21	-23	51

APPENDIX C.4: PUGH CHART - SEPARATION

Impact	
+	Positive
-	Negative

Customer Requirement	Weight	Previous group	Idea 1	Idea 2
Component		Separation	Separation	Separation
Description		"Donutfuge" centrifuge	Centrifuge with stationary valves.	Water washing column.
Sketches				
Safe to operate	10	-	+	+
Enclosed system components	10	-	+	+
Limited manual labor	10	-	+	
Easy to supply inputs/receive outputs	8	-	+	-
Small amount of time required per batch	8		+	-
Easy to clean and maintain	6		-	
Quick to start/shutdown	4		+	
Small unit size	4		+	-
Easy to relocate	4	-		-
Low cost	3		-	-
Low operating noise	1		+	
Good visual appeal	1	-	+	
	Total +	0	9	2
	Total -	6	2	5
	Total	-6	7	-3
	Weighted Total	-43	47	-7

APPENDIX D: FMEA DIAGRAM

Component	Failure Modes	Failure Effect	Severity	Failure Cause	Frequency	Current control/solution	Subtlety	RPN	Actions Recommended	Additional Equipment Needed	New Severity	New Frequency	New Subtlety	New RPN	% Reduction of RPN
NaOH Container	Leaks NaOH	Safety hazard for user	10	Holes in tank, low strength	1	Make sure container is strong and without defect, prevent mechanical failure through calculations.	3	**30**	Current control is sufficient.		10	1	3	**30**	0%
	Container corrodes	Contaminated reaction process	6	Unexpected material reaction with NaOH	1	Correctly choose container material	10	**60**	Current control is sufficient.		6	1	10	**60**	0%
NaOH Delivery Valve	Both valves fail to shut	Excess NaOH will be added, contaminating the reaction	9	Poor valve, incorrect control scheme	1	Spec high quality valves, choose correct control scheme	3	**27**	Current control is sufficient.		9	1	3	**27**	0%
	Valves leak	NaOH will be added during reaction, during other system operations, contaminating batches	9	Poor valve quality, valve degradation or corrosion	5	Spec high quality valves, ensure material compatibility	10	**450**	Incorporate a flow sensor which sends an alarm to the system if reactants are flowing at inappropriate times.	Fluid or flow sensor.	9	5	1	**45**	90%
	Valve corrodes	Valve material will be introduced into reaction, valve will be damaged	7	Incompatible material in valve	5	Spec high quality valves, ensure material compatibility	10	**350**	Inspect valve after 5+ runs.		7	3	4	**84**	76%
Methanol Container (2)	Leaks methanol	Safety hazard for user	7	Holes in tank, low strength	1	Make sure container is strong and without defect	3	**21**	Current control is sufficient.		7	1	3	**21**	0%
	Container corrodes	Contaminated reaction process	6	Unexpected material reaction with Methanol	1	Correctly choose container material	10	**60**	Current control is sufficient.		6	1	10	**60**	0%
Methanol Delivery Valve	Both valves fail to shut	Excess Methanol will be added, contaminating the reaction	9	Poor valve, incorrect control scheme	1	Spec high quality valves, choose correct control scheme	3	**27**	Current control is sufficient.		9	1	3	**27**	0%
	Valves leak	Methanol will be added during reaction, during other system operations, contaminating batches	9	Poor valve quality, valve degradation or corrosion	5	Spec high quality valves, ensure material compatibility	10	**450**	Incorporate a flow sensor which sends an alarm to the system if reactants are flowing at inappropriate times.	Fluid or flow sensor.	9	5	1	**45**	90%
	Valve corrodes	Valve material will be introduced into reaction, valve will be damaged	7	Incompatible material in valve	5	Spec high quality valves, ensure material compatibility	10	**350**	Inspect valve after 5+ runs.		7	3	4	**84**	76%
Oil Pump	Doesn't pump at all	The oil will not fill the mixing chamber, the level sensor will not actuate the valve or pump, and the process will not continue.	4	Broken or clogged pump, possible filter clogging, incorrect control signal.	3	High quality pump with appropriate control.	4	**48**	If flow from a flow meter is below a certain value, shut down the process.	Flow meter on oil input line.	4	3	1	**12**	75%
	Pumps with insufficient pressure	The oil will take excessively long to fill mixing tank or process will not continue if no fluid flows.	4	Pump power is too low, filter pressure drop is too high.	3	High power pump.	6	**72**	Current control is sufficient.		4	3	6	**72**	0%
	Reverse pumps	Entire oil batch will be contaminated	9	Poor quality pump, incorrect electrical input	2	Do a good job of spec-ing pump, buying high quality	9	**162**	Add check valve to oil inlet line	Check valve.	9	1	9	**81**	50%
Filtering Unit	Clogs with debris (no flow)	Level sensor will not actuate valve and pump shutoff. Manual filter cleaning will be necessary.	9	Improper pre-filtering, too fine a secondary filter. Grease with an excessive particle count.	4	Filter in at least 2 stages, making sure that the filtration isn't too fine.	2	**72**	Make filter easy to remove and clean.		7	4	1	**28**	61%
	Allows very low flow	Filling will take an excessively long time.	2	Improper pre-filtering, too fine a secondary filter. Grease with an excessive particle count.	5	Filter in at least 2 stages, making sure that the filtration isn't too fine.	4	**40**	Current control is sufficient.		2	5	4	**40**	0%
Oil Delivery Check Valve	Fails to restrict opposite flow	NaOH and methanol could enter the grease tank and contaminate.	7	Faulty valve, improper control output	3	Spec proper valve, use proper control	7	**147**	Test with water.		7	2	6	**84**	43%

Mixing Pump	Pump fails	Reactants are not mixed, products are not as desired.	8	Faulty pump, pump power too low.	2	Properly spec pump.	4	**64**	If flowmeter senses no flow, send command to stop process and seek maintenance.	Fluid or flow sensor after the mixing pump.	8	2	2	**32**	50%
	Either valve fails to actuate	Reactants either go straight to the separation unit or products keep circulating in mixing tank.	8	Poor valve quality, valve degradation or corrosion, poor control design	2	Properly spec valves.	5	**80**	Current control is sufficient.		8	2	5	**80**	0%
Mixing Pump Check Valve	Fails to open during pumping	The pump will run dry, possibly causing damage to the rotating group, the reactants will not be mixed, causing a compromised batch.	8	Check valve requires too much pressure to force open (the spring is too stiff).	3	Choose valves that require low pressure (may be costly or compromising to do so).	4	**96**	Test possible valves with water at pump pressure.		8	1	3	**24**	75%
Motor	Motor fails	Separation unit does not spin and the system will release unseparated glycerin and FAME.	8	Faulty motor, improper control input	2	Properly spec motor, proper control system.	2	**32**	If no rotation is sensed by the tachometer, display warning message and halt all processes.	Tachometer on the motor.	8	2	1	**16**	50%
Separation Tank / Bearing	Central bearing(s) fails	The separation unit may become unstable, creating a danger; motor may be overtaxed. Could spin the pipe and valve system, creating damage to the hardware.	10	Dirty internal surfaces of bearing, faulty bearing.	4	Spec self contained, well lubricated bearings.	1	**40**	Current control is sufficient.		10	4	1	**40**	0%
	Roller(s) bearing(s) fails	The wheel will provide increased resistance to the tank and the motor may become overtaxed.	2	Dirty internal surfaces of bearing, faulty bearing.	3	Spec self contained, well lubricated bearings.	5	**30**	Current control is sufficient.		2	3	5	**30**	0%
	Gear disengages	Gear may come loose and create a user hazard; the tank will come to a rest and the separation will not occur.	10	Improper matching of gears or unacceptable height difference due to poor stackup.	4	Properly spec belt/gear and provide reliable tensioning method.	1	**40**	If the separation tank quickly loses speed, display warning message, halt all processes, cut off motor power.	Tachometer on the motor.	7	4	1	**28**	30%
2-way Outlet Valve	Fails to shut	All reactants are poured straight into waste tank, all reactants are wasted.	3	Faulty valve, poor control.	2	Use high quality valve.	3	**18**	Current control is sufficient.		3	2	3	**18**	0%
	Valve Leaks	Small amounts of reactants flow into the glycerin tank and are wasted.	2	Faulty valve	2	Use high quality valve.	10	**40**	Current control is sufficient.		2	2	10	**40**	0%
3-way Outlet Valve to Holding Tanks	Fails to switch direction of flow	Glycerin flows into the FAME tank or vice-versa and contaminates the whole batch.	9	Faulty valve	3	Use high quality valve.	3	**81**	Current control is sufficient.		9	3	3	**81**	0%
	Valve Leaks	Small amounts of glycerin may flow into the FAME tank and contaminate the whole batch.	8	Faulty valve	3	Use high quality valve.	10	**240**	Incorporate a flow sensor which sends an alarm to the system if reactants are flowing at inappropriate times.	Flow sensor or fluid sensor downstream of the biodiesel outlet 3-way valve.	8	3	5	**120**	50%
***All scales from 1-10															
RPN Code															
0-100															
100-200															
200-300															
300-above															

APPENDIX E.1: MANUFACTURING PLAN – FILTER COUPLING

Step	Material	Operation	Tool	Description
1	4” D PVC pipe	Cutting	Band saw	Cut pipe to 4” length, ensure smooth edges
2	PVC end cap	Attaching	PVC adhesive	Attach endcap to one end of the 4” PVC pipe
3	PVC	Drilling	1” Drill bit	Drill hole through one side of 4” PVC pipe
4	PVC	Drilling	1” Drill bit	Drill hole through center of end cap
5	Steel 1” D pipe	Cutting	Band saw	Cut inlet pipe to desired length
6	Steel 1”D pipe	Threading	Die	Thread end of pipe to mate with oil filter
7	Steel	Welding	Shielded metal arc welder	Attach stopper around diameter of steel pipe
8	-	Attaching	Adhesive	Insert steel pipe through end cap hole, making sure threads extend beyond the pipe and stopper touches end cap, attach.
9	1” D PVC pipe	Cutting	Band saw	Cut to desired length
10	-	Attaching	PVC adhesive	Insert PVC pipe into previously drilled side hole, attach

APPENDIX E.2: MANUFACTURING PLAN – METHANOL METERING

Step	Material	Operation	Tool	Description
1	4” D PVC pipe	Cutting	Band saw	Cut pipe to 16.4” length
2	PVC end cap	Attaching	PVC adhesive	Attach end caps to ends of PVC pipe
3	PVC	Drilling	1” Drill bit	Drill inlet and outlet tube on opposite sides of 4” D PVC pipe
4	1” D PVC pipe	Cutting	Band saw	Cut two lengths of pipe to length
5	-	Attaching	PVC adhesive	Insert PVC pipes into either hole, attach
6	1” manual valve	Attaching	Adhesive	Attach valves to ends of PVC pipes

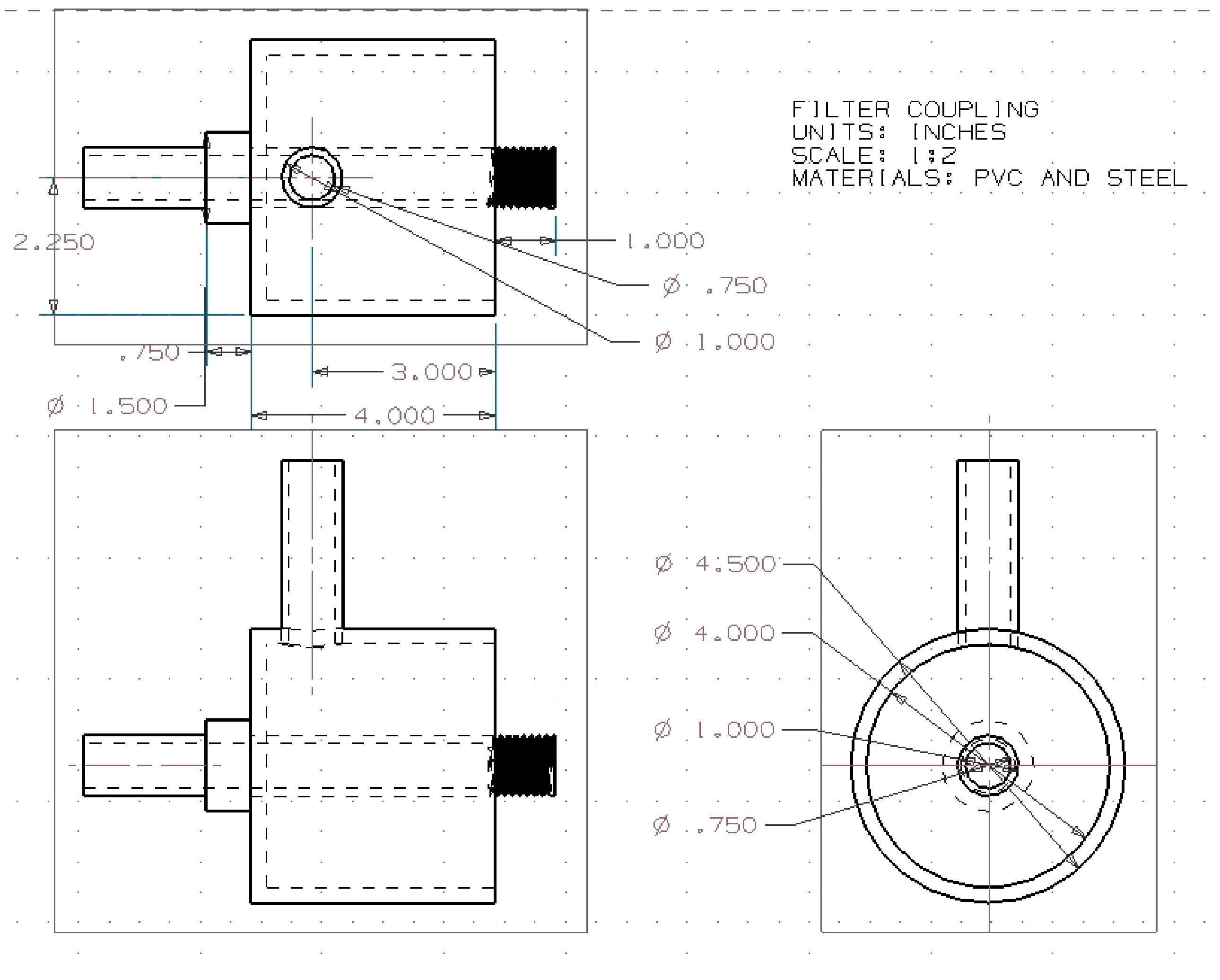
APPENDIX E.3: MANUFACTURING PLAN – NAOH METERING

Step	Material	Operation	Tool	Description
1	1" D PVC pipe	Cutting	Band saw	Cut pipe to desired length
2	1" manual valve	Attaching	Adhesive	Attach valves to both ends of pipe

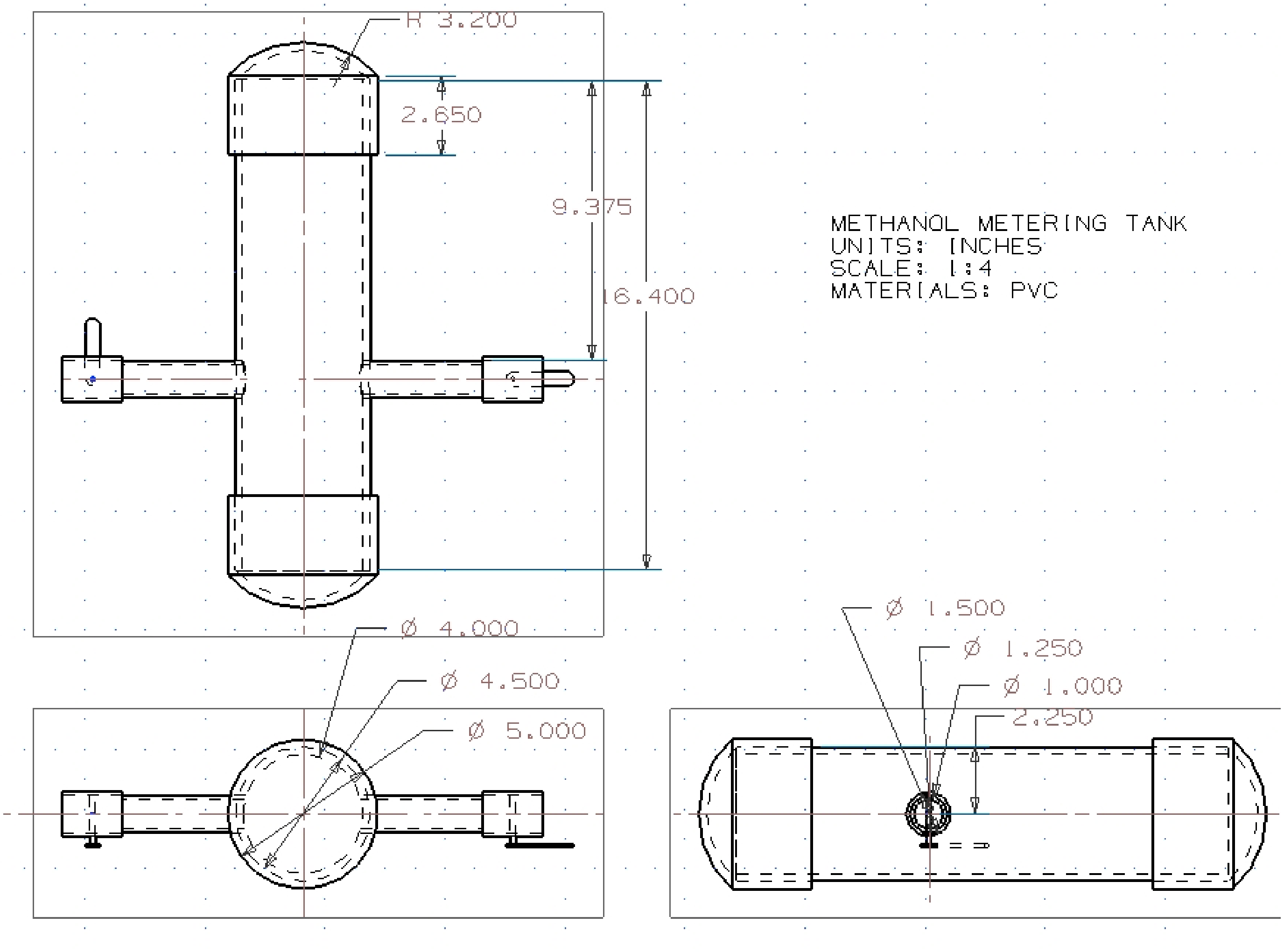
APPENDIX E.4: MANUFACTURING PLAN – SUPPORT STRUCTURE

Step	Material	Operation	Tool	Description
1	2" Steel L-bracket	Cutting	Band saw	Cut 4 main support legs to desired length
2	1" square steel stock	Cutting	Band saw	Cut 8 side supports to desired length with 45 deg. end angles
3	-	Welding	SMA welder	Weld side supports to support legs
4	2" Steel plate	Cutting	Band saw	Cut 3 tank supports to desired lengths
5	2" Steel L-bracket	Cutting	Band saw	Cut 2 center support lengths
6	Steel	Welding	SMA welder	Weld 2 center supports lengthwise to form 2" square support
7	Steel	Drilling	1" Drill bit	Drill hole through center of two tank support plates (for pipe to secure to)
8	Steel	Welding	SMA welder	Weld top tank support to support structure
9	Steel	Drilling	¼" Drill bit	Drill holes in bottom 1" square side supports and through bottom tank supports
10	Steel	Attaching	¼" bolts	Bolt tank supports to side supports
11	Steel	Welding	SMA welder	Weld center support to underside of tank supports
12	2" Steel plate	Cutting	Band saw	Cut wheel support brackets
13	Steel	Drilling	½" Drill bit	Drill holes through wheel support brackets for wheel axles
14	Steel	Welding	SMA welder	Weld wheel brackets to support structure in desired locations

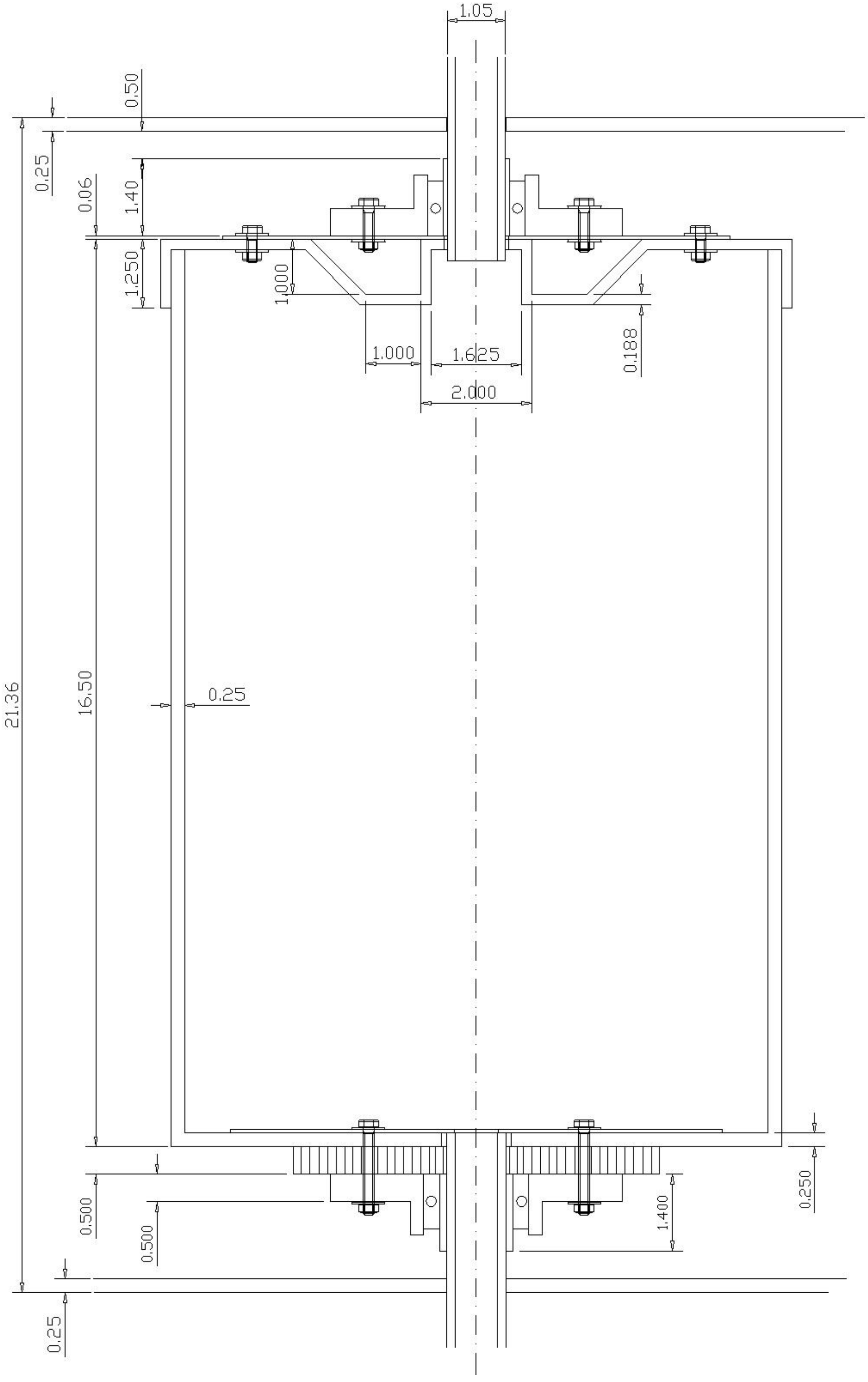
APPENDIX F.1 OIL FILTER COUPLING ENGINEERING DRAWING



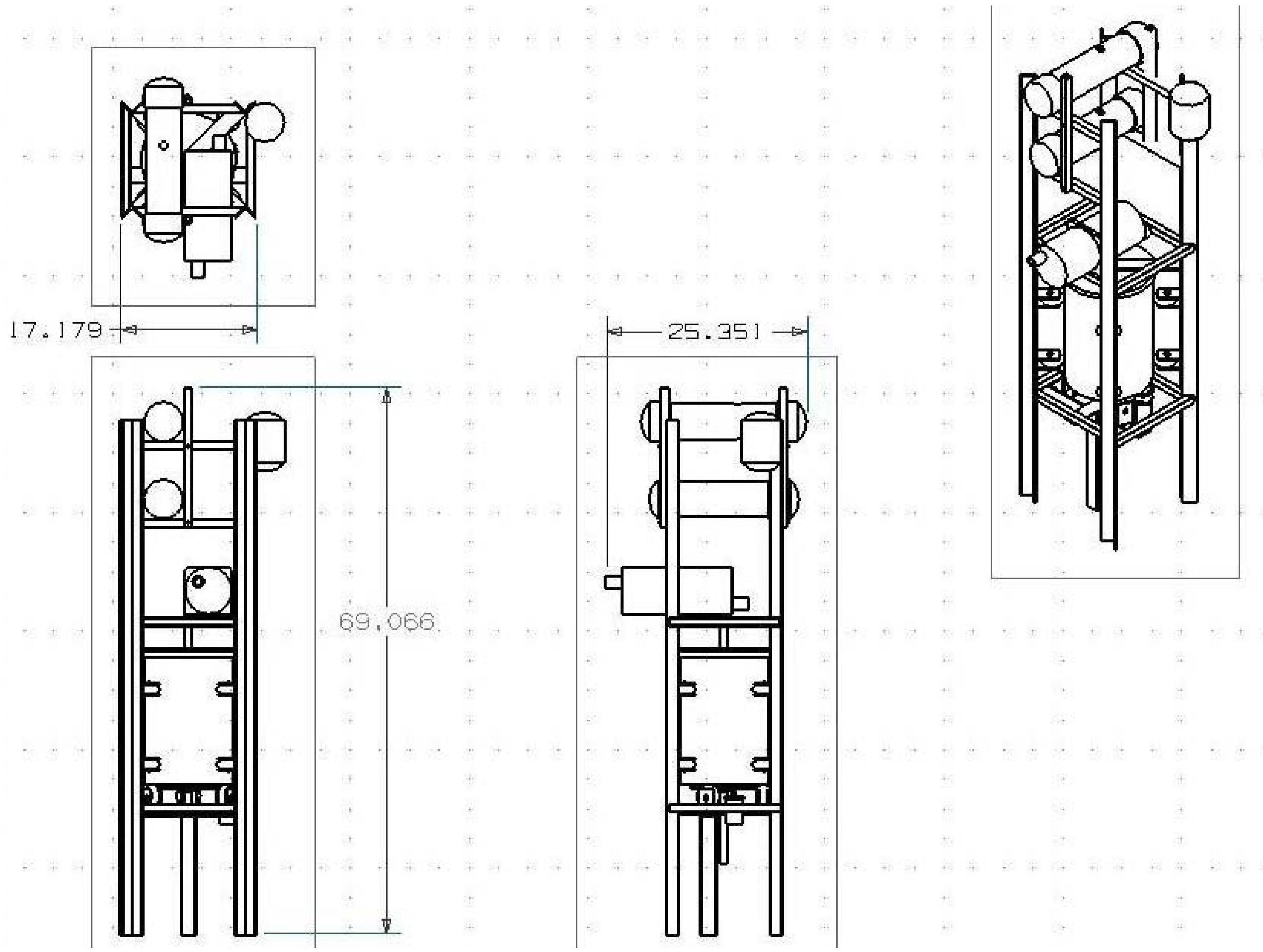
APPENDIX F.2 METHANOL METERING TANK ENGINEERING DRAWING



APPENDIX F.3: TANK ASSEMBLY ENGINEERING DRAWING



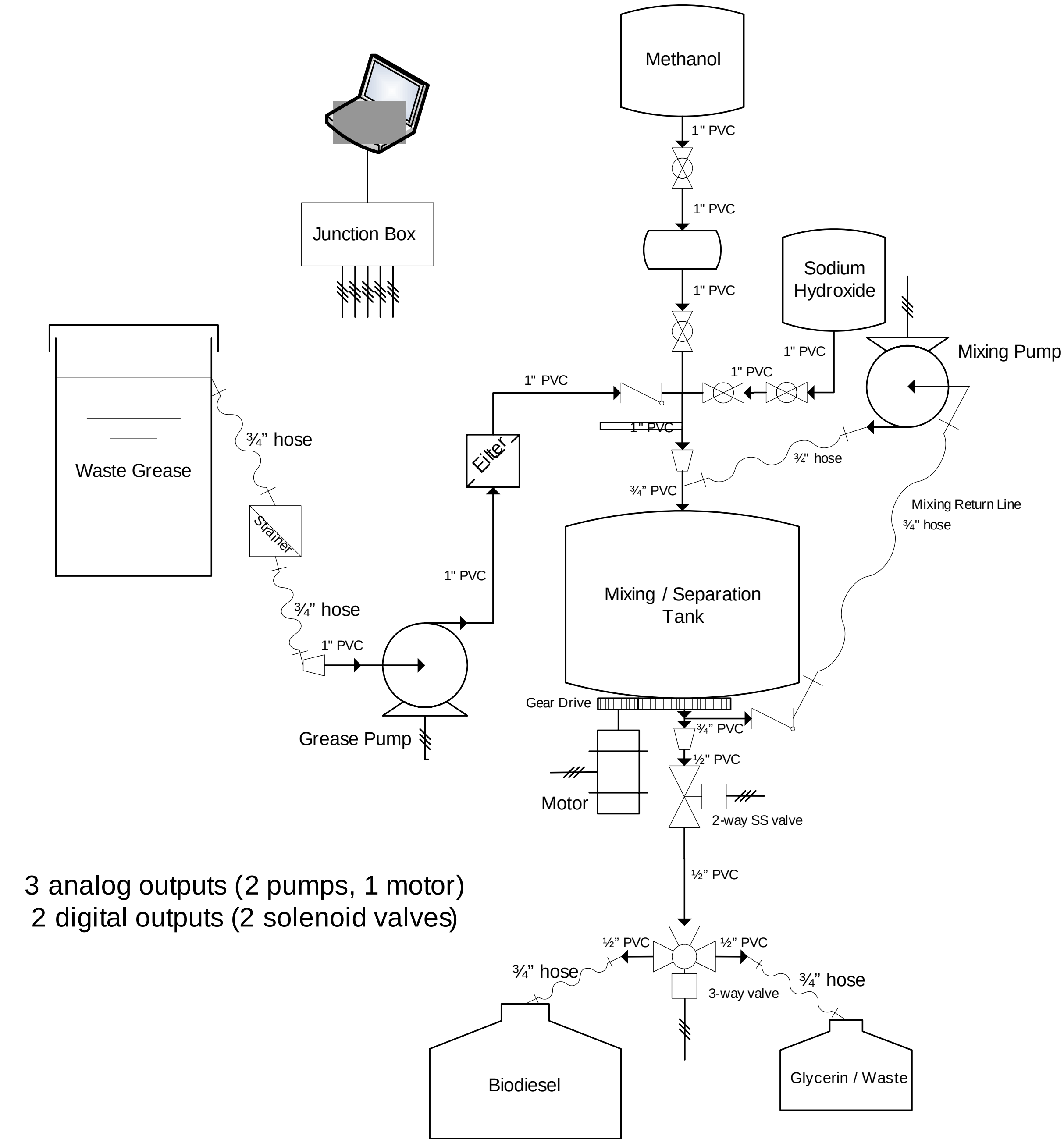
APPENDIX F.4: SUPPORT STRUCTURE ENGINEERING DRAWING



APPENDIX G.1: ASSEMBLY INSTRUCTIONS

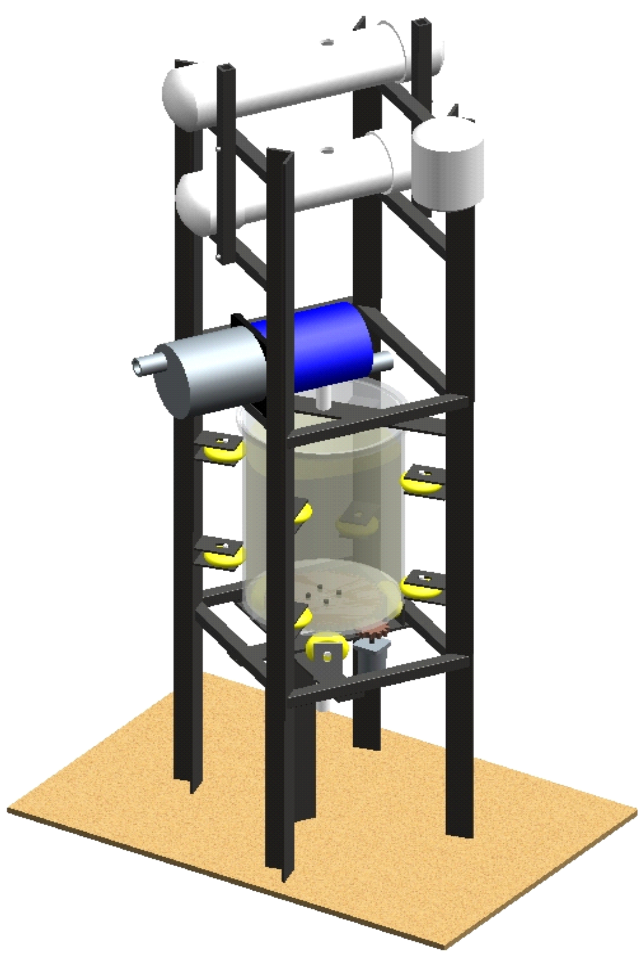
Category	Step	Action
Support Structure	1	Attach rollers to support structure
	2	Attach driven gear to mixing/separation tank
	3	Place mixing/separation tank in support structure
	4	Enclose mixing/separation tank with top set of rollers and support structure
Below Tank	5	Attach driving gear to motor
	6	Attach motor to support structure
	7	Insert 3/4" inch PVC pipe into bottom of mixing/separation tank
	8	Connect 3/4" 3-way connector below 3/4" inch PVC pipe
	9	Connect 3/4" inch PVC pipe below 3/4" 3-way connector
	10	Connect 1/2" pipe below 3/4" pipe with reducer
	11	Connect 2-way solenoid valve to bottom 1/2" PVC pipe
	12	Connect 1/2" PVC pipe to bottom of 2-way solenoid valve
	13	Connect 3-way solenoid valve to bottom of 1/2" PVC pipe
	14	Connect 1/2" PVC pipe to 2 outlets of 3-way solenoid valve
	15	Use fittings to connect 3/4" hose to each outlet 1/2" PVC pipe
	16	Place biodiesel and waste containers on floor below support structure
	17	Feed 3/4" hose into biodiesel and waste containers
Above Tank	18	Insert 3/4" PVC pipe into top of mixing/separation tank
	19	Connect 3/4" 3-way connector above 3/4" PVC pipe
	20	Connect 3/4" PVC pipe directly above 3-way connector
	21	Connect 1" PVC pipe above the 3/4" PVC pipe with reducer
	22	Connect a 4-way connector above 1" PVC pipe
Methanol Track	23	Connect 1" PVC pipe directly above 4-way connector
	24	Connect 1" manual valve above 1" PVC pipe
	25	Connect 1" PVC pipe directly above manual valve
	26	Connect methanol metering tank above 1" PVC pipe
	27	Connect 1" PVC pipe above metering tank
	28	Connect 1" manual valve above 1" PVC pipe
	29	Attach the methanol holding tank to support structure
	30	Connect the methanol holding tank above 1"PVC pipe
NaOH Track	31	Connect 1" PVC pipe to the right of the 4-way connector
	32	Connect 1" manual valve above 1" PVC pipe
	33	Connect 1" PVC pipe above manual valve
	34	Connect 1" manual valve above 1" PVC pipe
	35	Attach NaOH holding tank to support structure
	36	Connect the NaOH holding tank above 1" PVC pipe
Grease Pump	37	Connect 1" PVC pipe to the left of the 4-way connector
	38	Connect check valve ahead of 1" PVC pipe
	39	Connect filter housing ahead of 1" PVC pipe
	40	Connect 1" PVC pipe ahead of filter
	41	Connect outlet of grease pump to 1" PVC pipe
	42	Connect 1" PVC pipe to inlet of grease pump
	43	Connect 3/4" hose ahead of 1" PVC pipe with expander
	44	Connect strainer outlet to 3/4" hose
	45	Connect 3/4" hose to strainer inlet
	46	Feed 3/4" hose into waste grease holding container
Mixing Pump	47	Connect 3/4" hose to open end of 3/4" 3-way connector above mixing/separation tank
	48	Attach mixing pump to support structure
	49	Connect inlet of mixing pump to 3/4" hose
	50	Connect 3/4" hose to outlet of mixing pump
	51	Connect check valve after 3/4" hose
	52	Connect 3/4" PVC pipe after check valve
	53	Connect 3/4" PVC pipe to open end of 3/4" 3-way connector below mixing/separation tank
Electrical Connections	54	Attach electrical connections to grease pump, mixing pump, motor, and 2 solenoid valves
	55	Attach electrical connections to junction box

APPENDIX G.2: ASSEMBLY SCHEMATIC

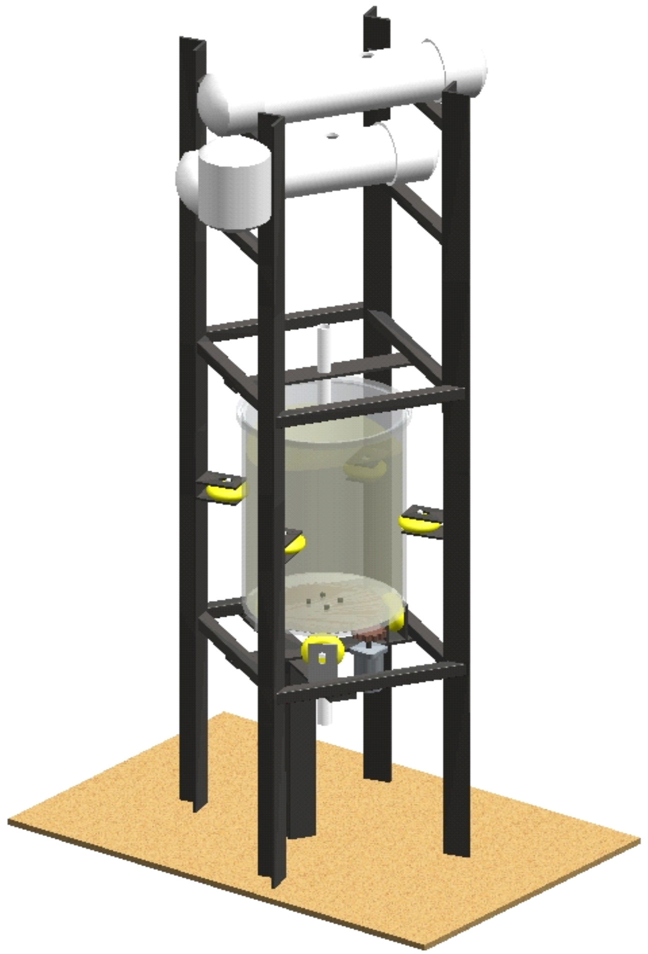


APPENDIX H: ASSEMBLY SCHEMATIC

WAS:



IS:



Notes:
1. Mixing pump mounting point moved off support structure because to reduce overall system CG height.
2. 8 wheels reduced to 4 surrounding tank because only 4 were required to limit eccentric tank motion
3. Methanol tanks offset because piping required more space than original design allowed. This also necessitated removal of vertical square bars.
4. Sodium hydroxide tank moved on support leg because zip-ties were used to secure it instead of bolts.

Team 21	Support Structure Design					
	Engineering Change Notice					
Engineer: J. Snow 04/27/07	SIZE	FSCM NO		DWG NO 1		REV 1
	SCALE N/A			SHEET 1 OF 1		