ENGR 491

SENIOR
DESIGN PROJECT

Production of Biodiesel

Engineering Design Report

2003-2004

Messiah College
Department of Engineering

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ABSTRACT

The goal of our project was to research, design, test, and construct a prototype of a piece of equipment that will transform vegetable oil from Messiah College Dining Services into Biodiesel that will conform to ASTM standards (kinematic viscosity and cloud point). Our group consists of Jon Bitterman, Becky Gast, Kyle McNamara, and Brandon Apple. The advisor for this project is Professor Carl Erikson.

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1. INTRODUCTION

1.1 Description

The goal of our senior project was to research, design, test, and construct a prototype of a machine that transformed used cooking oil from Messiah College Dining Services into Biodiesel that conformed to the ASTM standards for kinematic viscosity and cloud point. Since there was another senior project group working on Biodiesel production automation, we wanted to create a Biodiesel processor that could be automated to some degree. Our intent was not to create a Biodiesel processor that mass produced Biodiesel fuel for use in Messiah College Ground Services vehicles, but instead to research the best process for application here at Messiah and to build a prototype that could eventually be expanded to a larger scale for full-scale production. Our group made this decision because we felt that this was more feasible than trying to go directly to a full-scale processor. We also felt that this allowed us to troubleshoot any problems easily and make improvements on our design more quickly, more easily, and at a lower expense.

The Biodiesel processor must, as we stated before, be able to produce Biodiesel that conforms to the ASTM standards for kinematic viscosity and cloud point. ASTM already has standards in the area of Biodiesel, and we felt that these requirements gave us a good objective to try to attain to ensure the quality of our product. We chose kinematic viscosity and cloud point only because of the limitations on testing equipment that was readily available to us.

1.1.1 Justification

The primary justification for the Biodiesel project was financial. Messiah College currently has two expenses that, through our project, could be offset. Messiah College pays approximately $450 a year to have 1600 gallons of used cooking oil removed from campus. Messiah College also buys petroleum diesel fuel (non-road grade) used to run many of the campus vehicles for $1.37 a gallon. This totals $5480 for 4000 gallons of diesel fuel a year. Our goal was to take the expensive waste product and turn it into something not only usable but also necessary and cost-effective for Messiah College. We were able to produce Biodiesel for $0.26 a gallon ($0.54 for raw materials and -$0.28 for cooking oil disposal) saving Messiah College $4440 a year. Since the Biodiesel manufacturing process was adopted as an engineering senior project, the capital start-up costs involved were covered by Messiah College Engineering Department senior project budget. A less obvious economic benefit of this project resulted from the origin of the oil. Biodiesel had positive implications for the United States' agricultural industry, as opposed to purchasing foreign petroleum oil. The project had initial costs, but very few continuing costs once the process was decided upon and up and running.

Another justification for the Biodiesel project was environmental. Biodiesel is more environmentally friendly than petroleum diesel. The Clean Air Act from the Environmental Protection Agency concluded that toxic emissions from Biodiesel were less than the emissions from petroleum diesel, and the carbon monoxide emissions were less than half those of petroleum diesel. Biodiesel is safer to handle than petroleum diesel because it is biodegradable and non-toxic. According to the National Biodiesel Board, "neat Biodiesel is as biodegradable as sugar and less toxic than salt."

Another justification for the Biodiesel project was safety. Biodiesel is a safer fuel to work with than petroleum diesel. Biodiesel has a high flash point, or ignition temperature, of about 300°F compared to petroleum diesel fuel, which has a flash point of 125°F. Biodiesel also benefits the Messiah College employees who come in contact with petroleum diesel everyday. The cleaner fumes and the non-toxic properties of Biodiesel not make it a safer choice in comparison to petroleum diesel.

1.1.2 Objectives

1. To design a piece of equipment that will output 3 gallons of Biodiesel per day, using the used cooking oil from Messiah College Dining Services. The overall process will not exceed 48 hours per batch.

2. The Biodiesel generator will be able to produce Biodiesel that will conform to the ASTM standards (D 6751) for viscosity and cloud point.

3. A physical prototype will be completed for the E-Biodiesel Senior Project group to automate the process, excluding the addition of the raw materials.

4. The Biodiesel generator must be scalable to a large-scale system in the event that another group in the future elects to continue the project.

5. The Biodiesel generator must produce Biodiesel fuel for less than $1.00 per gallon (not including the costs of start-up and labor).

1.1.3 Purpose/Benefits

Dr. Rudolf Diesel invented the Diesel engine in 1885 with the vision that the engine could be run on fuels made from the crops readily grown by an average farmer. In fact, when Dr. Diesel revealed his invention at the 1900 World's Fair in Paris, his engine was run on peanut oil. As petroleum fuels became inexpensive and widely available, people began to switch to running their diesel engines on petroleum based diesel fuel. In the recent quarter century, however, with the dramatic rise in the price of petroleum diesel fuel and the depletion of the earth's petroleum reserves, Dr. Diesel's vision has become even more relevant than when he first put forth the idea of an engine that would run on an inexpensive, renewable, and clean burning fuel.

The Messiah College community is committed to being good stewards of the resources that God has given to us. This project seeks to honor that commitment by developing a production prototype that transforms waste cooking oil from the Dining Services Department into a clean burning fuel for Messiah College Ground Services' diesel vehicles. This could potentially eliminate the cost of disposing of used cooking oil, as well as reduce the cost of fueling campus vehicles. The afore mentioned reasons would therefore serve Messiah in better fulfilling the mission and goals of the college and increase the witness that the Messiah College Community is to the Message of the Gospel of Jesus Christ.

Biodiesel has been around for some time and has been produced in large-scale quantities. However, we saw it fit to design and build a piece of equipment to produce Biodiesel here at Messiah for our specific application.

1.2 Literature Review

Current resources indicated that extensive research has been done in the field of Biodiesel production. Recent estimates put the United States among the world's leaders in manufacturing Biodiesel, producing an estimated 60 to 80 million gallons per year (N.B.B., sec1). Many large-scale producers were unwilling to publish their methods, while most small-scale operations eagerly published what they have achieved. This resulted in a variety of processes for the "do-it-yourself" systems.

From large-scale to "do-it-yourself" systems, every model used a process called transesterification to convert the waste oil to usable fuel. This simply involved a chemical reaction that caused the glycerin present in the waste oil to settle out of solution. The crude fuel could simply be taken off of the top of a settling tank while the glycerin is left behind. This basic process was the only agreed upon characteristic in the different types of systems. Nearly every system that we had found performed each step in different ways. From pre-filtering to the final refinery steps, most users have developed their own methods or mechanisms. The different processes that we saw use methods of distillation, thermal treatment, evaporation, mixing, water or bubble washing, and others (Durkee, J.T.F). Many producers used gravity feed systems with some type of mechanical stirring device, while others used pumps to transport and mix the reactants (Tickell, Veggie Van). There was no agreed upon standard except for the specifications of the final product.

While there were large-scale systems that companies have fully automated, our research has shown that no fully automated small-scale systems have been developed. Accomplishing our objectives in collaboration with the E-Biodiesel senior project group would make our processor the first working small-scale fully-automated systems.

1.3 Solution

Many feasible solutions have been presented to making Biodiesel a more versatile and attainable fuel. Some have limited the waste oil that they attempt to convert based on its purity. This is not an ideal solution because it restricted the possible sources for the waste or required every producer of the waste to filter or pre-treat it. The capability of our system was to accept a variety of purity levels and refine the oil to a usable level. Even though we were able to accept a variety of different purity levels of used oil, we did not accept oil from different sources due to our goal of eliminating a campus waste product. Our primary source was Messiah College Dining Services, so our system was designed to accept the variation within Dining Services' oil. Oil from different sources would be acceptable for our system as long as an accurate titration of the oil precluded the production of Biodiesel.

After our research, we decided upon a chemical process for producing our Biodiesel fuel. Our goal was to make three-gallon batches of Biodiesel fuel at a time. We performed a titration on multiple used cooking oil samples from Dining Services to determine the appropriate amount of catalyst to add for a complete reaction. The goal was to neutralize the free fatty acids in the used cooking oil. The titration described in Section 2.1 shows the results.

2. DESIGN PROCESS

2.1 Analysis and experimental work

Once the base-catalyzed transesterification was chosen, the focus turned to testing the pH of the used oil collected from Lottie Nelson Dining Hall. A titration was performed on samples of oil collected at different times to determine the fatty free acid content of the used oil. This method of titration was obtained from the "Journey to Forever" website. The results of these titrations gave an indication of how much lye must be added to the methanol to neutralize the acid in the used oil. Below are the results of the titrations.

Used Cooking Oil Testing (See ***Section 8.3*** for pictures)

Testing Procedure

1. Weigh out 1 gram of used cooking oil into an Erlenmeyer flask.
2. Add 10 mL of Isopropyl Alcohol to the oil sample and mix vigorously.
3. Add one packet of phenolphthalein to the mixture and mix vigorously.
4. Record initial volume of Sodium Hydroxide in buret.
5. Titrate sample using 0.1 M Sodium Hydroxide until mixture changes color and color remains.
6. Record final volume of Sodium Hydroxide in buret.

Testing Results

Oil Sample Date	***Amount of Sodium Hydroxide [mL]***	***Concentration of Sodium Hydroxide [M]***
10/29/2003	0.9	0.1
11/5/2003	1.0	0.1
11/12/2003	0.3	0.1
11/19/2003	1.0	0.1
3/24/2004	0.5	0.1
3/24/2004	0.5	0.1
3/24/2004	0.5	0.1
4/23/2004	1.0	0.1
4/26/2004	1.0	0.1
Average	0.74	0.1

Table 2.1.1 Titration results for used cooking oil

Testing Conclusions

From the tests we determined that 4.5 grams of lye needed to be added to every 200 mL of the methanol. With this amount, a full reaction would be ensured based on the sample we collected. We have not tested enough samples to ensure that 4.5 grams of lye will be sufficient for all used cooking oil samples from Lottie Nelson Dining Hall. More tests could possibly conclude that the oil is consistent enough to eliminate the titration; however, it is recommended that a titration be performed before every batch.

Thermal Stress Analysis

We performed an analysis of the thermal transfer between the oil and the mixing tank. Using I-DEAS Finite Element Analysis, we were able model the settling tank in a three-dimensional environment and apply temperature restraints, convection, and loading caused by the pressure of the oil and the reaction of the tank stand. This analysis shows the tank's response to the loading conditions and whether or not failure would occur. The simulation and analysis can be found as *Biodiesel Settling Tank Analysis* in the Supplemental Reading section at the end of this report. We concluded from the results that the tank would not reach a failure point within the conditions described in the Design section of the *Biodiesel Settling Tank Analysis* report.

Fuel Tests

Many tests could be done to the fuel to ensure the quality of the Biodiesel. The tests we chose to perform were specific gravity, cloud point, and kinematic viscosity. The reasons for our selection of these tests and the final results of our fuel testing are discussed in Section 3.2.1. Many tests could also be done to the vehicles that are running on Biodiesel. Emissions tests, maintenance requirements, and performance could all be observed and evaluated, along with comparisons to the same aspects when the vehicles are operating on petroleum diesel fuel.

2.2 Design Specifications

Biodiesel Production Machine

Cost	< $500.00
Size	Fits in a 10 ft by 10 ft space
Operating Temperature	≤ 100ºC
Production Amounts	≥ 3 gallons per day
Production Time	< 48 hours per batch
Methanol Consumption	3/5 gallon per 3 gallon batch
Lye Consumption	51.1 g per 3 gallon batch (4.5 g per 200 mL methanol)
% Transform oil to Biodiesel	≥ 85%

Produced Biodiesel

Cost	≤ $1.00 per gallon in production quantities
ASTM Standards (D 6751)	
Cloud point	≤ 50ºF (This is not specified in the ASTM standard for Biodiesel)
Kinematic viscosity, 40ºC	1.9 - 6.0 mm^2/s

Repeatability	$\leq$ 5% difference in above ASTM Standards

2.3 Design

Note: It is recommended to reference the schematic of the system found in Section 8.2 and the pictures of the constructed parts found in Section 3.1 during the reading of this section.

Heating Phase

Our design begins with the dumping of used cooking oil through a filter into the heating tank. The purpose of the filter is to remove any large excess particles remaining from food deep-frying, so a screen for a window, fastened to a steel ring sufficed. The heating tank is a fifteen-gallon steel drum with a polyethylene fitting in the bottom center of the tank. This tank is also equipped with two water heating elements mounted on the side of the tank. These heating elements are used to heat the used oil to a temperature between 50^{o}C and 60^{o}C, which can be done with sufficient accuracy for the required application.

Post-Heating Phase

Once the oil is filtered and heated to the specified temperature, it is then released by opening a valve (valve 1) located at the outlet hole of the heating tank. The oil is gravity fed through a hose to a mixing tank located beneath the heating tank. This tank will hold the heated used oil as the chemicals are added and the reaction occurs. This tank must be able to withstand temperatures of up to 60^{o}C and corrosion from the added chemicals. Due to these factors, we chose to use a tank made of polyethylene with a temperature range of up to 60^{o}C to ensure the durability of the tank.

Methoxide Mixing Phase

The chemical solution that will be added to the used oil is first mixed in the methoxide tank. The methoxide tank is a 5-gallon polyethylene tank with plastic fittings in the bottom, top, and side. After preliminary calculations to determine the appropriate amounts of lye and methanol that are necessary to create Biodiesel (refer to Section 2.1), the lye and methanol are both poured into the methoxide tank. A circulating pump, connected to the methoxide tank outlet, immediately begins to mix the lye and methanol by circulating the solution back into the methoxide tank. The circulating pump is a Little Giant® Seal-Less Magnetic Drive Pump that is designed for corrosive chemicals and solutions. The pump design of titanium shaft and thrust washer, uncoated ceramic (barium ferrite) driven magnet, glass-filled polypropylene pumping head, and impeller Nitrile O-ring ensure protection against chemical corrosion from methanol and the methoxide solution. The ½ inch inlet/outlet size and 3.0 gallons per minute max flow are also suited to our methoxide mixing design. Once inside the methoxide tank, the solution is forced through a 12 inch long piece of ½ inch PVC pipe with six small holes located in the bottom to induce a turbulent mixing of the lye with the methanol. This circulation process is repeated until a thorough mixing of the chemicals is evident.

Biodiesel Mixing Phase

Once the chemicals are mixed thoroughly, the methoxide circulating pump is turned off and the valve (valve 5) located beneath the circulation pump is opened and the methoxide begins to gravity feed into a hose attached to the main circulating loop before the pump. As the methoxide is filling the hose, the valve (valve 2) at the bottom of the mixing tank is opened and a valve (valve 4) between the magnetic drive pump and the mixing tank is opened to allow the circulation of the oil back into the top of the mixing tank. A magnetic drive pump located between the outlet and top opening of the reacting-settling-washing tank is turned on to cause this circulation. The magnetic drive pump is a March® Metal-Less Magnetic Drive Pump-Model MDX-MT3 that is designed for pumping high concentrations of acids and bases, high specific gravities, and other highly corrosive solutions. The pump design of Ryton® glass filled polypropylene housing and impeller-magnet, porcelain-ceramic spindle, ceramic impeller thrust washer, and pump cover Viton® O-ring seals ensure protection against chemical corrosion from the used cooking oil and Biodiesel. The ½ inch inlet/outlet size and 7.5 gallons per minute max flow are also suited to our circulation design. As the oil is circulating, the valve (valve 3) at the junction of the methoxide hose and the main circulating hose is opened and the methoxide is released into the circulating loop before the magnetic drive pump and is therefore added to the flowing oil. This ensures a thorough and dynamic mixing of the heated used oil and the methoxide.

The circulation by the magnetic drive pump is continued until the methoxide from the methoxide tank has been completely released and a thorough mixing of the oil and methoxide has occurred. When the methoxide has completely mixed with the used oil, the two valves (valves 3 and 5) controlling the flow of the methoxide into the main circulation loop are closed. After the used oil has been circulating for an hour, the magnetic drive pump is shut off and the valve (valve 2) at the bottom of the mixing tank is closed. The valve (valve 6) located beneath the mixing tank, which controls the flow into the waste container, is opened to allow any excess solution that has not reached the mixing tank to be emptied from the circulating hose. The valve (valve 4) located between the magnetic drive pump and the mixing tank is then also closed.

Settling Phase

The mixture is now given time to react and settle into separating layers of Biodiesel and glycerin. The glycerin formed settles to the bottom of the mixing tank and is removed from the tank by a hose that leads to a glycerin/waste container after opening two valves (valves 2 and 6) at the bottom of the mixing tank. We used a translucent mixing tank so the separation can easily be seen and the glycerin can be removed without losing much Biodiesel. The tank also has a conical bottom to ensure that the glycerin is removed without mixing into the layer of Biodiesel. Once the glycerin is completely removed, the valve (valve 6) that diverts the oil to the glycerin/waste container is closed.

Biodiesel Storage Phase

Once the settling phase is completed, the valve (valve 7) located between the pump and the Biodiesel storage tank is opened along with the already opened valve (valve 2) beneath the mixing tank allowing the Biodiesel to prime the pump. The magnetic drive pump is then turned on which allows the Biodiesel stored in the mixing tank to be pumped to the storage tank. In the process, the Biodiesel is filtered through a 5-micron filter to ensure as pure a Biodiesel as possible. The 5-micron filter is a standard household water filtration system. The storage tank is a polyethylene barrel, which should be stored in a cool, dark area to maintain the properties of the Biodiesel.

3. IMPLEMENTATION

3.1 Construction

In order to construct a prototype, we first looked at some of the key issues that were necessary in the design of a stand for our system. One of these key issues was the heights of our tanks. Since the transfer of the oil between the heating tank and the mixing tank is performed using gravity feeding, it is necessary that the heating tank be at an elevation greater than that of the mixing tank. In order to build an appropriate structure we determined that wood would be the easiest to work with and the most cost-effective. Originally we were going to build the structure completely from the ground up, but then decided that using last year's structure would be quicker, simpler, and also recycle the materials last year's group used. However, last year's group constructed their structure outdoors, and we decided that we wanted to move indoors after Professor Erikson graciously allowed us to use his barn. In order to move indoors, we simply cut last year's structure right above the ground, moved it indoors, leveled it off, and added some extra supports.

With the main structure in place we then had to modify it to fulfill the needs of our system. This simply involved building a shelf to support the mixing tank, a shelf to support some of the plumbing and the 5-micron filter, and cutting some holes for our plumbing to run from the top portion of the structure to the lower portion. Once all of this was done, all that was left was assembling each of the components and putting them together to complete our system. In the section below we will discuss how each of the major components were built or modified to fit the needs of our system.

Heating Tank

The heating tank is the tank in which all of the used oil that will eventually be used to make Biodiesel is heated to the appropriate temperature. This ensures first of all that the oil will be completely liquefied and flow properly through the lines, and also that the oil is at the appropriate temperature for the reaction to occur. In order to perform this operation, our water heater heating element needed to be mounted in the tank and a fitting needed to be mounted on the bottom of the tank for the oil to exit after it has been heated. Originally we had planned to weld both the fitting and the heating element to the tank, but after talking with John Meyer decided that due to the thickness of the tank wall and floor, welding would be an extremely difficult process. Instead we decided to drill a hole for each component and by using a nut, neoprene washer, and threaded fitting / heating element a water-tight seal was created. The first component we attached was the heating element. The mounted heating element can be seen below. (***Figures 3.1.1*** and ***3.1.2***)

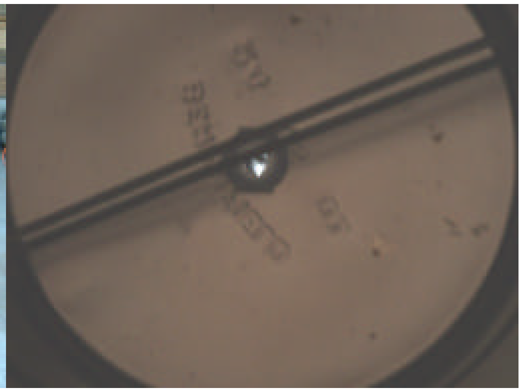


Figure 3.1.1 Heating element as seen from outside of tank

Figure 3.1.2 Heating element as seen from inside of tank

The other component of the heating tank was the bottom tank fitting. This was mounted in a similar fashion and can be seen in the figure below (***Figure 3.1.3***)

Figure 3.1.3 Heating tank fitting as seen from bottom of tank

Mixing Tank

The mixing tank did not require any modifications. The only construction involved with the mixing tank was adding the fittings at the bottom of the tank and some Silicon at the bottom-inside of the tank to ensure that no liquid will be left in the tank. The fittings attached at the bottom of the tank were all screw fittings so no major construction was required (***Figure 3.1.4***).

Figure 3.1.4 Fittings on bottom of mixing tank

The other construction, namely adding Silicon to the bottom-inside of the tank, can be seen in the figures below (***Figure 3.1.5*** and ***Figure 3.1.6***)

Figure 3.1.5 Bottom of RSW Tank before adding Silicon

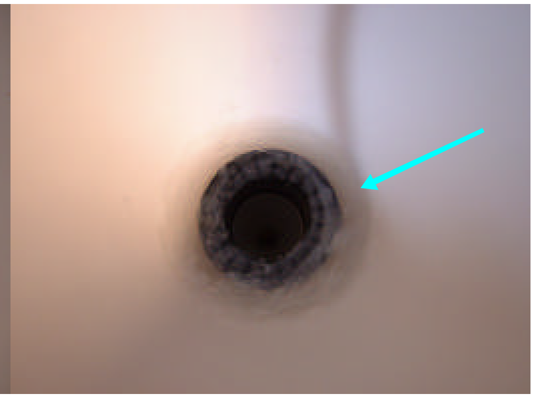


Figure 3.1.6 Bottom of RSW Tank after adding Silicon

Methoxide Mixing Tank

The methoxide mixing tank is a 5 gallon, translucent, polyethylene tank. In order for this tank to fit its function in our system it was necessary to add two fittings to the tank walls so that it could be plumbed in a circuit. This was done in a similar fashion to the tank fitting for the heating tank. A hole was drilled in the wall of the tank, then using a nut, neoprene washer, and threaded fitting we created a water-tight seal. The fittings in the tank wall can be seen below (***Figure 3.1.7*** and ***Figure 3.1.8***).

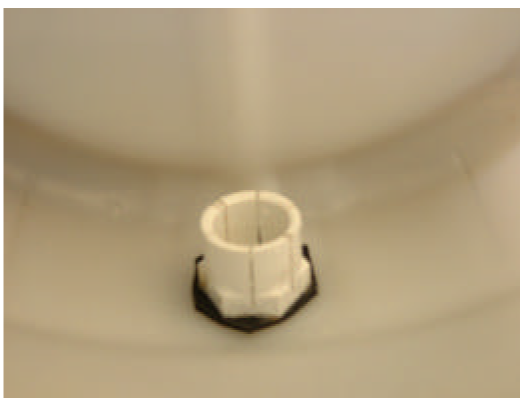


Figure 3.1.7 Methoxide Mixing Tank fitting as seen from inside the tan

Figure 3.1.8 Outside View of Methoxide Mixing tank

In ***Figure 3.1.8*** a funnel can be seen in the Methoxide Mixing Tank. This funnel is a standard-issue funnel with a short piece of clear vinyl tubing attached. The purpose of the funnel is to make the addition of the raw materials (lye and methanol) easier.

Valves, Pump, and Filter

The valves that we used in our system required that fittings be added in order for a connection to the clear vinyl tubing to be accomplished. This was done by using a ½ inch barb to ½ inch threaded fitting piece (this size was chosen because all of the lines are ½ inch clear vinyl tubing). The valve assembly can be seen below (***Figure 3.1.9***).

Figure 3.1.9 Valve assembly (same for all valves)

Hose clamps were used at every tube-barb connection to ensure that the tubing will not come off the barb fitting.

The same fittings and clamps were used to plumb the lines into the magnetic drive pump (***Figure 3.1.10***).

Figure 3.1.10 Pump assembly

The filter was plumbed in a similar fashion to the valves and pump (***Figure 3.1.11***).

Figure 3.1.11 Filter assembly

Design Changes

We did not encounter too many problems during construction / production that required the change of our design, however there were some problems. The first problem that we encountered came while making our first batch. When we were mixing the Methanol and Lye in the Methoxide Mixing circuit, the drill pump in our initial design failed. It began circulating the chemicals fine, however the drive shaft became detached from the impellors. We determined that this was due to the corrosive nature of the chemicals. Although replacing the pump would work for some time, it will be just a matter of time until that pump would also fail. So we decided to change the pump to a magnetic drive pump (similar to the main circulation magnetic drive pump) that is constructed with better quality / durability in mind and is approved for use with corrosive chemicals.

Another problem arose in the actual methoxide mixing tank. Following the initial run of the methoxide circulation, it was found that the lye and methanol were not completely mixing in the circulation cycle. In order to remedy this situation a twelve inch piece of ½ inch PVC pipe was mounted inside the tank. Small holes were drilled into the bottom of this piece of pipe to increase the velocity of the fluid and ensure that the methanol and lye completely mix (***Figure 3.1.12***).

Figure 3.1.12 Methoxide mixing tank redesign

A third problem encountered during the initial production run was there was not a good collision of the molecules of the methoxide and used cooking oil. Initially we had designed our system to include an in-line mixer. However, this piece was fairly expensive and outside our financial boundaries. During our initial production run both of the liquids were drained into the tank, but this method did not create the necessary turbulence to completely mix the liquids. In order to fix this problem we plumbed the methoxide line directly into the circulation line immediately upstream from the pump. This allowed us to add the methoxide directly into the line and the main magnetic drive served as a mixer for our system. This created the turbulence needed to ensure a good collision of the molecules.

Another problem that was encountered during the initial production run occurred in the heating tank. The problem was that the oil would not heat up to the desired temperature very quickly or uniformly. This was not a major problem because the oil did heat to the desired temperature. In order to speed up the heating process and attain a more uniform heating, a second heating element was mounted perpendicular to the first element.

3.2 Operation

3.2.1 Biodiesel Testing

ASTM Standard Testing

Once our prototype was completed, several tests were performed on the quality of the Biodiesel. The Biodiesel was tested to determine its kinematic viscosity, for which the ASTM standard (D 6751) states the actual limits. A cloud point test was also performed, and the results were compared with the standard. The Biodiesel produced in our processor was also tested for specific gravity. This test was not specified by our objectives, however, upon research it was determined that the specific gravity of the produced Biodiesel is one of the most telling signs of whether or not Biodiesel was truly produced. The results for all three of these tests are seen below (***Table 3.2.1***).

	Our Value	***Standard Value***
PENNDOT Testing		
Cloud Point	40°F	= 50°F
Specific Gravity	0.88	0.88
Chemistry Lab Testing		
Kinematic Viscosity	6.41 mm^2/s	1.9 - 6.0 mm^2/s

Table 3.2.1 Standard Testing Results

Many other tests could also have been performed on the fuel to determine if it meets all of the standards set forth by ASTM, but our group lacked the resources or funding to perform these tests. Cloud point and kinematic viscosity were chosen because the chemistry department has the equipment needed to perform these tests.

Quality Testing

A simple quality test was also performed on our Biodiesel to determine if the right amount of lye was added. This test is performed by taking 150 mL of Biodiesel and pouring it in a container with 150 mL of water. The mixture is then shaken for at least 10 seconds so that the two liquids can mix. Then the mixture is allowed to sit so that the Biodiesel and water can separate. After about ten minutes the two should be completely separated. If there is a "milky" middle layer between the two (***Figure 3.2.1***), then too much lye has been added. Also if the mixture takes longer than thirty minutes to separate or does not separate at all, then the Biodiesel is not of good quality. If this occurs, either too much catalyst was added and soap was made (better titration is needed), or a poor conversion has left mono- and di-glycerides (more methanol, better agitation, longer processing time, better temperature control are needed), or both.

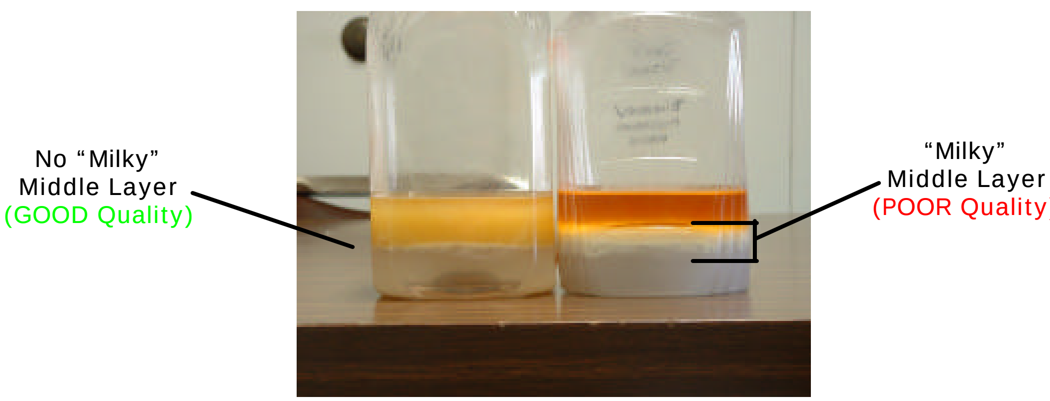


Figure 3.2.1 Quality Testing results on two different Biodiesel samples

After performing this test on our Biodiesel, we determined that the batches that we ran in the Gator were of good quality with little to no "milky" middle layer (See ***Figure 3.2.1***, Left).

Gator Testing

We also performed tests of the Biodiesel in a diesel engine to determine if the fuel causes abnormalities in operational use. To perform these tests, we had the opportunity to use one of Messiah College Ground Services' John Deere Gators (***Figure 3.2.2***).

Figure 3.2.2 John Deere Gator #6 (Messiah Ground Services)

Our testing procedure consisted of running some simple hill-climb tests and recording the amount of time it took the Gator to climb the hill with petroleum diesel and Biodiesel. However, this testing was not completed due to some problems we encountered while running the Gator on Biodiesel. The Biodiesel that we produced burned well in the Gator with clean fumes and white smoke exhaust. However, we noticed that after approximately ten minutes of running the Gator on Biodiesel the vehicle would lose power. Upon further research into this matter, we found that sometimes when Biodiesel is run through an engine for the first time; it tends to loosen any dirt particles inside the tank and fuel line. This causes the fuel filter to clog, which in turn causes the engine to lose power. In order to test this theory, the fuel filter was changed. This however did not solve the problem. We also noticed that even though after approximately ten minutes of running Biodiesel the engine would lose power, if the Gator was allowed to sit for approximately ten minutes then restarted, it would run normally for another ten minutes. This led us to further investigation into the situation. After some further research we determined that the reason the engine was losing power after ten minutes was because it was starving for fuel. This was caused by the fact that the Biodiesel produced was thicker than the petroleum diesel used in the Gator. Because of this difference in thickness the Biodiesel could not flow through the small fuel filter as quickly, and when the engine was demanding fuel it could not flow through the filter fast enough causing a lack of power. The reason that the Gator would run normally again after ten minutes of not running, was because this provided the necessary time for some Biodiesel to flow through the fuel filter and get to the engine. This conclusion was reached by running mixes of Biodiesel and petroleum diesel to thin out the Biodiesel. Each time more petroleum diesel was added the Biodiesel was thinned-out more and the engine would run for a longer period of time before a loss of power was noticed.

3.2.2 Processor Operation

For complete instructions for making Biodiesel in our processor refer to *Biodiesel Production User's Manual*.

3.2.3 Operators Warnings

Our design has brought forth four potentially dangerous features: chemical, thermal, mechanical, and electrical. The product and some of the reactants of the system are harmful if contact or ingestion occurs. Safety measures, like inhalation and skin protection, must be utilized when operating. Heat is also generated inside the heating tank and could potentially cause burns if not controlled appropriately. The pumps in our system could also present risk of mechanical injury to a user. Along with the pumps and heaters comes the risk of electrical shock.

4. PROJECT MANAGEMENT

4.1 Project Organization

Research	All
Construction of Prototype	All
Testing and Adjusting of Prototype	All
Team Leader	Brandon Apple
Contact with E-Biodiesel Group	Brandon Apple
Responsible for Completion of Written Assignments	Brandon Apple
Contact with Chemistry Department	Jon Bitterman
Responsible for Testing Used Oil Samples	Jon Bitterman
Responsible for Acquiring Motors and Heating Elements	Jon Bitterman
Contact with Dining Services	Becky Gast
Collect Oil Weekly	Becky Gast
Responsible for Acquiring Tanks	Becky Gast
Responsible for Budget	Becky Gast
Contact with Wilson College	Kyle McNamara
Responsible for Acquiring Pipes and Fittings	Kyle McNamara
Responsible for Acquiring Chemicals	Kyle McNamara

4.2 Gantt Chart

Gantt Chart of Biodiesel Project found in Section 8.1

4.3 Schedule Contingencies

We projected our Gantt Chart at the beginning of this project with some uncertainty of not only the steps we should take to finish the project successfully but also the amount of time that should be dedicated to each of these steps. In comparison of our predicted time table with our actual time table, some variation is evident.

One example of this variation is the selection of our Biodiesel process recipe. We began this task sooner than we expected because we realized, after reviewing last years project, that more time needed to be devoted to research and development of the recipe. The recipe is a key component of our success, and we wanted to ensure that there were no problems in this area of the project. Another example is the purchasing of the components for our prototype, construction, and testing. Although we purchased the major components early, we inaccurately predicted the number of miscellaneous parts we would need to finish the construction. Also, we made some slight changes in the construction as we began building the prototype. As a result, we had to make several trips to Lowe's/Home Depot to purchase necessary hose, fittings, valves, and other components. Finally, there is some variation in times for the writing of the Final EDR and the preparation of the user's manual. Both of these reports are essential elements of the project, and we wanted to give plenty of time and attention to each of them. Since we became pressed for time in other areas of the project, we were unable to complete these elements of the project during the time allotted by the actual time table.

Despite some of our setbacks and delays, we have accomplished all of our assigned reports and project tasks in a timely manner. Our diligence is evidenced by the fact that we were able to test and troubleshoot our prototype for much of March and April. We used our time as effectively as possible which resulted in a complete and successful design project.

5. BUDGET

ITEM	ESTIMATED COST	ACTUAL COST
RESEARCH		
Biodiesel book*	$25.00	$0.00
TESTING		
Sodium Hydroxide	$10.00	$0.00
Isopropyl alcohol, 99% pure	$10.00	$0.00
Phenolphthalein	$10.00	$0.00
Distilled water*	$5.00	$0.00
PROTOTYPE CONSTRUCTION		
Used vegetable oil	none	none
Electric water heater elements*	$20.00	$0.00
Valves	$2,000.00**	$30.00†
Methanol	$15.00	$9.50
Sodium Hydroxide (Lye)	$5.00	$4.00
15 gallon conical tank and stand	$65.00	$65.00
Magnetic drive pump*	$235.00	$140.00
Drill pump	$7.00	$7.00
Tanks/Drums	$30.00	$33.00
Frame Materials	$15.00	$0.00
5 Micron Filter	$30.00	$25.00
Miscellaneous Parts	$75.00	$163.00
Shipping and Handling	$20.00	$20.00
Total Expenses	***$2,607.00***	***$496.50***

*This represents an item donated or previously purchased.

**This represents the estimated cost for fully corrosion resistant solenoid valves

†This represents the cost of manual valves only (Our purchased solenoid valves cost $490.00)

6. CONCLUSIONS

6.1 Quality of Our Biodiesel

We knew from the beginning about many of the benefits of producing and using Biodiesel at Messiah College. We did our research and built the processor, but in order to be successful, we had to produce Biodiesel fuel what would be able to be run in any diesel engine. We tested the Biodiesel we produced in three different ways. First, we did a simple test called a Water-Shake test. To perform this test, equal parts of Biodiesel and water are put in a bottle and shaken then allowed to settle. If the Biodiesel and water separate cleanly then it is evident that good Biodiesel has been produced. If a "milky" middle layer forms, then the Biodiesel has contaminants that the layer is comprised of. This means either the reaction did not occur correctly or the fuel needs to be filtered better.

We also tested one sample of our Biodiesel for specific ASTM standards. We tested the standards of cloud point and kinematic viscosity and also tested specific gravity (while not an ASTM standard, this property is very telling of Biodiesel fuel). For cloud point and specific gravity standards we tested our Biodiesel at the PENNDOT Testing Lab. The cloud point result was 40°F compared to the standard of less than or equal to 50°F, and specific gravity came out exactly at the standard of 0.88. Kinematic viscosity was tested in the chemistry lab at Messiah College and was 6.41 mm^2/s at 40°C, just out of the standard range of 1.9-6.0 mm^2/s. Only one sample of our Biodiesel was tested due to time constraints. More testing should be performed on different samples to better determine the values of cloud point, kinematic viscosity, and specific gravity for our Biodiesel.

Our final and most telling method of testing our Biodiesel fuel was to run it in a diesel engine. We were given the use of a John Deere Diesel Gator from the Messiah College Ground Services department on campus to test our Biodiesel. We ran 100% Biodiesel or B100, and our Biodiesel ran in the engine. We ran the Gator on multiple batches of Biodiesel we had made and tested for three weeks. Since Biodiesel has qualities of oil that petroleum diesel does not, our Biodiesel acted as a lubricant in the engine. Because of this, the Biodiesel loosened sediments in the tank and lines which the filter then picked up. Since the filter was catching all of the sediments, the engine appeared to be starved for fuel. We noticed a slight power loss as a result. To address this issue, we bought new filters and changed them a few times initially to get the sediments that the Biodiesel loosed in the tank. This however did not solve the problem of the engine losing power. We also noticed that even though after approximately ten minutes of running Biodiesel the engine would lose power, if the Gator was allowed to sit for approximately ten minutes then restarted, it would run normally for another ten minutes. This led us to further investigation into the situation. After some further research we determined that the reason the engine was losing power after ten minutes was because it was starving for fuel. This was caused by the fact that the Biodiesel produced was thicker than the petroleum diesel used in the Gator. Because of this difference in thickness the Biodiesel could not flow through the small fuel filter as quickly, and when the engine was demanding fuel it could not flow through the filter fast enough causing a lack of power. The reason that the Gator would run normally again after ten minutes of not running, was because this provided the necessary time for some Biodiesel to flow through the fuel filter and get to the engine. This conclusion was reached by running mixes of Biodiesel and petroleum diesel to thin out the Biodiesel. Each time more petroleum diesel was added the Biodiesel was thinned-out more and the engine would run for a longer period of time before a loss of power was noticed.

6.2 Objectives Revisited

1. We designed a piece of equipment that outputted 3 gallons of Biodiesel per day, using the used cooking oil from Messiah College Dining Services. The overall process did not exceed 48 hours per batch. Our system is capable of producing up to 15 gallons per batch.

2. The Biodiesel generator produced Biodiesel that conformed to the ASTM standard for cloud point and was very close for kinematic viscosity for the batch we tested. We also exactly met the most telling property of specific gravity.

3. A physical prototype was completed for the E-Biodiesel Senior Project group to automate the process, excluding the addition of the raw materials.

4. The Biodiesel generator was scalable to a large-scale system in the event that another group in the future elects to continue the project.

5. The Biodiesel generator produced Biodiesel fuel for less than $1.00 per gallon (this price includes only the cost of materials necessary to produce the Biodiesel, not the start-up cost or cost of labor). For Messiah College, we produced Biodiesel for $0.26 a gallon saving the school $4400 a year.

7. FUTURE WORK

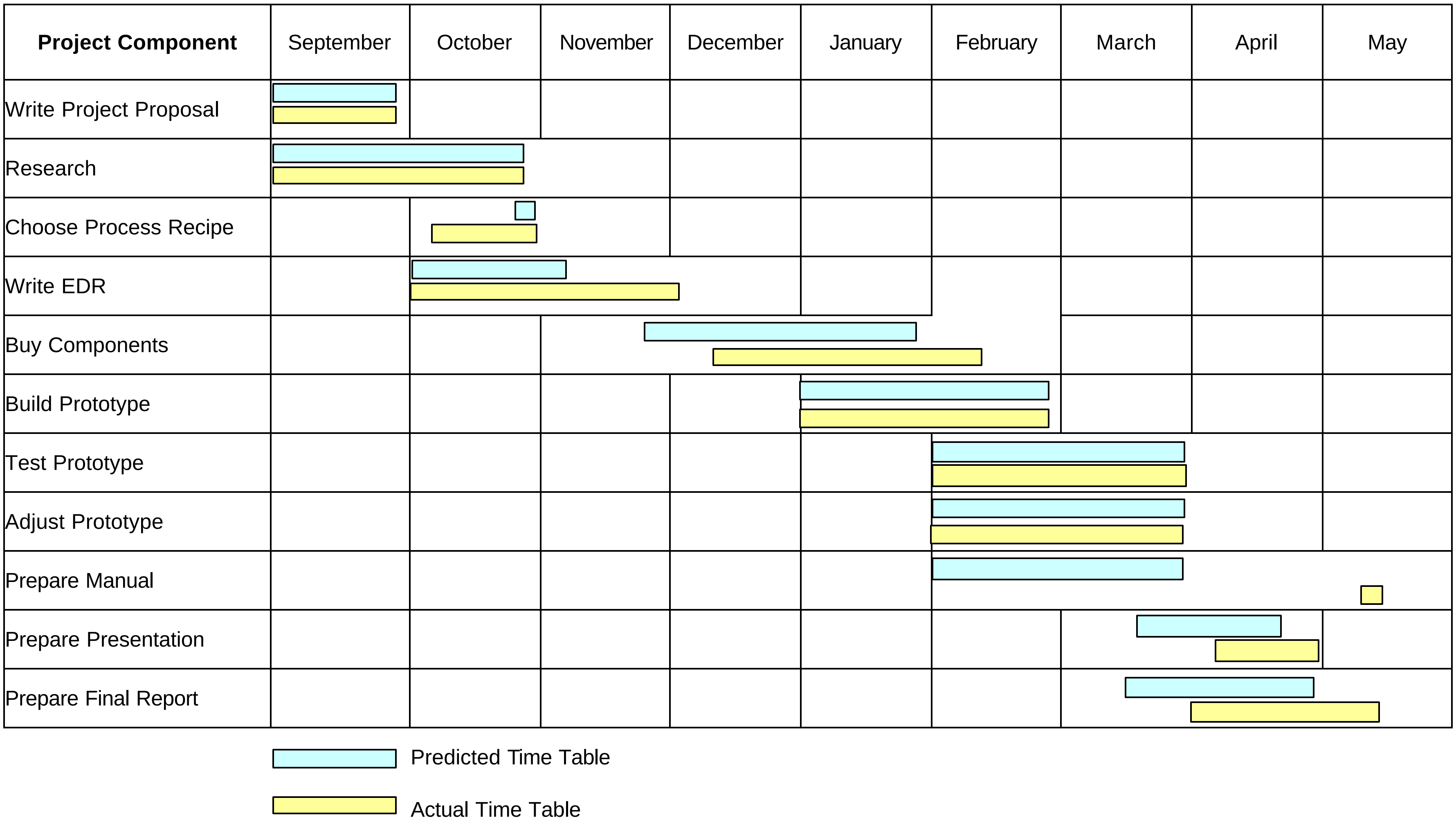
In the event that another engineering senior project group continues the Biodiesel Production project, we have recommendations for future work. Regarding mechanical components that could be added to the system, air lines would be beneficial to flush excess liquids out of the lines that did not run out due to gravity. Also a more uniform and efficient means of heating the oil could be established. The oil at the bottom of the tank under the heating elements currently does not heat as quickly as the oil above the heating elements.

A system could also be established to better mix the methanol and oil since on very few occasions we did not have enough of a collision for a reaction. Also, a wash system could be added to possibly produce purer Biodiesel fuel. Another goal would be to bring the processor on Messiah College's campus or on a trailer for demonstration purposes. This would make the system more accessible for dealing with the used cooking oil, making the batches of Biodiesel, and also filling the diesel vehicles with Biodiesel.

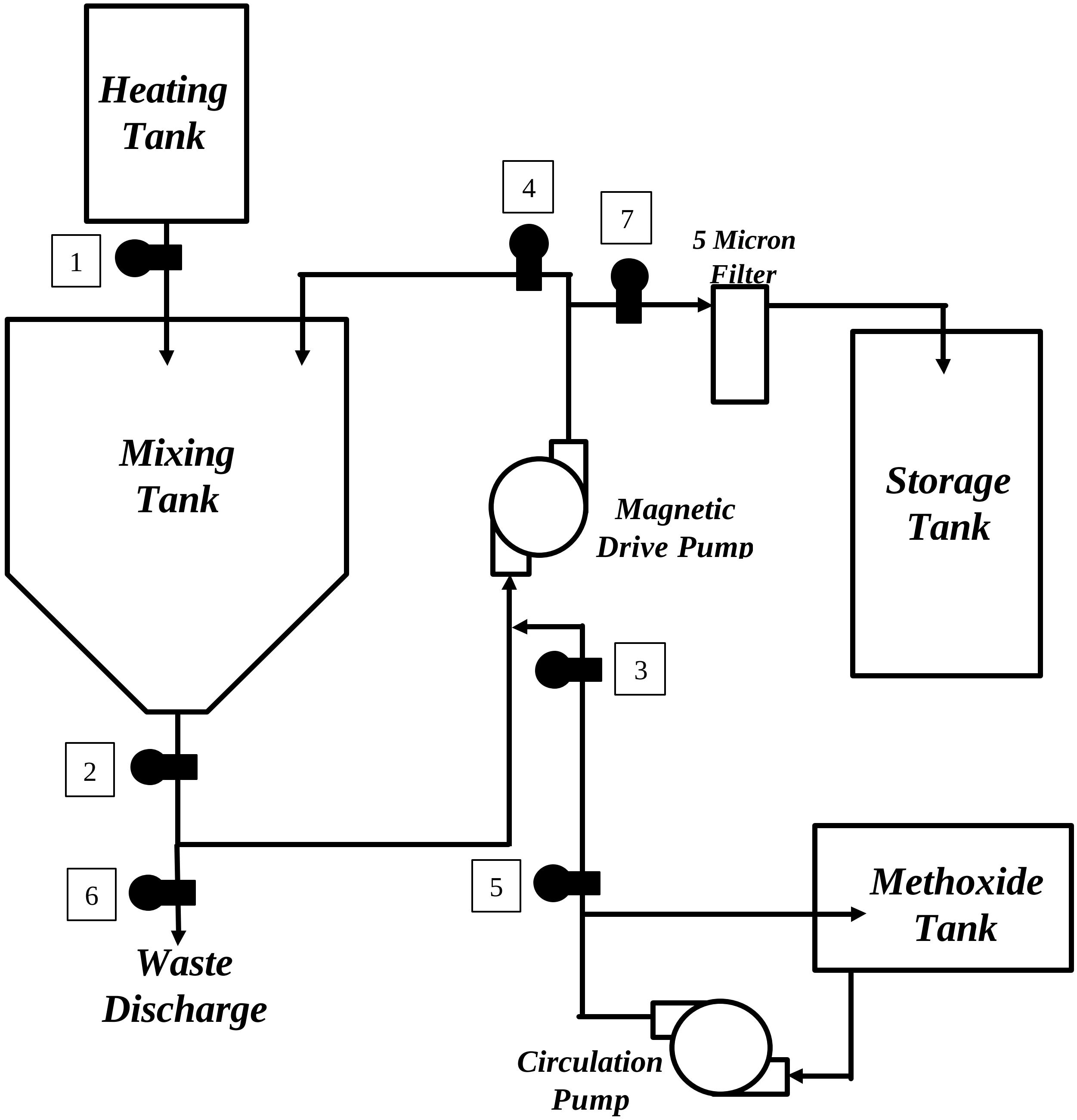
Another situation we encountered was diesel fuel's, including Biodiesel's, dislike of cold weather. This can be addressed in two manners, both during production and performance. During production, the processor and especially the tanks could be insulated to retain the temperature needed to carry out the reaction process. When using the Biodiesel fuel, regular diesel additives could be added to the engine or Biodiesel/diesel mixes could be run in the engine during cold weather. Also, there can always be continuing research in the chemistry of the process and possible engine modifications.

8. APPENDIX

8.1 Gantt Chart



8.2 Process Diagram



8.3 Pictures

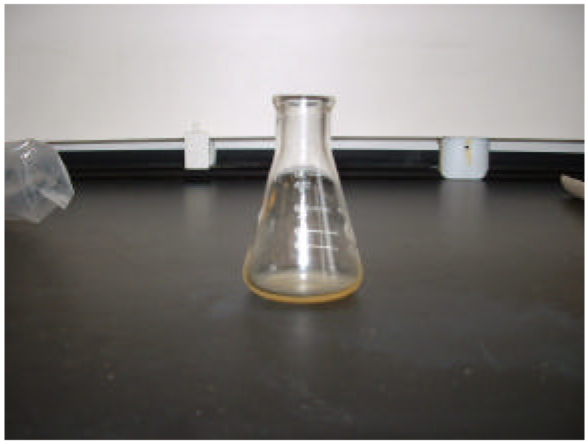


Figure 8.3.1 1 gram of used cooking oil in an Erlenmeyer flask

Figure 8.3.2 Addition of Isopropyl Alcohol to oil sample

Figure 8.3.3 Addition of phenolphthalein to sample

Figure 8.3.4 Color change after titration

Figure 8.3.5 Wilson College's Biodiesel Producer

Figure 8.3.6 Wilson College's Biodiesel Producer

Figure 8.3.7 Wilson College's Biodiesel shown with Biodiesel / Glycerin separation

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