

Introduction/Objectives

Gasoline prices have been on the rise for about the past two years. In order to combat the rising cost of petroleum fuel, Rensselaer Polytechnic Institute is investing in a campus Biodiesel plant. There are three main goals for the plant. The first is to produce approximately 100 gallons per week to run the campus shuttle buses currently running on petroleum diesel. Another objective for the research project is to reduce the amount of waste produced by the campus dining facilities. In the past the dining halls have had to pay a fee to have their waste cooking oil disposed of, but with the biodiesel plant, this waste can be recycled into biodiesel. This will reduce two costs, the amount spent on diesel fuel and waste cooking oil removal. The final goal of the plant is to serve as an educational tool for the students. The plant has already allowed students to get hands on experience in the laboratory as well as in the design and construction of the facility. Students will also have the opportunity to run the plant once it is erected and operational. This will give students a unique chance to run a plant before entering industry for their first job.

Literature Review/Background Information

Abstract

Today, the majority of the world's energy needs are supplied by petrochemical sources such as coal and natural gas, and supplemented by hydroelectric and nuclear power. The problem we as a nation are facing now is the fact that we depend on non-renewable energy sources and as we constantly increase our usage, the supply is being depleted at an alarming rate. [1] One of the major areas of concern is the supply of oil. The widespread use of fossil fuels creates pollution and environmental problems which makes it increasingly necessary to develop a cleaner, renewable energy source of limitless duration. This has spurred the most recent interest in the development of an alternate source for petroleum-based fuels. When seeking an alternative fuel, considerations must be made to ensure that the technology is feasible, that the product is both economical and environmentally friendly, and that the process is repeatable using materials that are readily available. Biodiesel is one possible alternative to fossil fuels. The biodiesel process uses oils of plant origin such as soybean or vegetable oil. One of the attractive features of biodiesel is that it is biodegradable, non-toxic, and has a low emissions profile compared to petroleum diesel.

Before the development of products such as biodiesel, the idea of using vegetable oils as fuel had been around for 100 years. Rudolph Diesel, the inventor of the diesel engine, tested peanut oil in his first engines. He said, "The use of vegetable oils for engine fuels may seem insignificant today. But such oils may in course of time be as important as petroleum and the coal tar products of the present time." However, these non-conventional fuels never were developed because at the time the petroleum products were much cheaper. There were also many problems associated with using vegetable oils directly into older diesel engines.

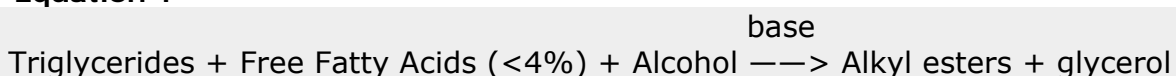
Biodiesel is the mono-alkyl ester of long chain fatty acids. It is a clean burning alternative fuel, domestically manufactured from renewable resources such as soybean oil, canola oil, waste cooking oil, vegetable oils, animal fats, or recycled restaurant greases. Through the use of biodiesel serious air pollutants such as particulates, carbon monoxide, hydrocarbons, sulfur, aromatics, and air toxins are reduced and a safe, biodegradable alternate fuel source is produced. Biodiesel has very similar characteristics to conventional diesel fuel and can be found mainly in two forms, B20 and B100. B20 is a blend of twenty percent biodiesel and eighty percent petroleum diesel, which can, in most cases, be used in unmodified diesel engines. The pure form of biodiesel is B100, but it often requires engine modifications to avoid maintenance and performance problems.

Plant oils usually contain free fatty acids, phospholipids, sterols, water, odorants and other impurities. Therefore the oils as mentioned above cannot be used directly as fuel. Currently, there is one major process for producing biodiesel, but with the growing interest in alternatives to petroleum-based fuels other technological innovations are evolving. Biodiesel is one of the only renewable alternative liquid fuels for transportation, so it will be a priority to find new more efficient and effective methods of production.

Transesterification:

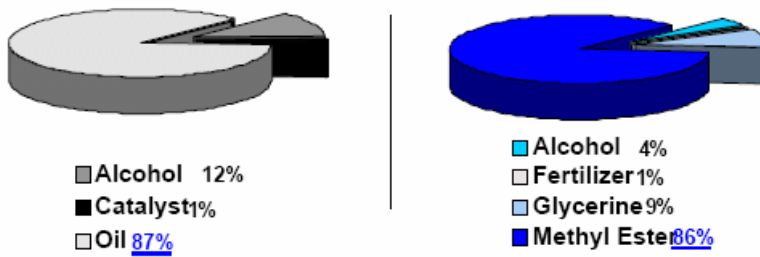
Transesterification is the main reaction in the conversion of oils to biodiesel. It is the reaction of an alcohol, in most cases methanol, with the triglyceride oils from oils, fats, or recycled grease, forming biodiesel (fatty acid alkyl esters) and glycerol. The reaction requires heat and a strong base catalyst, such as sodium hydroxide or potassium hydroxide. A simplified form of the transesterification reaction is shown below.

Equation 1



If the feedstock has more than four percent free fatty acids, it must go through a pretreatment reaction called acid esterification. Typically, vegetable oils and some food-grade animal fats do not need this pretreatment. However, some of the edible animal fats and the recycled grease often contain greater than four percent free fatty acids and need to undergo acid esterification. The feedstock is filtered and processed to remove the water and contaminants, then fed to the acid esterification process. The acid esterification process is to increase the yield of biodiesel by converting the free fatty acids into biodiesel in the presence of a strong acid catalyst, such as sulfuric acid. After the completion of the acid esterification process, it is dewatered and sent to the transesterification reaction. After the transesterification, the biodiesel and the glycerol are separated and the methanol is then recovered from the biodiesel, cleaned and recycled into the feed stream. The next step in the process is to refine the biodiesel and the glycerol. [3]

Process Input Levels = Process Output Levels



Nothing is wasted

Advantages of a Base Catalyzed Reaction

- * Low temperature (150 F) and pressure (20 psi) processing.
- * High conversion (98%) with minimal side reactions and reaction time.
- * Direct conversion to methyl ester with no intermediate steps.
- * Exotic materials of construction are not necessary.

[4]
Figure 1

The refining of biodiesel includes one or more washing to remove excess alcohol, catalyst, and soap, then it is dried and sent to storage. In some cases the biodiesel is distilled to produce colorless, odorless, zero-sulfur biodiesel. The refining of glycerol involves neutralizing unreacted catalysts and soaps with acid. Then the water and alcohol are removed to produce 50%-80% crude glycerol. The next step is to remove the unreacted fats or oils or other contaminants. Finally, if the plant is large enough it might further refine the glycerol to 99% for sale to the pharmaceutical and cosmetic industries. [3] The overall process would look some thing like the following:

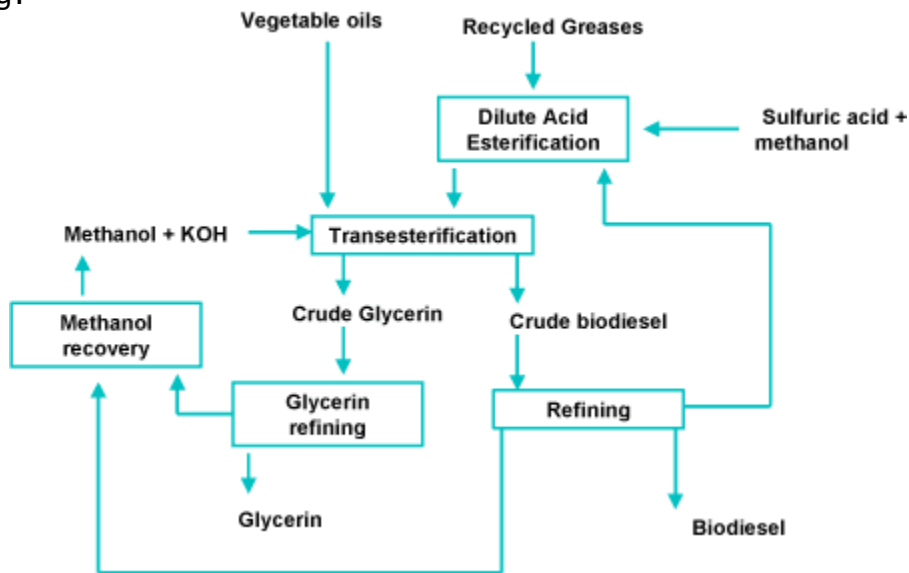


Figure 2
[3]

There are several factors that affect the quality of conversion by the transesterification process. The first factors to be concerned with are the free fatty acid and moisture content, which are key in determining the

viability of the vegetable oil transesterification process. For the base catalyzed reaction to proceed to completion the free fatty acid value has to be less than 4%. Higher acidity oil will lead to a less efficient conversion. Both, excess as well as insufficient amount of catalyst may cause soap formation. [5]

When selecting the starting materials it is important that they meet certain criterion. The triglycerides should have a low acidity and all materials should be relatively anhydrous. Care should be exercised when adding sodium hydroxide to compensate for a high acid value. The addition of excess sodium hydroxide will cause soap to form which will increase the viscosity of the formation of gels and interfere with the reaction and the separation of glycerol. [6] When the above requirements are not met there can be a significant decrease in product yield.

Most of the biodiesel is currently made from edible oils by using methanol and alkaline catalyst. However, there are large amounts of low cost oils and fats that could be converted to biodiesel. The problems with processing these low cost oils and fats is that they often contain large amounts of free fatty acids (FFA) that cannot be converted to biodiesel using alkaline (basic) catalyst. Therefore, two-step esterification process is required for these feed stocks. Initially the FFA of these can be converted to fatty acid methyl esters by an acid catalyzed pretreatment and in the second step transesterification is completed by using alkaline catalyst to complete the reaction. [7] Initial process development was performed with synthetic mixture containing 20 and 40% free fatty acids prepared by using palmitic acid. Process parameters such as molar ratio of alcohol to oil, type of alcohol, amount of acid catalyst, reaction time, and free fatty acid level were investigated to determine the best strategy for converting the free fatty acids to usable esters. Research has shown that the acid level of the high free fatty acids feed stocks could be reduced to less than 1% with a two-step pretreatment reaction. The reaction mixture was allowed to settle between steps so that the water phase could be removed. The two-step pretreatment reaction was demonstrated with actual feedstock, including yellow grease with 12% free fatty acid and brown grease with 33% free fatty acids. After reducing the acid levels of the feedstock to less than 1%, the transesterification reaction was completed with an alkaline catalyst to produce fuel grade biodiesel [2].

Turck et al. [8] have investigated the negative influence of base catalyzed transesterification of triglycerides containing substantial amounts of free fatty acids. Free fatty acids react with the basic catalyst added for the reaction and give rise to soap, resulting in the materialization of one part of the catalyst which is neutralized and is therefore no longer available for transesterification. These high FFA content oils/fats are processed with an immiscible basic glycerol phase to neutralize the free fatty acids and cause them to pass over into the glycerol phase by means of monovalent alcohols. The triglycerides are subjected to transesterification using a base as catalyst, to form fatty acid alkyl esters, characterized in that after its separation, the basic glycerol phase produced during transesterification of the triglycerides is used for processing the oils/fats for removal of free fatty acids. The minimum

amount of catalyst required for this process was calculated, relative to 1000 g of the oil to be processed, as a function of the acid value and the mean molar mass of the oil/fat.

Other parameters affecting the transesterification process are the catalyst type and concentration. Catalysts used in the transesterification process can be classified in the following categories: alkali, acid, enzyme, or heterogeneous (for examples of catalysts from each category see Table 1).

Table 1

Categories	Alkali	Acid	Enzyme
Catalysts:	sodium hydroxide, potassium hydroxide	sulfuric acid, phosphoric acid	lipases

Although chemical transesterification using an alkaline catalysis process gives high conversion levels of triglycerides to their corresponding methyl esters in short reaction times, the reaction has several drawbacks: it is energy intensive, recovery of glycerol is difficult, the acidic or alkaline catalyst has to be removed from the product, alkaline waste water require treatment, and free fatty acid and water interfere the reaction. Enzymatic catalysts like lipases are able to effectively catalyze the transesterification of triglycerides in either aqueous or non-aqueous systems, which can overcome the problems mentioned above. [9] In particular, the glycerol can be easily removed without any complex process, and also that free fatty acids contained in waste oils and fats can be completely converted to alkyl esters. On the other hand, in general the production cost of a lipase catalyst is significantly greater than that of an alkaline catalyst.

The molar ratio of alcohol to triglyceride is one of the most important variables affecting the yield of ester. The stoichiometric ratio for transesterification requires three moles of alcohol and one mole of triglyceride to yield three moles of fatty acid alkyl esters and one mole of glycerol. However, the transesterification reaction is an equilibrium reaction so the ratio will be higher than the stoichiometric ratio to drive the reaction towards the desired products. The desired ratio varies depending on the type of oil being converted and careful consideration of the ratio is necessary to ensure it is not too difficult to extract the glycerol. It took a lot of trial and error testing to determine the correct ratios, but the values are now tabulated for most of the major triglycerides.

Other variables that affect the process yield are reaction time, temperature, and mixing intensity. The reaction time seems to have the most effect, essentially the longer the reaction time the better the conversion percentage. Freedman et al. [10] transesterified peanut, cotton-seed, sunflower and soybean oil under the condition of methanol-oil molar ratio 6:1, 0.5% sodium methoxide catalyst and 60 °C. An approximate yield of

80% was observed after 1 min for soybean and sunflower oils. After 1 hour, the conversion was almost the same for all four oils (93–98%). Depending on the oil used, there will be a corresponding temperature at which transesterification occurs. Mixing is very important to get the reaction started, but once the two phases are mixed the reaction will continue on its own.

Fuel Properties and Specifications of Biodiesel:

Since biodiesel is produced from vegetable oils of varying origin and quality, it was necessary to install a standardization of fuel quality to guarantee engine performance. Austria was the first country in the world to define and approve the standards for rapeseed oil methyl esters as diesel fuel. As standardization is a prerequisite for successful market introduction and penetration of biodiesel, standards or guidelines for the quality of biodiesel have also been defined in other countries like Germany, Italy, France, the Czech Republic and in the United states.

The parameters that are used to define the quality of biodiesel are divided into two groups: general parameters (see Table 2) and chemical composition and purity (see Table 3). [11]

Table 2 - General parameters of the quality of biodiesel

Parameters	Austria (ON)	Czech republic (CSN)	France (journal official)	Germany (DIN)	Italy (UNI)	USA (ASTM)
Density at 15 °C g/cm ³	0.85–0.89	0.87–0.89	0.87–0.89	0.875–0.89	0.86–0.90	–
Viscosity at 40 mm ² /s	3.5–5.0	3.5–5.0	3.5–5.0	3.5–5.0	3.5–5.0	1.9–6.0
Flash point (°C)	100	110	100	110	100	130
CFPP (°C)	0/–5	–5	–	0–10/–20	–	–
Pour point (°C)	–	–	–10	–	0/–5	–
Cetane number	≥49	≥48	≥49	≥49	–	≥47
Neutralization number (mgKOH/g)	≤0.8	≤0.5	≤0.5	≤0.5	≤0.5	≤0.8
Conradson carbon residue (%)	0.05	0.05	–	0.05	–	0.05

Table 3 - Vegetable oil specific parameters for the quality of biodiesel

Parameters	Austria (ON)	Czech republic (CSN)	France (journal official)	Germany (DIN)	Italy (UNI)	USA (ASTM)
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Parameters	Austria (ON)	Czech republic (CSN)	France (journal official)	Germany (DIN)	Italy (UNI)	USA (ASTM)
Methanol/ethanol (% mass)	≤0.2	–	≤0.1	≤0.3	≤0.2	–
Ester content (% mass)	–	–	≥96.5	–	≥98	–
Monoglyceride (% mass)	–	–	≤0.8	≤0.8	≤0.8	–
Diglyceride (% mass)	–	–	≤0.2	≤0.4	≤0.2	–
Triglyceride (% mass)	–	–	≤0.2	≤0.4	≤0.1	–
Free glycerol (% mass)	≤0.02	≤0.02	≤0.02	≤0.02	≤0.05	≤0.02
Total glycerol (% mass)	≤0.24	≤0.24	≤0.25	≤0.25	–	≤0.24
Iodine number	≤120	–	≤115	≤115	–	–

Among the general parameters for biodiesel, the viscosity controls the characteristics of the injection from the diesel injector. The flash point is the temperature at which it will ignite when exposed to a flame or spark. Cold filter plugging point (CFPP) of a fuel reflects its cold weather performance. At low operating temperature fuel may thicken and might not flow properly affecting the performance of fuel lines, fuel pumps and injectors. CFPP defines the fuels limit of filterability, having a better correlation than cloud point for biodiesel as well as petroleum-based diesel. Cetane number is indicative of its ignition characteristics. The cetane number measures how easily ignition occurs and the smoothness of combustion. The higher the cetane number, the better its ignition properties will be. Cetane number affects a number of engine performance parameters like combustion, stability, drivability, white smoke, noise and emissions of carbon monoxide and hydrocarbons. Biodiesel has higher cetane number than conventional diesel fuel, which results in higher combustion efficiency. Neutralization number is specified to ensure proper ageing properties of the fuel and/or a good manufacturing process. It is also important to control the amount of alcohol because the presence of a high level of alcohol deteriorates natural rubber seals and gaskets. [2]

Alkali Catalyst Research

The process for producing biodiesel, transesterification, has been around for many years. It was originally used to produce soap in the 1940s and 1950s. The process was carried out in the presence of a base catalyst, typically sodium hydroxide (NaOH) or potassium hydroxide (KOH). The early work in soap production yielded many patents providing information to help develop the process for biodiesel production. Many of these patents are held by Colgate-Palmolive-Peet. In U.S. Patent # 2,383,579, H. D. Allan discovered that an alkali or acid catalyst could be used in the transesterification reaction. He also found that the reaction time with an alkali catalyst was significantly shorter. The base catalyzed reaction was later studied in the late 1980s and early 1990s as an alternative fuel source that we now call biodiesel.^[1] Biodiesel can be produced using base catalyzed transesterification of the oil, direct acid catalyzed transesterification of the oil or using an enzyme catalyst. The most commonly used method to produce biodiesel is the base catalyzed reaction. The benefits of an alkali catalyst are: low temperature and pressure reaction, high conversion (up to 98%) and few side reactions, quicker reaction time than the other two methods, direct synthesis of biodiesel with no intermediate compounds, and relatively low materials and equipment costs.^[2] The cost is low because no exotic equipment or materials are involved.

The article, *Optimization of Base-Catalyzed Transesterification Reaction of Used Cooking Oil*, raised some interesting points concerning the ratios of oil/methanol and amounts of catalysts depending on whether or not a methanol recovery component is integrated into the plant and how many batches are run each day. Their suggestions were:

1. Oil/alcohol molar ratio, 1:6; temperature, 55 (1°C; NaOH amount, 1% (by the weight of the oil); stirring speed, 40 rpm; pressure, atmospheric; and reaction time, 60 min.
2. Oil/alcohol molar ratio, 1:5; temperature, 55 (1°C; NaOH amount, 2% (by the weight of the oil); stirring speed, 40 rpm; pressure, atmospheric; and reaction time, 120 min.
3. Oil/alcohol molar ratio, 1:6; temperature, 55 (1°C; NaOH amount, 2% (by the weight of the oil); stirring speed, 40 rpm; pressure, atmospheric; and reaction time, 30 min.^[1]

These suggested proportions will be experimentally examined in future laboratory testing to determine the feasibility for use in the present pilot plant.

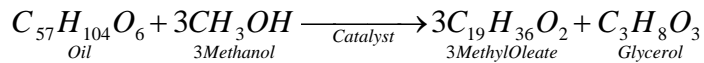
The use of an alkali catalyst presents some potential problems. One of the major problems with base catalysts is that they are highly hygroscopic. As a result, water will be absorbed when the catalyst is exposed to air and form chemical water when dissolved in alcohol.^[4] Base catalysts also are less effective when there is a high concentration of free fatty acids creating a necessity for an acid catalyzed pretreatment step. The pretreatment step

may improve the conversion when running batches with the used cooking oil, which has a higher free fatty acid content than the virgin oil. Despite the prospective drawbacks, the quick reaction time and relatively low cost make the use of a base catalyst the most viable option for producing biodiesel.

Mass Balance around the Reactor

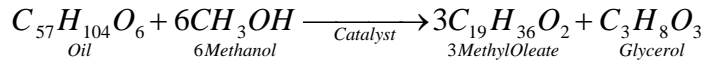
The first step in the designing of the reactor is to complete a mass balance around the reactor to determine in the ideal case what is entering and leaving the reactor. The flow rates are necessary to choose the size of the pipes and pumps. The stoichiometry reaction for the production of biodiesel is as follows:

Equation 2



The oil used in this case is trolein. However, it is desirable to use excess methanol to drive the react to near completion. That means that all of the oil is converted to biodiesel. Therefore, typically six moles of methanol is used for ever mole of oil as seen in the following reaction:

Equation 3



If this excess methanol was not used, then that would contribute to an oil/biodiesel mixture leaving the reactor stream, which would cause problems with the actual use of the fuel. Therefore, I can assume that if we want to produce 100 gallons of biodiesel and know the densities of all components, we can calculate the amount of oil needed. It was also assumed that methanol was 100% in excess and that 50% of the excess methanol was in the biodiesel layer and 50% of the excess methanol was in the glycerol phase. The catalyst was used in a ratio of five grams of solid catalyst per liter of oil used; this equates to one mole of sodium hydroxide catalyst per eight moles of oil used [14]. The figure below shows the overall mole balance around the reactor.

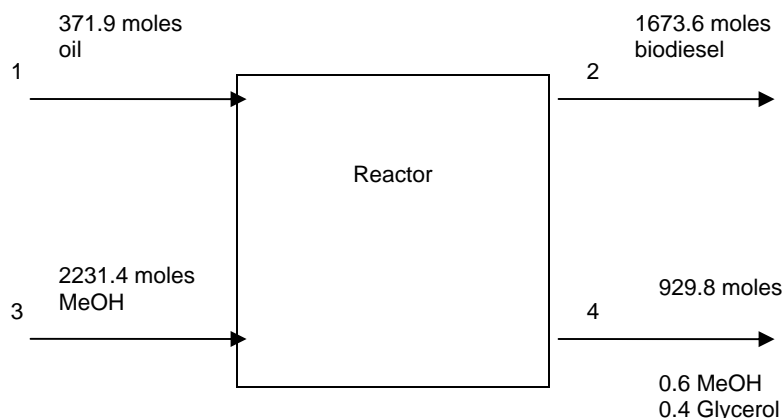


Figure 3 - Mole balance around the biodiesel reactor

The following stream summary table, Table 4, shows more information about each stream and component in this reactor diagram. We assumed that the solid sodium hydroxide catalyst has a negligible effect on the total volume and density of the flow streams.

Table 4 – Stream summary table for the streams labeled 1-4 in Figure 3 and also component data for all chemicals in the reactor system

Stream Table for Reactor					
	Total Volume (L)	Total Mass (kg)	Total Mass (g)	Total Moles	Mole Fraction
1	366.3835398	329.3055255	329305.5255	371.9033333	pure Oil
2	90.33952085	71.4946968	71494.6968	2231.42	pure Methanol
3	401.1270647	348.6816892	348681.6892	1673.565	0.67 Biodiesel 0.33 Methanol
4	300.8452985	261.5112669	261511.2669	929.7583333	0.4 Glycerol 0.6 Methanol

Components					
	Formula	MW (g/mol)	Density (kg/L)	Moles In	Moles Out
Oil	C57H104O6	885.46	0.8988	371.9033333	
Methanol	CH3OH	32.04	0.7914	2231.42	1115.71
Biodiesel	C19H36O2	296.5	0.8739		1115.71
Glycerol	C3H8O3	92.1	1.2613		371.9033333

Furthermore, once the stock of oil is chosen, titrations can be performed to calculate the exact amount of methanol and catalyst needed to ensure complete reactions.

Economic Considerations

To construct an economically feasible biodiesel plant several important factors must be considered. First is the cost of raw materials such as feedstock, alcohol, and catalyst. "The cost of the fat or oil used to produce biodiesel affects the cost of the finished product, up to 60%-75%; therefore, less-expensive raw materials are preferred."^[1] Due to this factor we are currently running small-scale batch experiments on used cooking oil, which we can obtain for free. The second important economic consideration for the process is to produce a high-value co-product, glycerin. One of the potential uses for this glycerin includes selling it for use in cosmetics, pharmaceuticals, or for a de-icing agent as outlined in US Patent # 6,890,451. The final consideration is a methanol recovery system since there is a significant amount of unreacted methanol in both the biodiesel and glycerin phases. The recovery system allows an increased use of methanol as it reduces the waste, thus rendering the system more cost effective. The benefit of using excess methanol is a higher yield of biodiesel. In US Patent # 2,383,580 and # 2,383,581 Colgate-Palmolive-Peet states that using a larger ratio of methanol to oil improves the yield by reducing the amount of catalyst needed, as well as the reaction time.

Methanol Recovery

Since the plant is operating on a limited budget, it is crucial to make the most of the raw materials as possible. This creates the necessity to recover the excess methanol from the glycerol stream and recycle it into the reactor. The separation is to be done using a flash chamber operating under a vacuum. It is possible to use a flash instead of a distillation column because the difference in boiling points between methanol and glycerol is so large. Operating in a vacuum lowers the boiling point of the components so less duty of the reboiler is lower. Also it allows us to use cooling water in the condenser. We are also making an assumption that glycerol is non-boiling.

To find the pressure for the flash chamber I used the Antoine equation for methanol:

Equation 4

$$\text{Antoine's } \log(P^*) = 8.08097 - \frac{1582.271}{T + 239.726}$$

Where T (boiling point) is in degrees Celsius and P* (saturation pressure) is measured in mmHg. For our calculation we set T to be 110°F or 43.3°C, which allows us to use cooling water in the condenser, and yields a saturation pressure of 295.527 mmHg. Then Raoult's law gives us the operating pressure for our flash.

Equation 5

$$\text{Raoult's } P y_i = P_i^* x_i$$

Where P is total pressure, y_i is the mole fraction of methanol in the vapor phase, P_i^* is the saturation pressure of methanol and x_i is the mole fraction of methanol in the liquid phase. We know that only methanol is evaporating so y_i is equal to one. This yields an operating pressure of 177.32 mmHg.

Solving equation 4 for P^* , substituting that expression into equation 25 and solving the resulting equation for T gives the following equation, 6.

Equation 6

$$T = \frac{1582.271}{-\log\left(\frac{P}{x}\right) + 8.08097} - 239.726$$

From this equation, we can set an operating pressure and then observe the temperature changes with respect to liquid mole fraction. For the calculations it was also assumed that we want 95% recovery of methanol. The evaluation of equation 6 shows a boiling point elevation from 43.3°C to 109.5°C. It may also be desirable to know the amount of liquid remaining in the still at a particular mole fraction. This is value may be obtained from equation 7.

Equation 7

$$\int_{x_0}^x \frac{dx}{y-x} = \ln\left(\frac{W}{W_0}\right)$$

Where y is the mole fraction of methanol in the vapor phase (equal to 1), x is the mole fraction of methanol in the liquid phase, W is the total number of moles left in the still at x , and W_0 is the initial number of moles in the still at x_0 . The results of the calculations can be seen in appendix 1 along with plots of the boiling point elevation of methanol.

After doing the first pass calculations, the assumption that glycerol was non-boiling was verified using the Antoine equation for glycerol and found that at a saturation pressure of 295.527 mmHg the boiling point of glycerol is 252.34°C (Antoine Parameter can be found in Appendix 1). This confirms that glycerol is non-boiling. Then next pass of calculations should be done using a computer-based simulation software, such as Aspen.

Finally, the heat duty of the reboiler was found using equation 8.

Equation 8

$$\dot{Q} = \dot{n}_v \Delta H_{MeOH}^{vap}$$

Where \dot{Q} is the heat duty required for the reboiler, \dot{n}_v is the rate at which methanol is going into the vapor phase, and ΔH_{MeOH}^{vap} is the heat of vaporization for methanol. The heat duty required for our reboiler is 16208.22 BTU/hr

Uses of Glycerol

Glycerol is being investigated to determine the value of purifying and selling the glycerol generated by the campus biodiesel plant. It is widely used in a variety of industries as it has thousands of uses. Some of the more common industries that use glycerol are: food and beverage, pharmaceuticals, cosmetics and toiletries, tobacco, paper and printing, and textiles. The food and beverage industry uses glycerol to "moisten, sweeten and preserve foods and drinks." Glycerol is used to coat drugs, make elixirs, and prevent creams and ointments for drying out. It is present in cosmetics and toiletries "because glycerol is nontoxic, non-irritating and odorless, it is used as a moisturizing agent and softening agent for cosmetics and toiletries." In the paper industry, glycerol is primarily used to soften and reduce shrinkage during the manufacturing process. Glycerol is also used in the textile industry to soften yarn and fabric. It is sometimes used to lubricate fibers to facilitate easier spinning, knitting and weaving of cloths and garments. [13]

Experimental

Once an understanding of the chemical processes required to make biodiesel is achieved, it is necessary to perform test reactions to ensure the methods are viable. Tests were conducted to verify the alkali catalyst method, as well as the volumetric ratios of reactants and products. Additional tests were conducted substituting dolemetic lyme for the traditional NaOH catalyst with the intention of increasing settling times and creating another useful byproduct.

Three different sets of experimentations were carried out. The first were methanol-oil reactions with Sodium hydroxide (NaOH) as a catalyst, with both waste and virgin vegetable oil. A last set was carried out with virgin oil using dolemetic lyme (CaO) as the catalyst, with intentions to produce Calcium magnesium acetate (CMA).

In order to push the oil esterification to completion, an excess of methanol was used during the tests, 25% by volume. The beaker was stirred for approximately 30 minutes, and then allowed to settle and separate. Two layers evolved—in the virgin oil, a semi-transparent, assumed biodiesel layer on top, and a darker glycerin layer underneath. In testing the waste vegetable oil, there were still two distinct layers, both layers were simply darker. All particulates that may have been in the waste oil were filtered out before reacting.

In an initial experiment of the lyme reaction, there were 2-3 various sized layers in the settled product. On top was a very small clear layer, unidentified as of yet. A second, larger reaction was carried out with hopes that the layer would be larger and easier to identify. Because the lyme used was a mixture of several different calcium and magnesium oxides and carbonates, an excess of both lyme and methanol was used. Eight grams of lyme was dissolved in 200 milliliters of methanol before being added to 800 milliliters of oil. So far the results have been inconclusive.

The next step for students in the lab is to actually test the products of our experiments. Currently we only have two methods for testing to determine if we have biodiesel. The first method is testing the pH and the second is testing the viscosity using a viscometer.

Equipment

Current Equipment:

1. pH meter
2. Viscometer
3. Limited glassware
4. 2 magnetic stirring bars
5. 1 hotplate with stirring capability
6. A fume hood
7. Necessary chemicals

Equipment Needed:

1. More glassware to allow for larger batches and to be used to create a display of raw materials and finished products for visitors to the lab to observe.
2. Cleaning supplies to clean our glassware
3. A gas chromatography column
4. A device to test the flash point

Maybe we will also be able to go to the new biodiesel facility in the Port of Albany and use some of their equipment to test our finished product to determine if we are meeting the standards. This could be done once a month or every two months to ensure we are producing a quality product. I recommend this because all the necessary testing equipment would be too costly of an investment at this time.

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Appendix 1

Antoine Parameters			
	A	B	C
Methanol	8.08097	1582.271	239.726
Glycerol	6.16501	1036.065	28.097

Boiling Point Elevation of Methanol			
P_star	x	P_total	Temp
295.527	0.6	177.3162	42.3
	0.55	177.3162	44.21246
	0.5	177.3162	46.33731
	0.45	177.3162	48.72355
	0.4	177.3162	51.43871
	0.35	177.3162	54.57939
	0.3	177.3162	58.29035
	0.25	177.3162	62.80213
	0.2	177.3162	68.51352
	0.15	177.3162	76.20295
	0.1	177.3162	87.71573
	0.05	177.3162	109.4693

Evaluation of Equation									
x0	x	lower	upper	int	exp(dx/(1-x))	W (moles)		time (min)	Temp (deg C)
	0.6					929.7583		0	42.29999837
0.6	0.55	0.916291	0.798508	-0.11778	0.888888889	826.4498	10	10.33062	44.21246054
0.6	0.5	0.916291	0.693147	-0.22314	0.8	743.8048	10	18.59512	46.33731468
0.6	0.45	0.916291	0.597837	-0.31845	0.727272727	676.1862	10	25.35698	48.72355051
0.6	0.4	0.916291	0.510826	-0.40547	0.666666667	619.8373	10	30.99187	51.43870649
0.6	0.35	0.916291	0.430783	-0.48551	0.615384615	572.1575	10	35.75985	54.57938703
0.6	0.3	0.916291	0.356675	-0.55962	0.571428571	531.2891	10	39.84669	58.29035493
0.6	0.25	0.916291	0.287682	-0.62861	0.533333333	495.8699	10	43.38861	62.80212878
0.6	0.2	0.916291	0.223144	-0.69315	0.5	464.878	10	46.4878	68.5135194
0.6	0.15	0.916291	0.162519	-0.75377	0.470588235	437.5322	10	49.22238	76.20294642
0.6	0.1	0.916291	0.105361	-0.81093	0.444444444	413.2249	10	51.65311	87.71573096
0.6	0.05	0.916291	0.051293	-0.865	0.421052632	391.4762	10	53.82798	109.4693428

$$Q = 285.010101 \text{ kJ/min} \quad 16208.22 \text{ btu/hr}$$

