AC 2008-701: ENERGIZING AN INTRODUCTORY CHEMICAL ENGINEERING COURSE WITH BIODIESEL

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Energizing an Introductory Chemical Engineering Course with Biodiesel

Abstract

The biorefining industry is experiencing tremendous growth in the United States as well as in the State of Alabama. Over the past several years, domestic production of ethanol has doubled, while biodiesel production has more than tripled. Media attention highlighting the current high price and limited supply of crude oil and continually escalating environmental concerns with the use of petroleum fuels has increased interest in and awareness of renewable energy and biofuels, especially among students. Since chemical engineers play a vital role in the advancement of the biorefining industry, biofuel production is an excellent vehicle to make chemical engineering "come alive" for students and stimulate interest in the field as both a discipline and a profession.

The Department of Chemical and Materials Engineering at the University of Alabama in Huntsville has developed a hands-on laboratory activity allowing students to produce their own biodiesel. Biodiesel production is a relatively simple, safe, and inexpensive laboratory exercise, making it well-suited for use in outreach activities and introductory-level chemical engineering courses. At UA Huntsville, the activity is currently being used to introduce high school students as well as freshmen and transfer students to the field of chemical engineering. A modified version of the activity is utilized in the College of Engineering Summer Camp for high school students, while a more comprehensive version is used in the introductory chemical engineering course that is part of the department's core curriculum. The laboratory activity is supplemented with a lecture that provides students with an overview of biofuels production and utilization and discusses the scientific and engineering aspects of biodiesel production.

This paper provides the materials, supplies, and procedures necessary to implement and execute the biodiesel production activity along with cost estimates. Also included are examples of supplemental lecture material and assignments and calculations appropriate for use in an introductory-level course.

Introduction

The biofuels industry has experienced significant and well-publicized growth in recent years. Favorable tax incentives, the current high price and limited supply of crude oil, and continually escalating environmental concerns with the use of petroleum fuels have facilitated tremendous increases in production of the two primary biofuels, biodiesel and ethanol. Domestic biodiesel production more than tripled between 2005 and 2007, while ethanol production doubled between 2005 and 2006. Growth is certain to continue, as the U.S. Department of Energy has set the goal of replacing 30% of petroleum fuels with biofuels by 2030. Biofuels production in the state of Alabama is also experiencing significant growth. Currently, over 23 million gallons of biodiesel are produced in Alabama, with an additional 114 million gallons of capacity under construction. Various companies in the state are also developing ethanol production facilities.

The Department of Chemical and Materials Engineering at University of Alabama in Huntsville has developed and implemented a hands-on laboratory activity to educate potential and current students about various aspects of biofuels production and utilization. The activity was developed specifically for students enrolled in the 3-hour introductory chemical engineering course: CHE 197- Computer Methods for Chemical Engineers. As in many chemical engineering departments, one goal of this course is to introduce freshman and transfer students to the chemical engineering curriculum and faculty. In order to fulfill the College of Engineering core curriculum, the course must also provide instruction in introductory computer programming. The Department uses the course to introduce students to the chemical engineering faculty, curriculum, and research activities. The content of the course includes lectures on various aspects of chemical engineering from each of the Department's faculty members, as well as instruction to develop fundamental computational and computer skills, including spreadsheet utilization, graphing, data analysis, basic statistical calculations, and simple computer programming. Enrollment in this class is typically comprised of first-time freshmen and transfer students who may or may not have declared chemical engineering as their major. The College specifies co-enrollment or completion of pre-calculus as the pre-requisite for all 100-level introductory engineering courses. As a result, students enrolled in CHE 197 often have quite varied and somewhat limited mathematics and chemistry skills, and many of them admittedly have little or no understanding of what chemical engineering really is, either as a discipline or as a profession.

Perhaps more than ever, today's students learn by doing. Unfortunately, entry-level engineering students often have difficulty realizing how entry-level classes apply to "being an engineer". For chemical engineering, this problem can be especially challenging to overcome. Many traditional chemical engineering processes, such as crude oil refining, are difficult, if not impossible, to demonstrate in the lab. Others, such as paper-making, are significantly altered from the actual industrial process and lack the "wow" factor that sparks student interest. Therefore, the goal of this activity is to make chemical engineering "come alive" for freshman and transfer students who often do not have an accurate understanding of the discipline. Fundamental science and core chemical engineering concepts are reinforced through the hands-on aspect of this activity, which is based on the concept of active learning. The students also work in groups, which facilitates collaborative learning. The purpose of active and collaborative learning techniques is to engage students in the learning process and to exercise critical thinking and problem-solving skills. Many researchers have noted the positive effect of using active and cooperative learning techniques to stimulate student interest and improve the quality of learning[1,2]. For many students, course material becomes more interesting and easy to retain when they can experience or observe a concept rather than simply listen to an instructor lecture. Active learning techniques also address various different types of learning styles, including sensory and active learners, both of which are prevalent learning types among engineering students[3]. While it is important to note that retention of freshmen is affected by a number of social and economic factors[4], providing opportunities for students to experience science and engineering in a fun and educational way will help foster the interest and curiosity that motivates students to choose chemical engineering as their major in the first place.

Other departments have reported successful implementation of hands-on activities within a freshman course. Perhaps the most successful example is Rowan University's Freshman Clinic sequence that uses coffee making, beer brewing, olive oil and chocolate manufacturing, and human respiration to demonstrate chemical engineering principles[5-10]. The goal of the Freshmen Clinic sequence is to introduce a multi-disciplinary cohort of students to each of the engineering disciplines and teach students how to perform engineering measurements and analyze data. Coronella[11] has successfully implemented a semester-long design project to build, test, and evaluate an evaporative cooler into the introductory chemical engineering course. Minerick and Schulz[12] have developed several desk-top experiments for freshmen that demonstrate topics such as fermentation and electrophoresis in a single contact session.

Various papers describing the activities used in Rowan's Freshman Clinic have reported that students are excited and motivated by the hands-on activities[6-8]. Coronella[11] performed a thorough course assessment of his project and reported that the activity seemed to positively affect the persistence rate, as higher numbers of students enrolled in the succeeding course upon completing the first semester introductory course. He also reported that the majority of students indicated that the project enhanced their teamwork skills and reinforced engineering calculations. Surprising, Coronella also reported that a significant number of students reported that they "saw no connection between the project and chemical engineering." Minerick and Schulz[12] also noted that student feedback was positive, and many students indicated the hands-on activities were the highlight of the course.

Several departments have developed biofuels, bioprocessing, and biotechnology courses and laboratories[13-19]. However, most of these activities were implemented in senior-level courses and would not be appropriate for entry-level students. Other educators have successfully incorporated biodiesel production projects into both introductory- and senior-level chemical engineering courses. Hernandez et al.[20] developed a senior-level plant design project to evaluate the production and economics of converting waste grease into biodiesel. The University of Virginia has implemented a biodiesel design project into the freshman engineering course[21]. This project is similar to that developed by Coronella[11], in that it challenges students to build a biodiesel reactor over a semester-long course.

Since the introductory chemical engineering course at UA Huntsville has a variety of departmental and college objectives that must be met, the faculty agreed that implementation of a hands-on activity should not replace any of the existing course content. Therefore, implementation of a semester-long design project was not a practical option. The lecture and laboratory exercises associated with this activity require approximately 3-4 one-hour contact sessions to complete, depending on the depth of the lecture material and the extent to which the biodiesel production procedure is completed. The authors have found that this is sufficient time for students to learn about biofuels production and complete the activity without affecting the quality of instruction on the other required topics for the course. As previously discussed, biofuels production and utilization was chosen as the broad topic given the rapid growth of this area in recent years. The topic also ties-in with current research efforts by department faculty, as well as with a senior-level elective sequence that includes courses in bioprocessing and bioseparations. In order to accommodate the lab activity, some of the stand-alone presentations given by the faculty in CHE 197 (covering topics such as the curriculum and faculty research), have been merged with the lecture for this activity. This has helped ensure that the lectures and lab for this activity can be completed without compromising the time spent on other topics.

The specific laboratory activity developed for the introductory chemical engineering course at UA Huntsville is the transesterification of oil to produce biodiesel. Biodiesel production was chosen for a several reasons, including the relative ease and safety of the procedures and the low cost of the supplies and chemicals. The experiment also allows instructors to use the lab activity as a platform to introduce students to fundamental chemistry and chemical engineering principles, including unit conversions, stoichiometry, kinetics and catalysis, and conservation of mass. The activity has an even broader impact on students' perceptions of chemical engineering, as it generates a product that nearly all students use on a daily basis and illustrates how chemical engineering has a direct impact on their lives and society as a whole. Students become aware of the future of the chemical process industry by demonstrating technology from a rapidly growing industry that is poised to transform fuel and chemical production. The activity also emphasizes the critical role that chemical engineers play in developing efficient and economical processes for the production of renewable, sustainable, and environmentally friendly fuels.

Technical Background and Lecture Content

Biodiesel is produced via a transesterification reaction in which triglycerides (oil) react with an alcohol (methanol) to produce a mixture of fatty esters (biodiesel) and glycerol. The reaction takes place in the presence of either an acid or base catalyst, depending on the source of the oil feedstock. The most commonly used catalysts are sodium hydroxide (NaOH) and potassium hydroxide (KOH). The catalyst does not participate in the chemical reaction, but it does allow the reaction to proceed more rapidly.

Soybean oil is the most common oil used for biodiesel production in the U.S. Although soybean oil is a mixture of triglycerides, it can be assumed that soybean oil primarily consists of triolein. Triolein is a triglyceride in which all three fatty acid chains are oleic acid. Similarly, biodiesel produced from soybean oil primarily consists of methyl oleate, which is the methyl ester of oleic acid. The simplified mass-based chemical reaction for biodiesel production is given in Equation 1[22].

$$\textbf{100 lbs soybean oil + 10 lbs methanol} \xrightarrow{\textbf{NaOH}} \textbf{100 lbs biodiesel + 10 lbs glycerol} \qquad \text{(Eq. 1)}$$

In order to produce fuel grade biodiesel, at least 99.7% of the soybean oil must be converted into products. However, adding stoichiometric amounts of oil and methanol is not sufficient for the reaction to proceed to completion. In reality, anywhere from 60%-100% excess methanol is added to the reaction to ensure that all of the soybean oil is converted. As a result, some excess, unreacted methanol remains in the biodiesel/glycerol product. Biodiesel and glycerol are not miscible and will separate into two distinct product layers. The excess methanol will partition between these two products; therefore, both the biodiesel and glycerol phases will contain some methanol. The catalyst remaining in the biodiesel/glycerol mixture tends to partition into the glycerol phase, although some will remain in the biodiesel.

Typical biodiesel production processes use 0.3-1.5% by weight catalyst and a 6:1 molar ratio of methanol to oil. Conversions of 85%-94% are usually achieved[22]. Most of the glycerol can be separated from the methanol by simply allowing the mixture to settle. The crude biodiesel product obtained from the settling process contains biodiesel, water, some methanol and glycerol, and catalyst. The catalyst in the crude glycerol is neutralized, and the biodiesel is water-washed to remove impurities. Finally, the biodiesel is dried to remove the wash-water. The crude glycerol mixture obtained from the settling process also contains water, methanol, some biodiesel, and catalyst. The excess catalyst in the crude glycerol is also neutralized, and the crude glycerol is distilled to remove the excess methanol, water, and residual biodiesel. The excess methanol is recycled back into the chemical reaction. It is important to recover the excess methanol in order to keep manufacturing costs low and prevent waste. A simplified process flow diagram illustrating a typical biodiesel production process is given in Figure 1.

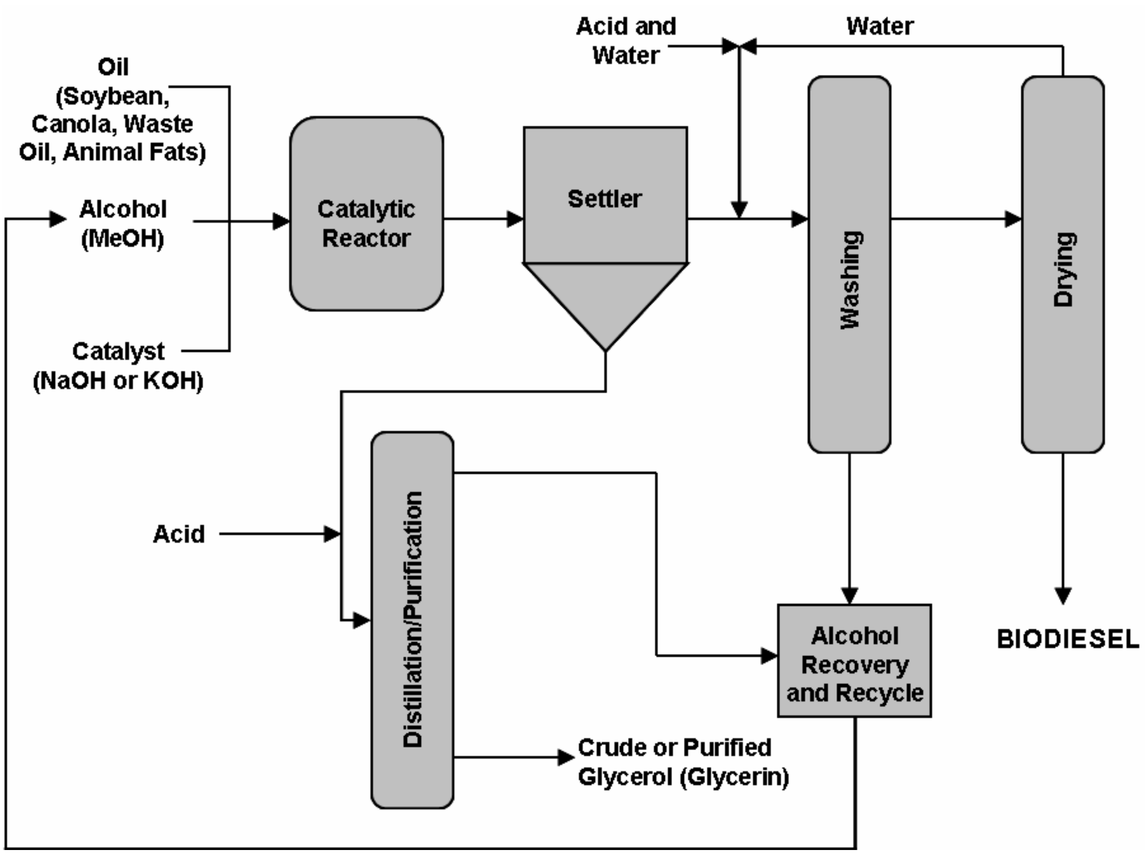


Figure 1: Process Flow Diagram for Biodiesel Production

Students are provided with a handout containing the information in the previous few paragraphs. The authors specifically elected to use a mass-based form of the chemical reaction to describe biodiesel production. Since many of the students enrolled in the course have a limited chemistry background, the authors felt that presenting students with a molar chemical equation using the chemical formulas for triolein, methanol, methyl oleate, and glycerol might be too complex for students with limited knowledge of chemistry. For readers interested in the stoichiometric reaction using the chemical formulas for each of the products and reactants, this equation can be found in the Appendix.

The mass-based chemical reaction also presents an opportunity to introduce students to the concept of conservation of mass. Since the transesterification reaction does not produce any gaseous by-products, it is easy to measure the mass and volume of each of the reactants and products. Using the physical properties of each reactant and product, such as molecular weight and density, students can easily investigate this reaction on mass, molar, and volume basis and do not need to be able to balance a molecular chemical equation. The student handout also includes physical properties of the reactants and products as shown in Table 1. The authors specifically elected to provide the chemical reaction in English units (pounds) but provide the physical properties of the reactants and products in SI units (grams/mole and grams/cm^3). This mix of units requires that students be able to understand and perform basic unit conversions in order to successfully complete the required calculations. Given the predominance of SI units in science and engineering education, these calculations provide students with an opportunity to practice calculations using units that are important in industry but not as widely used in education.

Chemical	**Density g/cm^3**	**Molecular Weight g/mole**
Soybean oil (triolein)	0.90	885.46
Methanol	0.79	32
Biodiesel (methyl oleate)	0.88	296.5
Glycerol	1.26	92.1

Table 1: Physical Properties of Reactants and Products

Supplemental Lecture Content

In addition to providing the handout, students attend a lecture discussing various aspects of biodiesel production, as well as the production of other biofuels and bioproducts. Although the lab exercise is specific to biodiesel production, the authors have found that the lecture is an excellent opportunity to educate students about ethanol production and other biorefining processes, especially as compared to petroleum refining. Specific topics and current statistics relevant to each topic, as presented in the lecture, are provided below. The presentation also includes process flow diagrams for biodiesel and ethanol production.

Current U.S. Fuel Production and Utilization

- Petroleum gas consumption – 142 billion gallons per year[23]
- Petroleum diesel consumption – 55 billion gallons per year[23]
- Ethanol production – 4.4-6 billion gallons per year[24]
    - 3-4% of petroleum gas demand
- Biodiesel production – 200-250 million gallons per year[25]
    - Less than 1% of petroleum diesel demand
- Only about 60% of a barrel of crude oil is used to produce gas and diesel fuel
    - Remainder produces other heating fuels and chemicals used to produce petroleum-based products
    - Plastics, synthetic fibers, household chemicals, fertilizer, pesticides, lubricants, oils, asphalt, etc.

Why Alternative Fuels?

- Can be produced from many renewable, plant-based resources
- Are produced from a carbon source that is native to the biosphere
    - Reduces greenhouse gas emissions

- Reduces U.S. dependence on foreign oil
- Government goal to displace 30% of petroleum fuels with biofuels by 2030

Biodiesel Production and Utilization

- 100 lbs soybean oil + 10 lbs methanol $\xrightarrow{NaOH}$ 100 lbs biodiesel + 10 lbs glycerol
- 85% of U.S biodiesel is produced from soybean oil
- Main co-product is glycerol
  - Need to find alternative uses for glycerol to improve overall economics
- Advantages of current biodiesel production technology
  - Well-proven on an industrial scale
  - Occurs at relatively mild temperature and pressure conditions
  - High conversion
  - Requires relatively simple and low-cost equipment
- Disadvantages of current biodiesel production technology
  - Expensive feedstock: soybean oil accounts for ~88% of the total cost
  - Use of soybean oil impacts the food supply
  - Typically a batch process, which requires increased time and labor
- Price: ~$2.84-$3.38/gallon, compared to ~$3.00-3.15 for petro-diesel[26]
- Biodiesel/petro-diesel blends as well as pure biodiesel can be used in most diesel engines
  - Blends range from B99 (99% biodiesel) to B1 (1% biodiesel); most common is B20 (20% biodiesel)
- Significant reduction in emissions resulting from combustion
  - Up to 75% less carbon dioxide, 50% less carbon monoxide, 70% less particulates, 40% less hydrocarbon, 100% less sulfate

Ethanol Production and Utilization

- 1 bushel (56 lbs) corn → 6.56 lbs ethanol + 17 lbs CO_2 + 17 lbs DDG
- Fermentation reaction – living cells consume sugar and produce ethanol and cell mass
- 99% of U.S. ethanol is produced from corn
- Utilizes ~14% of the U.S. corn crop
- 75-86% of capacity is based in 5 states
- Main co-products are animal feed (produced from DDG) and carbon dioxide
- Advantages of current ethanol production technology
  - Well-proven on an industrial scale
  - Process is relatively simple and well-understood
  - Dry distiller's grains (DDG) product can be sold as animal feed
- Disadvantages of current ethanol production technology
  - Expensive
  - Uses only ~30% of corn plant – stalks, husks, and cobs are wasted
  - Facility must be located in a corn-growing region
  - Impacts the food supply
  - Production limit of ~15 billion gallons/year
- Cost: ~$2.40-$2.63/gallon for E85, compared to $2.75-$3.05 for gasoline[26]
- About 15% of U.S. gas supply is E85
  - Use of E85 possible in select "Flex Fuel" vehicles manufactured by Chrysler, Ford, GM, and other auto companies

    - E10 can be used in nearly all modern autos
    - E85 requires a separate transportation and distribution system
- Significant reduction in emissions resulting from combustion
    - 15% less ozone forming toxics, 40% less carbon monoxide, 20% less particulates, 10% less nitrogen oxide, 80% less sulfate

The Future of Alternative Fuels

- Biorefining – convert biomass into a wide range of products including transportation fuels as well as other chemicals and products that are typically produced in a petroleum refinery
- Technologies for biorefining
    - Sugar platform – breakdown biomass into sugars and use microganisms to ferment the sugars into biofuels and biochemicals
    - Thermochemical platform – combust biomass to produce gases and catalytically convert the gases into biofuels and biochemicals
    - Carbon-rich chains platform – chemically convert natural plant oils into biofuels and biochemicals
- Identify alternative feedstocks for ethanol production
    - Lignocellulosic biomass – corn stover, straw, wood
    - Agricultural wastes – wood pulp waste, sawdust
    - Cultured biomass – switchgrass, fast growing trees
- Identify alternative feedstocks for biodiesel production
    - Jatropha oil and algae oil
- Develop economic and efficient methods to produce sugars from biomass
    - Acid and/or enzyme pre-treatment used to breakdown complex cellulose into sugar is the most expensive step in biofuel/biochemical production
- Develop economic and efficient processes to produce other value-added chemicals from biomass and biofuel co-products
    - Glycerol can be used to produce propylene glycol, butanol, 1,3-propandiol, and other chemicals that are typically produced from petroleum
    - Sugars can be used to produce chemicals used in the production of plastics, polymers, carpets, fabrics, detergents, lubricants, and many other chemicals and products typically produced from petroleum

Materials and Procedures

Biodiesel production is a relatively easy, safe, and inexpensive laboratory exercise. Table 2 summarizes the necessary chemicals and supplies needed to carry out the experiment.

Safety supplies	Equipment
• Gloves	• Hot plates
• Safety glasses	• Blenders
• Thermometers	• Analytical balance
• Pot holders or heat-resistant gloves	• Ring stands
• Weigh boats	
• Scoopula measuring spatulas	

Chemicals	Measuring devices and glassware
• Vegetable cooking oil • Methanol, 99% purity • Sodium hydroxide (or potassium hydroxide), 97%+ purity	• Beakers, 1000 or 2000 mL • Graduated cylinders, 500 mL • Separatory funnels • Storage containers (mason jars)

Table 2: Supplies Needed for Biodiesel Production Activity

The procedure for biodiesel production is provided below. This procedure produces approximately 1000 mL of a biodiesel/glycerol mixture, but could be modified to produce more or less. Students are provided with a handout on which to record specific data.

1. Using the hot plate, heat 1 L of oil in a glass beaker to 55° C.
2. Measure out 200 mL of methanol (99% purity).
3. Weigh out 3.5 grams of sodium hydroxide.
4. Carefully add the NaOH to the methanol, gently swirling to mix. The mixture may become warm to the touch. Most of the NaOH should dissolve.
5. When the oil reaches 55° C, carefully add it to the blender.
6. Carefully add the methanol/NaOH mixture to the blender.
7. Secure the lid of the blender tightly into place. Turn the blender on to a low speed and blend the mixture for 20 minutes.
8. Once the biodiesel mixture is cool, pour it into a separatory funnel mounted on a ring stand and allow the mixture to settle for 12-24 hours. The darker colored glycerol by-product will collect in a distinct layer at the bottom of the container. The pale liquid above is the biodiesel.
9. Carefully decant the glycerol into a graduated cylinder and determine the volume. Record this value in the designated space on the handout provided.
10. Carefully decant the biodiesel into a graduated cylinder and determine the volume. Record this value in the designated space on the handout provided.
11. Upon completion of the experiment, pour the biodiesel and glycerol into properly labeled waste containers.

Since freshman students may have limited or no experience working with chemicals in a laboratory setting, laboratory safety is strongly emphasized in both the lecture and the written information that is provided to students. Students are instructed to wear safety glasses and gloves at all times and are informed that food, drink, and chewing gum are prohibited in the lab. Methanol and sodium hydroxide are skin and eye irritants; therefore students are instructed to avoid ingestion or contact with skin and eyes. They are also encouraged to handle the hot oil with care and instructed to properly dispose of the biodiesel/glycerol mixture in a provided waste container.

As a supplement to the procedure, students were also asked to “calibrate” the separatory funnels. The instructor provided a paper ruler which the students taped to the outside of the funnel, starting at the stopcock. Students were instructed to add known volumes of water to the funnel in 100 mL increments and measure the corresponding slant height using a ruler. Students then pooled their data and used them in an exercise to determine the average and standard deviation of the slant height for each volume increment. Graphing the data demonstrates that the relationship between volume and slant height is not linear, and students can compare the actual volume of biodiesel and glycerol produce to the amount predicted by the funnel calibration data. Since teaching basic statistical calculations, graphing, and curve-fitting are important objectives for the CHE 197 course, this supplemental activity fits in well with the existing course curriculum.

Estimated Cost

Table 3 provides an itemized cost estimate to obtain the supplies and chemicals necessary to perform this experiment (as described in the procedure) in a class with 25 students (12 groups of 2-3 students). The cost estimate assumes that two groups share one hot plate to heat the oil. With the exception of the oil, all of the chemicals were purchased from Fisher Scientific. With the exception of the blenders, pot holders, and mason jars, all of the supplies were also purchased form Fisher Scientific. The price estimate for the blenders is $20 each, based on the cost of blenders purchased from a major home improvement warehouse. It is not necessary to purchase laboratory grade blenders, and in fact, not all of the lab grade blenders can accommodate the reaction mixture without significant leakage.

Item	**Estimated Cost**
Hot plates	$300
Blenders	$250
Chemicals – sodium hydroxide, methanol, oil	$100
Beakers (2000 mL)	$275
Graduated cylinders (500 mL)	$75
Thermometers (alcohol, extra long length)	$150
Separatory funnels	$300-$675 (depending on type and size)
Ring stands	$460
Safety supplies – glasses, gloves, pot holders	$75
Miscellaneous supplies – weigh boats, spatulas, mason jars	$120
Total Initial Cost (Estimated for 25 students)	**$2105-$2480**
Initial Cost per Student	**$84-$100**

Table 3: Estimated Cost of Biodiesel Production Activity

Once all of the non-consumable supplies are purchased (hot plates, blenders, glassware, etc.), it is estimated that the annual cost for chemicals and consumable supplies will be approximately $300.

Data Collection and Results

Students are asked to identify how much of each reactant (oil and methanol) is used in the procedure in terms of mass, volume, and moles. After allowing the biodiesel/glycerol mixture to separate, students measure the volume of each and convert this value to mass and moles using the molecular weight and density information provided in the handout.

The actual volume ratio of biodiesel:glycerol produced during experimentation varied from 7.3:1-11.4:1. The theoretical volume ratio of biodiesel:glycerol as given in Equation 1 is 14.3:1.

Since the excess methanol is not removed, it partitions into each of the product phases. However, the methanol preferentially partitions into the glycerol. Therefore, it makes sense that the biodiesel:glycerol volume ratio would be lower if the excess methanol is not removed. Similarly, the theoretical mass and molar ratios of biodiesel:glycerol are 10:1 and 3.1:1, respectively. Student results ranged from 7.3:1-11.4:1 (mass ratio) and 1.6:1-2.5:1 (molar ratio).

Calculations

The data collected during the procedure are used to introduce students to the concept of conservation of mass and develop the ability to perform unit conversions. Upon completion of the experiment, students are asked to complete a series of tasks to further evaluate the chemistry of biodiesel production. One important objective of these calculations is to compare the stoichiometric reaction to the actual chemical reaction that is performed during experimentation. The specific procedure for this activity utilizes about 75% (by weight) excess methanol, but this is not disclosed to the students. Instead, students are asked to use Equation 1 and the physical properties of the reactants and products (as given in Table 1) to determine the theoretical amount of methanol that reacts with 1 L of oil. They are then asked to compare this value to the actual amount of methanol used and re-write the equation to include the excess methanol. Each of the specific tasks assigned as part of this activity are described below.

Task #1: Re-write the stoichiometric chemical reaction for biodiesel production in terms of a.) moles of products and reactants, and b.) volume of products and reactants.

Task #2: Record or calculate the following information while completing the biodiesel production lab.

Volume of oil in reactor	Moles of methanol in reactor
Mass of oil in reactor	Mass of catalyst in reactor
Moles of oil in reactor	Volume of methanol needed to react with 1000 mL of oil
Volume of methanol in reactor	Mass of methanol needed to react with 1000 mL of oil
Mass of methanol in reactor	Moles of methanol needed to react with 1000 mL of oil

Task #3: Compare the stoichiometric amount of methanol required to react with 1000 mL of oil to the actual amount of methanol added to the reactor for this procedure by determining the following:

Volume of methanol added to experiment	Moles of methanol reacted
Mass of methanol added to experiment	Volume of methanol remaining in product
Moles of methanol added to experiment	Mass of methanol remaining in product
Volume of methanol reacted	Moles of methanol remaining in product
Mass of methanol reacted	

For the entire reaction procedure, determine the following, and compare the ratios to those specified by the theoretical equations.

Moles methanol:moles oil
Mass methanol:mass oil
Volume methanol:volume oil

Task #4: Re-write the chemical reaction on a mass, molar, and volume basis, to reflect the actual amount of oil used, the total amount of methanol added as a reactant, the theoretical amounts of biodiesel and glycerol produced, and the amount of methanol remaining as a "product."

Example: 1000 mL oil + X methanol → X biodiesel + X glycerol + X methanol

Task #5: Calculate and determine the following information assuming 100% conversion of the oil. The calculated values should be based on the amount of reactants used in the procedure and the stoichiometry of the theoretical chemical reaction. The actual values should be based on the actual volumes of biodiesel and glycerol measured upon completion of the reaction and settling steps. Use the density and molecular weight of the chemicals as needed.

Actual Values	Calculated Values
Volume of biodiesel produced	Volume of biodiesel produced
Mass of biodiesel produced	Mass of biodiesel produced
Moles of biodiesel produced	Moles of biodiesel produced
Volume of glycerol produced	Volume of glycerol produced
Mass of glycerol produced	Mass of glycerol produced
Moles of glycerol produced	Moles of glycerol produced

Task #6: Briefly discuss each of the results from Task #5. Are the actual values and calculated values equal? Why or why not? Base the discussion on the information provided in the handout and the lecture as well as your own knowledge of science and chemical reactions.

Assessment

The authors first implemented this activity in the CHE 197 course in the Fall of 2007. At the end of the activity, the instructor surveyed the students' opinions of the activity. Nearly all of the students surveyed (20 of 21) stated that they enjoyed the activity and felt that they better understood chemical engineering as both a discipline and profession. A few students indicated that they better understood unit conversion and stoichiometric calculations after completing the activity. Some specific highlights of the activity, as identified by the students, include:

- Calibrating the funnel (as the student had never done anything like this before)
- Visually observing the reaction process and separation of the biodiesel product
- Working in teams
- Producing a fuel that is currently attracting much publicity and interest

Some specific comments provided by the students suggested the following changes and improvements:

- Provide more instruction regarding how to complete the unit conversions and stoichiometric calculations prior to beginning the lab activity

- Add additional steps to purify the biodiesel, separate the methanol, and actually use the biodiesel as fuel
- Have more space, more supplies, and more time to complete the experiment

Future assessment will attempt to determine if participation in this activity positively affects student performance in the sophomore-level chemical engineering course that teaches stoichiometry and mass balances.

Conclusions and Lessons Learned

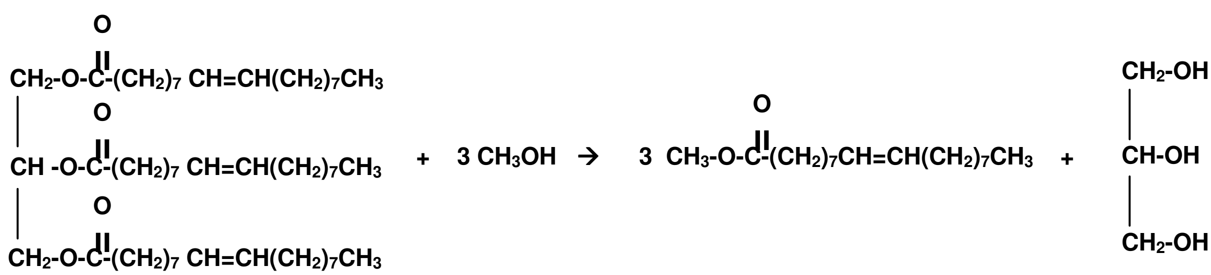
Having completed this activity both as part of the College of Engineering Summer Camp and as part of the introductory chemical engineering course, the authors have a number of observations to optimize the integration and execution of this activity.

- The experiment works best using groups of 2-3 students. This arrangement helps minimize costs but still allows each student to participate significantly in the procedure.
- The experiment can make a big mess, as the reaction mixture is quite sticky and spills are inevitable. A teaching assistant is essential to help clean the glassware, blenders, and lab after completion of the experiment.
- Glassware and equipment should be purchased and dedicated solely to this experiment. In addition to the convenience, the reactants and products are messy, and other faculty and researchers may not appreciate having their glassware and equipment returned with an oily, sticky residue.
- In order to minimize the cost of the hot plates and glassware, two groups can heat the oil using one 2000 mL beaker and one hot plate.
- Similarly, the biodiesel/glycerol product from multiple groups can be combined for the separation step, depending on the number and size of separatory funnels purchased.
- The oil should be heated using low- to moderate-heat. If the oil is heated using too high of a setting, the oil will overheat and require significant time to cool to a usable temperature. On a moderate-heat setting, it will take about 20 minutes to heat the oil. In order to save time, a teaching assistant can begin pre-heating the oil prior to students arriving in the lab.
- It is very important to use blenders that have glass pitchers and very tight-fitting lids that form a seal with the pitcher. Plastic pitchers will crack, and ultimately fail, after only one or two uses. Tight-fitting lids will prevent the reaction mixture from leaking out of the pitcher during blending. Laboratory-grade blenders are not necessary, and in some cases, do not have lids that seal and are not large enough to contain the 1200 mL of reactants. The authors have purchased high-quality, durable blenders with heavy glass pitchers and lids that form a very tight seal at a national home improvement chain for about $20.
- In an introductory course, it may be necessary to provide additional instruction regarding unit conversions, moles, and stoichiometry. The instructor at UA Huntsville found it necessary to explain these topics in more detail for a few students in the course. The authors feel it is important to note, however, that this additional instruction was not provided until *after* students were given the assignment sheet and attempted to complete the specified calculations and tasks on their own.

Overall, this activity has worked very well in the introductory chemical engineering course at UA Huntsville. Students were eager to participate in the activity and indicated that it successfully illustrated chemical engineering as both a discipline and profession. The activity is relatively easy to implement and execute, and the supplies and equipment are fairly inexpensive. The experiment can easily be scaled to produce more or less biodiesel and to accommodate different numbers of student participants. The authors also utilize this activity to demonstrate chemical engineering during the College of Engineering Summer Camp, and it has been very well received by the high school students who participate in that camp. The experiment can also be used as a demonstration, as the authors produced biodiesel for elementary- and middle school-aged girls as part of the Sally Ride Festival held at UA Huntsville. The supplies and equipment are fairly portable, and could be taken to local elementary, middle, and high schools to demonstrate chemical engineering to a broader audience. The authors have observed very positive reactions to both the lecture and the activity, as students of all ages seem to be very interested in biofuel production and utilization. As a result, this is a very effective activity to educate students about chemical engineering and the impact the discipline has, not only on biofuel production, but society as a whole.

Appendix

Triolein + 3 Methanol → 3 Methyl Oleate + Glycerol



Equation 2: Molar Stoichiometric Transesterification Reaction

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