Virginia Cooperative Extension

PUBLICATION 442-885

Small-Scale Biodiesel Production: Safety, Fuel Quality, and Waste Disposal Considerations

Zhiyou Wen, Department of Biological Systems Engineering, Virginia Tech
Steve A. Bantz, Department of Integrated Science and Technology, James Madison University
Christopher G. Bachmann, Department of Integrated Science and Technology, James Madison University
Christie-Joy Brodrick, Department of Integrated Science and Technology, James Madison University
Lisa A. Schweitzer, School of Policy, Planning, and Development, University of Southern California

Biodiesel is a cleaner-burning, renewable fuel that is a feasible alternative to fossil-based diesel fuel. Largely due to historically high energy prices, concerns over the environmental impact of fossil fuel, and a desire for energy independence, citizens of Virginia have become increasingly interested in renewable alternative fuels, including biodiesel fuel. A previous Virginia Cooperative Extension publication (see *Biodiesel Fuel* under References) discusses the basics of biodiesel fuel, including terminology, engine compatibility, engine warranty, biodiesel storage, fuel performance, cold temperature concerns, and emissions. This publication addresses producing one's own biodiesel fuel from waste oil, fats, and oilseed crops. Currently, there are many small-scale biodiesel producers (ranging in size from several gallons to several hundred gallons per batch). There are significant safety considerations when operating small-scale processors. In addition, the fuel quality and the by-product disposal need to be closely monitored to assure engines are not damaged and regulations are met. The purpose of this document is to address safety, fuel quality, and waste disposal related to small-scale production. We present a general discussion of these issues based on a case study of four small-scale biodiesel processors conducted cooperatively by James Madison University (JMU), Virginia Tech (VT), the Virginia Clean Cities Collation, and Blue Ridge Clean Fuels Inc.

How Biodiesel Is Made

Biodiesel is made through a chemical reaction between oils or fats and an alcohol (usually methanol). Common feedstocks are pure vegetable oil (e.g., soybean, canola, sunflower), rendered animal fats, or waste vegetable oils (WVO). The major components of these feedstocks are triglyceride molecules, which resemble the capital letter "E" in structure (Figure 1). The three arms of the "E" each represent long-chain fatty acids, and the vertical backbone is glycerol. In the reaction between oil and methanol, which is termed transesterification, methanol molecules replace the glycerol backbone. Three linear methyl-ester molecules are formed along with a glycerol byproduct. Methyl-ester is a scientific term for the biodiesel fuel produced when methanol is used in the biodiesel production process.

CH_2O – $OCHCH_2CH_2$……..CH_2CH_3					CH_2OH
CHO – $OCHCH_2CH_2$……..CH_2CH_3	+ 3 CH_3O-H	Catalyst ------>	3 $CH_3OOCHCH_2$…..CH_2CH_3	+	$CHOH$
CH_2O – $OCHCH_2CH_2$……..CH_2CH_3					CH_2OH
Triglyceride (oil or fat) (100 lb)	Methanol (10 lbs)		Methyl Esters (Biodiesel) (100 lbs)		Glycerol (10 lbs)

Figure 1. Chemical reaction for biodiesel production – transesterification

www.ext.vt.edu

Virginia Tech Invent the Future

Produced by Communications and Marketing, College of Agriculture and Life Sciences, Virginia Polytechnic Institute and State University, 2009

VIRGINIA STATE UNIVERSITY

Transesterification requires a catalyst to drive the reaction. Strong bases such as sodium hydroxide (NaOH) or potassium hydroxide (KOH) are commonly used as catalysts. A water-washing step is included to purify the biodiesel. The wastewater as well as the glycerol by-product contains residual catalyst, alcohol, and unreacted feedstock. Excess alcohol is hazardous and needs to be recovered for reuse or disposal. The glycerol must also be disposed of properly.

Using waste cooking oil as a feedstock has been popularized by grassroots films and demonstrations. When waste cooking oil is used, more catalyst is needed because free fatty acids (FFAs) generated during high-temperature cooking will neutralize some catalyst. The conversion process requires an extra step, a procedure called titration, to determine the amount of catalyst needed in the reaction.

Safety Concerns

Safety is an important consideration when using any hazardous chemicals – that includes biodiesel production. There are a multitude of processor configurations, each with its own specifications and considerations. Many safety considerations are a function of installation, operation, and supervision. Some modification of commercially purchased systems is often necessary to maximize safety in individual situations and to meet regulatory guidelines. We discuss the most common safety considerations. Potential biodiesel producers should take courses from accredited institutions to fully understand the multitude of processes and the safety issues that are not covered in this document. For example, the National Alternative Fuels Training Consortium (*www.naftc.wvu.edu/*) in Morgantown, West Virginia, offers classes and materials documenting the biodiesel process.

Hardware

Tank Design: The reaction tank is the main vessel in small-scale biodiesel processor systems. Some tank design criteria include: (1) temperature/pressure requirements, (2) chemical compatibility, (3) physical durability, (4) ability to be completely sealed (i.e. to be a truly "closed" system), (5) insulation, (6) electrical grounding, and (7) tank entry (for inspection and cleaning).

In general, the plastic conical has been the tank of choice for small-scale biodiesel processors because it is less expensive, easy to access for maintenance, allows visibility of the reaction process, and makes glycerol separation easy. Both pressure and temperature increases are popular because they can increase the rate of reaction in the biodiesel process. However, plastic cone-bottom tanks are designed for use at atmospheric pressure and relatively low temperatures. If pressure or vacuum is applied to the plastic conical tank system, it can cause excessive deformation or damage to the tanks. Temperatures exceeding the manufacturer's recommended maximum may also reduce the strength of the tank. Many plastic conical tanks eventually leak after long-term use. Further, it is difficult to provide adequate electrical grounding for nonmetallic materials to avoid a static charge that could produce a flash fire or explosion.

Piping, Tubing, Hoses, Valves, and Gaskets: Piping, tubing, hoses, valves, and gaskets should meet the system temperature/pressure, chemical compatibility, and long-term durability requirements. Biodiesel can soften or degrade natural rubber hoses and gaskets, leading to fuel leaks and spills. Also, brass, bronze, copper, lead, tin, and zinc can interfere with the chemical reaction and be corroded by the reaction chemicals.

Electrical Equipment: Electrical equipment includes motors, pumps, heating elements, fans, and lighting. Potentially, these parts can ignite alcohol vapors through arcs and sparks, high surface temperatures, and electrical equipment failure. The National Electric Code (NEC) has specifications for the design and installation of electrical equipment in hazardous locations (U.S. Department of Labor Occupational Safety and Health Administration, *Construction Safety and Health Outreach Program: Hazardous [Classified] Locations* (*www.osha.gov/doc/outreachtraining/htmlfiles/hazloc.html)).* The selection, placement, design, and power source of the electrical components should comply with these codes.

The electrically powered pumps (centrifugal or positive displacement) used to transfer and circulate liquid need specific attention. In general, these pumps are sized between 300 gph to 500 gph. A hazardous situation can be caused by (1) over-temperature due to deadheading the pump (centrifugal) or a locked rotor; (2) over-pressurized piping if deadheading a positive displacement pump with no internal pressure relief valve; and (3) motor overheating or arcing due to inadequate motor size or improper installation. We use an explosion-proof motor to prevent an explosion from leaving the motor enclosure.

Chemicals

Biodiesel producers should be familiar with the Material Safety Data Sheet (MSDS) for each chemical used in the biodiesel production process. An MSDS contains comprehensive information on product identification; ingredients and hazardous classification; physical and chemical characteristics; fire- and explosion-hazard data; fire-fighting measures; accidental release measures; health-hazard data; first-aid measures; toxicology; reactivity (and stability) data; precautions for safe handling, storage, and use; control measures; transportation; disposal; and regulatory information. MSDSs are available from the chemical vendors.

When handling chemicals, it is important to always wear proper personal protection equipment (PPE) such as protective gloves, an apron, and eye protection and to not inhale any vapors. Further, always have running water available. The workspace should be thoroughly ventilated. Operation should be conducted under a fume hood. No children or pets should be allowed in the work area. A co-worker should be present to seek assistance. For university biodiesel production, emergency eye-wash stations and emergency full-body showers are needed.

Producers should exercise caution when handling methanol and methanol-catalyst mixes (methoxide). Methoxide is very caustic and can result in chemical burns. Methanol is a poisonous chemical that can cause blindness. It can be absorbed directly through the skin or inhaled as a vapor. Methanol is a flammable liquid with a flash point of 51°F and boiling point at or above 100°F (depending upon pressure). Therefore, all methanol containers should be kept tightly closed to prevent evaporation and exposure of people and the environment to hazardous fumes. When transferring methanol to the catalyst-mixing vessel, always use a closed circuit. This can be achieved using an explosion-proof induction pump. It is optimal for the process and also for safety if methoxide is pumped slowly into the reaction vessel via a closed circuit with an explosion-proof induction pump. Though the mixture gets quite hot at first, no fumes will escape if the container is kept closed.

For detailed safety instructions on methanol use, please refer to safety guidelines provided by methanol suppliers, such as Methanex (*www.methanex.com/products/technical.html*). System owner/operators should be aware that the storage, handling, and use of methanol in larger amounts may be subject to permitting issues depending on the state and local fire-prevention agencies. The limits for the Commonwealth of Virginia are greater than 5 gallons inside and greater than 10 gallons outside (*The Virginia Statewide Fire Prevention Code (www.vbcoa.org/2003%20USBC%20Codes/Virginia%20Statewide%20Fire%20Prevention%20Code.pdf)).*

Ethanol can be used instead of methanol, although it is less common. Ethanol is bio-based and has lesser toxicity issues, but is still a chemical and a fire safety concern.

Containment and Location

Secondary containment will provide material containment in case of a leak or spills out of the reaction vessels, storage containers, or piping and tubing of the processor system. We found no commercial systems that came with secondary containment.

Vessel entry should also be considered. Plastic tanks have screw-top lids that provide the operator with easy access for cleaning and maintenance. The operator must be cautious when accessing the tank by opening the screw-top lid. Just because the vessel may be empty does not mean there are no hazards. Vessels will contain residual chemicals and fumes. The operator must make sure adequate ventilation and personal protection equipment are used when the vessel top is removed for inspection, cleaning, or maintenance.

The following is a partial list of common safety considerations for locating a processor:

- Area well ventilated
- No open flames (water heater, clothes dryer, or other device nearby)
- Adequate lighting
- Clearances for operation
- Limited access
- Eye-wash station
- Fire extinguisher
- Titration area
- Fume hood (or some other forced draft system that vents to the outside)

Siting is also subject to building and fire codes. The Commonwealth of Virginia Biodiesel Environmental

Compliance Primer cites the Department of Housing and Community Development Web page that identifies local fire marshal contacts.

Fuel Quality

Depending on the type of engine, fuel-quality testing can be extremely important. Low-grade or poor-quality biodiesel can corrode fuel injectors, block injector spray holes, and increase injection pressure. The use of poor-quality biodiesel can result in vehicle damage, including filter plugging, fuel injector failure, and repair costs that would not be covered by the manufacturer's warranty. The detailed specifications of fuel quality are described by ASTM standard D6751 (see *Biodiesel Fuel* under References). Currently, complete ASTM D6751 testing is conducted exclusively by certified laboratories, and the cost is not economical for small-scale producers. A "reduced-slate" test for a limited number of key quality parameters, such as total and free glycerin, can be ordered at less expense. Quality often differs between batches, so each batch must be tested.

Some of the basic tests are discussed here. The flash-point test is used to show the content of excess alcohol. This is a challenging test unless adequate alcohol recovery methods are employed with the reactor. The water-and-sediment test is used to monitor water and sediment that may corrode engines and encourage the growth of microbes in the fuel. The kinematic-viscosity test detects fuel that is too high in viscosity, which can cause engine seizures and injector problems. This test is related to the amount of residual glycerin present in the finished fuel. Another common reason is fuel oxidation during storage. The polymers produced by oxidation can raise the viscosity above the value allowed by ASTM D6751, The sulfated-ash test measures potassium, sodium, magnesium, and calcium that remain in biodiesel. These impurities may increase piston wear, filter clogging, and injector wear. Sulfur emissions are regulated; the EPA has set standards for diesel fuel, and this sulfur test is designed to see if the biodiesel complies with these standards. Copper strip corrosion is a test used to test whether the biodiesel is corrosive. Cetane number reflects the fuel's ignitability, while cloud point qualitatively demonstrates the fuel's properties at low temperatures. The carbon-residue test reports the carbon depositing tendencies of the fuel to prevent deposition of carbon in the engine. Acid number can be an indicator of fuel degradation during storage. A common problem is the production of short-chain acids during fuel oxidation in storage. Phosphorus content, which should not exceed 10 ppm, is measured because it can interfere with the operation of pollution control exhaust catalysts.

For our small-scale production tests, fuel-quality failure is common in four categories: free glycerin, total glycerin, viscosity, and distillation temperature. The free glycerin is an indication of inadequate fuel washing following the reaction step, so simply increasing the wash time and adding additional wash cycles could solve this problem. Excess total glycerin correlates with elevated viscosities and distillation temperatures. It is a major cause of engine and fuel injector failure and one of the most difficult standards for biodiesel producers to pass.

Our excess total glycerin is attributed to residual and unreacted triglycerides contained in the resultant biodiesel, which indicates two problems of the processors: 1) incomplete reaction resulting from inadequate mixing (either in preparation of the methoxide or during the trans-esterification reaction) or 2) degradation of the catalyst and/or alcohol used in the reaction.

In the first case, insufficient blending of the alcohol and catalyst used for the transesterification results in an incomplete reaction. The undissolved catalyst yields a heterogeneous distribution of KOH or NaOH, with highly concentrated regions being likely to induce soap formation and low concentration regions yielding incomplete reactions. Another scenario is the insufficient mixing of the methoxide with the oil feedstock; thus, it forms a layer at the top of the reaction vessel when it is added to the heated oil. Although most of these designs are intended to induce an emulsion, incomplete mixing was observed often. Longer mixing times and a more powerful mixing attachment (either a static mixer or propeller) would likely resolve this issue.

In the second case, the catalyst and/or alcohol may have degraded. Both the alcohol and the catalyst must be stored in tightly sealed containers to avoid moisture contamination. KOH and NaOH are very hygroscopic, rapidly developing a slimy film from moisture absorbed from the local atmosphere. Even slight exposure of the catalyst to moisture can result in an incomplete trans-esterification reaction or soap production. The same is true for the alcohol used in the reaction. Although methanol does not form an azeotrope (as ethanol does), it still has a propensity for collecting water, especially in humid climates. Repeated opening of the catalyst and alcohol containers can affect the moisture level in the catalyst and/or alcohol used in the reaction. These issues can be addressed by implementing the use of environmentally controlled storage facilities and tightly sealed containers.

Waste Streams Disposal

One of the largest issues facing small-scale producers may be penalties for violating hazardous waste-disposal regulations. Glycerol and wastewater are two major waste streams in the biodiesel production process that must be disposed of. The glycerin and wash water are contaminated with catalyst and alcohol. Due to this, disposal processes that occur in other states, such as composting, dust suppression, and use as fuel oil, are not allowed in the Commonwealth of Virginia. While it is possible to purify the glycerol, this is often cost prohibitive. There are also safety considerations related to removing and recovering the methanol from the glycerol. The Virginia Department of Environmental Quality (VDEQ) has issued a guidance document on environmental compliance for biodiesel producers pertaining to air pollution, water, wastewater, storage, waste management, health, safety, and taxes: the *Virginia Biodiesel Environmental Compliance Primer* (see References).

Summary

As small-scale production becomes attractive to the general public, there is a need for scientific information. This publication is a starting point for those considering conducting small-scale production. This is by no means a comprehensive guideline, but a discussion of some of the many key issues that potential small-scale producers should consider. We introduce safety, quality control, and by-product disposal considerations for biodiesel production. Further references that expand on these topics and address other key areas of biodiesel production are provided at the end of this publication. These scientific references discuss the basics of biofuels, the home processing process, biodiesel handling and use, costs of small-scale production, and Commonwealth of Virginia environmental regulations.

Acknowledgments

The authors would like to thank the Virginia Department of Mines, Minerals, and Energy for the seed grants, along with the JMU administration and the Virginia Tech College of Architecture and Urban Affairs and School of Public and International Affairs for funding. Special thanks go to Blue Ridge Clean Fuels Inc. (BRCFI) and Virginia Clean Cities (VCC), for supplying the financial support for the ASTM testing. Also, we would like to acknowledge the work of over two dozen students who have contributed to this project. Special thanks go to Lucian Reynolds, Ian Doran, Luis Folgar, Alex Porteous, and Eric Howard. We thank Carolyn Oglesby, Randy Poag, and Chuck McCarthy for their leadership in the biodiesel laboratory work. The authors would like to express their appreciation for the reviewer's comments.

Reviewers

Jon Van Gerpen, professor, University of Idaho, *jonvg@uidaho.edu*

Al Christopher, director, Virginia Clean Cities, *al.christopher@hrccc.org*

Rodney Sobin, environmental engineer consultant, Virginia Department of Environmental Quality, *rsobin@deq.virginia.gov*

Robert Grisso, professor, Virginia Tech, *rgrisso@vt.edu*

Robert Lane, Extension specialist, Virginia Seafood Agricultural Research and Extension Center, *rlane@vt.edu*

References (accessed 10/15/07)

1) *Biodiesel Fuel,* Virginia Cooperative Extension publication 442-880

   www.ext.vt.edu/pubs/ageng/442-880/442-880.html

2) *Biodiesel Tech Notes #7 – Home Brewing Biodiesel www.uidaho.edu/bioenergy/NewsReleases/Technote7_HB.pdf*

3) *Biodiesel Handling and Use Guidelines www.nrel.gov/vehiclesandfuels/npbf/feature_guidelines.html*

4) *The Biodiesel Handbook*

   Publisher: AOCS Publishing (January 30, 2005), ISBN-10: 1893997790

5) *Small-scale Biodiesel Production: An Overview- www.ampc.montana.edu/policypaper/policy22.pdf*

6) *Virginia Biodiesel Environmental Compliance Primer www.deq.state.ve.us/export/sites/default/osba/pdf/VDEQBiodieselPrimer2008.pdf*