Journal of Undergraduate Research at Minnesota State University, Mankato

Volume 4 Article 7

2004

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Recommended Citation

Haase, Scott and Craig, Benjamin (2004) "An Economic Analysis of Small-Scale Biodiesel Production: Implementation of Ethyl Ester Production in a Job Shop Setting," *Journal of Undergraduate Research at Minnesota State University, Mankato*: Vol. 4, Article 7.
DOI: https://doi.org/10.56816/2378-6949.1159
Available at: https://cornerstone.lib.mnsu.edu/jur/vol4/iss1/7

05-11-2004

AN ECONOMIC ANALYSIS OF SMALL-SCALE BIODIESEL PRODUCTION: Implementation of Ethyl Ester Production in a Job Shop Setting

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ABSTRACT

Biodiesel is becoming a demanded consumer automotive alternative fuel used in diesel vehicles today. An emerging trend is toward small-scale biodiesel production performed by the final consumer. A limited source of commercially available production systems exists and has resulted in many systems being designed and built by the user. Preliminary research conducted by the authors has shown biodiesel to be the least-cost alternative to petroleum diesel after as few as 8 months of system use. This study examines the economic viability of building and producing biodiesel using a small-scale production system versus buying consumer petroleum diesel. During production, measurements were taken to determine labor hours, energy consumed and total cost of system construction. These results generate an economic view of biodiesel production.

INTRODUCTION

There is considerable uncertainty in the future about the world's fuel supply. Prices, further impacted by availability, economic and political factors, will almost certainly continue to rise over the next decade. Measures must be taken to guard against the potentially disastrous consequences of shortages in the fuel supply. While biodiesel is not a complete solution to the current problems, it is one way to alleviate them by offsetting demand for fossil fuels while making use of locally produced resources.

Biodiesel is primarily derived from vegetable oils, a renewable source. These oils may be new or used, such as waste cooking oils which are common in large quantities in most industrialized countries. The use of waste cooking oils as feedstock greatly decreases costs of production. In most cases biodiesel can be used as a direct substitute for petroleum based diesel fuel with little or no engine or fuel system modifications. It may also be blended in any proportion with petroleum diesel.

The environmental benefits of biodiesel over petroleum based diesel fuel have been well documented. Biodiesel breaks down in the environment at a rate approximately four times that of petroleum diesel (U.S. Dept. of Energy 18). It is generally accepted that the levels of carbon dioxide, hydrocarbons, particulates, and net life-cycle carbon dioxide are significantly reduced, as well as many others, when biodiesel is burned in comparison with petroleum based diesel. There is still debate about whether or not nitrous oxide emissions increase or decrease. Some studies, including one prepared for the U.S. Department of energy, indicate that levels may rise nearly 6% over that of regular diesel fuel (7).

With these facts in hand, it has been established that biodiesel production is worthy of continued study and optimization of applications because of its environmentally beneficial attributes and its renewable nature.

Biodiesel is usually produced by reacting a feedstock oil with either methanol or ethanol. Ethanol was chosen as a reactant for this study because it is renewable and produced locally. Also, ethanol is safer to handle than methanol making it more suitable for application.

Small-scale production, for the purposes of this research, includes all biodiesel production activities undertaken by individuals or locally based or operated operations. The capacity and scope of small-scale production depends on the availability of local feedstock as well as the needs of the consumer. In this study a batch size of approximately 150 L (40 U.S. gallons) was used for data gathering purposes.

The authors of this study believe that small-scale application is the best method of implementation for the following reasons:

- It enables the point of production to be nearer to the point of consumption, making the process more efficient from an energy standpoint.
- It allows operations to be initiated with relatively low start-up cost that is within the reach of many diesel fuel consumers.
- Small-scale operations can be tailored to the size of the demand by building in flexibility and modularity.

Small-scale application has the potential of facilitating conversion from petroleum based diesel to biodiesel more quickly and seamlessly than larger scale operations. Using simple technology and basic facilities it is reasonable to say that an operation could begin production within a month or two of project initiation.

Environmental responsibilities are more likely to be met through small-scale production. Although this claim cannot be proven directly (and is only one part of the argument for small scale production) it is best summarized by Schumacher:

> Small-scale operations, no matter how numerous, are always less likely to be harmful to the natural environment than large scale ones, simply because their individual force is small in relation to the recuperative forces of nature. (37)

The authors will attempt to validate the claim that the small-scale production of biodiesel carried out by consumers is an economically viable alternative to the purchase of petroleum based diesel fuels.

METHODOLOGY

ASSEMBLY AND IMPLEMENTATION

The design of a small-scale, batch-type production apparatus was developed under the following criteria; it uses common inexpensive materials, requires little floor space, uses a flexible, modular design approach, and has a minimum processing capacity of 150 L per cycle.

After reviewing designs currently used in small-scale operations and considering the criteria, a design was developed and an apparatus was assembled. Assembly time and material costs were recorded and a total assembly cost was calculated by assigning a labor rate.

<u>Materials</u>

The apparatus consisted essentially of two common 55 gallon drums, a welded steel support frame consisting of angle iron and square tubing, an agitator assembly with motor, an oil transferring system, and a heating system. Technical drawings of the major components and subassemblies are included in appendix B.

Many of the materials used were obtained from salvaged or surplus items greatly reducing the overall implementation cost. The costs assigned for these items were determined by obtaining prices for similar items from local retailers. In addition, allocations were made for basic safety and laboratory testing equipment. See appendix A for the complete bill of materials.

<u>Reactants</u>

The ethanol used in this experiment was obtained from a fuel production plant. It was believed have a water content of approximately 0.8% and was denatured by adding 10% methanol by volume. Fuel grade ethanol sold in the Midwest region of the U.S. is commonly in the form of a mixture of 85% ethanol and 15% gasoline known as E-85 for a price of approximately $1.50 per U.S. gallon at the time this research was conducted.

This study did not attempt to observe the effects of using E-85 as a reactant. It was assumed that a small-scale producer could obtain ethanol without gasoline added, or that presence of gasoline in small percentages (3-4% of total volume) would not significantly affect the reaction.

KOH (Potassium Hydroxide) was used as a catalyst for the reaction. The KOH was ordered through a chemical supplier for $8.26 per kg ($3.74/ lb).

The feedstock used was waste cooking oil and fat obtained from several restaurants as well as a university cafeteria. For the purposes of this study, waste cooking oil is considered free of cost.

PRODUCTION OF BIODIESEL

The production methodology followed was obtained by researching current methods of small-scale production[1].

Waste cooking oil was placed in the first tank of the assembly where it was heated in excess of 110° C and held until a noticeable decrease in bubbling and steaming occurred. While the oil was heating, a test specimen was taken and a titration was performed to determine the amount of catalyst necessary to neutralize free fatty acids present in the oil. Also at this time, test sized batches of the waste oil were reacted in a common household blender.

Once the majority of the water was evaporated out of the oil (indicated by a reduction of steaming) it was allowed to cool to approximately 65° C. The oil was then transferred through a fuel-type filter (rated 10 micron), and into the reaction tank using a hand operated rotary vane pump (fuel transfer type).

Once in the reaction tank, a solution of ethanol and KOH was added and the mixture was agitated for 2 hours followed by a settling period of at least 12 hours to allow glycerol to separate from the esters (biodiesel). After the settling period, glycerol could be drained from the bottom and the esters transferred to a third tank.

A washing step was planned using a technique involving passing air bubbles through a phase of water and then

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[1] The general procedures here were obtained from material published on www.journeytoforever.org. See references for a complete list of sources.

through the biodiesel. After many hours of bubbling, the water would be allowed to settle out leaving two phases. The water is changed and the process is repeated 2-3 times. Once the water is completely settled from the ester phase after the final cycle it is ready for use in a diesel engine (Peterson et al.). The process of washing was not conducted in this study because of difficulties in the preceding steps.

<u>Titrations</u>

Titrations were carried out following procedures commonly available. They were conducted for each of the full scale batches using pH test strips (wide range, 1-12), distilled water, and isopropyl alcohol in the form of the common automotive product, Iso-Heet®.

<u>Test batches</u>

Test sized batches were carried out to ensure that any full scale batches would be successful. The volume of oil reacted in the tests ranged from 1 to 0.5 liters. A sample was taken from the waste cooking oil and placed in a blender. KOH was measured on a digital scale and dissolved in alcohol measured using a livestock-medication syringe (60cc). The solution was added to the oil and mixed for approximately 15 minutes after which it was poured into containers and allowed to settle. The initial temperature of the oil varied from 25° to 55° C and increased as it was mixed.

The data used to estimate batch quantities of reactants and yields was derived from test batches. A summary of test batch data is included in appendix D. Because the product had not been washed prior to testing, the actual yields may be lower than those calculated. Washing is expected to decrease the observed yield by removing excess reactants and impurities present in the measured volume of product.

Data used for yield calculations was obtained by placing entire test batches into a household measuring cup, allowing the mixture to settle, and measuring the volume of glycerol. Two different methodologies were used when assigning a yield value. The first method considered the amount of product in relation to the total volume of the reactants and the second method considered the product and the volume of the oil only.

<u>Full-scale batches</u>

Full-scale batches, in the context of this paper, refer to tests conducted using the apparatus assembled for this experiment in which a volume of 150 L was processed.

An estimate of the ongoing cost of small-scale production, in terms of dollars/ U.S. gallon, was calculated from the full-scale batch trials. The factors of electrical energy input and labor time per batch were considered along with the cost of the reactants. Overhead costs such as facilities or administrative costs were not factored in to the overall cost.

The first full-scale batch was unsuccessful apparently because the reaction was not complete enough to cause the phases to separate. Through experimentation it was determined that adding methanol to the reaction could increase its completeness enough for adequate separation. Thus a cost for methanol was considered in the overall cost of production. The second full-scale batch was not completed due the inability to obtain the required quantity of methanol within the allotted time.

Electrical costs were calculated by determining the power consumed by the heating elements and by the electric motor. The power required to heat the oil was determined by measuring the resistance of the heating system using a digital multi-meter and assuming a source voltage of 120 V. Power consumed by the motor was calculated using its rated current and again assuming 120 V.

The labor time recorded included the time spent mixing the catalyst with the alcohol and transferring the catalyst and oil into the reaction vessel. Time required for washing the product and maintaining the equipment was estimated. The total cycle time (2-3 days) was not directly included in any cost calculations.

RESULTS

COST OF IMPLEMENTATION

An estimate of the implementation cost was obtained by calculating the sum of all materials and labor expenses. For this estimate to hold true for real applications conditions such as adequate floor space and ventilation must be available. Methanol and ethanol fumes are hazardous and must be contained or eliminated from the working area. Safety guidelines also must be set in place and followed.

<u>Materials</u>

The total cost of materials and equipment was nearly $1,200.00 U.S. in 2004. Most of the purchased items were obtained from local retailers. The costs of the individual items are included in the bill of materials in appendix A.

The total cost of materials includes all parts of the assembly as well as equipment required to carry out titrations and test batches. The 55 gallon drums used in the apparatus, as well as common items such as rags and buckets were assumed to be free of cost and generally available.

Assembly time

Approximately 61 labor hours were spent building the production apparatus. This value does not reflect the time spent researching the design or gathering the materials. For calculation purposes the authors have chosen an arbitrary value for the labor rate of $10.00 per hour. This rate will vary depending on the circumstances of any small-scale production initiative and does not take any taxes or overhead into account.

By assigning the rate of $10.00 per hour to 61 hours of assembly time and assembly time cost is determined to be $610 U.S.

Start-up cost

By simply adding materials and labor cost, the total start-up cost is approximately $1,800. Although this cost will certainly vary regionally and depending on the organization in which a biodiesel initiative is undertaken, the authors believe that this is a reasonable estimate for the small-scale production which is the scope of this study.

COST OF PRODUCTION

Materials

The primary materials consumed during production were the waste cooking oil, ethanol, methanol, and KOH. Additional supplies included pH test strips, rags, filters, and blenders. The cost of several additional items was not included in the calculations because their cost was relatively small and the overall process was not stabilized and subject to modification.

It was observed that the reactants may have an adverse affect on common household blenders. As a result, a magnetic stirrer was added to the bill of materials.

The filter used for the first full-scale batch would not allow the oil used in the second batch to pass through. It was not clear whether or not pre-heating the filter would allow oil to flow through it once again by liquefying grease trapped inside of it. After the first batch the filter was changed from a “water block” filter to a more conventional design. Therefore, filter life expectancy (beyond one batch) was not determined by this study.

To calculate the cost of KOH, ethanol, and methanol, test batch data used. The authors chose to use the quantities of reactants in test batch 21 to calculate full-batch costs (appendix D). This batch was selected because of its relatively high ethanol to methanol ratio and its estimated yield.

The values of 201 mL of ethanol and 60 mL of methanol per liter of oil along with 13 g of KOH per liter of oil were used to calculate the following totals for a 150 L batch:

30.15 L ethanol (7.96 U.S. gallons)

9 L methanol (2.38 U.S. gallons)

1.95 Kg KOH

As stated earlier, the cost of waste cooking oil was considered to be negligible. Using the values of $8.26 per Kg for KOH, $1.50 per gallon for ethanol, and $1.24 per gallon for methanol the total cost per 150 L batch is $31.00. This equates to approximately $0.78 per gallon, which falls within the range of costs commonly claimed by small-scale producers.

Labor cost of production

Labor time was required for waste oil collection, production preparation, and production operation.

The collection of waste oil was typically performed by one person and required 30 minutes to complete. This included retrieving the oil and transporting it to the production site using a handcart as well as transferring it from collection containers into the production apparatus.

During production preparation, a titration and test batch were necessary. The titration process was completed by one person in approximately 10 minutes. Test batch work was also performed by one person and took 25 minutes per batch.

Production operation was completed in two steps. The first was heating and filtering of the waste oil. During this time the oil was not observed continuously and required an operator time of 25 minutes. 9 minutes were needed to pump the oil, through a filter, from the first tank to the second tank in which the reaction would occur.

The second stage of the production operation included the measuring and mixing of the reactants and the agitation of the product. For mixing the alcohol and catalyst, a vessel of adequate size was not available resulting in the reactants being prepared in three equal sized batches. For this reason mixing times were longer than anticipated. Each batch of reactants took 5 minutes to measure, mix, and add to the heated and filtered oil. The agitation of the product lasted for 2 hours but an operator was not required for the entire time. Operator time during the agitation process was only 10 minutes.

As stated previously, the time required to complete the biodiesel by moving it to a third tank, washing it, and transferring it to a storage container was estimated. Anticipating that three wash water changes are sufficient the authors have projected the labor time required for that stage to be approximately 45 minutes. This result was obtained by using the measured time required to transfer 150 L of oil from the first to the second tank multiplied by 5. The reason being, that the oil is again

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DOI: 10.56816/2378-6949.1159

being moved between tanks on two occasions, and water is being added to and drained from the wash tank 3 times. The transfer of this smaller volume of water is expected to take about the same amount of time as that needed to pump the oil, or less.

Considering all of the recorded and estimated times, 2.82 labor hours are required throughout the production process. By assigning the rate used previously in the assembly cost calculations of $10.00 per hour, the cost of labor is $28.20 U.S. per 150 L batch of waste cooking oil.

Electricity

Electricity used directly by the process powered two heating elements which together consumed 2149 Watts and an electric motor that consumed 1080 Watts.

The time required to heat the oil and drive off water is expected to vary depending on the water content as well as ambient temperatures. In trials, the temperature of the oil approached 100° C in approximately 8 hours (see appendix E). The total heating time of the second full-scale batch was 11 hours. This value was used to calculate electricity cost for the heating of oil. It is likely that the efficiency of the heating process can be improved by placing a reflector and insulation around the element at the base of the tank.

The electric motor ran for two hours during the agitation phase of the first full-scale batch. This time was also used for the calculation of electricity cost.

Using the values above the total power consumed per batch was 25.80 KWH. By assigning a rate obtained from a local electrical bill of $0.077 per KWH the total electrical cost of production is $1.99 per 150 L batch. Other factors that may contribute additional electricity cost include those associated with lighting and ventilation.

Total production cost

Adding the cost of materials, electricity, and labor cost, the total production cost is approximately $1.63 per gallon. Again, this cost dependent on factors internal and external to organizations implementing small-scale production. Most significant among these factors is the availability of the reactants and the ability of an organization or individual to streamline the production process.

CONCLUSIONS

Because of the difficulties encountered in the production of ethyl esters in this study, the authors have not proven economic benefits of small-scale biodiesel production. However, if estimates are correct and the procedure can be optimized, it is reasonable to assume that biodiesel can be produced in a small-scale setting for approximately the same cost as buying petroleum based diesel. According to the U.S. Energy Information association, the average consumer price of diesel fuel from 02/02/04 through 05/10/04 was $1.60 per gallon. This value is close to $1.63 per gallon estimate concluded in this study.

The authors have conducted a case study to illustrate the economic effects of a biodiesel initiative at Minnesota State University, Mankato (see appendix F). By using only waste cooking oil collected from on-site, over one third of the current diesel fuel demand could be eliminated. If the fuel was purchased at $1.50 per gallon the result would be a fuel cost increase of $259.35 per year. One should take note that this is assuming a consumer road-taxed price for diesel fuel. If, for example, the untaxed diesel fuel were 20 cents per gallon cheaper, the increased yearly fuel cost would be $658.35 or about 9% of the total diesel fuel budget.

From the results of this study it appears that the economic viability of small-scale production lies most heavily on the factors of petroleum based diesel fuel prices and the cost of labor for production. Road taxes on fuels are a major consideration as well. At present, it is assumed that parties undertaking a biodiesel initiative are not required to pay tax on fuels produced for their own consumption.

Cost of production may be further reduced if the reactants could be purchased for less. Also, as shown by its popularity among small-scale producers, biodiesel produced using methanol alone may be cheaper and more reliable to use. Environmental and safety benefits however, weigh in favor of ethanol.

This study has demonstrated that biodiesel production can be initiated with relatively little capital investment. It was determined that in the Midwest United States one can obtain nearly all necessary materials, from retail suppliers, for under $1,500 (2004 prices). By using surplus and scrap materials the authors were able to construct an apparatus for just over $400.00, not including a borrowed electric motor and scale.

It can be assumed that petroleum fuel prices will continue to rise in the future, making it likely that biodiesel will become the least-cost alternative to petroleum diesel, at a later date.

What also must be remembered is that this study fails to take into account the environmental and social impacts of replacing petroleum diesel with biodiesel. Conventional economics usually do not consider ecological consequences and the well-being of local populations when projects are deemed economical or not (Schumaker 21).

As a result of this study, one undertaking a small-scale biodiesel production initiative will have a reasonable estimate of what costs to expect. More work is needed to perfect the production procedure outlined above in order to make it simple and reliable enough for application in a wide variety of environments, while producing a quality fuel capable of meeting ASTM standards. In addition, this study failed to determine the life expectancy of the equipment used. Further research into these topics is recommended.

ACKNOWLEDGEMENTS

This research would not have been possible without the generous support of sponsors and Minnesota State University faculty and staff. The authors would especially like to thank Corn Plus of Winnebago, MN for supplying the ethanol, the Ken Haase Farm of Blue Earth, MN for many of the materials required for the assembly, Culver's, Holiday Inn, and Carkowski Commons all of Mankato, MN for supplying waste cooking oil, Prof. Ann Goebel and Dr. Harry Petersen of the Manufacturing Engineering Technology department for their support and guidance, Dr. Michael Lusch, of the Chemistry and Geology department, and Robert McGinn, Director of Risk Management Health & Safety. Special thanks to Scott Durkee, Mike Pelly, and Orion Polinsky for their encouragement and advice.

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Scott Haase graduated from Minnesota State University Mankato in the spring of 2004. He received a B.S. in Manufacturing Engineering Technology and a B.F.A. in the visual arts, specializing in painting and ceramic sculpture. Scott's interest in biodiesel stems from a project undertaken in a course taught by Prof. Ann Goebel, and from his agricultural background in southern Minnesota. He plans to continue research involving small-scale production and pursue a career involving sustainable technology.
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Ben Craig began his career at Michigan Technological University in Houghton, Michigan where there he studied engineering. Ben transferred to Minnesota State University in 2002. He will be graduating in July of 2004 with a B.S. in Manufacturing Engineering Technology with a minor in mathematics.
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Faculty Mentor Biography:
Ann Goebel has been immersed in the manufacturing arena for the past 11 years, building off a 10 year career in sales, operations management, and business development. She has held or been appointed to many leadership roles in applied areas of lean technology, ISO 9001 quality systems, ergonomics, process re-engineering, safety, strategic planning, and employee development. In 1999, she earned a Masters Degree in Manufacturing Engineering Technology (MET). Since 2000, she has been a full-time faculty in the Department of Automotive and Manufacturing Engineering Technology (AMET) at Minnesota State University, Mankato. Key focus areas are teaching and advising in upper level MET coursework, in addition to development of industry outreach for the department. In addition to gathering and guiding over 40 applied student industry projects, she has been an active industry process engineering consultant for over 6 years. Prior to that time, her tenure was as a Quality Manager/Safety Director with a light industrial design, production, and distribution organization having international market scope. Her professional mission is to be an advocate for manufacturing excellence in both the public and private sector through educating the engineers, and managers of the future.

DOI: 10.56816/2378-6949.1159

APPENDIX

A. Bill of Materials
B. Technical Drawings
    1. Production apparatus solid model rendering
    2. Production apparatus assembly drawing
    3. Frame assembly drawing
    4. Agitator assembly drawing
    5. Wiring schematic
C. Cost calculations
D. Test batch data summary
E. Production data (temp / time)
F. Minnesota State University, Mankato case study

Appendix A

Bill of Materials

Category	Item	Price($)	quant.	Total($)	Actual total($)
Electrical					
	Conduit Connectors	0.39	8	3.12	3.12
	Power cord	0.95/ft	5	4.75	4.75
	1/2"DX10' conduit	2.09	1	2.09	
	12 gage wire	0.42/ft	20	8.50	8.50
	Plug	2.36	1	2.36	2.36
	High limit switch	3.06	2	6.12	6.12
	High temperature wire	2.00/ft	7	14.00	
	High temperature terminals	0.20	14	2.80	5.07
	Infinite switch, temp. controller	35.00	2	70.00	
	Sheet metal screws		1	0.00	
	Fuses		4	2.49	2.49
	Thermal fuses	1.49	2	2.98	2.89
	Fuse terminals	1.49/2	1	1.49	1.49
	Heating element 1500W	25.00	1	25.00	25.00
	Heating element 1600W	46.99	1	46.99	
Steel Plumbing					
	1" male threaded pipe		30"	1.53	
	1" male threaded pipe		10"	3.49	
	3/4" male threaded pipe		4"	1.49	
	3/4" 90 degree elbow		1	1.39	
	3/4" female adapter		1	2.29	
	1" street elbow		1	2.99	
	1" male threaded pipe		3"	1.89	
	1"-3/4" bushing		1	2.99	1.25
	Filter + Filter Plate		1	17.49	17.49
	Pump		1	129.99	129.99
Pulley Assembly					
	1/2 Horse power Electric Motor	111.99	1	111.99	
	V' belt	5.35	1	5.35	
	12" pulley	11.69	1	11.69	
	Pulley center, 3/4" bore	4.89	1	4.89	
	2-1/2" pulley	7.99	1	7.99	

	Bearings assembly	20.00	1	20.00	20.00
Plastic Plumbing					
	Plastic ball valves	16.99	3	50.97	
	1" T plastic fitting female	2.79	1	2.79	
	1" Plastic 90 Degree Elbow	1.99	4	7.96	
	1"x 4"Plastic male threaded pipe	3.19	1	3.19	
	1" plastic male-male adaptor	0.99	1	0.99	
	1"/1.5" plastic male-female adaptor	4.49	1	4.49	
	2"/1.5" PVC Adaptor	2.19	1	2.19	2.19
	2"/3" PVC adaptor	2.39	1	2.39	2.39
	2" PVC pipe	0.62/ft	3	1.86	1.86
Plate Steel					
	3/8"X4"X4" plate steel	0.8	1	0.80	
Sheet Metal					
	4'X8' sheet metal	36.00	1	36.00	
Flat Steel					
	3/16"X1"X20' flat bar	5.85	1	5.85	
Angle Iron					
	1/4"X2"X20' angle iron	11.25	2	22.50	
Steel Rod					
	3/8"DX20' Rebar	3.70	1	3.70	
Tubular Steel					
	1"X square steel tube	0.97/ft	18	17.46	
Measuring and					
Testing Devices	Scale	120.00	1	120.00	
	Graduated Cylinder 250mL	2.60	2	5.20	
	Measuring Syringes, various	n/a	2	2.34	2.34
	Magnetic stirrer	84.50	1	84.50	5.50
	Beakers 600mL	5.35	4	21.40	
	Pitcher	7.99	1	7.99	7.99
	pH Meter	100.00	1	100.00	
Process Equipment					
	.17"IDX10' Vinyl tubing	0.99	1	0.99	0.99
	Linear stroke pump	25.00	3	75.00	
Miscellaneous					
	Insulation	10.66	1	10.66	10.66
	PVC glue	3.00	1	3.00	3.00
	Paint	3.16	1	3.16	3.16
	Aquarium air pump	20.35	1	20.35	20.35
	Air stones	3.15	1	3.15	3.15
	Hose clamps	2.15	1	2.15	2.15
Personal Protective					
Equipment	Goggles	4.99	1	4.99	4.99
	Respirator	18.99	1	18.99	18.99
	gloves	3.99	1	3.99	3.99
	Apron	8.50	1	8.50	
	Face shield	10.95	1	10.95	
			total:	$1,190.59	$417.84

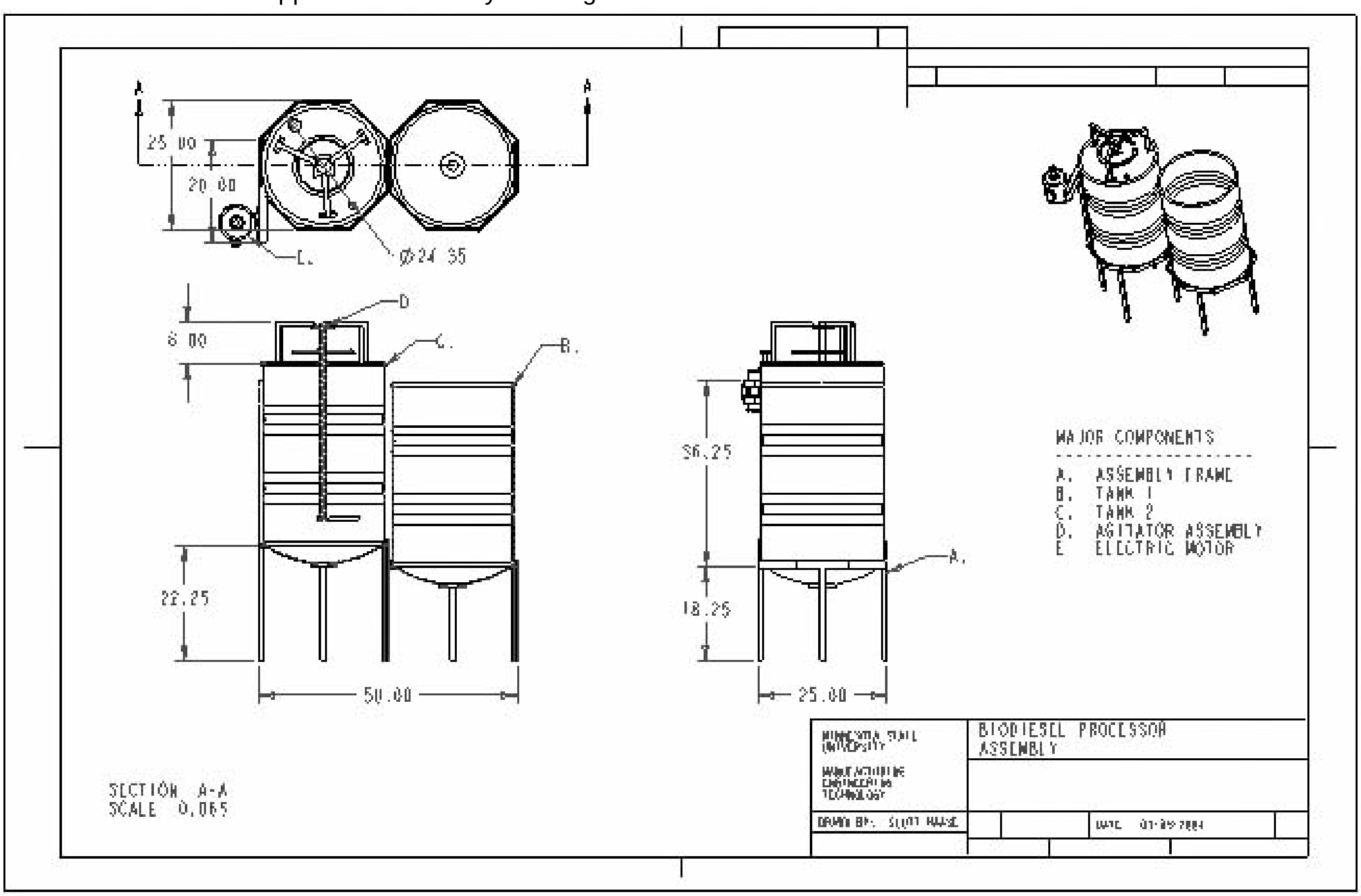
DOI: 10.56816/2378-6949.1159

Appendix B

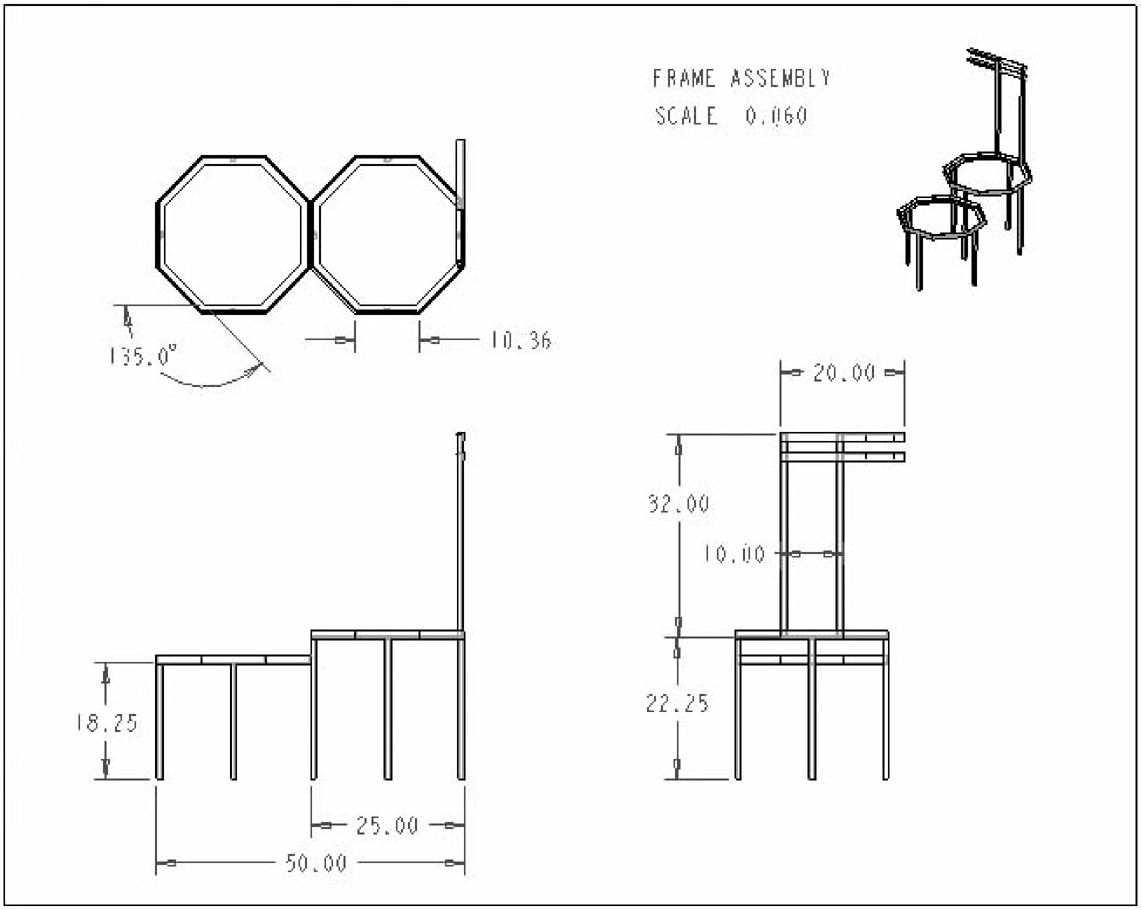
Technical Drawings

1. Production apparatus solid model rendering

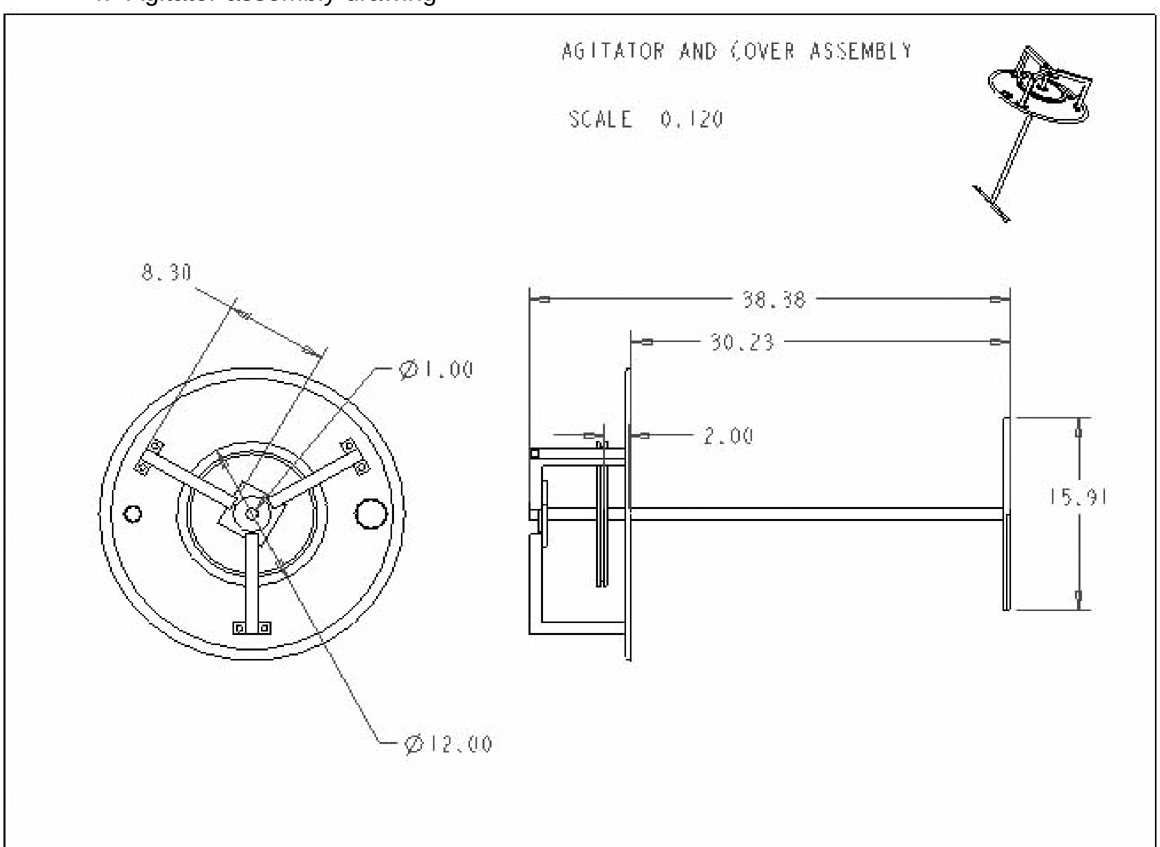
2. Production apparatus assembly drawing



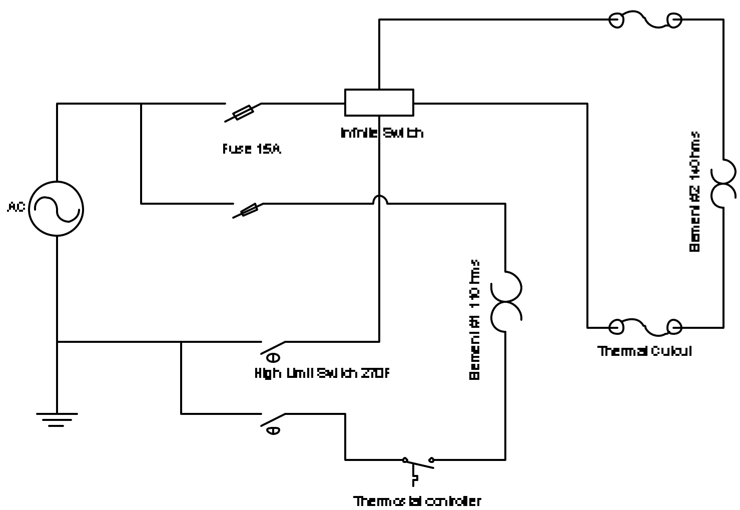
3. Frame assembly drawing



4. Agitator assembly drawing



5. Wiring schematic for heating system



Appendix **C**

Cost Calculations

Start-up Cost Calculations

Labor rate (dollars / hr):	$10.00
Total direct labor cost of assembly:	$610.00
Total from bill of materials:	$1,190.59
Total direct cost of implementation:	$1,800.59

Biodiesel Production Costs

Electrical consumption for batch (KWH):	25.8		Batch size (liters):	150
Rate (dollars / KWH):	$0.077		Expected yield:	95%
Total electical cost:	$1.99		Product yield (liters):	142.5
Cost of KOH for batch:	$16.11			
Ethanol used for batch (gallons):	8.0			
Methanol used for batch (gallons):	2.4			
Cost of ethanol / gallon:	$1.50		Total production cost for batch:	$61.19
Cost of ethanol for batch:	$11.94			
Cost of methanol / gallon:	$1.24			
Cost of methanol / batch:	$2.95			
Total materials cost for batch:	$31.00		Cost of Biodiesel (dollars / liter):	$0.43
			Cost per gallon of Biodiesel:	$1.63
Labor time for batch (hours):	2.82			
Labor rate (dollars / hr):	$10.00			
total direct labor cost of batch:	$28.20			

DOI: 10.56816/2378-6949.1159

Appendix D

Test Batch Data

Batch #	Oil Type	Alcohol Type	g KOH / Liter of Oil	ml Alcohol / Liter of Oil	Liters of Oil	Total KOH Used (g)	Total Alcohol Used (L)	Comments
1	WVO	Ethanol	9.9	220	1	9.9	0.22	Separation failed
2	WVO	Ethanol	12.5	220	1	12.5	0.22	Separation failed
3	WVO	Ethanol	13.9	220	1	13.9	0.22	Separation failed
4	WVO	Ethanol	20.3	270	1	20.3	0.27	Separation failed
5	WVO	Ethanol	17	300	1	17	0.3	Separation failed
6	WVO	Ethanol	10	285	0.5	5	0.1425	Separation failed, homogenous
7	WVO	Solvent Alcohol	5	250	0.5	2.5	0.125	Separation successful
8	Batch 1	Methanol	5	55	0.5	2.5	0.0275	Separation failed
9	Batch 1	Methanol	5	100	0.5	2.5	0.05	Separation failed
10	Batch 1	Methanol	5	150	0.5	2.5	0.075	Separation failed
11	Batch 1	Methanol	7.5	150	0.5	3.75	0.075	Separation failed
12	Batch 1	Methanol	10	150	0.5	5	0.075	Separation failed
13	Batch 1	Methanol	15	200	0.5	7.5	0.1	Separation after extended period (40+ hours
14	WVO	144ml/100ml Eth/meth	9	244	0.5	4.5	0.122	Separation after 15min
15	WVO	144ml/100ml Eth/meth	11	244	0.5	5.5	0.122	Separation, yield>#14
16	WVO	201ml/60ml Eth/meth	10	261	0.5	5	0.1305	Separation failed
17	WVO	172ml/80ml Eth/meth	10	252	0.5	5	0.126	Separation failed
18	WVO	110ml/90ml Eth/meth	10	248	0.5	5	0.124	Separated
19	WVO	172ml/80ml Eth/meth	13	252	0.5	6.5	0.126	Separated
20	WVO	201ml/60ml Eth/meth	13	261	0.5	6.5	0.1305	Separated
21	WVO	201ml/60ml Eth/meth	17	261	0.5	8.5	0.1305	Separated
22	WVO	Ethanol	15	288	0.5	7.5	0.144	Separated
23	WVO	Methanol	13	300	0.5	6.5	0.15	Separated

Appendix E

Production Data (Temperature / Time)

First Run Fluid Temperature		
Start	8:06pm	3/31/04
Time (min)	Temperature (°F)	
0	78	
10	78	
20	83	
30	86	
40	88	
50	96	
60	102	
70	104	
80	110	
90	119	
100	120	
110	125	
120	129	
130	132	
140	134	
150	136	
160	138	
170	140	
180	143	
190	146	
200	148	
210	150	
220	155	
230	159	
240	162	
250	164	
260	167	
270	170	
280	172	
290	174	
300	178	
310	180	

Second Run Fluid Temperature		
Start	4:45pm	4/1/04
Time (sec)	Temperature (F)	
0	125	
10	131	
20	139	
30	144	
40	148	
50	151	
60	153	
70	154	
80	156	
90	159	
100	161	
110	162	
120	164	
130	166	
140	170	
150	174	
160	176	
170	177	
180	180	
190	183	
200	184	
210	186	
220	188	
230	193	
240	195	
250	198	
260	198	
270	199	
280	199	
290	201	
300	204	
310	204	
320	207	
330	207	
340	213	
350	213	
360	213	

Appendix F

Minnesota State University, Mankato case study

MSU annual diesel consumption (gallons):	5500
Cost per gallon for diesel fuel:	$1.50

Yearly diesel fuel costs:	$8,250.00
Yearly costs using Biodiesel:	$8,509.35
Savings:	$-259.35

MSU annual cooking oil consumption (gallons):	2100
Theoretical Yield:	95%
Potential annual Biodiesel production (gallons):	1995
Estimated cost per gallon for Biodiesel:	$1.63
Total annual cost for Biodiesel production:	$3,251.85

Diesel fuel demand offset by Biodiesel:	36.3%