University of Southern Queensland
Faculty of Engineering and Surveying

THE USE OF WASTE COOKING OIL AS AN ALTERNATIVE FUEL FOR THE DIESEL ENGINE

A Dissertation Submitted by

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Abstract

This research project is directed toward those who are looking for an alternative source of fuel for the diesel engine. This report is an investigation on how a sole user can design and fabricate a machine to manufacture biodiesel, how well the biodiesel compares with diesel in regards to performance and also the economical benefits which can be achieved by using biodiesel blended fuels.

This report firstly analyses what biodiesel is, and how it can be made from waste cooking oil through both a chemical and physical process. Based on these processes, a conceptual design analysis of a biodiesel plant was then conducted and a final design proposal was developed. The proposal was then commissioned for construction and completed several months later. The biodiesel that was produced by the newly manufactured biodiesel plant was then tested at the University of Southern Queensland's engine testing laboratory. Several blends of biodiesel with diesel were tested ranging from pure diesel, to 100% biodiesel in a small IC engine. It was found that the biodiesel blends compared quite well to the overall performance of diesel, where B25 (25% biodiesel, 75% diesel) was found to replicate the general performance of diesel the closest, B50 (50% biodiesel, 50% diesel) produced the lowest brake specific fuel consumption, B75 (75% biodiesel, 25% diesel) produced the highest usable power and torque and B100 (100% biodiesel) was found to have the highest thermal efficiency.

An economical analysis was then conducted for each blend of fuel where the aim was to determine which blend of fuel was the most economical alternative to diesel. Assuming that the general maintenance (oil change etc) of using biodiesel remained the same as that of diesel, it was found that using B100 will provide the highest economical gains when used and the initial cost of the biodiesel plant will be recovered the quickest.

Based on these investigations it was concluded that biodiesel is indeed a feasible alternative to diesel that can save the user in excess of 28% on their fuel costs, and that will yield similar performance characteristics when used in a common IC engine.

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ENG4111 Research Project Part 1

EMG4112 Research Project Part 2

Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Signature

Date

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Glossary of Technical Terms

ASTM-D6751:	(American Society for Testing Materials) American biodiesel fuel standard
Biodiesel:	A diesel equivalent fuel derived from vegetable oil
BSFC:	Brake Specific Fuel Consumption
BTU100A:	The name given to the biodiesel plant that is constructed in this project
Ethyl Ester:	Biodiesel that has been created using ethanol as the source of alcohol
EN-14214:	(European Norm) European biodiesel fuel standard
FFA:	Free Fatty Acid: Contaminants that must be removed from biodiesel
Glycerine:	The dark brown by-product which separates from the biodiesel after transesterification (see transesterification) has completed
Magnesol:	The name of the absorbent filter power used in the purification process
Methoxide:	The name given to the methanol and sodium hydroxide solution once it has been mixed
Methyl Ester:	Biodiesel that has been created using methanol as the source of alcohol
SVO:	Straight Vegetable Oil
Transesterification:	The chemical process required to convert vegetable oil into biodiesel
Triglycerides:	Vegetable oils are otherwise known as triglycerides
WVO:	Waste Vegetable Oil

Chapter 1

INTRODUCTION

1.1 Introduction

As a result of technological evolution, it is becoming more and more common to exchange money in place of a service or product. The dependence on ones personal ability to provide for their individual needs is diminishing. For example, why would someone cut their own fire wood if they can pay someone to do it for them, or even easier, buy it from a shop. But what happens when the price of fire wood goes up? The consumer pays more. Generally speaking, the consumer won't cut their own wood, they will continue to pay more and more and the consumer will feel as if they are forced to pay these prices because they have no choice.

The situation represented above is comparable to the current fuel situation in Australia. Diesel for example, a fuel which should be cheaper than the lowest quality petrol, is generally priced higher than the highest quality petrol and the consumers are at the mercy of those which set the prices at the fuel stations. Regardless of the reasons why these prices are higher and who is responsible, there is little one can do about the situation of overpriced fuel but pay the price and complain to whoever is willing to listen. But every now and then you hear about people who are making their own diesel, or biodiesel as it is known, from waste cooking oil – people who are no longer at the mercy of the commercial fuel giants who extort your hard earned money for a product which is a necessity in today's society. But how do these people make their own fuel, how does it compare to diesel and just how much money (if any) do they save? This report will investigate these areas and first-hand information will be provided on how biodiesel can be made, how well it compares with diesel and the typical savings that can be achieved when using fuel derived from waste cooking oil.

1.2 Project Outline

This purpose of this research project was to investigate how a individual user can design and fabricate a machine to manufacture biodiesel, how well the biodiesel compares with diesel in regards to performance, and also the economical benefits which can be achieved by using biodiesel blended fuels.

The objectives of this research project are to:

1. Determine what biodiesel is
2. Determine what chemical and physical processes are required to make biodiesel
3. Design and construct a machine to make biodiesel that is suitable for the home user
4. Test and compare performance of biodiesel blends with diesel in a small IC engine
5. Conduct an economic analysis to determine the savings that can be achieved when biodiesel blends are used in place of diesel
6. Conclude the report and summarise the findings

Chapter 2

LITERATURE REVIEW

Objectives

The objectives of this chapter are to analyse the literature available on biodiesel and determine how biodiesel is made, how it has performed in other studies, and typical cost benefits that can be achieved by using biodiesel blended fuels. Based on the information found from the literature review, a summary of key points will be made which will set the foundations of how this research project will progress.

2.1 Introduction

Biodiesel is a diesel-equivalent fuel extracted from biological sources. Biodiesel can be made from a wide range of renewable, readily available materials including vegetable oils from rapeseed, palm, and soybeans as well as animal fats such as tallow, lard and fish oil or in this case, waste cooking oil.

The process of extracting biodiesel from vegetable oil is called 'Transesterification'. Transesterification is the process of using an alcohol (e.g., methanol or ethanol) in the presence of a catalyst, such as sodium hydroxide or potassium hydroxide, to chemically break the molecule of the raw renewable oil into methyl or ethyl esters (biodiesel) of the renewable oil with glycerine as a by-product.

2.2 Literature Review: Transesterification

Researchers have also investigated the important reaction conditions and parameters on the transesterification of triglycerides, such as fish oils, soybean, rapeseed, cottonseed, sunflower, safflower, peanut and linseed oils to produce ethyl and methyl esters [1][8][9][10][13][14].

Almost all the investigators concluded that for a successful transesterification, preheating and/or heating the mixture of oil, alcohol, and catalyst during the reaction was necessary to get satisfactory results.

The two types of alcohol commonly used in the transesterification process are

1. Ethyl alcohol or Ethanol
2. Methyl alcohol or Methanol

Ethanol is also a preferred alcohol in this process compared to methanol because it is derived from agricultural products and is renewable and biologically less objectionable in the environment [1][2]. However, according to Provost [16], to an unexperienced manufacturer of biodiesel ethyl esters are much more difficult to obtain than methyl esters.

When using ethanol in the transesterification process, potassium hydroxide KOH appears to be the most effective catalyst to use [16]. When using methanol in the transesterification processes, sodium hydroxide (NaOH) has been found to be most effective catalyst [17].

There are also multiple washing techniques used to purify the raw esters produced from transesterification. Water washing has been proven to be a quite inefficient, difficult and time consuming method of purifying the raw biodiesel or acidic esters [3] [23]. Waterless washing using synthetic magnesium-aluminium-silicate has proven to be a much more effective means of purifying biodiesel. However, using this technique can increase the cost of production up to 23c per litre of biodiesel [23]

2.3 Literature Review: Performance Characteristics

According to the University of Idaho, biodiesel blended fuels compare quite well to diesel. It was found that biodiesel blended fuels have lower power (4.9% loss) and torque (5% loss) outputs when used in an in-line four cylinder John Deere 4239T turbocharged, direct injected diesel engine [5].

A study conducted by Professor Barry Hertz of the University of Saskatchewan (BioBus Project) has shown that biodiesel blends as low as 5% can reduce engine wear by 7.8 – 23.4%. What this indicates is that biodiesel can significantly increase the engine life in terms of frictional losses. What has also been found is that biodiesel is a very good cleaner and that it will remove all of the deposits within the fuel system [19]. However when the transition is made from diesel to biodiesl, the fuel filter must be changed several times so that the fuel filtration system does not clog from the deposits that are being removed [19]. While biodiesel in general may be a good cleaner of foreign deposits, biodiesel that is of low quality and has a high FFA level may leave its own deposits in the fuel and combustion system which may cause sticking valves, sticking piston rings and injector coking [20]. It is therefore very important that a high quality biodiesel is produced.

In terms of emissions, it has been found by U.S E.P.A that the overall emissions of biodiesel are lower than that of diesel with the acception of NOx emissions. From this study it was found that for biodiesel blends of 20% biodiel and 80% diesel (B20), there was a 2% increase in NOx emissions, however particulate matter, hydrocarbons and carbon monoxide were down 10.1%, 21.1% and 21.1% respectively. A separate study conducted by the society of automotive engineers concluded that the increased levels of NOx produced by using biodiesel can be reduced by retarding the injector timing 2 – 3 degrees and or fitting a calyletic convertor [21].

2.4 Literature Review: Economical Benifets

The major influencing factors on the price of biodiesel are the cost of the alcohol used for the transesterification and purification process which is used to purify the raw biodiesel. Biodiesel produced using water purification is dependent on the cost of alcohol only (provided that the water is free) and can be manufactured for 0.58c/litre (cost of materials only). Biodiesel that has been purified using synthetic magnesium silicate absorbent powder can incur an additional cost of up to 23¢ per litre. Overall, regardless of the purification, biodiesel can generally be produced at a lower can than what diesel can be purchased for at commercial fuel distributors.

2.5 Summary

It has been found that biodiesel is made from a process called transesterification. The materials that can achieve transesterification involving the least complications are methanol and sodium hydroxide in the presence of the waste cooking oil. It was also found that biodiesel purified using synthetic magnesium silicate produced superior quality biodiesel that is capable of meeting the ASTM and EN fuel standards.

In terms of performance, Biodiesel should compare quite well to diesel and should produce lower overall emissions with the exception of NOx. To reduce the NOx emissions the injection timing can be changed and or a catalytic converter can be fitted to the exhaust system. It was also found that high quality biodiesel can have a positive impact on engine life and substantially reduce friction. However, low quality biodiesel can be detrimental to engine life and can cause injector coking as well as valves and rings sticking which ultimately can result in engine failure. The emphasis of biodiesel production must therefore be on quality.

Finally it was found that biodiesel can generally be produced at a lower cost than what diesel can be purchased for, where the major influencing factors which affect the cost of biodiesel are the materials used in the purification process and the alcohol used for the transesterification reaction.

Chapter 3

SYSTEM DESIGN & CONSTRUCTION

Objectives

The objective if this chapter is to design and construct a prototype machine that can make biodiesel from waste cooking oil that is suitable for the small-volume individual user.

3.1 Introduction

This chapter will firstly analyse the design requirements and constraints that apply to the design and construction of the biodiesel plant which is to be developed for this project. The basic chemical and physical requirements to produce biodiesel will then be analysed where a list of basic physical requirements will be developed. From this list, a conceptual design analysis will be conducted to develop a machine that is capable of completing all of the physical requirements, thus creating a machine that is capable of manufacturing biodiesel. A final 2-D design will then be developed where a detailed process list will analysed. After analysing the process list and identifying any problems which may occur when making biodiesel, a 3-D model will be developed and construction will begin. Once completed, the newly manufactured biodiesel plant will be put into practice where biodiesel will be produced and analysed for quality. Finally, an appraisal on the entire design and construction process will be performed and any design changes and future work regarding the biodiesel plant will be listed.

3.2 Design Requirements & Constraints

The design requirements of the system are guidelines which dictate the direction of the overall design of the system.

The ***design requirements*** of the system are:

1. The system must produce biodiesel capable of meeting the ASTM and EN standards

It is the biodiesel that is the emphasis of this investigation. The quality of the biodiesel will not only influence the performance characteristics of the fuel, but also the impact it has on the internal engine components. The use of poor quality biodiesel has been can result in poor performance and can substantially reduce the life of the engine [20]. It is therefore imperative that the emphasis on the biodiesel production be on quality. Unfortunately the Australian government has not yet officially released standards regarding the quality requirements on biodiesel, however the American (ATSM-D6751) and European (EN-14214) standards are currently being used by industry as an alternative. Therefore the fuel produced by the system must be capable of meeting these standards so that a high quality of fuel is maintained.

2. The system must be designed to minimise operator interaction

There are two basic factors that must be addressed in this area. That is the time spent to manufacture the biodiesel, and the physical requirements needed by the operator to produce biodiesel. It is essentially the operator that will be in control of producing the biodiesel. As time is of value, the system must be designed so that the overall interaction of the operator is kept to a minimum.

3. The total storage area required by the system must be kept to a minimum

By minimising the room that the unit occupies the emphasis of the design will be on a smarter, more efficient design as opposed to a bulkier less efficient design.

4. Recover any materials that can be used

Throughout the process of manufacturing biodiesel there are certain products which can be reclaimed for use in the next batch of biodiesel. Therefore, a system must be designed to capture any products that can be reused whereby the aim is to minimise fuel production costs.

The system constraints indicate the limitations of the design. A design which perfectly addresses the design requirements is not necessarily the ‘best’ design, as there may be conflict with the constraints set forth on the design.

The ***design constraints*** are:

1. The prototype system must cost no more than $2000 to manufacture (excluding labour)

This is the major factor which will stifle the ‘best’ solution from prevailing. However, it does constrain the project from becoming so expensive that biodiesel production is no longer an economical alternative for the small-volume user. In this instance, this particular constraint may be beneficial

2. The system must be designed to operate in accordance with E.P.A regulations

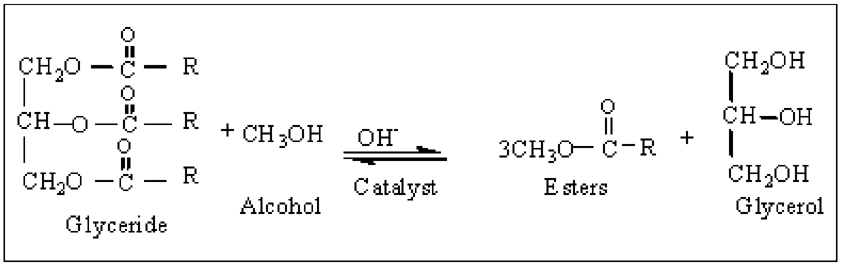
To avoid any conflict with the Environmental Protection Agency and to also conserve the environment, the system must be designed so that the biodiesel plant operates in compliance with the regulations set forth by the E.P.A.

3.3 System Processes

3.3.1 The Chemical Process

The process that occurs when vegetable oil is converted into biodiesel is 'Transesterification'. Transesterification occurs when alcohol, an acid catalyst and vegetable oil are mixed together in the correct proportions. The major products of the reaction are either methyl esters (methanol as source of alcohol) or ethyl esters (ethanol as the source of alcohol) where both 'esters' are what is classified as biodiesel. The bi-product of the reaction which must be removed is glycerine. Glycerine can be seen as the impurities and particulate matter that is removed from the oil after transesterification.

The figure below shows the chemical process for methyl ester biodiesel. The reaction between the oil and the alcohol is a reversible reaction and so the alcohol must be added in excess to drive the reaction towards the right and ensure complete conversion.



$$\mathrm{Glyceride} + CH_3OH \xrightleftharpoons[\text{Catalyst}]{OH^-} 3CH_3O-\overset{O}{\overset{\|}{C}}-R + \mathrm{Glycerol}$$

Figure 3.1: Transesterification Process

Vegetable oils are triglycerides, composed of three chains of fatty acids bound by a glycerine molecule. In the above figure the oil component of reactants is the 'Glyceride' or more accurately 'Tri-Glyceride', as there are three glycerides linked together per molecule of vegetable oil. When the oil is mixed with the alcohol and catalyst, esters and glycerine molecules are formed. A successful transesterification reaction is signified by the separation of the ester and glycerol layers after the reaction time.

Research has shown that the simplest way to achieve transesterification is through the use of methanol as the 'alcohol' and sodium hydroxide as the 'catalyst' [17]. Other substances may be used such as ethanol and potassium hydroxide, but the process is more complicated and therefore more difficult to achieve a complete conversion for an inexperienced user.

As the aim of this investigation is to determine whether or not it is feasible for an average individual to manufacture biodiesel for personal use, the easiest and most common form of transesterification will be used, whereby alleviating the host of technical issues which can arise by using the more complicated processes.

3.3.2 The Physical Process

The physical process to convert WVO into biodiesel is quite simple in comparison to what is happening on a molecular level. There are three general ingredients required to make biodiesel

1. Vegetable Oil (triglyceride)
2. Methanol (alcohol)
3. Sodium Hydroxide NaOH (catalyst)

The steps required to convert WVO into biodiesel are:

1. Titration of the WVO to determine how much sodium hydroxide to add
2. Mix the sodium hydroxide with the methanol until completely dissolved
3. Add the sodium hydroxide and methanol mixture (methoxide) to the specific amount of oil that is to be transesterified
4. Heat the oil and methoxide mixture to enhance the rate of reaction until the reaction is complete
5. Allow time for the newly converted esters (biodiesel) and glycerine to separate
6. Remove the glycerine and leave the remaining biodiesel for further refinement
7. Remove impurities from the biodiesel
8. Test and store

Generalising the above process, the steps involved in making biodiesel can be broken down into the following ***subgroups***:

1. **Titration**
2. **Alcohol and Catalyst mixing**
3. **Transesterification**
4. **Purification**

A ***design analysis*** will be conducted within each of these subgroups whereby the best design will be selected from each analysis.

3.4 Conceptual Design Analysis

3.4.1 Titration

As has been previously stated, vegetable oils are triglycerides, composed of three chains of fatty acids bound by a glycerine molecule.

Free fatty acids (FFA’s) are fatty acids that have become separated from the triglycerides, leaving diglycerides, monoglycerides and free glycerine. This is caused by heat, water in the foods cooked in the oil, or oxidation. The hotter the oil gets and the longer it's cooked, the more FFA’s it will contain.

There is a basic amount of sodium hydroxide (NaOH)required as catalyst to transesterify fresh, uncooked oil and neutralise any FFA’s and that is 3.5 grams(NaOH)/litre. When transesterification is performed on waste vegetable oil (WVO) however, an additional amount of NaOH is needed to neutralise the additional FFA’s within the WVO, turning them to soaps. The majority of the soaps sink to the bottom along with the glycerine product created by the reaction, however some soap still remains within the biodiesel. The remaining soap must be removed in the purification process which will be addressed later in the paper.

If too much NaOH is used as a catalyst, the biodiesel ester bonds will break where some of the bonds will mate with the NaOH forming excess soap, and other with any water in the WVO which will form additional FFA’s that dissolve back into the biodiesel. Excess soap formation will form a very alkaline biodiesel that's difficult to purify, with loss of production, or it can ruin the reaction when the ratio of soap to biodiesel reaches a point where the whole batch turns into "glop soap".

While it is unavoidable that some FFA’s are formed by biodiesel ester bonds being broken, excess NaOH increases the proportion.

So why it is that FFA's are so undesirable in biodiesel? According to the Fuel Injection Equipment Manufacturers (Delphi, Stanadyne, Denso, Bosch), FFA's can corrode fuel injection equipment, cause filter plugging and the build-up of sediments on fuel injection parts.

The process used to determine how much additional sodium hydroxide is needed for a specific batch of WVO is titration. Titration measures the pH of the oil, that is, the acid-alkaline level (pH7 is neutral, lower values are increasingly acidic, higher than 7 is increasingly alkaline, or "base"). From this you can calculate how much extra NaOH will be needed.

The manual titration process is as follows:

1. Measure out 1g of NaOH with 1liter of distilled water, and mix (test solution)
2. Add 10 ml of Methanol to a glass container
3. Test the Ph of the methanol and add a few drops of the test solution to neutralise the methanol if required
4. Add 1 gram of oil to the methanol and stir
5. Add a sufficient amount of test solution (drop by drop) until the Ph of the oil/methanol solution reaches 8.5 (within 4-8 ml)
6. Calculate the amount of NaOH required/litre to bring the solution up to a PH of 8.5.

Example Calculation:

If titration showed 2 ml, that translates to 2 extra grams for each liter of oil. Using 90 liters for example,

90 liters oil x (3.5 grams NaOH + 2)

Where the 3.5 grams is the amount of NaOH required as catalyst to transesterify fresh, uncooked oil

The total amount of NaOH required is:

90 x 5.5 = 495 grams

Mechanising the titration process will be quite difficult and expensive to do. To do so would require the use of highly calibrated ph measuring device, data acquisition and recording device and a programmed CPU at the very least. This device in itself would be quite difficult, time consuming and expensive to manufacture. An automatic titration device may be purchased however, the cost of such a device amounts to thousands of dollars. For this particular application it is not justifiable to spend this amount of time or money constructing or purchasing an automatic titration apparatus, where the titration procedure when performed manually can be completed easily within 10 minutes. Therefore, the titration process will be performed manually by following the same process listed above.

3.4.2 Alcohol & Catalyst Mixing

The alcohol used within this process is methanol. Methanol is a very dangerous and volatile substance and must be treated with caution. When mixed with an acid (NaOH in this case) the mixture is even more dangerous. It is therefore necessary to minimise the level of human interaction involved in all process where these chemicals are present.

The ***functional requirement*** of this system is:

- To mix the NaOH granules with the methanol until the NaOH is completely dissolved within the solution.

While this may seen like only a basic function, there are several specific design constraints which must be addressed in order to design the best overall system.

The specific ***design requirements*** are that:

- The proposed system can not have any device which has exposed electrical components or generate enough heat so that a fire or explosion will occur

- The proposed system must be sufficiently sealed so that harmful gasses, vapours or emissions given off by the reaction generated within the methoxide solution are not released into the atmosphere – (EPA regulations)

- The proposed system must incorporate sufficient apparatus to ensure the operator does not have to physically contact or inhale any chemicals used throughout the process

It is therefore important that any design proposal to mechanise this process must be based on these design requirements and limitations.

3.4.2.1 Conceptual Design Proposal 1

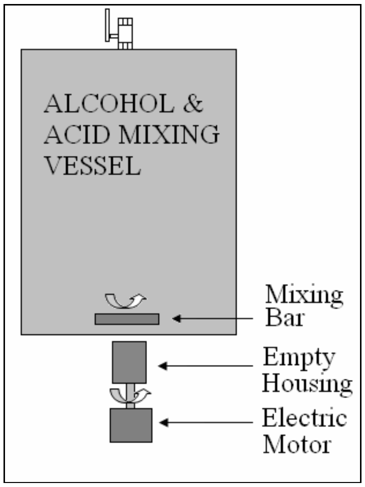


Figure 3.2: Magnetic Stirring Bar Mixer

How the device works: Take one sealed electric motor and another standard electric motor. Remove the armature of the standard electric motor and fix the housing of the standard electric motor to the output shaft of the electric motor as shown above. Mount the sealed electric motor now coupled with the standard electric housing beneath the sealed container. Place a mixing bar magnet inside the sealed container. Turn the sealed electric motor on. The rotating magnetic field produced by the housing of the standard electric motor in rotation, will cause the mixing bar to rotate and stir the solution within sealed vessel. The ball valve located on top of the tank can be opened to add Methanol and NaOH and then closed off to seal the system.

Advantages of this design:

- There are no input shafts or holes required to make this mixing apparatus work and therefore there is virtually no chance of this mixing device leaking
- As there is a low risk of this design leaking there is a low risk of the methanol igniting from the electric engine

Disadvantages of this design:

- The mixing bar may become stuck which will require human interaction to dislodge the bar – reliability issues – possible skin contamination
- Corrosion may take place between the mixing bar and methoxide solution
- Mixing bars are not readily available, they are a specialty item which may be difficult to get

3.4.2.2 Critical Factor Analysis: *Conceptual Design Proposal 1*

Power: The power required to operate the system is consumed via the electric motor at the base. The power consumed by this electric engine will only be marginal and will not be a problem.

Cost: The cost of this system would be quite cheap in terms of each component. The availability of the mixing bar however, may be a problem. While mixing bars can be ordered, they are more of a specialty item and are not readily available.

Reliability: The reliability of this unit is questionable. If the mixing bar were to become lodged in the alcohol/acid solution, the magnetic field generated by the rotating motor housing would most likely not be enough to dislodge it. Therefore, some human interaction would be required to dislodge it. This particular factor may have a significant impact on the ability of this design to perform the specified task.

Safety: This is a very safe design as there is only a very small chance of the mixing vessel leaking. As there are no shaft penetrating the wall of the mixing vessel, the only way the vessel could leak is that if there were a hole in the material in the missing vessel itself. Provided that the correct material were selected, this is highly unlikely.

Functionality: The functionality of this unit may be compromised by the reliability issues mentioned above. If it were guaranteed that the mixing bar would never become stuck, this system would most certainly be quite appropriate. However this is not the case, and therefore the functionality of this particular design is limited.

Ergonomics: The ergonomic attributes of this system are also compromised by its reliability issues. If the mixing bar were to become stuck, it would require the operator to dislodge it, and therefore resulting in negative ergonomic attributes.

Aesthetics: This design could most certainly be made to look attractive and there is also the illusion of some form of magical force which is causing the mixing bar to spin without being attached to a shaft. This system is not limited in any way by its aesthetic appearance. The influence of the manufacturer can make this design look either good or bad.

Maintainability: There are two areas which would require maintenance with this design; that is inside the tank where the mixing bar is, and the electric motor located on the outside of the tank. While only very little maintenance would be required on the electric motor, constant and regular maintenance would need to be performed on the inside of the mixing vessel to remove any build up of gummy partially dissolved acid and alcohol. This would be quite an annoying problem to address as it would occur quite consistently. In terms of maintenance, this particular design has quite a high level of maintenance required and rates quite poorly.

Manufacturability: This design would be relatively easy to manufacture, however vibration issues may become evident if the empty housing of the electric motor were not mounted perfectly. Offcourse excessive vibration would ultimately cause the unit to fail which is obviously an undesirable quality. This is the only area that would pose as a problem in terms of manufacturability.

3.4.2.3 Discussion: *Conceptual Design Proposal 1*

While the stirring bar mixer or design proposal 1 does have the advantage of being unlikely to leak, it does have a major disadvantage being unreliable as the stirring bar may get caught up and stop working properly. As the acid dissolves into the alcohol, some parts of the solution may become quite thick and viscous. This may cause the magnetically operated stirring bar to become lodged in some of the partially dissolved acid, and stop working. This is a very real scenario and is characteristic of acid when it is dissolved into alcohol. As the stirring bar rotates due to a rotating magnetic field, a very strong magnetic field may be required to overcome the 'lodging' that may occur. Relating this requirement of needing a large magnetic field back to the physical equipment which has a large magnetic field, it can be determined that the mixing device required to successfully and reliably mix the methanol and alcohol solution, is not feasible in terms of size and cost. The unit would simply be too large and too expensive and may still prove unreliable.

3.4.2.4 Conceptual Design Proposal 2

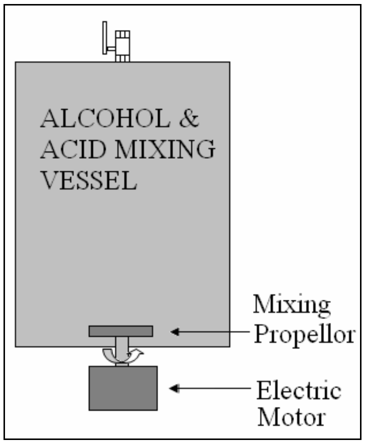


Figure 3.3: Stirring shaft mixer

How the device works: A brushless sealed electric engine with a mixing propeller is mounted to the base of a sealed mixing vessel. On top of the vessel is a ball valve where the alcohol and acid can be added. Once added the brushless engine will be turned on and the mixing propeller will stir the solution until the acid has dissolved.

Advantages of this design:

- High quality mixing possible, provided that rotation speed and mixing propeller is appropriately matched to avoid cavitation from vortex creation
- Better mixing motion than mixing bar, less friction
- Simple and cheap to construct

Disadvantages of this design:

- The system may leak though the seals surrounding the stirring shaft which may result in fire or area contamination
- Cavitation may occur if the pitch on the stirring propeller is too high or if rotation speed is too high
- Quality of mixing may be compromised if the pitch on the stirring propeller is too low or engine speed is too low

3.4.2.5 Critical Factor Analysis: *Conceptual Design Proposal 2*

Power: The power required to operate this system is consumed through the electric engine which is attached to the stirring shaft and mixing propeller. The power required by this electric engine will only be very small as the viscosity of the alcohol and acid solution is quite low. The power requirements of this motor will not be a problem.

Cost: The cost of this system will be quite low, and could be built under $30 not including labour. The parts required by this system are quite readily available and easy to make.

Reliability: The reliability of this system would be quite good provided that the correct materials were used throughout the construction. If and when the system fails, the problems it may cause could be fatal. If this particular system were to leak, alcohol and acid would be in direct contact with the electric engine mounted at the base of the mixing vessel. If for some reason a spark were created (highly possible) the mixture would most certainly ignite and could explode. This is a highly undesirable reliability issue to have.

Safety: The general safety of this system is compromised by the reliability issues mentioned above. Essentially this particular design is comparable to a time bomb, where eventually the seals holding the alcohol and acid will fail, and the unit may explode.

Functionality: The functionality of this system is quite good. The mixing properties achieved by the mixing propeller would be quite high and easily modifiable.

Ergonomics: The most that would be required of an operator using this design is to turn on and off a switch. Provided the switch is able to be turned on and off easily and is in an accessible position, the ergonomics are quite basic.

Aesthetics: The aesthetic appearance of this system can be made to look good or bad, depending on the manufacturer. This particular design is quite neutral in the fact that it neither looks good, nor bad.

Maintainability: The only problem that there will be with maintenance is the seal surrounding the input shaft protruding into the mixing tank. Provided that this seal is maintained, there should not be a problem. Other than that, this design will have very low, if any required maintenance.

Manufacturability: This system would be quite easy to manufacture. The most difficult task would be getting the engine shaft to seal within the mixing vessel. The additional tasks required to manufacture this system would be quite easy to perform.

3.4.2.6 Discussion: *Conceptual Design Proposal 2*

By analysing this particular design it can be seen that the major problem is that, if the seal surround the shaft did leak, highly flammable methanol and corrosive acid may leak directly onto the electric engine. This could most certainly cause a fire. To avoid this situation, some form of pinion and crown wheel assembly may be used whereby the electric engine could be located to the side of the mixing vessel, and the crown wheel and pinion arrangement could be placed directly beneath the point of entry. If the system now leaked it would not leak directly onto the electric engine, however, this is now not a very practical system as it now requires a gear box and additional shafts. Another alternate possibility is to locate the electric engine on the side of the unit and have the mixing shaft protrude into the mixing vessel from the side. If the seal around the shaft leaked in this configuration it would most likely not go into the motor, but it is still a possibility. Therefore, fire and site contamination is still a problem.

There are many ways at which this mixing system can be changed and altered, however the fact still remains that it is generally a clumsy system and perhaps not the best option.

3.4.2.7 Conceptual Design Proposal 3

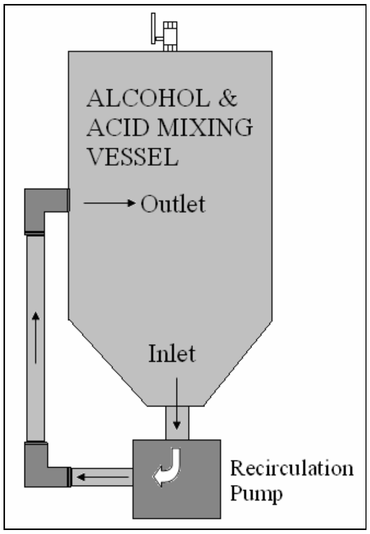


Figure 3.4: Pump Recirculation System

How the device works: A pump is externally mounted on the mixing vessel whereby the inlet of the pump draws from the base of the mixing vessel and the outlet of the pump connected toward the top of the mixing vessel. Connecting a pump in this configuration will form a closed loop system whereby the acid and alcohol will be stirred via the impellor of the pump.

Advantages of this design:

- This system has the potential to provide a much more superior mixing action than the other proposed systems due to a relatively low volume of liquid being rapidly stirred through the impellor of the mixing pump

- This pump could be used to transfer the mixture into a reaction vessel to commence transesterification

Disadvantages of this design:

- If a pump were selected that were not able to withstand the chemicals used within the mixing vessel the pump may fail and leak which may cause a fire or site contamination
- This design will require several joints and fittings which may not only be expensive, but may also leak

3.4.2.8 Critical Factor Analysis: *Conceptual Design Proposal 3*

Power: The power required by this system is consumed though the electric engine which powers the pump either directly or pneumatically. While the power required would be slightly higher than that of the other designs, it would not pose as a problem.

Cost: The cost of this system could be cheap and it could be expensive. If an explosion proof pump were used then the cost involved may be quite high. If however a chemical resistant pump were used then the cost would be quite low. An explosion proof pump would be ideal, however not necessary. Due to the nature of the design if a fire were to occur it would not be contained within the pump but propagate throughout the vessel. Therefore, a chemical resistant pump could be used with no loss in safety or functionality.

Reliability: Provided that the correct pump was used within this system, the reliability of this system would be very high. If however, a seal leaked within the pump and alcohol came in contact with the electric engine, a fire may occur. The systems ability to thoroughly mix the acid and alcohol together both completely and reliability is quite high. There are no inherent problems that this design will encounter while performing this task. Overall, this system is quite reliable.

Safety: The safety of this particular design may be compromised if the pump were to leak. As has been described above, if the pump were to leak, a fire may occur which may cause an explosion. While the chance of this occurring is only very low, the possibility is still there and it is debateable whether the risk is worth taking.

Functionality: The functionality of this system by far supersedes the previous designs that have been discussed. This system offers superior mixing ability when compared to that of the other systems and also, the path of the alcohol and acid solution can be diverted into the reactor while using the same mixing pump. As there are virtually no reliability issues which will affect the pumps ability to perform, the overall functionality of this system is quite good.

Ergonomics: This system also has limited ergonomic requirements. The most that the operator is required to do is to operate a switch and a few ball valves. Provided that the switches and valves are in an accessible location and have been ergonomically designed, there will be no ergonomic concerns.

Aesthetics: The aesthetic appearance of this system could be made to look quite appealing. This system has the advantage of requiring a certain amount of plumbing fittings. The system could be made to look quite good if chrome plated fittings and pipe were used.

Maintainability: Little if any maintenance is required to ensure the system keeps operating. If however, the seal within the mixing pump did fail there may be some maintenance issues. This seal may be difficult if not impossible to acquire. Therefore it may be necessary to change the pump rather than replace the seal.

Manufacturability: This system offers a few more challenges in terms of manufacturability. The pluming required by this system could be done a multitude of ways, however, there is obviously better ways than others. This particular task however will not be difficult. This system also requires the used of multiple connections which could leak if not installed properly. This should not be a problem, it’s just a matter of using the correct sealing compound (e.g. thread tape or thread sealer)

3.4.2.9 Discussion: *Conceptual Design Proposal 3*

There are several advantages that this system has over the other design proposal. The first is that this system will have a greater ability to mix the solution more consistently and thoroughly. A solution which has dissolved the entire contents of the acid within the alcohol will react much better with the waste vegetable oil and a complete conversion is far more likely. A solution where the acid has not completely dissolved into the alcohol will result in and inconsistent and incomplete reaction when added to the waste vegetable oil. It is therefore quite favourable that this system utilises a mixing process that will yield superior mixing results when compared to that of the other systems.

The other useful advantage of this system is that the mixing pump may be used as a transfer pump to pump the contents out of the mixing tank into a reaction tank. This is certainly a desirable quality to have as it eliminates any further chemical contact required once the alcohol and acid have been mixed, thus making the system safer.

The disadvantages however are that the pump and associated fittings may leak if the correct pump is not selected and the fittings not installed properly. The solution to this is to firstly select a pump that will not react with the chemicals required to make biodiesel, and also ensure that the fittings are correctly installed and maintained.

3.4.2.10 Conceptual Design Selection: *Alcohol & Catalyst Mixing*

It can be determined that from the analysis of the above systems that design proposal 3 or the ‘Pump Recirculation System’, is the ***best system to use***. This particular system offers superior mixing ability when compared to design proposal 1 & 2, and also minimises operator interaction both during and after the mixing process. The pump recirculation system has the potential to be the most reliable and economically feasible solution that requires the least amount of operator interaction. The recirculation pump can be employed for multiple uses. The first and primary function is to stir and dissolve the acid into the alcohol. The second function is that the recirculation pump can have the recirculation path altered to pump out the contents of acid and alcohol into a reaction vessel.

While there are some safety concerns, these can be minimised by utilising a suitable pump and mixing vessel and also following the correct materials handling procedures indicated in appendix 2 ‘Materials Safety Data Sheet: Methanol and Sodium Hydroxide.

Concluding this investigation into the most appropriate concept to mix the acid and alcohol together, it has been decided that the ‘Pump Recirculation System’ will be used.

3.4.3 Transesterification

Transesterification is the chemical reaction that occurs when alcohol, acid and waste vegetable oil are added together in the correct amounts. Once the reaction is complete and the solution has settled, two distinct layers will form. The upper layer is biodiesel and the lower is glycerine. Once sufficient time has been given for the solution to settle out completely, the glycerine must then be removed. The system that will be responsible for achieving transesterification will be the reactor.

The ***functional requirements*** of this system are:

- To successfully contain the oil, alcohol and acid and mix together until transesterification is complete
- To separate the glycerine from the biodiesel

The reactor is basically a larger, slightly more complex methanol and acid mixing vessel with similar design requirements.

The specific ***design requirements*** are that:

- The proposed system can not have any device which has exposed electrical components or generate enough heat so that a fire or explosion will occur
- The proposed system must be sufficiently sealed so that harmful gasses, vapours or emissions given off by the reaction generated within the methoxide solution are not released into the atmosphere – (EPA regulations)
- The proposed system must incorporate sufficient apparatus to ensure the operator does not have to physically contact or inhale any chemicals used throughout the process
- The proposed system must recapture any materials that can be re-used that would otherwise go to waste.

3.4.3.1 Conceptual Design Proposal

Analysing both the functional and specific design requirements, it can be seen that the reactor is basically a more complicated alcohol and acid mixing vessel, only now oil has been added to the solution. The method of mixing that will be adopted for this process will operate on the same principal as what has been developed for the alcohol and acid mixer.

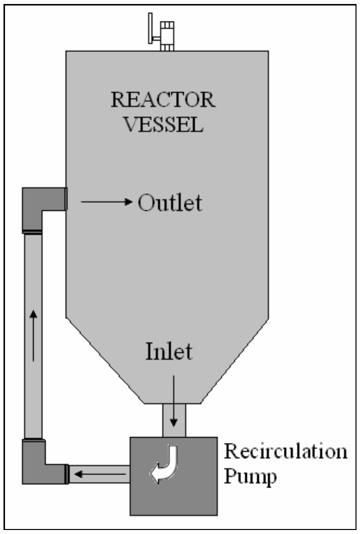


Figure 3.5: Basic Reactor Vessel

This principal alone however will not perform all the tasks required of the reactor. With this basic configuration the transesterification process would take several days to complete. There is no glycerine removal system and there is no system in place to recapture any materials that can be reused.

The following areas need to be addressed:

1. Increasing the rate of reaction
2. Glycerine Removal
3. Waste recovery system

3.4.3.2 Increasing the rate of reaction

There are a few techniques which can be introduced to this system to increase the rate of reaction. These techniques are:

i) Increasing the rate of reaction through better mixing
ii) Heating

3.4.3.2.1 i) Increasing the Rate of Reaction through better mixing

The first method which can be used to increase the rate of reaction is to adopt a more effective method of mixing. A spoon for example could be upgraded to a blender. As the basic design of the reactor incorporates a pump to do the stirring, it will be hard to achieve a mechanical device that can mix the solution better. The use of ultrasonic technology however, can substantially increase the rate of reaction by effectively mixing the solution more thoroughly. To do this, the pump is still set up the same way as a recirculation system, however, once the fluid exits the pump it then passes through a small vessel that is saturated with ultrasonic waves. The fluid then exits the ultrasonic vessel and flows back into the tank. What the ultrasonic waves do is agitate the acid, alcohol and oil solution on a molecular level. This agitation can substantially increase the level of molecular collisions that occur within the solution which in turn, increases the rate of reaction which also results in a more thorough and complete reaction.

If ultrasonic mixing were used in conjunction with a heating apparatus, reaction times could be cut back to less than 10 minutes for a 100ltr batch. However, if ultrasonic technology was used alone results are similar to that of heating.

Unfortunately incorporating ultrasonic technology into this system would cost in excess of $5000.

For large scale industrial biodiesel plants, ultrasonic technology would prove invaluable. However, utilising this technology in the prototype model of this project is not economically feasible.

3.4.3.2.2 ii) Increasing the Rate of Reaction through Heating

The second method of increasing the rate of reaction is though ***heating*** the reactant. Heating the reactant acts as an additional catalyst to the reaction and can cut the reaction time down to less than an hour. So simply by adding heat into the system the rate of reaction can be increased dramatically. The amount of heat however is what needs to be addressed. It has been found that temperatures between 48 - 54°C have provided the best environment for an accelerated reaction. If the contents are heated any more than this, the risk of methanol evaporation is increased which may result in a contaminated, semi converted biodiesel. It is therefore important to mention that if heat is used within the reactor, the temperature must be closely monitored.

Another important factor which needs to be considered is that, if heating is to be provided, what is the source of heat? Should it be electrical, chemical, solar or some other form? As there is certainly a risk that a fire could occur during biodiesel production, it seems logical to steer away from heat sources that utilise an open flame. The other options available are solar and electrical.

Solar power is unreliable and is difficult to achieve a high amount of heating energy in a low cost unit. These simple points alone are enough to eliminate the use of solar power in this situation.

So it seems that all we are left with is electrical power. Electrical heating energy is easy to achieve in large amounts, can be thermostatically controlled, however if not correctly set up, the electrical heating system could ignite the fuel if the heating element reached the auto ignition temperature of the reactant.

Now, the next question is, ***'what is the best method of electrical heating to use?'***
There are many methods which can be used however the most effective form of heating will be through physical conduction received though direct contact of a heating element or a hotplate type of arrangement. Heat through convection or radiation is not an option as the heat energy used to heat the reactant needs to be utilised as efficiently as possible so that costs are minimised.

So what are the best ways of applying heat to the reactant through conduction? There are two ways that will be analysed. The first is to have a hotplate mounted beneath the reactor.

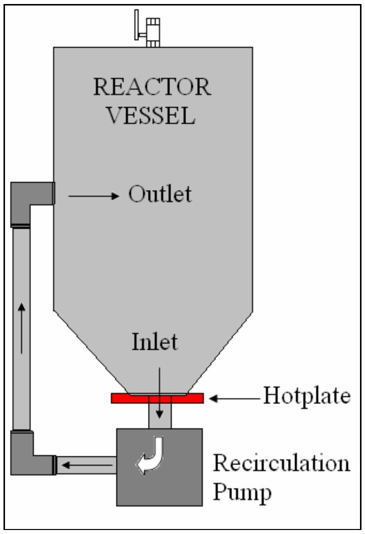


Figure 3.6: Basic Reactor Vessel with Hotplate

Without much investigation it can be seen that this may create several problems. Such problems include:

- The base of the reactor must be the same shape as the surface of the hotplate, otherwise heat localising will occur (hot spots)
- The hotplate may get in the way of the pluming of the reactor
- If any reactant were to fall on the exposed hotplate, a fire may occur
- If anyone were to touch the hotplate during operation they may be burnt

These factors are only some of the problems which can occur if a hot plate were used to heat the reactant. Based on these factors, it is safe to say that using a hot plate is not a good idea and no further investigation into this method of heating will be conducted.

Another way of heating the reactant is through incorporating one or several heating elements within the reactor similar to that of a hot water system or a kettle.

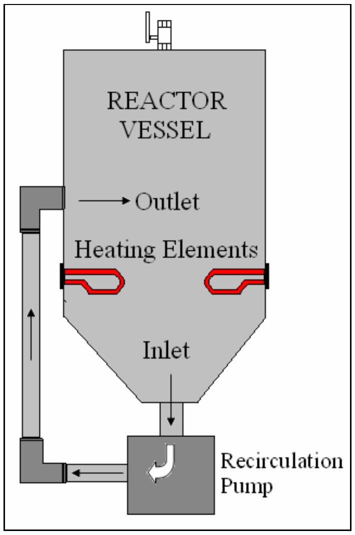


Figure 3.7: Basic Reactor Vessel with twin heating elements

The method of using heating elements to heat the reactant has been done successfully in many biodiesel plants [8] [9] [10] [13] [14]. In most cases the heating elements used are out of electric hot water systems which have provided many years of service without any problems.

The advantage a heating element system has over a hot plate system is that heat is conducted directly out of the element and into the reactant, therefore making the heat transfer more efficient. Heating elements can also be positioned anywhere beneath the fill line in the reactor making the elements versatile to mount.

The main problem with heating the reactant using this method is that, if the heating elements were ever exposed there may be the risk of them getting too hot and igniting any flammable gasses that are present. While this is a potential safety issue, the risk can be easily avoided by mounting the heating elements below the fill line and also through the use of a thermostat and common sense. Another way to avoid auto ignition though excessive heat is to use multiple, low wattage elements.

If for example the system required a 3.6kW heating element, instead of using 1 x 3.6kW element that can heat up very quickly, use 2 x 1.8 kW heating elements which will not heat up so quickly.

3.4.3.2.3 Critical Factor Analysis: *Heating elements*

Power: The power consumed by the heating elements will be between 1.8 and 3.6kW depending on the size of the reactor. This heating capacity has been proven to be effective on units up to 125ltr

Cost: The cost of the heating system will be very low as the heating elements for the prototype model can be used from old leaking hot water systems.

Reliability: Provided that the heating elements are in good condition, this method of heating has proven to be very reliable.

Safety: Provided that the heating elements are always submerged, the heating elements do not create any problems. If however a heating element became exposed, it could create an explosion. Again, this is an easy problem to avoid so it is left up to the common sense of the operator.

Functionality: The heating elements are certainly a very efficient method of heating the reactant and will be able to do so quite quickly.

Ergonomics: The most that the operator is required to do is to operate a switch. Provided that the switch is in an accessible location and has been ergonomically designed, there will be no ergonomic concerns.

Aesthetics: NIL – The heating elements are concealed

Maintainability: The heating elements will require virtually no maintenance provided that the heating element is still working and the outer seal is not leaking. If the element is not working or the seal is leaking, these components can be easily and cheaply replaced.

Manufacturability: Incorporating several heating elements into the reactor system is quite easy. Fitment and wiring will not be a problem however a heavy duty switch would be required to turn the heating elements on and off.

3.4.3.2.4 Conceptual Design Selection: *Increasing the rate of reaction*

Analysing the techniques that are available to increase the rate of reaction of the reactant, it can be determined that an electrical heating system utilising multiple heating elements is a feasible solution, and will be incorporated into the reactor design. As this method has been used within many biodiesel plants throughout the world, it is a proven and tested method of heating that is safe and that works and that is simple and cost effective.

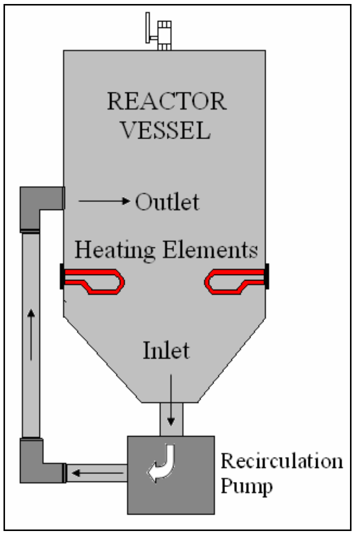


Figure 3.8: Basic Reactor Vessel with twin heating elements

The above design displays the simple concept that will be adopted to increase the rate of reaction of the reactant.

3.4.3.3 Glycerine removal

When the oil, alcohol and acid have been mixed together for a set period of time the transesterification process will be complete. Once the reaction is complete the mixing pump will need to be turned off and the product will need to settle. Once complete there will be two distinct layers that form, biodiesel and glycerine. The biodiesel will remain on the top layer and the glycerine will fall to the lower layer. A picture of the separation can be seen below.

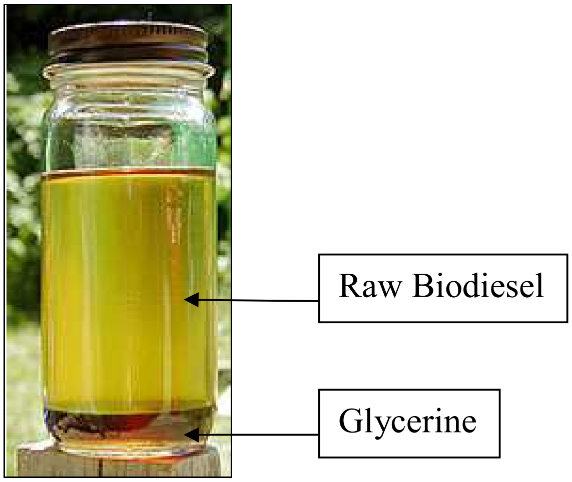


Figure 3.9: Biodiesel and Glycerine Separation

The above figure represents the separation that occurs after the oil, alcohol and acid have completed the transesterification process and formed biodiesel and glycerine.

There are two basic ways that the glycerine by-product can be removed.

1. Remove the biodiesel from the glycerine
2. Remove the glycerine from the biodiesel

3.4.3.1 Removing the biodiesel from the glycerine

The problem with removing the biodiesel and leaving the glycerine remain is firstly that the biodiesel needs to be transferred to another holding tank, even if only for the short term. This will require a larger overall system and could be quite messy. The second problem with removing the biodiesel from the glycerine, is how?

A siphon could be used but that is a technique that the operator would need to perform. Anyone that has ever used a siphon on petrol for example will know that manually siphoning fuel is not the most enjoyable past time.

A pump could be used to pump the biodiesel away from the glycerine but at what height should the inlet of the pump be mounted? The amount of glycerine produced in making biodiesel is certainly not consistent and therefore some form of adjustable pump inlet would need to be designed to accommodate for the variable glycerine heights.

3.4.3.3.2 Removing the glycerine from the biodiesel

The other method of separation is by removing the glycerine from the biodiesel. The most practical way of doing this would be to incorporate some form of tap or ball valve at the base of the reactor, whereby once the glycerine has settled out, the lower ball valve is opened (before the glycerine has solidified) and the glycerine is removed. Once the transparent biodiesel can be seen the ball valve is turned off.

3.4.3.3.3 Which method to use?

It is not difficult to see that better method is the latter of the two. That is to remove the glycerine from the biodiesel. This is not a complicated process and does not require a complicated solution.

The solution mentioned above, whereby the glycerine is removed via a ball valve or tap mounted in the base of the reactor, is a simple and very effective solution. The advantage of this system compared to the others, is that only one large tank is required, that is the reactor. The process is not messy and it only requires a minimum amount of operator interaction. The process could most certainly be made automated but this is beyond the scope of the project.

3.4.3.3.4 Conceptual Design Proposal: *Glycerine Removal*

It seems that a very simple solution can solve a potentially difficult problem with ease. The basic concept that will be used within the glycerine removal system is illustrated below.

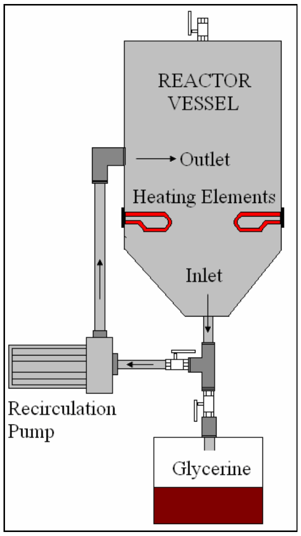


Figure 3.10: Reactor with heating elements & glycerine removal system

The way this process works is that, after the glycerine has settled to the bottom of the reactor, the glycerine will be removed by opening via the lower ball valve which will be directed into a glycerine storage container. Once biodiesel starts coming out of the outlet of the ball valve, the ball valve is switched off and the glycerine removal process is complete.

3.4.3.4 Waste Recovery System

The material that can be recaptured within the- process of making biodiesel is the alcohol. As the transesterification process is reversible, additional amounts of alcohol are required to drive the chemical reaction to the right (see Figure 3.1) to produce biodiesel and glycerine. Once the transesterification process is complete and all the alcohol that can be used has been used, there will be a certain amount of alcohol left within the solution of biodiesel and glycerine. The alcohol remaining in the biodiesel and glycerine can be either evaporated out or recaptured and used within the next batch of biodiesel. As the alcohol used within this project is methanol and costs around $2.50/litre, it makes economical sense to recapture as much of this valuable resource as possible to minimise the costs involved in making biodiesel.

Therefore, it is required that some form of waste recovery system be incorporated into the design of the biodiesel plant to recapture any methanol that would otherwise go to waste.

3.4.3.4.1 Methods of Recapturing Alcohol

There is a particular characteristic of alcohol that makes it quite easy to recapture, and that is its boiling temperature. The alcohol that will be used in this project (methanol) has a boiling point of 64.7°C under atmospheric conditions. Therefore, if the raw biodiesel and glycerine solution were exposed to temperatures that were above the boiling point, the methanol would evaporate from the solution where it could then be condensed and stored.

There are two ways to expose the biodiesel and glycerine to a situation where the alcohol is above its boiling temperature. These are by:

i) Pressure reduction
ii) The addition of heat

3.4.3.4.2 (i) Pressure Reduction

The first method is to decrease the pressure of the solution whereby the boiling point is reduced. This could be done by placing the solution into a vacuum vessel where a vacuum pump would be employed to lower the pressure within the vessel until the alcohol starts to boil out. The advantage of this method is that it can be performed using less energy than the second method. However, the actual device that recaptures and condenses the alcohol can become quite complicated and expensive to manufacture. This particular method will also require the use of a potentially expensive vacuum pump and vessel.

2.4.3.4.3 Critical Factor Analysis: Pressure Reduction

Power: The power used in this method is generally less than that used within the second method as the power consumed within the process is via the vacuum pump.

Cost: The cost of this system could be quite high, in excess of $500 for this project. The main cost involved is the pressures vessel, the vacuum pump and the associated parts and fittings to manufacture the condensation system.

Reliability: The reliability of this system is basically dependent upon cost. The main components that may have reliability issues are the vacuum pump and the vacuum vessel. However, provided that the correct vacuum pump and vessel have been suitably selected and constructed for the task it would not be a large concern. If the unit were made properly and without the compromise of quality components, the system would be very reliable.

Safety: This system is much safer than the second alternative as it does not require a great deal (if any) of heat to be introduced into the system. The outlet of the vacuum pump also needs to be channelled off to a well ventilated sink to prevent the build up of methanol vapour.

Provided that the vacuum pump were the correct unit for the task and that the outlet of the vacuum pump were vented to an appropriate sink, the risk of fire and site contamination is very low.

Functionality: This method of removing a particular product (alcohol in this case) from a solution has been used quite frequently in the petrochemical industry and is very effective provided that it is set up properly. In most cases the product that is being removed can be done so more thoroughly using this technique as opposed to the other. In terms of the functionality, this system will be able to extract more alcohol from the solution quicker and with less energy when compared to the other method

Ergonomics: The most that the operator is required to do is to operate a switch and a few ball valves. Provided that the switches and valves are in an accessible location and have been ergonomically designed, there would be no ergonomic concerns.

Aesthetics: The aesthetics of this method could be displeasing if the design were not neat and tidy and also if construction were completed poorly. If done properly this system should look ok.

Maintainability: Provided that the system were designed so that each component could be accessed quite easily, the system will be easy to maintain. While the pump and vacuum vessel are specialty items, there should not be a problems replacing or repairing these items.

Manufacturability: This system would be quite difficult to manufacture on a budget. It is hard to build a system like this when the most desirable parts can not be used due to cost restrictions. Construction quality also needs to be closely monitored as this vessel needs to be completely air tight and be able to hold a vacuum for it to work.

3.4.3.4.4 ii) Addition of Heat

The second and most obvious method of recapturing the alcohol is quite straight forward. The solution is heated in some way until it reaches a temperature above the boiling point of the alcohol where the alcohol would then evaporate out. The advantage of this system is that it requires no special vacuum vessel or pump and the systems used to capture the evaporated methanol are quite cheap and simple to manufacture.

3.4.3.4.5 Critical Factor Analysis: Addition of Heat

Power: The power used by this system could be quite high, especially in larger applications. While the specific heat of vegetable oil is quite low, in larger volumes of biodiesel production, the energy required to heat the solution up to over 64.7°C may be quite high. For this situation however, the power would not be excessive

Cost: The low setup cost is the major advantage of this system. For small volume applications of say <1000 litres, the setup and running costs would be quite low. In larger applications however, heating costs may become a problem. Therefore insulation techniques may need to be employed to reduce the heat losses and associated costs.

Reliability: Depending on the heat source, this method should be quite reliable. The most common heat sources used in this application are through an electrical heating element. The alkaline environment generated throughout the transesterification process does not significantly harm the heating elements so there should be not problem there. Provided that the correct electrical system is fitted to supply the heating elements with electricity, the electrical system should also not cause any reliability issues. Overall, this system has already been proven in other applications to be very reliable so there should be no significant reliability issues within this design. [8] [9] [10] [13] [14]

Safety: The safety of this system may be compromised if the heating elements heat up to a temperature above the auto ignition temperature of the mixture. There may also be an ignition problem if the heating elements became exposed while methanol is being boiled out of the solution. Both of these problems can be rectified by ensuring the heating elements are always submerged in the solution and that a sufficient stirring action is provided within the system to eliminate any stagnation that may occur.

Functionality: This method of separating the methanol from the solution is, and has been proven to be quite effective. Provided that a sufficient condensing system is in place to capture the methanol vapour, heating a solution to remove alcohol is quite effective. An advantage of this system is that, the same heating elements used to heat the solution to increase the rate of reaction could be used to further heat the solution to remove the methanol from the system. So essentially he heating system would have multiple requirements.

Ergonomics: Nil

Aesthetics: Nil

Maintainability: As the heating system used to remove the alcohol from the system would be the same heating system that was used to increase the rate of reaction, it has already been determined that the heating system alone will not cause any significant reliability problems.

Manufacturability: As the heating elements would already be in place as they will be used to increase the rate of reaction, no additional heating elements will be required. However, some form of condenser would need to be incorporated in the system so that the methanol vapour were captured, condensed and reused.

3.4.3.4.6 Which method to use?

Both systems have very good qualities in terms of functionality, however, as always, the distinguishing factors which will dictate the solution that is used is based around cost. While it is possible to develop a superior methanol removal system using the pressure reduction technique, this system would be quite costly for it to be as reliable as the heating system. As there is a certain cost constraint placed on the construction materials used within the prototype ($2000), using the pressure reduction technique to remove methanol from the system is not economically feasible in this instance. All is not lost however, the second system which utilises to vaporise the methanol from the solution can be easily and cheaply incorporated into the reactor design. As the reactor already has its own heating system to increase the rate of reaction, this heating system can be put to further use by also being utilised to heat the solution further to vaporise the methanol. Therefore, no additional heating system is required and it can be concluded that heat will be used as the primary technique to remove methanol from the system.

2.4.3.4.7 Methanol Condensation

From the previous section it has been determined that heat will be used to vaporise the alcohol out of the solution. It was also determined that no additional heating system would need to be incorporated within the reactor as there is already a heating system available to increase the rate of reaction. What is required however is a system that catches and condenses the methanol vapour for reuse in the next batch.

So, what happens with the methanol once it starts to vaporise from the solution? The methanol will rise, and will continue to rise until it has either condensed on a surface, or dissipated in the atmosphere. Offcourse the latter of the possibilities should be avoided as valuable methanol will be lost.

So it can be stated that the first requirements of the design (provided that it does not operate on vacuum) is to incorporate a surface for the methanol vapour to condense on.

Simple, put a roof on the reactor and keep it sealed.

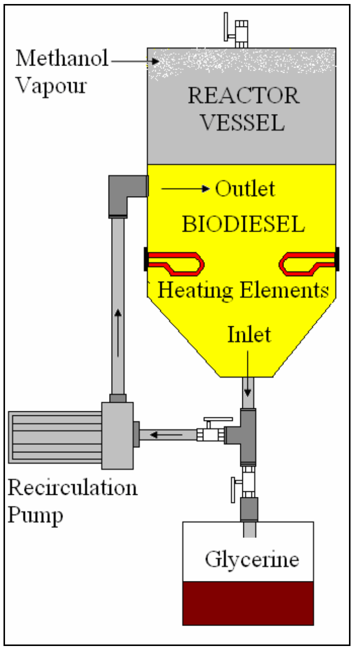


Figure 3.11: Reactor with heating elements vaporising methanol

But where will the methanol go? It will simply condense on the roof an fall back into the solution from which the methanol is being removed from. So some how, the system that condenses the methanol needs to channel off the methanol to some external reservoir.

If the lid of the reactor were tapered toward the centre like an upside down witches hat, the methanol vapour would condense on the roof of the reactor and fall to the centre of the tapered lid. If a tundish arrangement where then fitted underneath the lid, the condensed methanol could fall into the tundish and be channelled out of the reactor via a pipe which led to the outside. The methanol would then be in a condensed and ready to be reused for the next batch of biodiesel.

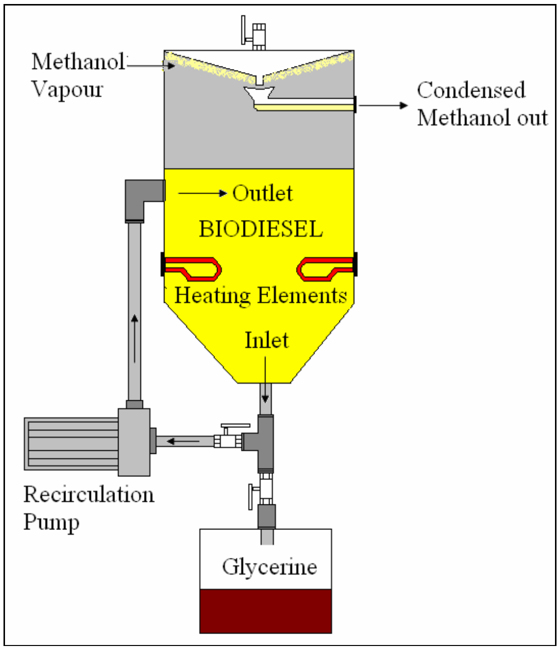


Figure 3.12: Reactor with heating elements and condenser

The above figure displays the reactor fitted with a condensing device to capture the methanol being evaporated out of the raw biodiesel. The way this technique works is that the raw biodiesel is heated to a temperature above the boiling point of the methanol whereby the methanol starts to boil. Once the methanol starts to boil, methanol vapour will rise out of the raw biodiesel toward the tapered roof of the reactor. The vapour will then condense on the roof and fall toward the small protrusion in the centre of the taper. The small protrusion will act as a region where the methanol can form small droplets which will fall and be captured by the tundish. The pipe mounted to the tundish will then channel the condensed methanol to the outside of the tank. It should be noted that for the methanol to proceed to the outside of the tank, the pipe channelling the condensed methanol out of the tank should have a slight fall. For example, where the pipe is attached to the tundish should be at a higher position than where the pipe is ducted to the outside. This will ensure that the methanol will be channelled toward the outside of the tank due to gravity, where the methanol can then be stored.

3.4.3.4.8 Critical Factor Analysis: Condenser

Power: The condenser itself will not use any power

Cost: The cost of the condenser will be very low as there are very few parts involved. It would require several hours to construct however, as a reasonable degree of accuracy will need to be achieved for this technique to be successful

Reliability: There should be no reliability issues associated with this design provided that the correct materials were used and that construction was completed properly.

Safety: The major safety concern with the condenser is related to what happens with the methanol after it has condensed. Provided that the methanol is channelled off to a safe containing vessel with no leaks along the way, there should be no safety issues with the condenser.

Functionality: Provided that this technique was set up correctly, this method of condensing methanol would work very well. Similar methods have been tested and proven in stills and other devices to make alcoholic beverages (This was found out after this design had been devised).

Ergonomics: All an operator would be required to do to recapture the methanol within this design, is turn on the heating element/s via a switch and possibly operate a ball valve. Provided that the switch and associated valves are located in a position that can be accessed, there will be no ergonomic concern with this design

Aesthetics: NA – The condenser is concealed within the reactor

Maintainability: This method would be relatively maintenance free. The only problem which may occur is that some soap scum may build up in the catchment area of the condenser however, this is highly unlikely. If this did occur it could be easily removed by compressed air, water or some other method.

Manufacturability: The condenser would require some skill to manufacture however, this should not be that difficult, but more time consuming. The parts required by the system would be easy to acquire and would be available locally. Overall, this condenser system should not be a problem to manufacture.

2.4.3.4.9 Conceptual Design Proposal: *Waste Recovery System*

The above condenser design is quite a feasible method of condensing the methanol which could be easily incorporated within the system. This method is a cheap, reliable and functional solution that would be easy to manufacture and would require only very little operator interaction when in use. It can be concluded that it is not necessary to analyse any other designs at this stage, as this technique already satisfies all the requirements of a feasible solution.

Therefore, the proposed methanol removal system will be based on heating and condensing techniques whereby, the conceptual design can be seen below.

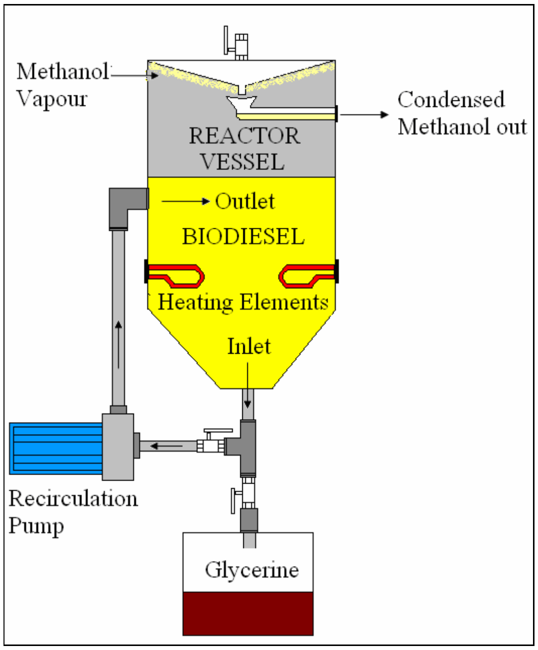


Figure 3.13: Reactor with glycerine removal system, heating elements and condenser

3.4.4 Purification

The purification process is one of the crucial processes that will determine the quality of the finished product. This process is commenced after the methanol has been removed from the raw biodiesel. So essentially, all that is remaining are some traces of glycerine, soap and acid and hopefully, if the transesterification process has completed properly, a very low free fatty acid level.

It is the purification process that is responsible for removing these contaminants, and it is therefore the ***functional requirement*** of the system to:

- Remove the impurities that remain in the raw biodiesel

Once the impurities have been removed the fuel is ready to go. However, it is not that simple to remove these impurities both cheaply and effectively.

The specific ***design requirement*** of the system is:

- The proposed system must not increase the cost of the biodiesel beyond the point at which it is not longer economically feasible (costs more produce than diesel does to buy)
- The proposed purification system must be capable of producing a fuel that can meet the ASTM and EN standards.

There are only a limited amount of techniques that can be used to purify biodiesel and unfortunately most of them are limited to large volume plants in order to maintain economic feasibility. The only purification techniques that remain feasible for low production units are:

1. Purification through Water
2. Purification through Absorbent Powder

3.4.4.1 Purification through Water

Purification through the use of water has been very popular for smaller producers of biodiesel as it is cheap and reasonably effective method of biodiesel purification, provided that it is done correctly. The way that the water purifies the biodiesel is through physically mixing water with the raw biodiesel. It sounds like quite a primitive method, and it is, but it works. Below is an illustration of how the system works

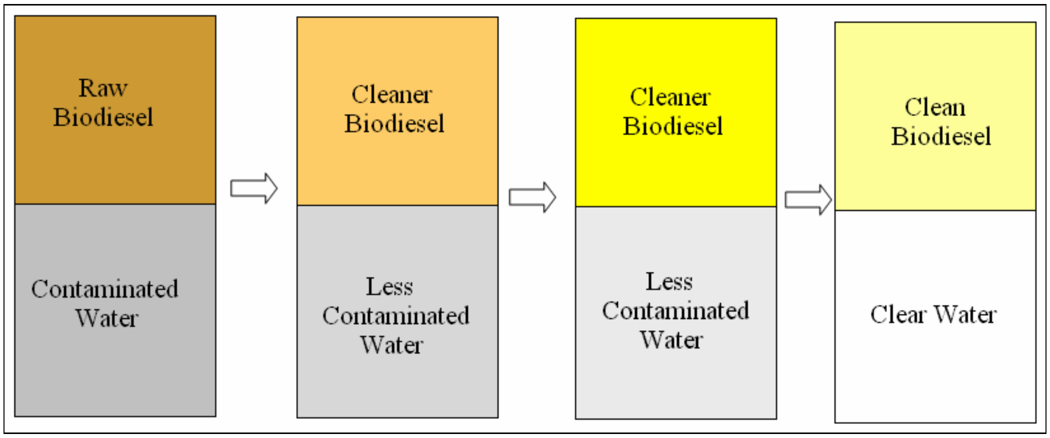


Figure 3.14: Typical Water Purification Process

The above figure displays a typal water purification process. The first step to the process is to add clean water up to a ratio of 1:1 to the raw biodiesel. The water is then gently mixed through the raw biodiesel and absorbs any water soluble impurities out of the raw biodiesel. As the water is being mixed through it will quickly turn a milky white colour indicating the presence of soap. The water and raw biodiesel is then allowed to settle and the water is removed as waste. The process is repeated several times until the water remains clear which will indicate the biodiesel is reasonably clean.

Now, anyone who has had anything to do with water coming into contact with oil will know that it is a bad idea. The first major downfall of this process is, if the water is mixed too excessively with the oil, it will create a mayonnaise like emulsion. If this happens it will takes quite some time to settle out, several days, maybe even weeks and this problem is characteristic of this process. Also, water can be quite a rare commodity in some places. To be wasting such a valuable resource (up to 4 times the amount of fuel produced by volume) on biodiesel, a fuel intended to be more environmentally friendly, does not make sense. On top of the large amount of water required, the waste water can be potentially damaging to the environment and can be difficult do dispose of.

There is a another major down fall, and that is caused by biodiesel's affinity to water. Although water is generally not soluble in biodiesel, biodiesel still has some affinity to water and a small amount will remain in the fuel unless it is removed. Obviously water within the fuel system of a vehicle is highly undesirable so any excess water needs to be removed if this process is used.

And the final major down fall, which is the most disappointing of all is that, when the fuel has been purified and the final wash water is clear and any remaining water in the biodiesel has been removed, the biodiesel will still not be safe to use. The water used to wash the biodiesel will only absorb the water soluble impurities out of the biodiesel. What remains are the oil soluble impurities such as any remaining free fatty acids, glycerine and vegetable gums. So even after the water purification process is complete the final product can still potentially harm the fuel system of the engine it is being used in.

So the question is now, why would anyone use water washing? The answer is simple, it is a cheap and relatively effective method of removing the water soluble impurities from raw biodiesel. The fuel can still be used offcourse, and in many cases the fuel will not cause a problem with the fuel system, however, in many cases it will.

Some vehicles like early model Mercedes can virtually run on sump oil and never have any problems.

This is due to their robust injection pumps which deliver relatively low pressure to an injector which has quite a large orifice. Therefore, the chances of the fuel clogging up the fuel system are minimal.

In modern fuel delivery systems however, diesel injector pumps are generally less robust, deliver higher pressure (increased stress) and also have much finer injector orifices. If a fuel that is less that satisfactory is used in such a system, there will most certainly be some problems. One of many problems caused by a poor quality biodiesel is fuel injector coking. It is not surprising that users of water purified biodiesel are those which experience this problem the most.

Summarising the advantages and disadvantages of using water to purify biodiesel we find:

Advantages:

- Very cheap, water is free (in most places)

Disadvantages:

- Uses excessive amounts of water (up to 4 times the amount of biodiesel produced)
- The waste water can be harmful to the environment
- Does not purify the biodiesel to a satisfactory level
- Takes a long time to complete (several days)
- Risk of mayonnaise like emulsion

And the list goes on. Without further investigation into the critical factors, it can already be determined that using water to purify the biodiesel will not be a feasible option.

3.4.4.2 Purification through Absorbent Powder

Another method of purifying biodiesel which is starting to become more commonly used, is through the use of an impurity absorbing powder. The powder that is used for this process is call Synthetic Magnesium Aluminium Silicate, or in simpler terms, a synthetic talcum powder. The way this method of purification works is by simply adding the powder to the raw biodiesel, mixing it through for approx 20 minutes, and filtering the powder out [23]. A system that could be incorporated into the reactor is illustrated below.

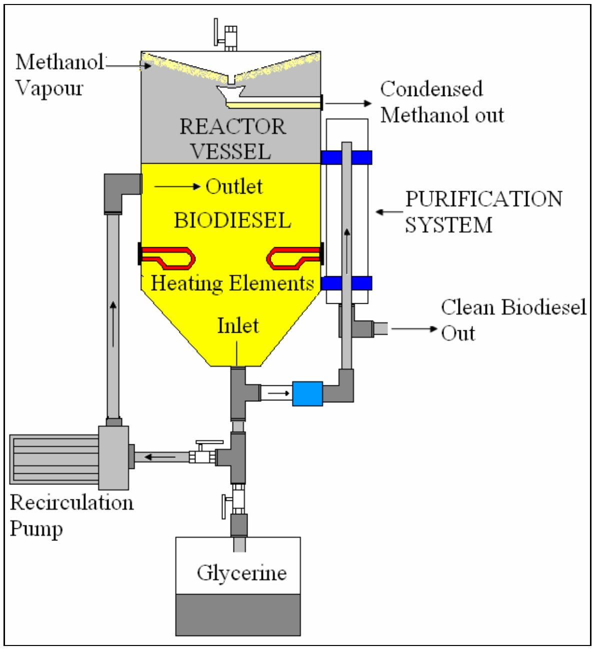


Figure 3.15: Reactor with glycerine removal system, heating elements, condenser and powder purification system.

The first step with this system is to firstly ensure all glycerine has been removed and the methanol has been evaporated off and condensed. Once these steps have been completed the absorbent powder can be added to the system through the 'Powder Inlet' where the recirculation pump will be turned on to mix the powder through. This would be done for several minutes to allow the powder to absorb all of the impurities from the biodiesel.

After several minutes have passed, the recirculation pump can then be turned off and the ‘small pump’ turned on to pump the biodiesel through the fine (5 micron or smaller) filter. The filter then removes the powder resulting in a very clear, low impurity biodiesel.

The ***advantages*** of purifying biodiesel with this powder are that:

- The powder absorbs both water soluble and oil soluble impurities resulting in a very high quality biodiesel [23]
- The FFA, glycerine, soap and vegetable gum content is dramatically decreased to barely recognisable levels [23]
- The process can be completed in as little as 20 minutes
- The waste powder is not harmful to the environment and is safe to use. It has also been shown to have some nutritional value [20]
- The biodiesel produced easily satisfies the ASTM and EN standards on biodiesel [3][23].

The ***disadvantages*** of purifying biodiesel with this powder are that:

- The powder is expensive, around \$12 - \$14/kg and requires approximately 1-2% powder by weight of biodiesel
- Can add up to an extra 23c/litre to production costs
- Is less effective when alcohol is present (all alcohol needs to be removed)
- Powder can cause engine damage if it is not sufficiently filtered out

While this method does have the inherent disadvantages of increasing production costs and the slight chance of engine damage, neither disadvantage is so severe that it renders this method unacceptable.

While production costs would increase using this method, biodiesel can still be manufactured at a much lower cost than what it is at the pump. Total production costs range between 0.70 – 90c/litre (estimate) depending on the amount of powder used, which is quite acceptable. The possibility of engine damage due to powder remaining in the biodiesel can be easily rectified by incorporating a fine and reliable filtration system that incurs regular maintenance.

3.4.4.3 Critical Factor Analysis: *Purification via Absorbent Powder*

Power: The power consumed in this process is through the recirculation pump and the small pump. Neither pump will consume an excessive amount of electricity

Cost: The additional cost incurred by purifying biodiesel with this method is the major downfall. At \$12-\$14 per kg this can increase biodiesel production costs by 12-23c/litre. While this may seem like a lot, the biodiesel will generally remain cheaper to produce than diesel. Obviously these costs could also be reduced if the fuel was being produced in larger volumes as both the methanol and the absorbent powder will be cheaper in bulk.

Reliability: Provided that a reliable filter and housing is used to remove the powder from the fuel, there should be no problems there. While it is unlikely, there may be a problem with the absorbent powder increasing the rate of wear on the recirculation pump. The absorbent powder is quite fine and abrasive so care should be taken to select a durable recirculation pump. Also, a reliable measuring device needs to be obtained so that the correct amount of absorbent powder can be added to the system with a reasonable level of consistency and accuracy.

Safety: This method of purification is very safe as all that is required is to simply add some powder to the system, mix it with the recirculation pump, and filter the powder. The only operator interaction in this instance would be measuring the powder and adding it into the tank.

While the absorbent powder relatively harmless, the operator still needs to take care not to inhale excessive amounts of the powder while it is being measured. Also care should be taken not to expose the vapours within the tank to an ignition source when the powder is added to the tank. Other than these minor points, this system is safe and should not cause any problems.

Functionality: This method is very good at removing the impurities from raw biodiesel and results have shown that if the process has been completed correctly, the quality of biodiesel produced meets and exceeds the ASTM and EN standards [3][23]. This technique is also very easy and quick to perform, especially compared to that of water purification. While water purification may be cheap, it takes time to produce. As time is money, it is debatable as to whether water purification is cheaper than absorbent powder purification at all. Overall, this technique is a very functional and user friendly method to purify biodiesel.

Ergonomics: All an operator would be required to do to purify the biodiesel with this method is open and close a few ball valves and operate a switch for the small pump that pumps the biodiesel through the filtration system. Provided that the switch and associated valves are located in a position that can be accessed, there will be no ergonomic concern here. Accessing and maintaining the filtration system should not be a problem provided that it is located in an easy to reach position.

Aesthetics: This system requires the addition of a ball valve or opening in the top, a small pump and a filtration system. Ideally the ball valve or tank opening would need to be easy to access so this may need to be exposed. The small pump can be concealed as it will not require regular access. Finally, the filtration system could either be exposed or concealed. It should be noted however, the filter cartridge may need to be changed quite frequently so it will need to be located in a position where this process can be completed easily.

Maintainability: The majority of the maintenance with this system will be with the filtration system. Depending on the volume of biodiesel that is being produced, the filter cartridge will need to be replaced accordingly. There should not be any other maintenance issues.

Manufacturability: This system would be very easy to manufacture as there are only a few components required to install this system. The majority of the work involved would be with the plumbing, which would not be difficult. Overall, this system would be quite easy to incorporate.

3.4.4.4 Which method to use?

It is not difficult to see that biodiesel purification through the addition of absorbent powder is certainly the best method to use when compared to that of water purification. This method has been proven by many successful biodiesel manufactures and is currently used in both low and high production plants with a high success rate.

3.4.4.5 Conceptual Design Proposal: *Purification*

Concluding the investigation of purification techniques, it can be determined that the used of absorbent powder as the method of biodiesel purification is the best overall technique to used in this situation. The conceptual design is illustrated below.

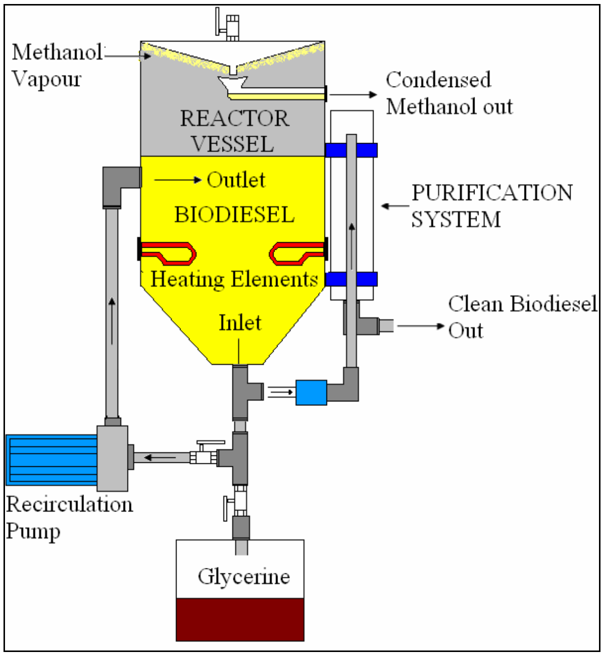


Figure 3.16: Reactor with additional powder purification system.

3.5 2-D Conceptual Plant Design

From the above design analysis, conceptual design proposals were developed which addressed each of the critical physical processes required to make biodiesel. Each of these design proposals were then combined and a two dimensional conceptual plant design has been developed which can be seen below.

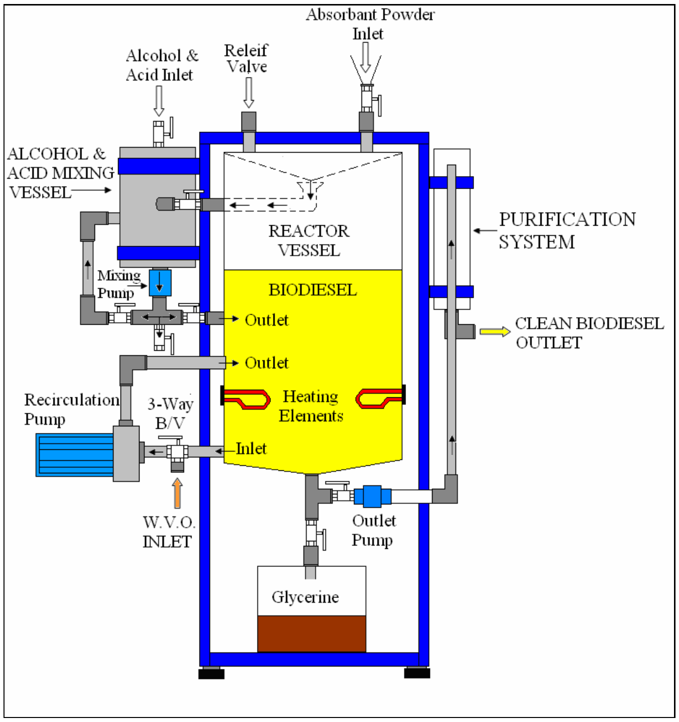


Figure 3.17: 2-D Conceptual Biodiesel Plant Design

A detailed process list has was then developed and the specific tasks required for each step involved toward making biodiesel will be analysed in fine detail. The reason this process list has been developed before any further design was developed is so that any further process requirements, problems and corresponding safety issues will be addressed and rectified prior to the biodiesel plant being further modelled and constructed.

2.6 Biodiesel Process List

NOTE: *Before any materials are used, the MSDS forms in Appendix 2 must be read and understood:*

The process required to make biodiesel consists of six steps. These are:

Step 1: *Add waste cooking oil into the reactor vessel via the waste cooking oil inlet and begin heating the oil.*

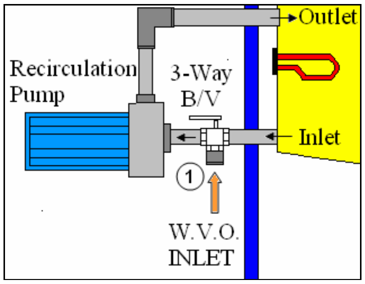


Figure 3.18: Step 1 Diagram

Process Requirements: *Step 1*

To add the waste vegetable oil into the system, the 3-way ball valve must be shifted to the secondary position. The primary position will allow the pump to draw from the inlet of the tank and pump it back into the reactor vessel creating a recirculation system. The secondary position of the 3-way ball valve will allow the pump to draw from an external source whereby the waste cooking oil can be introduced. This can be done by simply attaching a hose to the inlet of the 3-way ball valve and connecting it to a reservoir holding waste cooking oil. Provided that the outlet of the reservoir is initially higher than the inlet of the 3-way ball valve, the pump should prime itself and transfer the oil into the reactor vessel.

Once the oil has been added into the system **equal to or higher than** the minimum fill level, the 3-way ball valve can then be shifted to the primary position whereby the oil will begin to circulate within the system creating a stirring motion.

The heating elements can then be turned on until the oil reaches a temperature no higher than 54°C which will need to be monitored by an external temperature sensor.

Problems and Safety issues: *Step 1*

Care must be taken not to overload the pump. If the pump is overloaded there is a very real possibility that failure may occur (especially if the pump is electrical) which would then need replacing. Depending on the viscosity of the oil, preliminary heating may be required to avoid overloading the pump with oil that is too thick. This may be done through an electrical heating band being placed around the storage container of the waste vegetable oil, by some form of hot plate, or simply by putting out in the hot sun. Under no circumstances should a naked flame be used in the vicinity of the biodiesel plant. The associated valves and fittings and also reactor vessel will need to be checked to ensure there are no leaks. If there are leaks, the system must be turned off and the leak repaired properly.

Step 2: *Perform Titration on the Oil (see Titration) and determine the amount of acid required for the reaction. Add the acid and 22% methanol by volume of oil into the Alcohol and Acid Mixing vessel. Mix the acid and alcohol solution until the acid has dissolved into the alcohol and then pump the solution into the reactor vessel.*

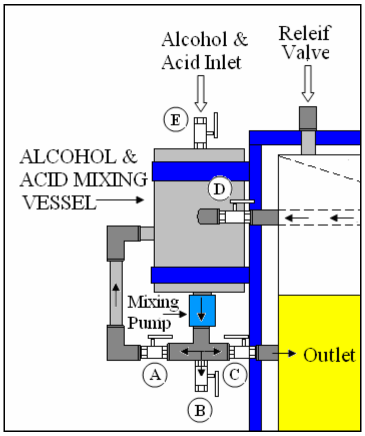


Figure 3.19: Step 2 Diagram

Warning:

Prior to commencing step 2, all power to the biodiesel unit must be shut off and any ignition sources must be removed. There should never be any ignition sources in the presence of alcohol or the biodiesel plant at any time.

Process Requirements: *Step 2*

The second step is to add the acid and alcohol into the reactor vessel. But before this can be done, the oil must firstly be titrated (see Titration) By titrating the oil, the amount of acid is determined that is required to convert the specific batch of oil into biodiesel. Once the amount of acid has been determined, the alcohol needs to be measured out manually whereby 20-22% methanol by volume of oil is used. For example, if 40 litres of oil were used, then (0.2*40 = 8) 8 litres of methanol will be required making a total solution of 48 litres.

Now that the specific amounts of acid and alcohol are measured out they need to be mixed together, this process is performed by the Alcohol and Acid mixing vessel.

Firstly, ensure ball valve ‘B’ and ‘C’ are closed. Secondly, ensure the remaining ball valves are adjusted to a position which forms a recirculation system within the methanol and alcohol mixing vessel.

The ball valves located on the top of the mixing vessel can now be opened and the alcohol and acid can be added to the system. Once the materials have been added, close the ball valve and seal the system. The operator will then turn on the switch for the mixing pump, however the main power must not be supplied to the unit until the operator is behind a fire safe enclosure. Once the operator reaches this enclosure, the main power can then be supplied to the unit where the mixing pump will then turn on where by the acid and alcohol will be recirculated within the mixing vessel until all the acid has dissolved in the alcohol.

While the acid is dissolving in the alcohol, monitor the temperature of the oil in the reactor vessel behind the enclosure and ensure it does not exceed 54°C. Once the acid has dissolved in the alcohol and the oil within the reactor vessel is between 48-54°C and the **heating elements have now been turned off for safety reasons**, the acid and alcohol solution can then be added into the reactor vessel. To do this, firstly shut the main power off to the biodiesel plant. Then close off ball valve ‘A’ and open ball valve ‘C’ which will change the pumping path from a recirculation system, to a pump out system where the alcohol and acid solution are pumped out and into the reactor vessel. Leave the switches located on the tank in the same position and return to the fire safe enclosure. Turn on the main power to the biodiesel plant and the alcohol and acid will now be pumped into the reactor vessel. Once the alcohol and acid solution have been completely pumped into the reactor vessel, shut the main power off, turn the mixing pump off then close off ball valve ‘C’ and return to the fire proof enclosure.

Note

While the alcohol and acid solution are being pumped into the reactor vessel, ensure that the main recirculation pump is still turned on. This is done for two reasons. The first is to reduce the concentration of flammable substances within the system by diluting the acid and alcohol as quickly as possible with the vegetable oil. The second reason is to achieve a homogenous solution of oil, acid and alcohol so that the reaction will occur consistently and completely.

Problems and Safety issues: *Step 2*

This step is potentially the most dangerous step in the process of manufacturing biodiesel. It requires the handling of both a highly corrosive acid and poisonous alcohol. Provided that the materials are handled correctly, the risks are minimised.

Analysing the worst case scenario, the methanol system could explode if it were ignited some how. While this is an unlikely event, it could happen. It is therefore highly recommended that any electrical equipment is turned off before the acid and alcohol are handled. Once the acid and alcohol have been added to the system, the mixing pump and associated fittings need to be observed for any leakages. Special attention should be payed to the mixing pump especially if it is electric as this could be an ignition source. If any leaks are found the biodiesel plant must be completely shut down, the acid and alcohol removed and neutralised and the leak must be properly repaired.

Step 3: *Mix the oil, acid and alcohol solution*

Process Requirements: ***Step 3***

After the second step, the operator will be behind the fire proof enclosure with the main power turned off and the entire contents of the alcohol and acid solution should be in the reactor. The main power to the biodiesel plant can then be turned on where the recirculation pump will be the only equipment in operation.

The recirculation pump should be left on for approximately 1 hour. The time required to complete the reaction will be dependent on the quality of the waste cooking oil being used, where more contaminated oils with a FFA level will require the full hour to fully process.

While the solution is being mixed within the vessel the temperature of the solution should be monitored and maintained within 48-54°C. If the heating element needs to be turned on, the main power to the biodiesel needs to be switched off and the heating element switch needs to be turned on. The operator must then return to the fireproof enclosure and can then turn on the main power to the biodiesel unit where the solution will begin to heat up. Once the temperature of the solution reaches a maximum of 54°C the heating elements will then need to be turned off by following the same previous process.

Finally, once an hour has passed turn off the main power to the biodiesel plant and then turn off the switch for the recirculation pump. Return to the fire proof enclosure

Problems and Safety issues: *Step 3*

Under no circumstances should the temperature of the solution exceed 54°C as this may cause the methanol to evaporate and the transesterification reaction will be compromised. If this occurs, the product of the incomplete reaction will be a contaminated biodiesel with a high level of FFA’s where only a small amount of glycerine will settle out after the reaction as most of it will still be within the contaminated biodiesel.

Step 4: *Allow the solution to settle and remove the glycerine*

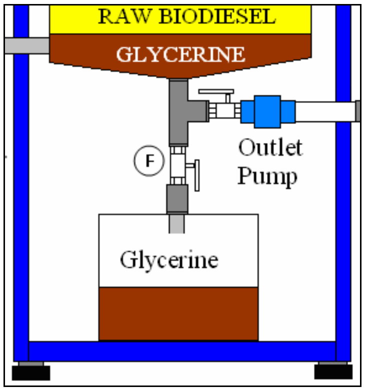


Figure 3.20: Step 4 Diagram

Process Requirements: *Step 4*

At this stage the solution within the reactor vessel should have been mixed for one hour and the transesterification process should be complete. The operator should be behind the fire proof enclosure and the main power to the biodiesel plant should be turned off.

The solution within the reactor should now be biodiesel and glycerine however some time will be required for the two phases to separate. Allow the solution to cool to 35°C. Do not let it cool to a temperature much lower than this otherwise the glycerine will solidify and will be difficult to remove.

Once the solution has cooled to 35°C, the glycerine will be ready to remove. Ball valve 'F' is then opened and the glycerine is captured in a storage container. The operator must continue to monitor the colour of the solution that is coming out of the ball valve where once clean biodiesel can be seen, the ball valve is then turned off. It is better to remove all traces of glycerine and lose some biodiesel than it is to leave some glycerine in the system. Any biodiesel that is lost with the glycerine can be recaptured for the next batch once the glycerine has solidified.

Once all the glycerine has been removed ensure all the ball valves within the system are in the closed position accept ball valve 'D' (see Figure 3.19).

Then seal and remove the glycerine storage container to a well ventilated area. The switch for the heating elements can then be turned on and the operator can then return to the fireproof enclosure.

Note

Care must be taken not to remove so much biodiesel from the system that the heating elements become exposed (below the fill level) as this could create an ignition source. If the biodiesel does fall below the fill level, top up the biodiesel reactor with clean biodiesel (definitely not diesel) from the previous batch until the heating elements are again fully submerged.

Problems and Safety issues: *Step 4*

The glycerine that has been removed from the biodiesel will be quite flammable as it will contain a relatively large concentration of methanol. Therefore, care must be taken not to expose the glycerine to any ignition source. Unfortunately the methanol can not be recaptured at the same time as the methanol within the biodiesel as it may reverse the transesterification reaction if this is attempted.
No device will be incorporated to remove the methanol from the glycerine as there is not a large amount that can be recaptured.

The glycerine must then be stored in a sealed container away from any naked flames where it can then be further processed or disposed of appropriately. The local refuse tip will be able to give advice as to where it can be disposed of.

Step 5: *Remove the excess methanol from the biodiesel and store*

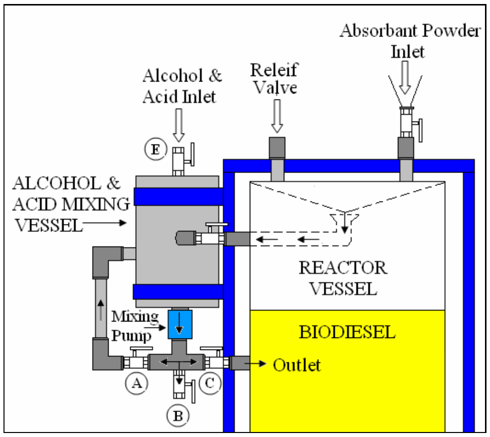


Figure 3.21: Step 4 Diagram

Process Requirements: *Step 5*

The raw biodiesel now needs to be heated to a temperature above the boiling temperature of the methanol. By doing this, the methanol will evaporate out of the biodiesel, condense on the roof and be captured in the centre where the condensed methanol will then pass back into the alcohol and acid mixing vessel.

At the end of the last step the operator should have removed all glycerine from the system, all ball valves should be in the closed position accept for ball valve 'D' (do not touch the 3-way ball valve) and the switch for the heating elements should be turned on The operator should be now be in the fireproof enclosure.

The power can now be turned on and the raw biodiesel will begin to heat. The operator needs to monitor the temperature of the raw biodiesel and turn the off the main power once a temperature of 90-100°C has been reached. The raw biodiesel should be maintained at this temperature until all excess methanol has been removed. To do this, maintain the raw biodiesel within the temperature range indicated above for 20 minutes and then turn off the main power. Open ball valve 'B' and capture the condensed methanol in a glass or HDPE container (do not use a normal plastic container as the methanol will dissolve it, if unsure use glass).

Ball valve ‘B’ can then be adjusted to the closed position and the process can be repeated until methanol stops coming out. This would indicate that is no or very little methanol left in the system.

Finally, once there is no methanol left in the system shut the main power off, remove any reclaimed methanol containers and store in a safe location.

Problems and Safety issues: *Step 5*

The main problems that can occur here is if a heating element became exposed by removing too much biodiesel with the glycerine in the glycerine removal step. This problem has been address in the problems and safety issues area of step 3.

The other problem associated with this step is that methanol will need to be physically handled. Provided that the correct materials handling process are adopted the risks will be minimised.

Step 6: *Add the absorbent filter powder and filter the biodiesel*

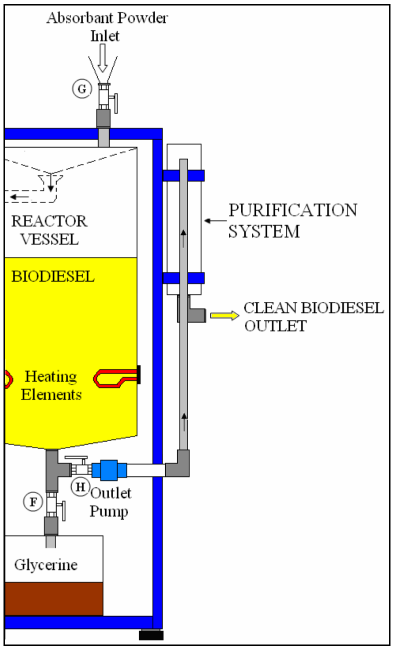


Figure 3.22: Step 4 Diagram

Process Requirements: *Step 6 – Final Step*

Prior to step 6 the operator should have removed any excess methanol, leaving raw, uncleaned biodiesel. This biodiesel now needs to be purified. To do this, the operator needs to add 2% absorbent filter powder by weight of biodiesel (density biodiesel = 0.87kg/litre). 100 Litres of biodiesel in the system will amount to a total of 87kg which would require 1.74kg of absorbent filter powder.

Once the required amount of powder has been measured out, carefully open ball valve ‘G’ (be weary of any pressure build up) and pour the powder into the reactor vessel. Once the powder has been added close off ball valve ‘G’, turn on the switch for the recirculation pump and proceed to the fireproof enclosure. The main power can then be turned back on where the recirculation pump will mix the powder through the system. After 20 minutes the powder will have absorbed all of the impurities that it can where the powder now needs to be removed. Turn off the main power to the biodiesel plant and then turn off the switch for the recirculation pump.

Allow several minutes for the biodiesel to settle and remove any settled out powder and contaminants by opening ball valve ‘F’ into a storage container. The ball valve will only need to be opened very briefly as the biodiesel will have quite a low viscosity and will flow very quickly.
(Any biodiesel lost can be added to the next batch with the waste vegetable oil)
Ball valve ‘H’ can now be opened and the switch that operates the outlet pump turned on.
The outlet of the filtration system will need to be directed to a storage reservoir where the operator can then proceed to the fireproof enclosure and turn the main power on. The outlet pump will then pump the biodiesel through the filtration system and remove the absorbent powder. Clean and pure biodiesel will then exit through the outlet of the filtration system and into the storage vessel.

The biodiesel should now be visually checked for clarity and particulate matter. A small amount of biodiesel should also be gently mixed with an equal amount of clean water to check for any soap content. If the biodiesel and water separate quickly and the water remains clear and free of any particulate matter, the biodiesel is ready for use.

The process of manufacturing biodiesel is now complete. The biodiesel plant should now be inspected for any maintenance that may be required and completed as necessary.

Problems and Safety issues: *Step 6*

A problem which can occur within this step is that the filter may not remove all of the absorbent powder with only one pass. If this happens the biodiesel can be pumped back into the system and recirculated through the filter for as many times as it takes to achieve absolute clarity. If the filter does not completely remove all the particulate matter, a finer filter may be required.

Provided that the biodiesel is stored in a cool safe place away from children and appropriately marked, there are no major safety issues associated with the storage of the biodiesel fuel.

3.7 3-D Prototype Design

The three dimensional prototype design has been developed from the concept of the two dimensional model, and further refined by analysing the specific system processes listed in the previous section and addressing any design problems which may occur during the course of manufacturing biodiesel. The following illustrations are a comparison of the two and three dimensional designs. The 3-D model in the first illustration has a transparent outer skin so the inner components can be visualised. The 3-D model in the second illustration has a coloured outer skin which is indicative of the finished product. The three dimensional models illustrated indicate the general shape and form of the prototype machine that will be developed to manufacture biodiesel from waste cooking oil.

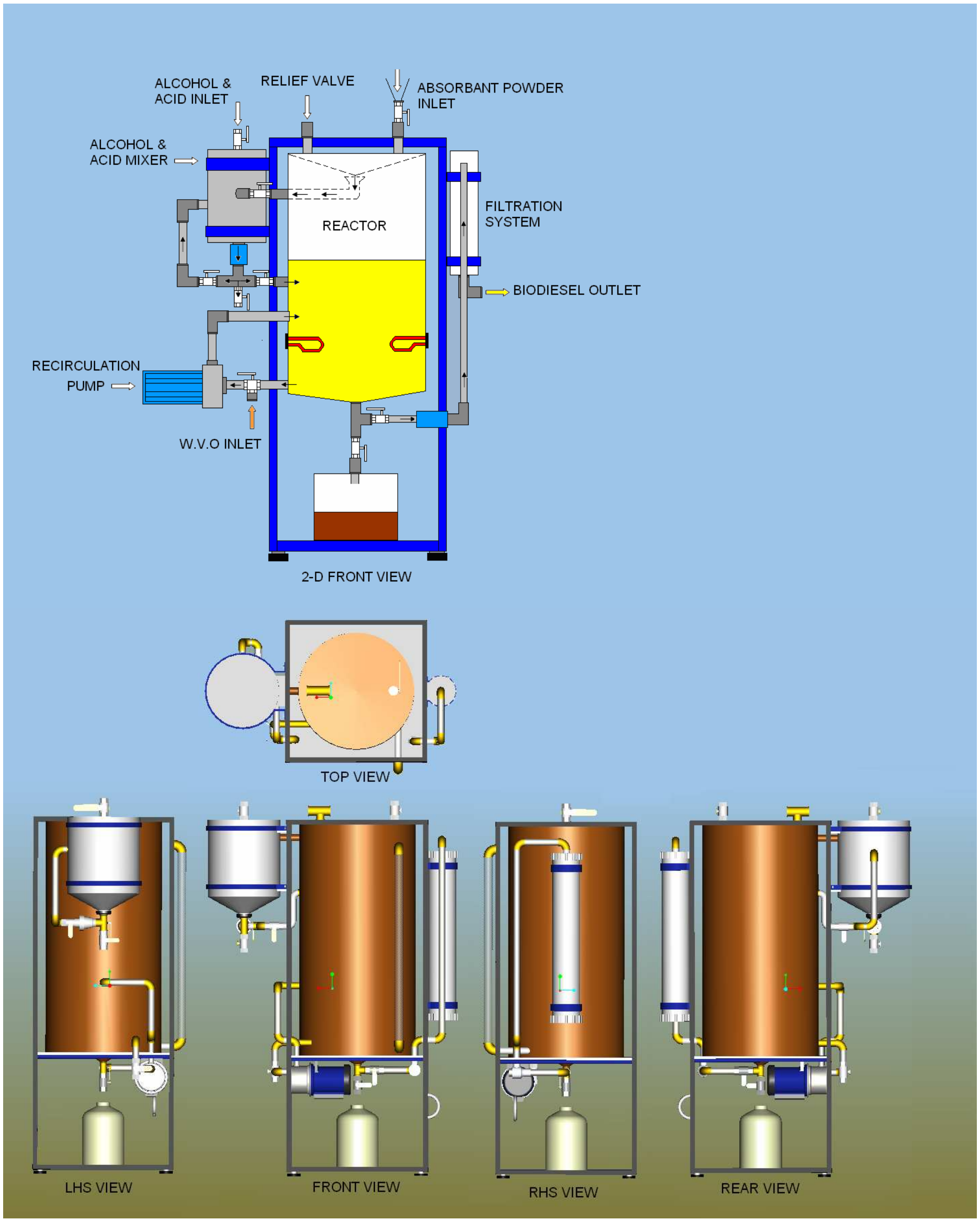


Figure 3.23(a): 3-D model with transparent outer skin

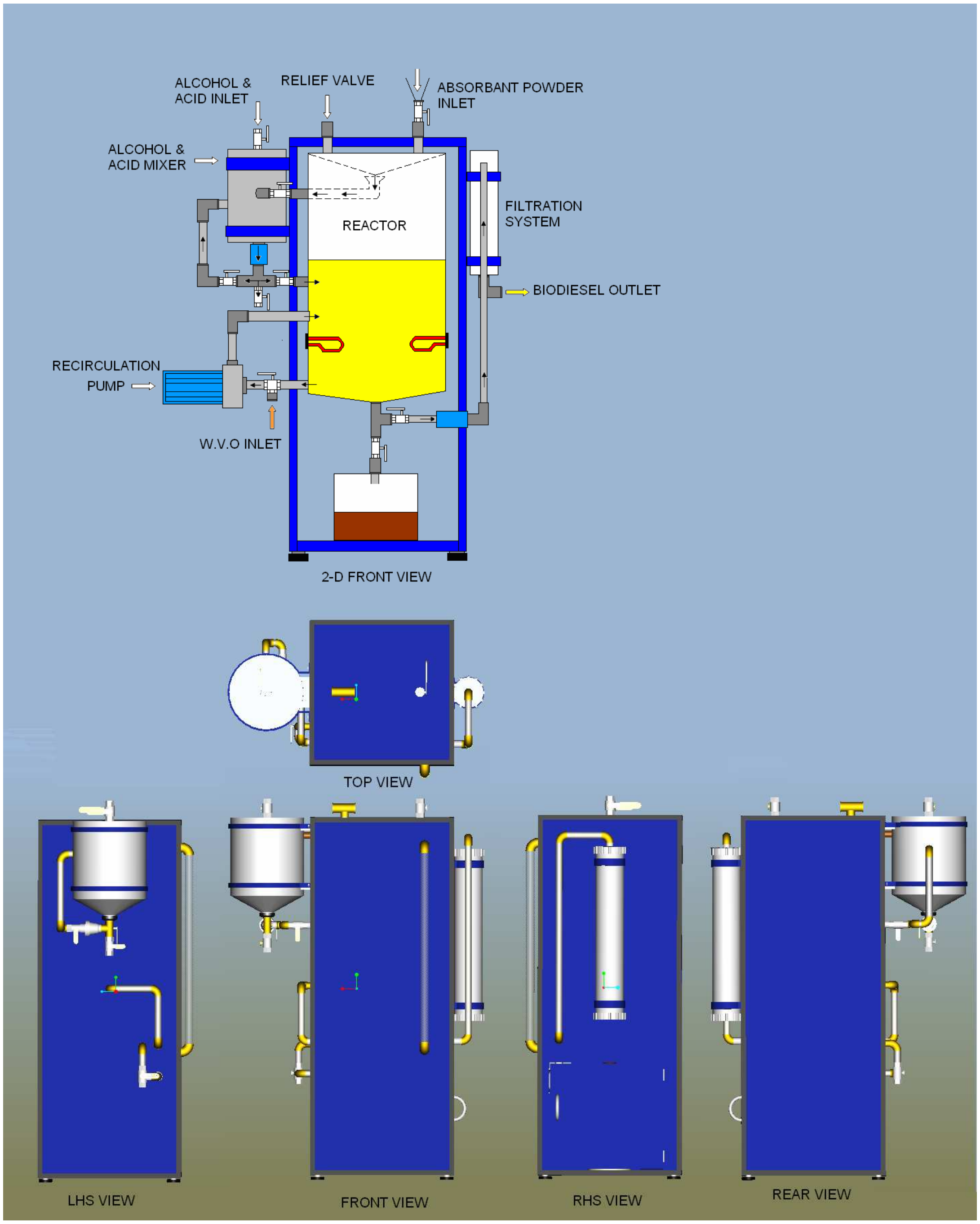


Figure 3.24(b): 3-D model with outer skin

3.8 Materials Selection

Titration: *Electronic P.H. Meter*

There are several methods of determining the PH of a solution, however from experience, the easiest and most consistently accurate method is through using an electronic PH meter. Therefore, an electronic PH meter will be used for the titration. The other materials used throughout the titration process are conventional and do not require any selection process

Alcohol and Catalyst mixer

Mixing Vessel: *High Density Polyethylene (HDPE)*

The materials used for the mixing vessel must be resistant to both methanol and sodium hydroxide. Common materials which are successfully used in these environments are stainless steel and high density polyethylene (HDPE) [17]. As stainless steel is very expensive and is also quite heavy, HDPE will be used as the material for the mixing vessel. HDPE or plain PE vessels can be easily obtained from local tank making suppliers at a low cost.

Mixing Pump: *Low volume, chemical Resistant - Electric*

There are several pumps which can be purchased to perform this task and the prices range from about $87 to $1000+. The ideal pump would be pneumatically operated and have a chemical resistant pump and housing, however, due to cost restrictions an electrically operated chemical resistant pump will be used. While this is not as safe, it will successfully perform the task with only a minimal risk. This risk can be alleviated by introducing further safety precautions into the steps involved in manufacturing biodiesel.

Reactor Vessel: *Copper hot water system tank*

Common materials that can be successfully used for the reactor vessel are stainless and copper [17]. HDPE can not be used as heat will be added to the system in this instance (up to 100°C) which may melt or soften the HDPE. As stainless is very expensive and quite heavy, copper will be used as the material for the reactor vessel and it can be sourced quite easily and at a low cost. The copper can be obtained from broken hot water systems (Saxon & Regal) at a very low cost. Usually it is the internal components of the hot water system that fail before any damage is caused to the tank, and therefore the internal components can be removed and the tank including heating element can be used. Copper is also a very easy material to work with and can be easily joined and fabricated.

Recirculation pump: *Stainless Steel High volume Water Pump INOX80*

The main characteristics a good recirculation pump will require is that it must be safe to use, the housing must be made of a chemical resistant material (plastic or stainless steel not cast iron) and must have a sufficient amount of power to pump WVO.

The pump selected is a high volume water pump with stainless steel housing and plastic impellor system. While there are more suitable pumps that could be used, this pump was acquired at a good price and was guaranteed to perform the task successfully. Being a water pump the impellor speeds will be quite high and therefore, mix the WVO solution quite vigorously. The stainless steel housing and plastic impellor system renders the pump both chemical resistant and durable and the high wattage electric engine will provide enough power to perform the task adequately.

Purification

Filtration: *Course sediment filter + 5μ water filter*

The particle size of the filtration powder is between 20 – 60 microns. A course sediment filter and a 5μ filter has been selected to firstly remove the larger particles through the course sediment filter, and then remove any smaller particles that remain with the 5μ water filter. Water filters have been selected as they are cheap, they can be easily sourced and replaced.

Outlet Pump: *Low volume, chemical Resistant – Electric*

The outlet pump will be the same as the pump used in the alcohol and acid mixing vessel.

Pipe and Fittings

The pipe and fittings used will be a combination of Brass, copper and stainless steel as these materials offer a high level of chemical resistance and have been implemented successfully in other biodiesel plant applications. Pipe and fittings made from these materials can be easily acquired through a local plumbing store and are standard stock items (e.g. Ball valves, compressions fittings etc).

3.9 Cutting List

Based on the materials chosen in the previous section, the following table is a simplified list of the components that were purchased for the construction of the biodiesel plant. The additional materials such as methanol, sodium hydroxide and absorbent powder have been included in a separate table as they are the materials that are required to make the biodiesel itself and not the plant. For a complete list of the materials that were purchased (see appendix 3)

Product Description		PRICE INC GST
Titration Materials		$82.10
Alcohol & Acid Mixing Vessel + Mixing Pump		$164.27
Reactor Vessel + Recirculation Pump		$395.43
Purification System + Outlet Pump		$88.40
Construction Materials		$234.19
Plumbing Fittings		$828.92
Electrical Fittings		$74.80
	TOTAL	**$ 1,868.11**

Table 3.1: Materials required for biodiesel plant construction

Materials required for Biodiesel Production		PRICE INC GST
Methanol - 20Ltr		$52.00
Sodium Hydroxide - 1Kg		$17.20
Magnesol - 18Kg		$247.61
	TOTAL	**$ 316.81**

Table 3.2: Materials required for biodiesel production

From table 3.1 the biodiesel plant can be manufactured for under $2000 which is the maximum value that was assigned to the construction of this project. Table 3.2 indicates the materials that need to be added into the biodiesel plant to make the biodiesel, so therefore their costing is independent of the construction cost as it is dependent of the amount of fuel that will be made. A further economical analysis will be performed in chapter 5

3.10 Construction

The steps that were performed during the construction of the biodiesel plant were to:

1. Gather Construction Materials
2. Construct Frame
3. Construct and Locate Reactor Vessel
4. Install Recirculation System
5. Install Alcohol and Acid Mixing system
6. Construct and Locate Filtration System
7. Wiring
8. Painting and finishing Touches

Step 1: *Gather Construction Materials*

Obviously the first step to any construction is to firstly gather the required construction materials. Fortunately all construction materials were able to be sourced from local suppliers.

Step 2: *Construct Frame*

The first step in the list of manufacturing process was to construct the frame which supported the entire system. The material that was purchased to construct the frame was ¾ box section which came in 6 meter lengths. Obviously the material must firstly be cut to length and then welded together

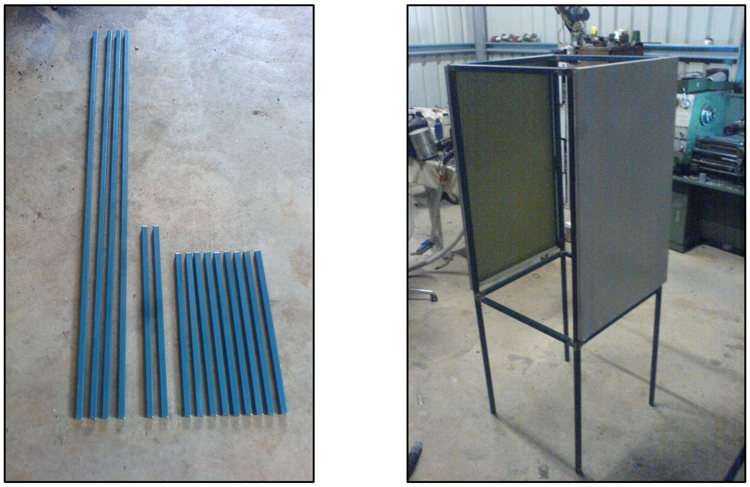


Figure 3.25: Cut lengths of ¾ Box section welded together to make frame (outer skin has already been added)

Step 3: *Construct and Locate Reactor Vessel*

The reactor vessel was made from a copper hot water system tank. The figure below shows two tanks which have just been removed from the housing of the hot water system

Figure 3.26: Copper hot water system tanks

Although only one tank was needed for the reactor vessel, a secondary tank was acquired just in case more copper plate was required. One tank was then selected and the outlets located on top of the tank were removed. The associated inlets and outlets required by the reactor vessel were then added by silver soldering the appropriate brass and copper fittings in the required locations (see below)

Figure 3.27: Copper tank with added inlets and outlets.

Once the associated inlets and outlets had been attached to the copper tank, the condenser system was then constructed.

Figure 3.28: Condenser System (Note the tapered in lid)

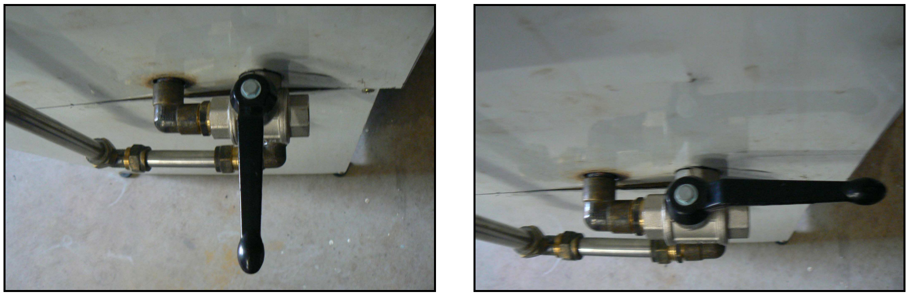
Now that the condenser and associated inlets and outlets had been added the system can now be officially called the reactor vessel. With the reactor vessel constructed, the next step was to locate and position both the reactor vessel and the recirculation pump. (See below)

Figure 3.29: Reactor Vessel and Recirculation pump fixed and located.

Step 4 & 5: *Install Recirculation System + Alcohol & Acid Mixing System*

With the reactor vessel and recirculation pump now located, the remaining outer skins can now be fitted. The Recirculation System and the Alcohol and Acid Mixing System can were then fitted. (See below)

Figure 3.30: Recirculation System + Alcohol and Acid Mixing System



Recirculate (mix)

Pump Oil in (Oil Inlet)

Figure 3.31: 3-Way Ball Valve positions

Step 6: *Construct and locate the Filtration System*

The left hand figure below figure the pressure relief/vacuum inlet valve (left hand fitting) and also the absorbent powder inlet (right hand ball valve) which are located on top of the reactor vessel on the lid of the condenser. The second image on the right is a closer view of the pressure relief/vacuum inlet valve with an additional outlet for the sight tube.

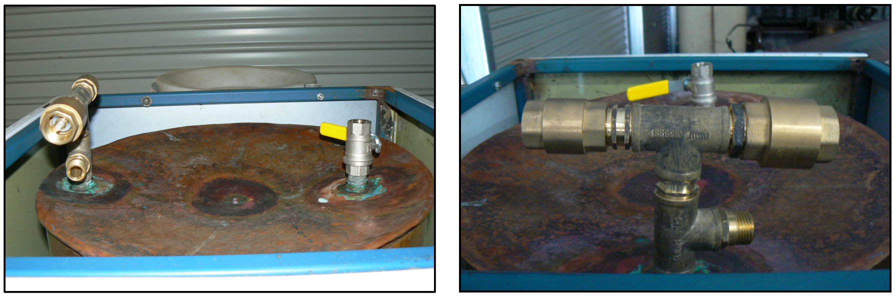


Figure 3.32: Relief valve (LHS) and inlet for absorbent powder (RHS)

The components of the filtration system can be seen below where the filter element is a 5 micron particle filter and the housing has been constructed from 100mm PVC (an additional filtration system has since been added). The housing was then located on the RHS of the overall unit where a door and the remaining outer skins were then fitted. (See below)

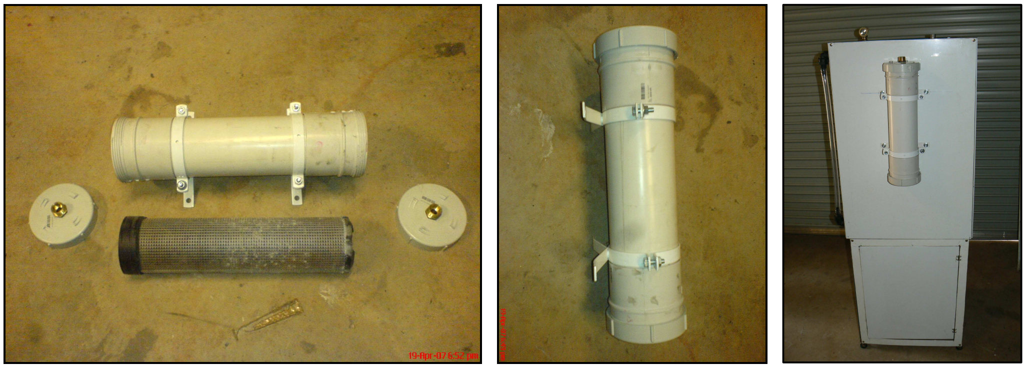


Figure 3.33: Filtration System (less piping)

Step 7: *Wiring*

Once all of the mechanical and electrical systems were installed, the system was then wired up and inspected by a qualified electrician. Once the wiring had been completed, each system was tested and checked to ensure everything was working properly. No photographs were taken during this step.

Step 8: *Painting and Finishing Touches*

Now that the system is completely functional and in working order, it is time to apply any finishing touches to add to the aesthetic appeal of the system. The pictures below display the biodiesel plant at about 95% completion.

Since the following photographs were taken the following items have been added:

- Temperature monitoring system
- Additional heating element (2 x 1.8kW in total)
- A floor at the base of the frame
- Labelling
- An Additional filtration unit
- A few slight plumbing changes

Overall however, the system remains virtually identical.

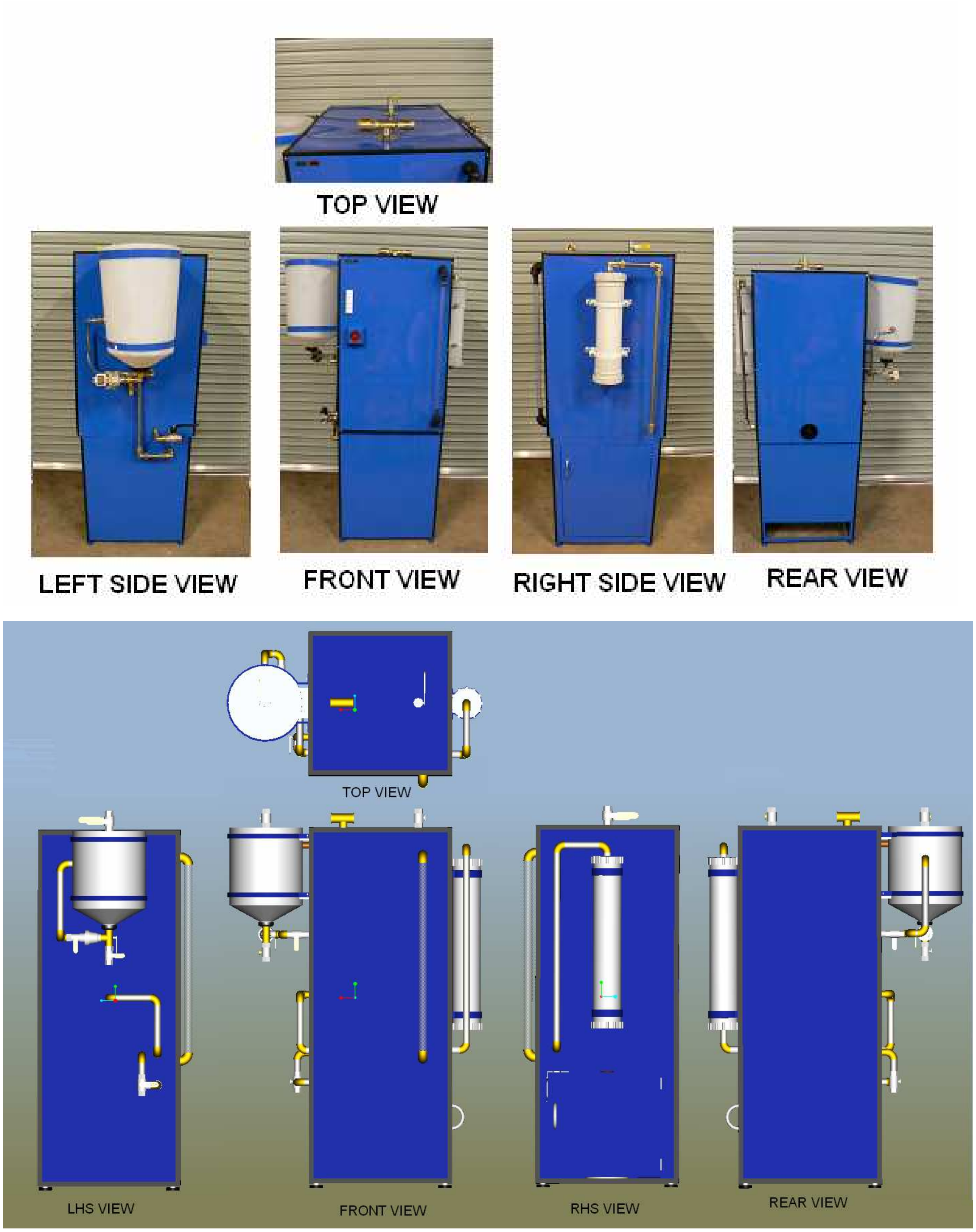


Figure 3.34: Physically Constructed Biodiesel Unit
Actual Prototype Compared with 3-D model

As can be seen from the above images, the BTU100A prototype has been constructed to successfully replicate the 3-D model that has been developed from the design analysis.

3.11 Biodiesel Production using the BTU100A

After several months of meticulously constructing the BTU100A, there was much anticipation as to how the newly constructed biodiesel plant (BTU100A) would perform. After carefully planning each step in the process to make biodiesel, the BTU100A was finally put into action. Several hours later out came beautiful, clean biodiesel which can bee seen in the figure below.

Figure 3.35: Biodiesel produced by the BTU100A

The quality of the biodiesel that this biodiesel plant produces is very high. There is no particulate matter suspended within the fuel (clean), the biodiesel separated quite rapidly after being mixed with water (complete reaction achieved) and the resultant wash water was clear and measured an almost neutral PH (very low soap content). While these tests seem quite primitive, they provide a good indication of the quality of fuel that has been produced [15]. Further tests can and were going to be performed which included a full lab analysis to test for compliance with Australian Standards, however due to funding limitations these tests were not performed.

The biodiesel that was produced from the BTU100A was then tested at the University of Southern Queensland’s Engine Testing Laboratory in a small IC engine under maximum operating conditions. Details of this investigation will be covered in the following chapter.

3.12 Design & Construction Appraisal

At the beginning of the design analysis, design requirements and constraints were developed in order to dictate the direction of the project.

The ***design requirements*** of the system were:

1. The system must produce biodiesel capable of meeting the ASTM and EN standards
2. The system must be designed to minimise operator interaction
3. The total storage area required by the system must be kept to a minimum
4. Recover any materials that can be used

The ***design constraints*** were:

1. The prototype system must cost no more than $2000 to manufacture (Excluding labour)
2. The system must be designed to act in accordance with the E.P.A regulations

The major requirement of the system is that the biodiesel that was produced must be of a high quality, similar to that of Diesel.

Unfortunately a full scale chemical analysis was not performed due to funding restrictions, however from the basic tests that can be performed the biodiesel produced by the BTU100A was found to be of very high quality.

With the budget that was provided, the BTU100A has performed well in terms of minimising the physical requirements of the operator. The most the operator has to do is operate a few switches and valves and add the raw materials to the appropriate vessel. The area that the BTU100A has not performed quite so well in is system monitoring. The operator still needs to closely monitor the system during the time it is in operation. This is due to the safety of the system, the temperature variations required and also the timing at which each process must be performed. With the budget that was allocated it is difficult to see how the design can be changed to improve the system monitoring problem. If however, there were a higher budget, a logic controller and solenoid valves could completely and automatically operate the BTU100A which would require virtually no operator interaction.

The storage area required by the system is quite minimal. The area consumed by the BTU100A is comparable to a refrigerator or a large hot water system. In comparison to other machines that have been developed throughout the world, this system is extremely compact and has utilised the area that it consumes very efficiently

The material that can be recovered in the process of making biodiesel is methanol. The methanol removal system that has been incorporated within the design of the BTU100A does a very good job of removing the excess methanol within the system and recapturing it for use within the next batch of biodiesel. Unfortunately however, there is some methanol that remains in the glycerine that is disposed of. The methanol present in the glycerine can be recaptured, however it is not feasible to do so with the current methanol removal system in place. An additional system would be required in this instance however, it was decided that the small amount of methanol that could be recaptured from the glycerine is not worth the additional resources.

Analysing the constraints placed on the biodiesel plant, the BTU100A’s total construction value was $1868.11 which is below the $2000 limit that was set. Therefore the BTU100A was successfully constructed below budget with a $131.89 surplus.

In terms of the EPA regulations that needed to be adhered to, there were not as many as one would have thought. Provided that the waste products were disposed of appropriately (see local refuse tip) and that methanol were not deliberately released into the atmosphere in large amounts, there were no associated problems with the EPA.

Evaluating how the biodiesel plant performed in terms of its design, it was found that 60litres of biodiesel took 4 hours to make. Unfortunately this is quite a long time and it is dependent on the volume of fuel that is being produced.

The areas within the process which took the most amount of time are:

1. Transesterification reaction time (approx 1 hour)
2. Settling time (1 – 2 hours)

Unfortunately there is not a great deal that can be done to increase the reaction time unless ultrasonic technology is used. As has been previously explained, ultrasonic technology is not feasible for a prototype model as it is too expensive. Something can be done about the settling time however. If the biodiesel plant were to be redesigned that incorporated methods of increasing the rate of cooling (radiator, cooling coils/fins, fans etc) the settling time may be substantially reduced as the settling time is dependent of the rate at which the solution is cooled.

Overall system safety is also an area which can be improved. This can be achieved through utilising pneumatic pumps instead of electrical pumps and perhaps solar energy instead of electrical.

Overall, with the budget that has been allocated, the BTU100A has performed very well. All of the design requirements were achieved while still staying within the boundaries of the design constraints.

The future work of the biodiesel plant includes:

- Automating the process through a logic controller, valves and associated monitoring components
- Improving the rate of cooling (radiator, fan etc)
- Increasing safety through pneumatics and solar energy

Chapter 4

PERFORMANCE TESTING

Objectives

The objectives of this chapter are to test and compare the performance characteristics of various blends of biodiesel with diesel in a small IC engine. Based on the results obtained in this chapter, an evaluation will be made as to how well biodiesel compares to diesel in terms of performance.

4.1 Introduction

This chapter will firstly discuss the physical properties of biodiesel and diesel and how these properties compare. The testing apparatus will then be observed and the corresponding test procedure will be discussed. The fuel will then be run through the small IC engine on the test rig under maximum loading conditions and the results will then be analysed. Finally a summary of important results will be tabulated and a conclusion will be drawn.

4.2 Fuel Analysis

The physical properties of biodiesel and diesel are compared in the following table.

Fuel properties of Diesel Compared with Biodiesel (100%)

	Diesel	**Biodiesel**
Density kgL-^{1} @ 15.5 °C	0.84	0.88
Calorific value MJL-^{1}	38.3	33
Viscosity mm^{2}s-^{1} @ 20°C	4-5	4-6
Cetane number	45	45-65

Table 4.1.: Comparative properties of diesel and biodiesel

From "Waste Vegetable Oil as a Diesel Replacement Fuel" by Phillip Calais, Environmental Science, Murdoch University, Perth, Australia, and A.R. (Tony) Clark, Western Australian Renewable Fuels Association Inc.

Important characteristics which have a large influence on how a fuel performs are the fuels calorific value and cetane rating. From the table above it can be seen that biodiesel has a slightly lower (8%) calorific value than Diesel. However, it can also be seen that biodiesel has a slightly higher cetane level than diesel. What these two properties indicate is that the lower calorific value of biodiesel may result in a lower power output, however the higher cetane rating of biodiesel produce higher relative efficiency under maximum load conditions when compared to diesel. The relative viscosities of both fuels are very similar which indicates that both fuels should have similar fuel atomisation properties. Overall it is expected that biodiesel blended fuels may produce less power than diesel, although a higher efficiency may be observed.

4.3 Test Apparatus

The specifications of the testing apparatus used in this investigation are displayed in the following tables:

Engine Specifications	
Engine Type	Yanmar L 48 AE
Fuel Delivery	Direct Injection
Displacement	211 cc / 12.88 cu. in
Bore x stroke	70x55 mm / 2.76x2.17 in
Max Speed	3600rpm
Max Power	3.5kW at 3600rpm

Table 4.2: Engine Specifications

Dynamometer Specifications	
Dyno Type	Hydro – closed loop recirculation system
Capacity	38cm^3/rev

Table 4.3: Dynamometer Specifications

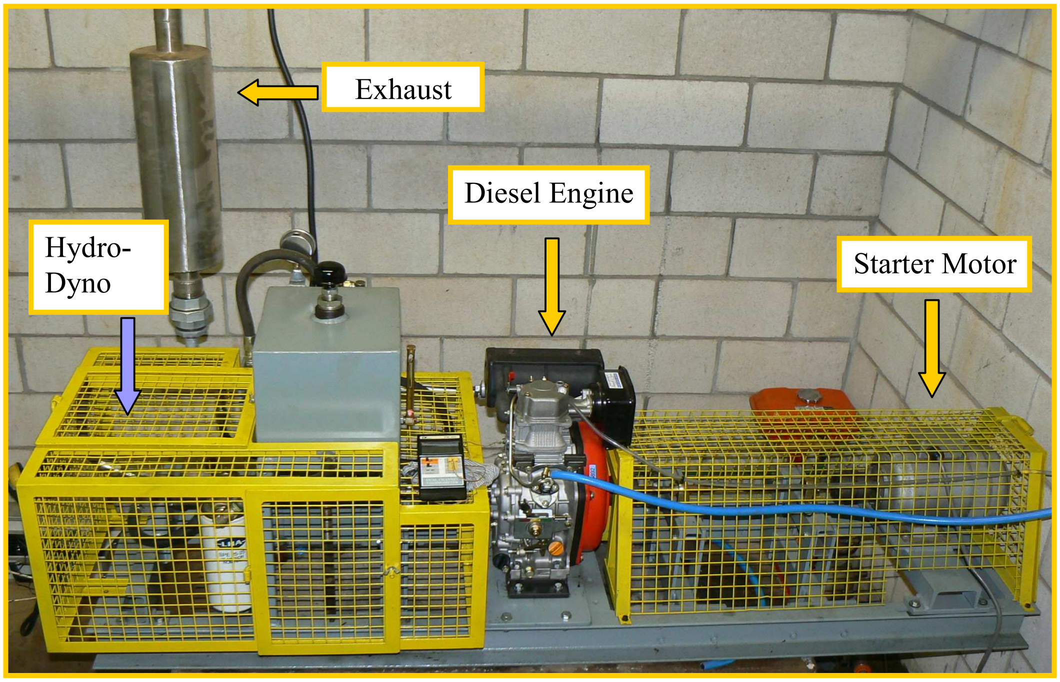


Figure 4.1: Test Rig (Front View)

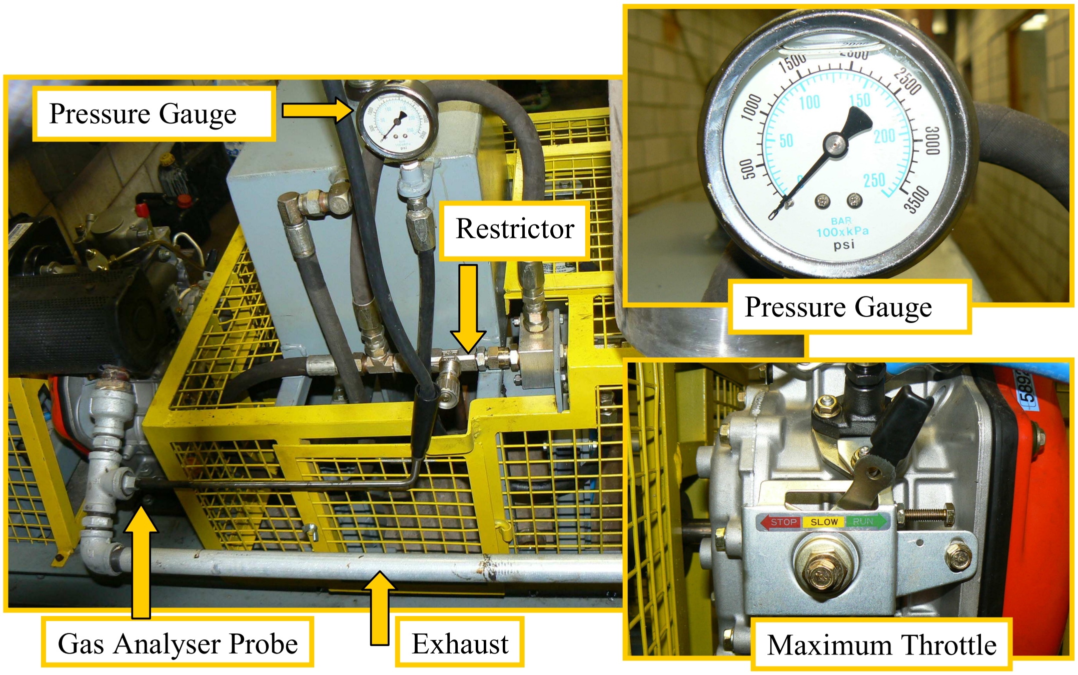


Figure 4.2: Test Rig Components

4.4 Test Procedure

The engines performance at full load was tested for each blend of fuel for a range of engine speeds between 1000rpm to 3400rpm. The various blends of fuel that were tested are:

1. B00 (100 % Diesel)
2. B25 (25% Biodiesel 75% Diesel)
3. B50 (50% Biodiesel 50% Diesel)
4. B75 (75% Biodiesel 25% Diesel)
5. B100 (100% Biodiesel)

The first step was to add the fuel that was currently being tested into the fuel reservoir of the test engine. The engine was then run for several minutes to remove any of the previous fuel blends that remained in the fuel system.

The throttle was then opened to the maximum position and load was applied to the engine through the restrictor in the hydro-dyno until the engine reduced to a speed of 3400rpm. Once the engine reached the equilibrium operating temperature, the following properties were then analysed in the order listed:

- Fuel consumption
- Engine Temperature
- % O_2
- Exhaust temperature
- Pressure (Hydro-Dyno pressure gauge)

The load was then increased to reduce the engine speed in steps of 200rpm and each variable was reanalysed. This process was performed between 3400rpm and 1000rpm.

Note: *This engine does not have an electronically controlled fuel injection system. Testing the engines performance with the throttle fully opened at each engine speed will yield the maximum performance at that RPM.*

After each test was performed the engine was run for several minutes while the next blend of fuel was introduced. This process was repeated for all blends listed above.

4.5 Results

4.5.1 Power

The graph below represents the power produced by the engine at each rpm for various blends of fuel between 1800 and 3400rpm. The power was calculated from the pressure readings that the engine produced on the hydro-dyno at each engine speed. The corresponding SAE correction factor has also been utilised to compensate for any variance in results associated with atmospheric conditions. *(See Appendix 1: Correction Factor & Power for calculations)*

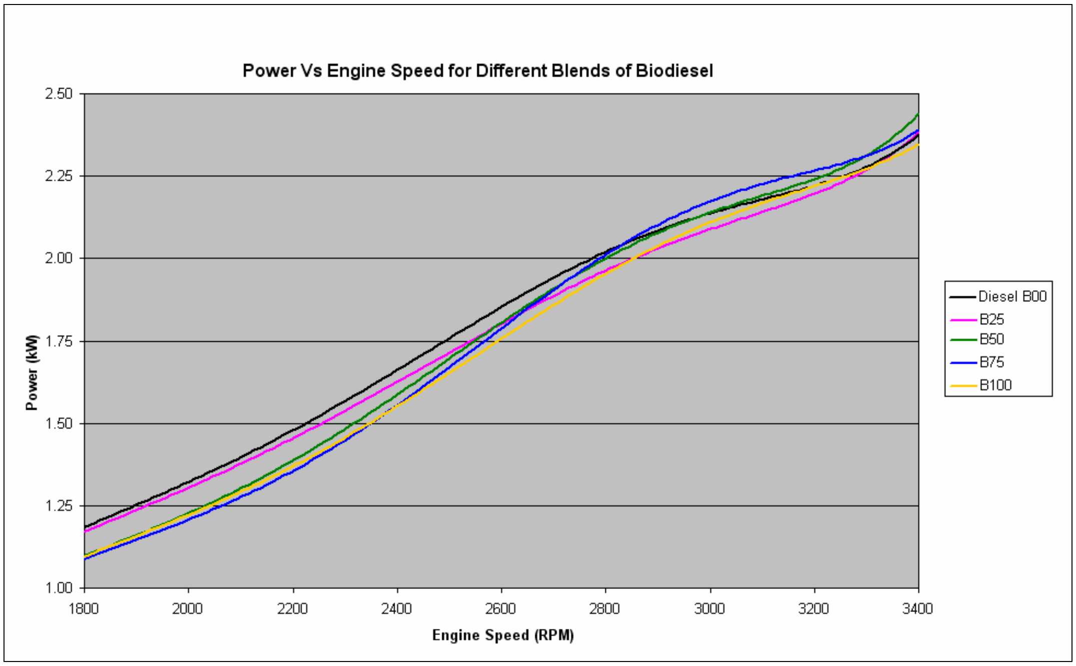


Figure 4.3: Graph of Power vs Engine speed for various fuel blends.

As can be seen from the above graph, the overall power produced by each blend of fuel is quite comparable to that of diesel (black line). Unfortunately though, the hypothesis that higher percentages of biodiesel will produce less power is not entirely accurate. At engine speeds between 1800 -2400rpm, the Diesel and B25 have almost identical performance. This behaviour can also be observed between the B50, B75 and B100 but each producing a slightly lower power.

After 2300 – 2400rpm, the B25 starts to fall away from the Diesel curve. However, the B50 and B75 blends break away from the consistently performing B100 and start to produce higher power than Diesel at approximately 2700 – 2800rpm.
The maximum performance was obtained by the B50 blend, however, B75 maintained the highest relative performance for the longest period between 2800 – 3300rpm.

Overall, the best performing fuel was found to be B75 as it had the highest relative performance over the most useful range of the engine.

4.5.2 Torque

The graph illustrated below shows the Torque that the engine produced over the range of engine speeds for each blend of fuel. The torque values on this plot were obtained from the power. *(See Appendix 1: Torque, for calculations)*

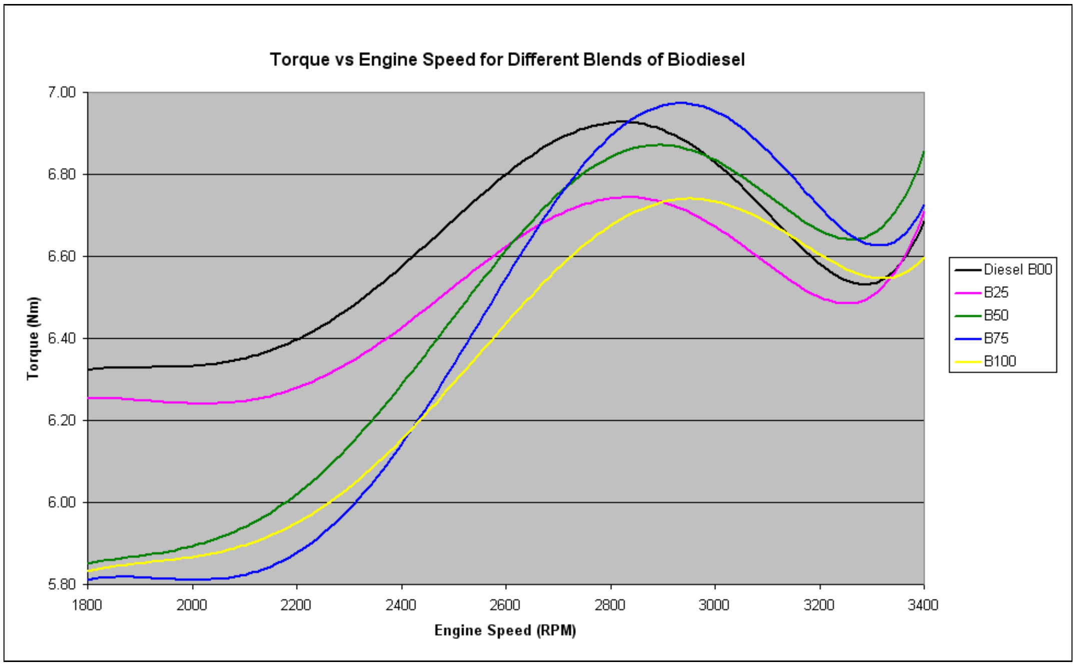


Figure 4.4: Graph of Torque vs Engine speed for various fuel blends.

Analysing the region between 1800 and 2800rpm for these blends, it can be seen that as the concentration of biodiesel increases, the corresponding torque produced in decreased. This relationship is expected due to the lower calorific value of the fuel. B75 however, appears to act beyond this predicable behaviour. From the plot of B75 it can be seen that for lower 1800 – 2300 this blend produces the lowest torque of all the blends. However, the B75 then experiences a rapid increase in torque as it approaches higher engine speeds where it exceeds the torque produced by diesel and maintains the maximum torque produced for all fuel blends between 2850- 3300 RPM.

From this graph it can be concluded that for an engine that will be only loaded within the higher engine speeds (a pump for example) the B75 would produce the best results. However, for an engine that will be loaded over a range of engine speeds, (a car for example) the B25 would produce the best results (not including diesel) as it performs consistently well over the range of engine speeds.

4.5.3 Brake Specific Fuel Consumption (BSFC)

The graph illustrated below is of the brake specific fuel consumption over the range of engine speeds for each blend of fuel. The brake specific fuel consumption (BSFC) is a measure of efficiency which is the fuel flow rate (g/h) divided by the engines brake power (kW) resulting in (g/kW.h). *(See Appendix 1: BSFC, for calculations)*

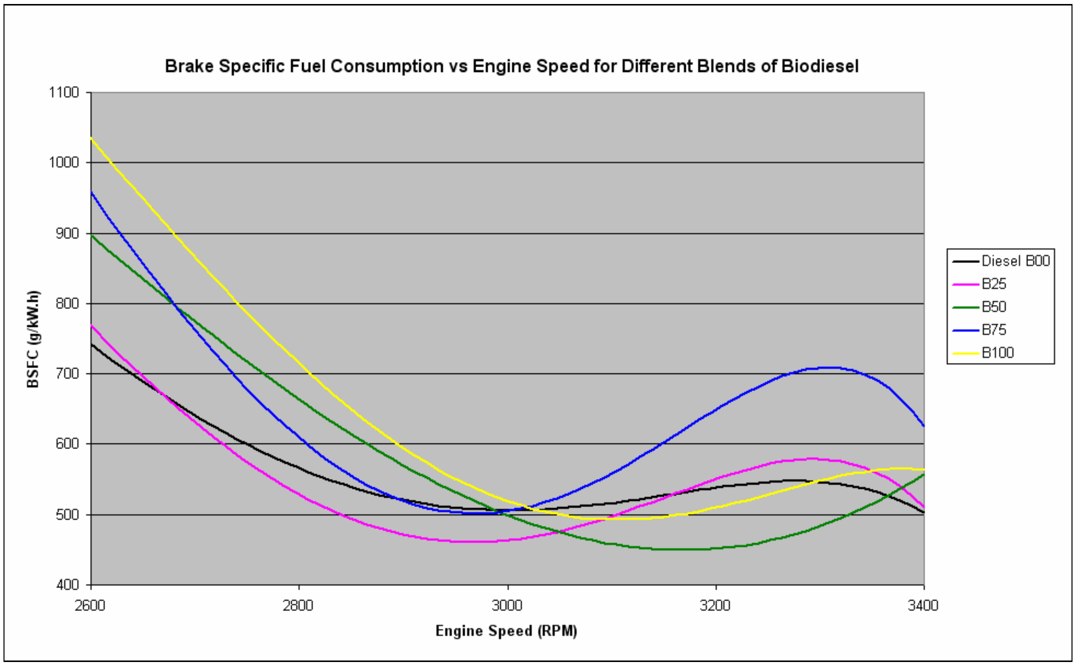


Figure 4.5: Graph of BSFC vs Engine speed for various fuel blends.

What the graph shows is that, at lower engine speeds the BSFC of the biodiesel blends are considerably higher than that of diesel. As the engine speed increases the BSFC of the biodiesel blends decrease at a higher rate than that of Diesel. This trend indicates that the biodiesel blends are achieving good combustion when subject to higher engine speeds. All biodiesel blends were found to have a lower BSFC than diesel within the efficiency range of the engine (2800 – 3200 rpm). Overall B50 produced the lowest BSFC of 470g/kW.h at 3200 RPM where the B25 produced results that were the closest to that of Diesel. As the engine speed increased out of the efficiency range it was found that the BSFC of B75 increased at the highest rate.

Overall, the BSFC produced by the biodiesel blends are quite comparable with that of diesel where in the efficiency range of the engine, the biodiesel blends proved more efficient with a lower overall BSFC value.

4.5.4 Thermal Efficiency (η_{th})

The graph illustrated below is of the thermal efficiency that was obtained for each blend of fuel over a range of engine speeds. The thermal efficiency is a measure of how well the engine has converted the calorific energy content of the fuel into mechanical work energy (η_{th} = *Input power (IP) / Output Power (OP)*)

(See Appendix 1: Thermal Efficiency, for calculations)

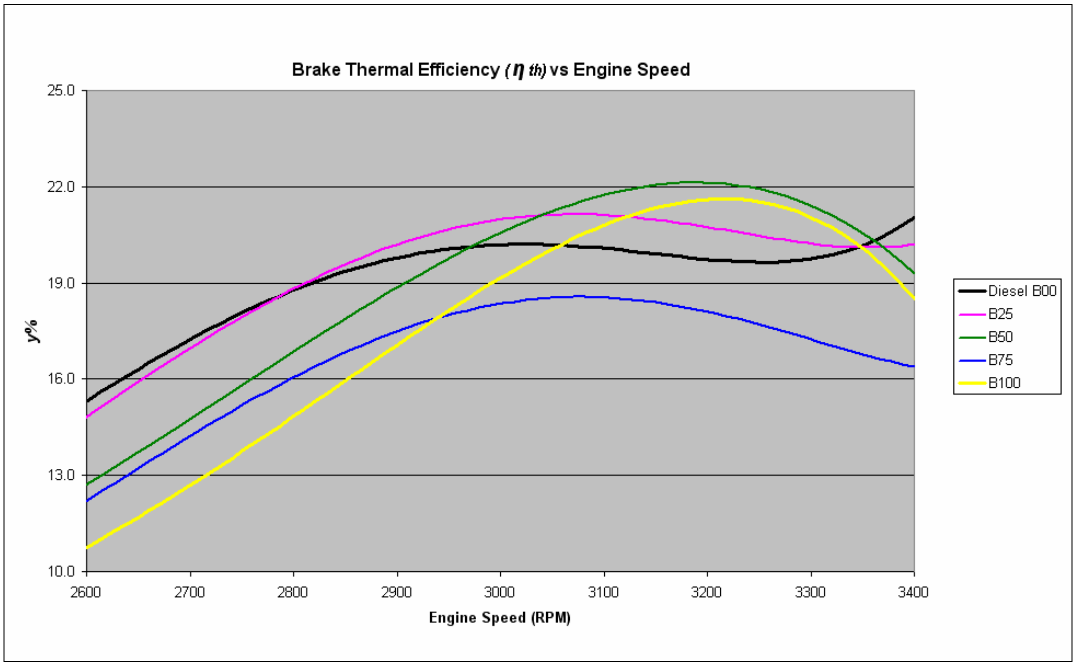


Figure 4.6: Thermal Efficiency vs Engine speed for various fuel blends.

The graph shows that at lower engine speeds the efficiency of the biodiesel blends are lower than that of diesel. As the engine speed increases and reaches the efficiency range of the engine (2800 – 3300rpm) the biodiesel blends are found to have a significantly higher efficiency than that of diesel.

The highest efficiency is achieved by B100 which is not surprising as it should have the highest cetane number of all the fuels.

Overall it can be seen that biodiesel blended fuels produce consistently higher levels of efficiency when operated under the efficiency range of the engine (2800 – 3300rpm)

4.5.5 Exhaust Gas Analysis: %O_2

The graph illustrated below is of the %O_2 found in the exhaust gasses over the range of engine speeds which was obtained from the gas analyser. Higher levels of oxygen indicate a more complete combustion where lower levels indicate incomplete combustion. *(See Appendix 1: Tabulated Data for actual values)*

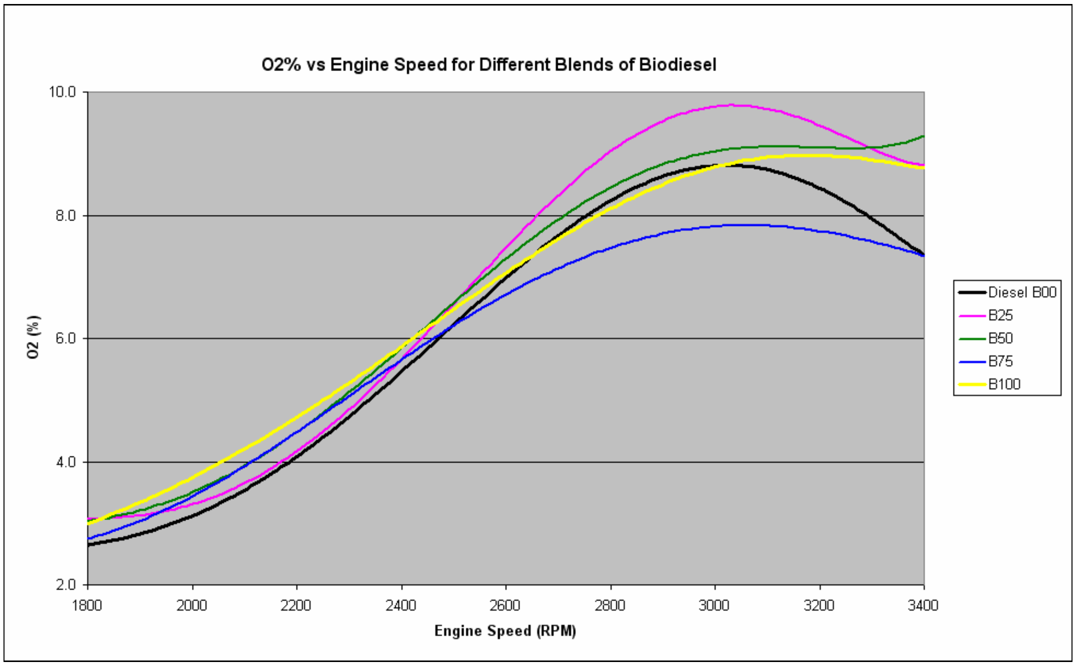


Figure 4.7: Graph of % O_2 vs Engine speed for various fuel blends.

It can be seen from the graph that the biodiesel fuel blends are generally producing higher levels of oxygen in the exhaust when compared to diesel which indicates that the biodiesel blends are achieving good combustion.

Overall it can be seen that, within the efficiency range of the engine (2800 – 3200rpm), B25 produces the highest level of oxygen, followed by B50, Diesel, B100 and B75. Overall it does not look like the combustive properties of biodiesel blended fuels are significantly affected by the presence of biodiesel. In fact, biodiesel blended fuels produce consistently higher oxygen levels than diesel, which may indicate that biodiesel can improve the quality of combustion that is achieved.

4.5.6 Exhaust Gas Analysis: Temperature

The graph illustrated below is of the exhaust temperature that was obtained for each blend of fuel over a range of engine speeds.

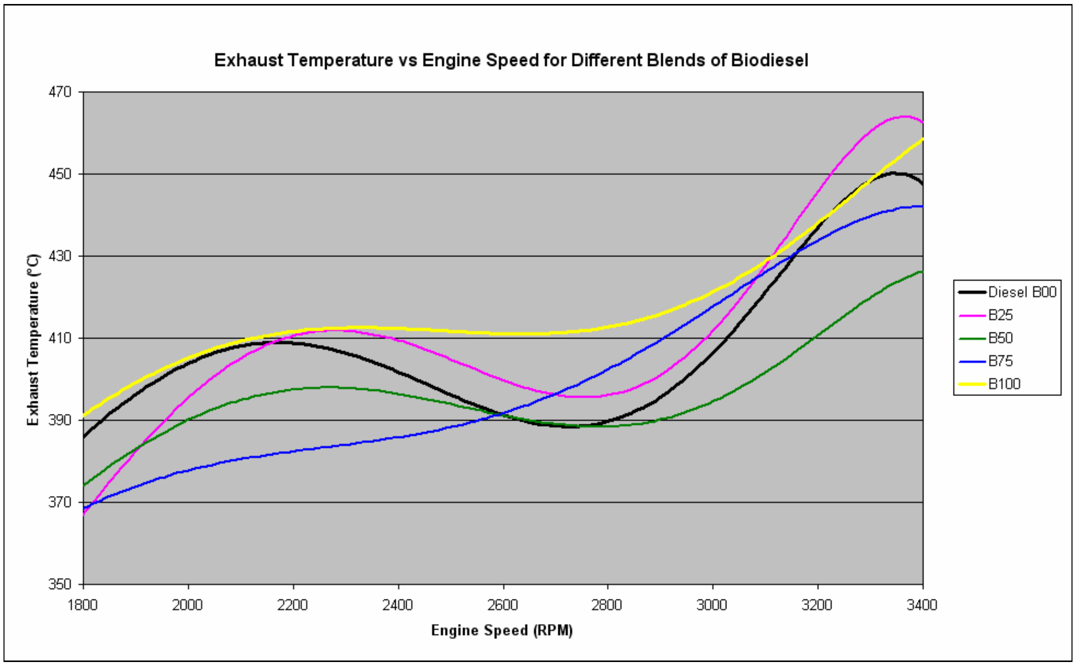


Figure 4.8: Graph of Exhaust Temperature vs Engine speed for various fuel blends.

The temperature of the exhaust is a good indication of the combustion temperature. The gas analyser used measures the temperature difference between the ambient temperature of the surroundings and the temperature of the exhaust gas.

(See Appendix 1: Tabulated Data for actual values)

From the above graph it can be seen that B100 has the highest overall exhaust temperature over the range of engine speeds. The B25 produced exhaust temperatures that were the closest to the Diesel and B50 produced exhaust temperatures which were the lowest and where also consistently lower than diesel. A high exhaust temperature indicates a higher formation of NOx, where a lower exhaust temperature indicates lower formation of NOx. Therefore it can be determined that B100 consistently produces higher NOx emissions than diesel and B50 produces the lowest NOx emissions which are consistently lower than diesel.

4.6 Summary of Results

Concluding this investigation, the following table summarises the key results found from the performance testing.

	Diesel	B25	B50	B75	B100
Max Power (kW)	2.64 kW @ 3400rpm	2.64 kW @ 3400rpm	2.71 kW @ 3400rpm	2.65 kW @ 3400rpm	2.61 kW @ 3400rpm
Average Power (kW)	1.49	1.46	1.44	1.423	1.419
Reduction Average Power (%)	N/A	1.59	3.24	4.24	4.56
Max Torque (Nm)	7.8 N.m @ 2600rpm	7.81 N.m @ 2600rpm	7.61 N.m @ 2600rpm	7.61 N.m @ 2800rpm	7.4 N.m @ 2800rpm
Av Torque (Nm)	6.28	6.17	5.98	5.89	5.94
Reduction Torque (%)	N/A	1.63	4.72	6.12	5.42
Max Thermal Efficiency (%)	21.2	21.6	22.4	18.2	21.5

Table 4.4: Summary of Results

4.7 Conclusion

From this investigation it was found that, from all the fuels tested:

- The fuel which produced the most power within the efficiency range of the engine (2800 – 3200) was B75
- The fuel that produced the highest power in comparison to all the fuels tested including diesel was B50 which produced 2.71kW (.07kW higher than diesel)
- Higher percentage blends of biodiesel produce lower average power, ranging from 1.59% for B25 to 4.56% for B100
- The fuel which produced the most torque within the efficiency range of the engine (2800 – 3200) was B75
- The fuel that produced the highest torque in comparison to all the fuels tested including diesel was B25 which produced 7.81Nm (.01Nm higher than diesel)
- Higher percentage blends of biodiesel generally produced lower average torque, ranging from 1.63% for B25 to 5.42% for B100
- The highest thermal efficiency observed from all the fuels including diesel was achieved by the B50 blend followed by B25, B100, Diesel and B75
- The highest exhaust temperature and corresponding NOx was produced by B100. The lowest exhaust temperature and corresponding NOx was produced by B50 (lower than diesel)

Chapter 5

ECONOMIC ANALYSIS

Objectives

The objective of this chapter is to analyse the variation in running costs associated with biodiesel blended fuels. Based on the results found from the cost analysis, a recommendation will be made as to what fuel blend is the most economically feasible alternative as a replacement fuel for diesel.

5.1 Introduction

This chapter will firstly discuss the costing of the individual products (oil, alcohol, acid) that are required to make biodiesel. The fuel consumption data obtained from the previous chapter will then be further analysed to determine how the increase or decrease in fuel consumption affects the running cost of each blend. A graph indicating the break even point of each fuel will then be constructed where the breakeven point is the point where the fuel blend in question starts to save the user money (after initial setup costs etc). Finally, a conclusion will be made as to which fuel is in fact the most economically feasible blend to use.

5.2 Economical Analysis

In order to accurately analyse the associated cost gains or losses associated with biodiesel blends, there are two major areas which must be addressed. These are:

1. Economical effects biodiesel has on engine life
2. Running costs of using biodiesel

Unfortunately an investigation has not been extended into the area of the economical effects that biodiesel has on the engine life due to both a lack of time and resources. Research has shown however that using biodiesel can substantially reduce the wear in an IC engine due to the increased lubricity of the fuel.

A study conducted by Professor Barry Hertz of the University of Saskatchewan (BioBus Project) has shown that biodiesel blends as low as 5% can reduce engine wear by 7.8 – 23.4%. What this indicates is that the corresponding engine maintenance related to engine wear may be reduced, and therefore money could be saved. While this may be the case, the economical effects biodiesel has on engine life will not be analysed and interpreted as an economic impact in this report, as the research has been conducted on a different engine with slightly different feedstock for the biodiesel. Therefore, the cost analysis will be limited to the running costs of biodiesel alone.

5.3 Costs Associated with Biodiesel Production

The materials required to manufacture biodiesel are listed in the following table including the amounts required and cost incurred per litre of biodiesel.

Product	Unit Cost	Amount Required	Cost/litre
Methanol	$2.52 / litre	20% by volume	$ 0.50
Absorbent Powder	$13.3 / kg	2% by weight biodiesel	$ 0.23
Sodium Hydroxide	$11.4 / kg	6g/litre	$ 0.07
		Total Cost/Litre	**$ 0.81**

Table 5.1: Cost of materials required for biodiesel production

What this table does not include is the labour involved in producing biodiesel, the electricity it consumes or any other overhead prices which may be involved. For the sake of this investigation, it has been assumed that the biodiesel plant is self operating and the power and overhead costs involved are negligible. This is not an outrageous assumption to be making for the small home brewer of biodiesel.

Now, the table above indicates that the material costs to produce biodiesel using the techniques that were discussed in chapter 3 will cost approximately \$0.81 per litre.

So the question is, if biodiesel costs \$0.81 per litre and diesel costs around \$1.30 per litre, it must be more economical to use biodiesel. Before this conclusion can be made, the increase or decrease associated with the fuel consumption of biodiesel blended fuels must be analysed.

Based on the previous chapter, the fuel consumption for the diesel and biodiesel blends were analysed. The following table indicates the average fuel consumption that was observed over the range of tested engine speeds, the equivalent volume of fuel, and finally the equivalent cost of fuel.

Fuel Type	Average Fuel Consumption (ml/s)	Equivalent Volume of Fuel (litre)	Equivalent Cost/litre (\$)
Diesel	0.490	1	1.3
B25	0.484	0.989	1.17
B50	0.527	1.076	1.10
B75	0.527	1.075	0.95
B100	0.570	1.164	0.94

Table 5.2: Comparative running costs between Biodiesel blended fuels and Diesel

From the table it can be seen that the average fuel consumption that was measured from chapter 4 of B100 is 0.57 ml/s. This average value was obtained by averaging the fuel consumption observed from 100rpm to 3400rpm. The equivalent volume is then calculated by determining how much extra fuel is used by the biodiesel blend. For example, the average consumption of diesel is 0.490 ml/s which is the benchmark for all the fuels as this is the fuel that the biodiesel blends are being compared to.

Analysing B100 again it can be seen from the equivalent volume of fuel that for every 1 litre of Diesel consumed, the B100 will need to consume 1.16 litres (an additional 16%). While this may seem like a lot of extra fuel, consideration must be made for the loading conditions which the test engine was subject to. For example, if a typical driver were to add B100 to their vehicle which was fitted with the same engine that was used in this investigation and drive around normally, they would not experience a 16% increase in fuel consumption. If however, a driver filled their vehicle with B100 and constantly loaded the engine to the limit (e.g. full throttle under heavy towing load) then it is possible that a 16% increase in consumption could be observed.

For the course of this investigation the additional consumption observed under maximum loading conditions will be analysed.

Analysing the B100 again, it has been discussed that B100 will consume an additional %16 on average. Comparing the increase in fuel consumption with a basic cost per litre it can be seen that, because of the additional fuel consumption of B100, the equivalent cost/litre when compared to diesel is now \$0.94. That is, the cost of 1.16 litres of biodiesel is \$0.94. Offcourse the biodiesel still costs \$0.81 per litre, it's just that more of it is used. Analysing B25 for example consisting of 25% biodiesel and 75% diesel, the equivalent cost is 0.989[(0.25 x 0.81)+(0.75 x 1.3)] = \$1.17 and so on for each blend.

Now that the comparative relationship has been established between the biodiesel blended fuels and diesel, an investigation can now be made toward the breakeven points of each blend. The breakeven points will determine how much of a particular blend will need to be used until the cost of the biodiesel plant has been recovered.

In this project, the cost of the biodiesel plant was \$1868.11 which included the cost of materials only. What is being assumed here is that an individual wants to use biodiesel for personal use and it will be the individual that constructs the biodiesel plant at a zero cost of labour. This is a valid assumption to make as it is a very real situation not only within Australia, but worldwide.

Therefore, before any money can accumulate from any potential savings that have been achieved by using biodiesel blends, the money which was spent on the biodiesel plant must firstly be recovered.

The following graph displays the relationship between the cost of fuel and the amount consumed for each blend.

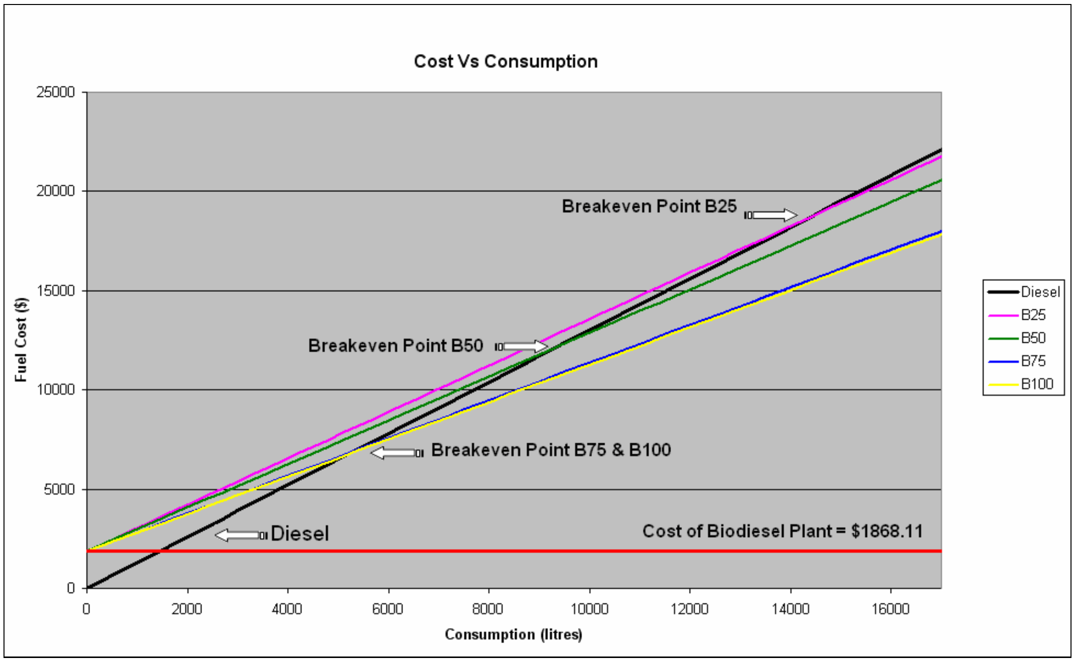


Figure 5.1: Fuel Cost vs Consumption for biodiesel and Diesel fuel blends

The black line of the figure represents diesel, where it can be seen that the line starts from zero and progresses at a rate of 1.3(x) where ‘1.3’ is the cost of fuel and ‘x’ is the amount of fuel used (e.g. 1.3 x 2 = $2.60 for 2 litres).

The horizontal line on the graph indicates the amount which was outlaid to construct the biodiesel plant. Each biodiesel blend must therefore start at this value which is $1868.11. It is assumed that the biodiesel consumed is produced by the user and the biodiesel plant must first be constructed before the fuel can be used.

Analysing B100 again, it can be seen that the trend line starts at $1868.11 (as all biodiesel blends do) and progresses at a rate of 0.94(x) where 0.94 is the equivalent cost of the fuel per litre and 'x' is the number of litres. The other biodiesel blends have been plotted in the same way where the only difference is the change in equivalent cost for each blend.

Something interesting happens when this plot is developed, and the area of interest is called the breakeven point. The line representing each blend of fuel will start at the initial value of \$1868.11 and progress at a rate dependent on the cost of fuel. When this line intersects with the line representing diesel (black line) we find the breakeven point. What this point represents is the amount of litres of that particular blend of fuel that will need to be used before the initial cost of the biodiesel plant is recovered. After that point money will be saved!

The breakeven points for each blend of fuel can be seen in the following table:

Fuel Type	Breakeven Point (litres)
B25	13 846
B50	9340
B75	5337
B100	5189

Table 5.3: Breakeven Points of each fuel blend

What the above table displays is that, for B25, 13 846 litres will need to be consumed before the cost of the biodiesel plant is recovered, and so on for each blend.

Once this amount is reached the user will now be saving money at a rate equal to the difference in price of the biodiesel fuel blend and the diesel. For example, if B100 is used and the equivalent cost is \$0.94 and the current cost of Diesel is \$1.3, then the savings that will be made are \$1.3 - \$0.94 = \$0.36/litre.

From the table it is easy to see that B100 is the most economical fuel. The initial cost of the biodiesel plant can be recovered the quickest and savings after this point will also be the highest in comparison to the other blends of fuel.

5.4 Conclusion

Based on the information found in this investigation, B100 appears to act as the most economical fuel and the cost of the biodiesel plant could be recovered after 5189 litres of B100 were used. If a further analysis were conducted on a standard vehicle under normal driving conditions it would be expected that potential savings a user could make by using biodiesel blended fuel would be even higher due to the reduced comparative fuel consumption rates and corresponding equivalent costs/litre

Chapter 6

PROJECT CONCLUSION

6.1 Conclusion

In this project the chemical and physical process involved in making biodiesel were investigated. Based on the chemical processes, the physical processes were broken down into small subgroups of activities which were required to manufacture biodiesel from waste cooking oil. Each of these subgroups were addressed in a conceptual design analysis where 2-D and corresponding 3-D models were developed. Based on these models, the prototype biodiesel plant (BTU100A) was constructed. Following the specific processes which were developed for the BTU100A, a high quality biodiesel (methyl ester) was produced using synthetic magnesium aluminium silicate (magnesol) as the purification technique.

The biodiesel produced by the BTU100A was then tested at the University of Southern Queensland's Engine Testing Laboratory, where it was found that biodiesel blended fuels compared quite well with diesel. It was found that the fuel which produced the most power and torque within the efficiency range of the engine (2800 – 3200) was B75. Overall however, biodiesel blended fuels produced lower average power and torque values as the percentage of biodiesel increased. Finally, the fuel which had the highest thermal efficiency was B50, and the fuel which produced the lowest exhaust temperature and corresponding NOx emissions was also B50.

Based on the economical analysis conducted in chapter 5, it was determined that, even with the increased fuel consumption associated with using biodiesel blended fuels, money can be saved using all the blends of biodiesel that were tested whereby the most money could be saved by using pure biodiesel (B100) as a replacement to diesel.

6.2 Future Work

The future work of the biodiesel plant includes:

- Automating the processor through a logic controller, valves and associated monitoring components
- Improving the rate of cooling (radiator, fan etc)
- Increasing safety through pneumatics and solar energy

The future work of the biodiesel testing includes:

- Test the biodiesel that is produced by the BTU100A for compliance with international ATSM standards
- Test the impact biodiesel has on engine life (injectors, bearings, lubricity)
- Investigate how biodiesel performs in IC engines of higher compression
- Compare the change in engine performance throughout a range of varying injector pressures while using various mixtures of BioDiesel
- Investigate how various injector pressures and combustion chamber configurations affect BP and BMEP using a commercial CFD package

The future work of the economical analysis includes:

- Investigate how the use of biodiesel affects engine life in economic terms (e.g. reduced cost due to lower scheduled maintenance, longer engine life etc)

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Appendix 1

PROJECT SPECIFICATIONS

ENG 4111/2 Research Project
PROJECT SPECIFICATION

FOR: **Luke HANSEN**

TOPIC: THE USE OF WASTE COOKING OIL AS AN ALTERNATIVE FUEL FOR DIESEL ENGINES

SUPERVISER: Dr Talal Yusaf

ENROLMENT: ENG4111 – S1, 2007
ENG4112 – S2, 2007

PROJECT AIM: The aim of this research project is to investigate the overall feasibility of using waste vegetable oil as an alternative source of fuel for diesel engines

PROGRAMME: **Issue B, 1st October, 2007 (UPDATED)**

1. Develop a literature review on methods used to extract BioDiesel from waste vegetable oil (WVO)

2. Design and construct a System to extract Biodiesel from WVO

3. Investigate the performance of a conventional diesel engine using various mixing ratios of Biodiesel and Diesel (Torque, BP, BSFC & efficiency)

4. Perform an economic analysis on the possible savings that can be achieved by a conventional user of biodiesel blended fuels

As time permits:

5. Test the Biodiesel for compliance with Australian standards

AGREED:______________ (Student) ______________ (Superviser)

Date: ____ / ____ / ______

Appendix 2

CALCULATIONS AND RAW DATA

A2.1 Correction Factor

$$\boxed{cf = 1.180 \times \left[\left(\frac{990}{P_d} \right) \times \sqrt{\frac{T_c + 273}{298}} \right] - 0.18}$$

SAE J1349 formula

cf is the final correction factor multiplier
Pd is the pressure of dry air in hPa
Tc is the air's temperature in degrees Celsius

The atmospheric conditions at the time of testing were:

Pd = 1071 hPa
Tc = 19°C

The resulting correction factor was therefore,

cf = 0.89971969851687

A2.2 Power

$$\boxed{P = pV' \text{ (W)}}$$

P = Power (watts)

p = Pressure (kPa)

The pressure was read from the pressure gauge of the hydro dynamometer in lb and converted to kPa
V´ = Volume Flow Rate (m^3/s)

The volume flow rate was calculated by multiplying the engine speed by the capacity of the hydraulic pump on hydro dynamometer

e.g. Let engine speed = 100RPM
The pump capacity is constant and is $38 cm^3/rev$.
Therefore, the volume flow rate the IC engine produces at 1000 rpm is
1000 x 38 = **38 000 cm^3/min**

A2.3 Torque

$$\boxed{T = \frac{60P}{2\pi N} \quad (\text{Nm})}$$

P = Power (W)
N = Engine speed (rpm)

The torque was calculated using the power ‘P’ from A2.2 at the engine speed ‘N’.

A2.4 Brake Specific Fuel Consumption (BSFC)

$$\boxed{BSFC = m'/P \quad (\text{g/kW.hr})}$$

m´ = Fuel Consumption g/hr
P = Power (kW)

A2.5 Thermal Efficiency

$$\boxed{\eta_{th} = \text{Input power (IP) / Output Power (OP) (\%)}}$$

Input Power (IP) = m´ LHV

m´ = Fuel Consumption g/hr
LHV = Lower Heating Value (MJ/L)

Output Power (OP) = P = pV´ (W)

m´ = Fuel Consumption g/hr

DIESEL (B00)

RPM	Pressure(lb)	Ex Temp	En Temp	%O2	Time 5ml	V'(m^3/s)	Power (kw)	Fuel Con (ml/s)	Torque (N.m)	BSFC (g/kW.h)	IP (watts)	Thermal Efficiency *y*%
3400	1800	447	118.0	7.5	13.0	0.22	2.37	0.38	6.66	496	11169	21.2
3200	1800	437	118.9	8.0	12.5	0.20	2.23	0.40	6.66	548	11616	19.2
3000	1850	414	113.3	8.6	13.5	0.19	2.15	0.37	6.85	527	10756	20.0
2800	1800	372	113.9	10.0	15.5	0.18	1.95	0.32	6.66	505	9368	20.8
2600	1900	405	115.0	5.4	10.0	0.16	1.91	0.50	7.03	799	14520	13.2
2400	1800	400	120.5	5.3	10.0	0.15	1.67	0.50	6.66	914	14520	11.5
2200	1700	408	121.1	4.2	8.0	0.14	1.45	0.63	6.29	1320	18150	8.0
2000	1700	408	121.2	3.7	7.5	0.13	1.32	0.67	6.29	1548	19360	6.8
1800	1700	376	121.9	2.8	7.5	0.11	1.19	0.67	6.29	1721	19360	6.1
1600	1700	363	124.5	2.2	10.0	0.10	1.05	0.50	6.29	1452	14520	7.3
1400	1600	349	126.6	2.0	7.0	0.09	0.87	0.71	5.92	2518	20743	4.2
1200	1400	313	127.6	3.1	13.0	0.08	0.65	0.38	5.18	1808	11169	5.8
1000	1300	297	129.4	2.2	15.0	0.06	0.50	0.33	4.81	2025	9680	5.2

B25

RPM	Pressure(lb)	Ex Temp	En Temp	%O2	Time 5ml	V'(m^3/s)	Power (kw)	Fuel Con (ml/s)	Torque (N.m)	BSFC (g/kW.h)	IP (watts)	Thermal Efficiency *y*%
3400	1800	**462**	122.0	**9.0**	12.5	0.22	2.37	0.40	6.66	516	11616	20.4
3200	1800	446	121.8	8.8	13.0	0.20	2.23	0.38	6.66	527	11169	20.0
3000	1800	418	120.5	10.0	15.0	0.19	2.09	0.33	6.66	487	9680	21.6
2800	1700	381	117.4	10.5	15.5	0.18	1.84	0.32	6.29	535	9368	19.7
2600	1900	412	123.1	5.8	10.0	0.16	1.91	0.50	7.03	799	14520	13.2
2400	1790	408	124.5	5.5	10.0	0.15	1.66	0.50	6.62	919	14520	11.5
2200	1650	406	125.6	4.7	7.0	0.14	1.41	0.71	6.11	1554	20743	6.8
2000	1600	408	127.4	3.6	8.5	0.13	1.24	0.59	5.92	1452	17082	7.3
1800	1750	349	124.2	3.2	7.0	0.11	1.22	0.71	6.48	1791	20743	5.9
1600	1700	343	123.6	2.7	10.0	0.10	1.05	0.50	6.29	1452	14520	7.3
1400	1550	326	123.2	2.9	8.5	0.09	0.84	0.59	5.74	2141	17082	4.9
1200	1400	304	123.5	3.2	12.0	0.08	0.65	0.42	5.18	1959	12100	5.4
1000	1250	294	125.2	2.5	15.0	0.06	0.48	0.33	4.63	2106	9680	5.0

B50

RPM	Pressure(lb)	Ex Temp	En Temp	%O2	Time 5ml	V'(m^3/s)	Power (kw)	Fuel Con (ml/s)	Torque (N.m)	BSFC (g/kW.h)	IP (watts)	Thermal Efficiency *y*%
3400	1850	426	111.5	9.4	11.5	0.22	2.44	0.43	6.85	546	12626	19.3
3200	1810	412	114.3	8.7	14.5	0.20	2.24	0.34	6.70	470	10014	22.4
3000	1850	394	113.2	9.2	13.0	0.19	2.15	0.38	6.85	547	11169	19.3
2800	1800	385	115.1	9.3	14.0	0.18	1.95	0.36	6.66	560	10371	18.8
2600	1850	396	118.9	6.3	9.5	0.16	1.86	0.53	6.85	864	15284	12.2
2400	1700	397	118.5	5.7	7.5	0.15	1.58	0.67	6.29	1290	19360	8.2
2200	1600	393	119.8	4.8	8.0	0.14	1.36	0.63	5.92	1402	18150	7.5
2000	1550	391	121.0	4.0	7.5	0.13	1.20	0.67	5.74	1698	19360	6.2
1800	1650	378	126.4	2.5	7.5	0.11	1.15	0.67	6.11	1773	19360	5.9
1600	1550	348	124.2	3.2	7.5	0.10	0.96	0.67	5.74	2123	19360	5.0
1400	1400	335	124.2	2.9	7.5	0.09	0.76	0.67	5.18	2686	19360	3.9
1200	1300	313	122.8	3.5	10.5	0.08	0.60	0.48	4.81	2411	13829	4.4
1000	1100	297	124.0	3.1	13.5	0.06	0.43	0.37	4.07	2659	10756	4.0

B75

RPM	Pressure(lb)	Ex Temp	En Temp	%O2	Time 5ml	V'(m^3/s)	Power (kw)	Fuel Con (ml/s)	Torque (N.m)	BSFC (g/kW.h)	IP (watts)	Thermal Efficiency *y*%
3400	1810	442	117.5	7.4	10.0	0.22	2.38	0.50	6.70	642	14520	16.4
3200	1850	434	119.2	7.5	11.5	0.20	2.29	0.43	6.85	580	12626	18.2
3000	1840	419	119.4	8.0	12.0	0.19	2.14	0.42	6.81	596	12100	17.7
2800	1850	399	120.1	7.9	12.5	0.18	2.01	0.40	6.85	610	11616	17.3
2600	1800	394	121.3	6.0	9.5	0.16	1.81	0.53	6.66	888	15284	11.9
2400	1700	387	120.8	5.7	7.0	0.15	1.58	0.71	6.29	1383	20743	7.6
2200	1550	381	121.9	4.8	7.0	0.14	1.32	0.71	5.74	1654	20743	6.4
2000	1500	378	121.5	3.6	7.0	0.13	1.16	0.71	5.55	1880	20743	5.6
1800	1650	367	125.8	2.5	7.5	0.11	1.15	0.67	6.11	1773	19360	5.9
1600	1550	355	127.2	2.3	10.0	0.10	0.96	0.50	5.74	1592	14520	6.6
1400	1300	329	125.9	3.3	10.0	0.09	0.71	0.50	4.81	2170	14520	4.9
1200	1200	307	125.1	3.1	12.0	0.08	0.56	0.42	4.44	2285	12100	4.6
1000	1100	293	125.6	3.2	14.5	0.06	0.43	0.34	4.07	2476	10014	4.3

B100

RPM	Pressure(lb)	Ex Temp	En Temp	%O2	Time 5ml	V'(m^3/s)	Power (kw)	Fuel Con (ml/s)	Torque (N.m)	BSFC (g/kW.h)	IP (watts)	Thermal Efficiency *y%*
3400	1780	458	115.8	8.9	11.5	0.22	2.35	0.43	6.59	567	12626	18.6
3200	1800	440	118.3	8.5	14.0	0.20	2.23	0.36	6.66	490	10371	21.5
3000	1800	420	118.5	9.0	13.0	0.19	2.09	0.38	6.66	562	11169	18.7
2800	1800	410	117.8	9.0	12.0	0.18	1.95	0.42	6.66	653	12100	16.1
2600	1750	414	119.6	6.1	8.0	0.16	1.76	0.63	6.48	1085	18150	9.7
2400	1700	414	119.9	5.6	7.0	0.15	1.58	0.71	6.29	1383	20743	7.6
2200	1575	410	121.0	4.9	7.5	0.14	1.34	0.67	5.83	1519	19360	6.9
2000	1525	404	121.7	4.5	7.0	0.13	1.18	0.71	5.64	1849	20743	5.7
1800	1650	391	125.2	2.7	7.0	0.11	1.15	0.71	6.11	1899	20743	5.5
1600	1575	372	127.1	2.0	7.0	0.10	0.98	0.71	5.83	2238	20743	4.7
1400	1350	348	127.0	2.4	8.5	0.09	0.73	0.59	5.00	2458	17082	4.3
1200	1350	326	126.9	2.3	8.0	0.08	0.63	0.63	5.00	3047	18150	3.5
1000	1200	317	127.1	2.9	11.0	0.06	0.46	0.45	4.44	2991	13200	3.5

Appendix 3

MSDS FORMS

Material Safety Data Sheet: Biodiesel

(http://nyc.tristatebiodiesel.com/safetysheet.pdf)

1. CHEMICAL PRODUCT

General Product Name: **Biodiesel (B100)**

Synonyms: Fatty Acid Methyl Esters

Product Description: Methyl Esters derived from oils and fats

CAS Number: 67784-80-9

2. COMPOSITION/INFORMATION ON INGREDIENTS

This product contains no hazardous materials.

3. HAZARDS IDENTIFICATION

Potential Health Effects:

INHALATION:

Negligible unless heated to produce vapors. Vapors or finely misted materials may irritate the mucous membranes and cause irritation, dizziness, and nausea. Remove to fresh air.

EYE CONTACT:

May cause irritation. Irrigate eye with water for at least 15 to 20 minutes. Seek medical attention if symptoms persist.

SKIN CONTACT:

Prolonged or repeated contact is not likely to cause significant skin irritation. Material is sometimes encountered at elevated temperatures. Thermal burns are possible.

INGESTION:

No hazards anticipated from ingestion incidental to industrial exposure.

4. FIRST AID MEASURES

EYES:

Irrigate eyes with a heavy stream of water for at least 15 to 20 minutes.

SKIN:

Wash exposed areas of the body with soap and water.

INHALATION:

Remove from area of exposure; seek medical attention if symptoms persist.

INGESTION:

Give one or two glasses of water to drink. If gastro-intestinal symptoms develop, consult medical personnel. (Never give anything by mouth to an unconscious person.)

5. FIRE FIGHTING MEASURES

Flash Point (Method Used): 130.0 C or 266.0 F min (ASTM 93)

Flammability Limits: None known

EXTINGUISHING MEDIA:

Dry chemical, foam, halon (may not be permissible in some countries), CO^2, water spray (fog). Water stream may splash the burning liquid and spread fire.

SPECIAL FIRE FIGHTING PROCEDURES:

Use water spray to cool drums exposed to fire.

UNUSUAL FIRE AND EXPLOSION HAZARDS:

Biodiesel soaked rags or spill absorbents (i.e. oil dry, polypropylene socks, sand, etc.) can cause spontaneous combustion if stored near combustibles and not handled properly. Store biodiesel soaked rags or spill absorbents in approved safety containers and dispose of properly. Oil soaked rags may be washed with soap and water and allowed to dry in well ventilated area. Firefighters should use self-contained breathing apparatus to avoid exposure to smoke and vapor.

6. ACCIDENTAL RELEASE MEASURES SPILL CLEAN-UP PROCEDURES

Remove sources of ignition, contain spill to smallest area possible. Stop leak if possible. Pick up small spills with absorbent materials and dispose of properly to avoid spontaneous combustion (see unusual fire and explosion hazards above). Recover large spills for salvage or disposal. Wash hard surfaces with safety solvent or detergent to remove remaining oil film. Greasy nature will result in a slippery surface.

7. HANDLING AND STORAGE

Store in closed containers between 50°F and 120°F. Keep away from oxidizing agents, excessive heat, and ignition sources. Store and use in well ventilated areas. Do not store or use near heat, spark, or flame, store out of sun. Do not puncture, drag, or slide this container. Drum is not a pressure vessel; never use pressure to empty.

8. EXPOSURE CONTROL /PERSONAL PROTECTION

RESPIRATORY PROTECTION:

If vapors or mists are generated, wear a NIOSH approved organic vapor/mist respirator.

PROTECTIVE CLOTHING:

Safety glasses, goggles, or face shield recommended to protect eyes from mists or splashing. PVC coated gloves recommended to prevent skin contact.

OTHER PROTECTIVE MEASURES:

Employees must practice good personal hygiene, washing exposed areas of skin several times daily and laundering contaminated clothing before re-use.

9. PHYSICAL AND CHEMICAL PROPERTIES

Boiling Point, 760 mm Hg:>200°C

Volatiles, % by Volume: <2

Specific Gravity (H^2O=1): 0.88

Solubility in H_2O, % by Volume: insoluble

Vapor Pressure, mm Hg: <2

Evaporation Rate, Butyl Acetate=1: <1

Vapor Density, Air=1:>1

Appearance and Odor: pale yellow liquid, mild odor

10. STABILITY AND REACTIVITY

GENERAL:

This product is stable and hazardous polymerization will not occur.

INCOMPATIBLE MATERIALS AND CONDITIONS TO AVOID:

Strong oxidizing agents

HAZARDOUS DECOMPOSITION PRODUCTS:

Combustion produces carbon monoxide, carbon dioxide along with thick smoke.

11. DISPOSAL CONSIDERATIONS

WASTE DISPOSAL:

Waste may be disposed of by a licensed waste disposal company. Contaminated absorbent material may be disposed of in an approved landfill. Follow local, state and federal disposal regulations.

12. TRANSPORT INFORMATION

UN HAZARD CLASS: N/A

NMFC (National Motor Freight Classification):

PROPER SHIPPING NAME: Fatty acid ester

IDENTIFICATION NUMBER: 144920

SHIPPING CLASSIFICATION: 65

13. REGULATORY INFORMATION:

OSHA STATUS:

This product is not hazardous under the criteria of the Federal OSHA Hazard Communication Standard 29 CFR 1910.1200. However, thermal processing and decomposition fumes from this product may be hazardous as noted in Sections 2 and 3.

TSCA STATUS:

This product is listed on TSCA.

CERCLA (Comprehensive Response Compensation and Liability Act):

NOT reportable.

SARA TITLE III (Superfund Amendments and Reauthorization Act):

Section 312 Extremely Hazardous Substances:

None

Section 311/312 Hazard Categories:

Non-hazardous under Section 311/312
Section 313 Toxic Chemicals:
None
RCRA STATUS:

If discarded in its purchased form, this product would not be a hazardous waste either by listing or by characteristic. However, under RCRA, it is the responsibility of the product user to determine at the time of disposal, whether a material containing the product or derived from the product should be classified as a hazardous waste,
(40 CFR 261.20-24)

CALIFORNIA PROPOSITION 65:

The following statement is made in order to comply with the California Safe Drinking Water and Toxic Enforcement Act of 1986. This product contains no chemicals known to the state of California to cause cancer.

14. OTHER INFORMATION:

This information relates only to the specific material designated and may not be valid for such material used in combination with any other materials or in any other process. Such information is to the best of the company's knowledge and believed accurate and reliable as of the date indicated. However, no representation, warranty or guarantee of any kind, express or implied, is made as to its accuracy, reliability or completeness and we assume no responsibility for any loss, damage or expense, direct or consequential, arising out of use. It is the user's responsibility to satisfy himself as to the suitableness and completeness of such information for his own particular use.

Material Safety Data Sheet: Methanol

(http://www.aaper.com/aapermsds/13Methanol.pdf)

AAPER MSDS NUMBER: M100 EFFECTIVE DATE: May 2005
AAPER Alcohol and Chemical Company
1101 Isaac Shelby Drive, P. O. Box 339
Shelbyville, Kentucky 40066-0339
Telephone: (502) 633-0650
For chemical emergency – spill, leak, fire, exposure, or accident, call CHEMTREC at 1-800-424-9300 day or night.

Outside the continental United States, call CHEMTREC at 1-703-527-3887 (collect calls accepted).
AAPER Alcohol and Chemical Company urges the customer receiving this Material Safety Data Sheet (MSDS) to study it carefully to become aware of hazards, if any, of the product involved. In the interest of safety, you should: (1) notify your employees, agents, and contractors of the
information on this sheet, and (2) furnish a copy to each of your customers to inform their employees and customers as well.

SECTION I – IDENTIFICATION

PRODUCT NAME: Methanol
SYNONYMS: Methyl Alcohol, Carbinol, Wood Alcohol, Methyl Hydroxide
CHEMICAL FAMILY: Alcohol
FORMULA: CH4O

Section II – INGREDIENTS

COMPOSITION CAS RN. NOMINAL WT/WT% PEL/TLV HAZARD
Methanol 67-56-1 >99 200 ppm Flammable/Poison

SECTION III – HEALTH INFORMATION

INHALATION: Prolonged or repeated exposure or breathing very high concentrations may cause headaches, nausea, vomiting,
dizziness, visual disturbances, giddiness, intoxication, sleepiness, unconsciousness, and death. Initial symptoms of
inhalation may only be mild intoxication, but may become more severe after 12 to 18 hours. Toxic effects are exerted on
the central nervous system, especially the optic nerve.
INGESTION: Swallowing 100 – 250 ml of Methanol can be fatal. Swallowing lesser quantities can cause blindness, dizziness,
headaches, or nausea. Absorption of Methanol is rapid but excretion is slow, resulting in delayed effects or compounding

effects of repeated exposure.
EYE CONTACT: Vapors will irritate the eyes. Liquid and mists will irritate and may burn the eyes.
SKIN CONTACT: Brief contact may dry the skin. Prolonged or repeated contact may irritate the skin, causing dermatitis. Methanol may be
absorbed through intact skin to produce systemic effects.

SECTION IV – EMERGENCY FIRST AID PROCEDURE

FOR OVEREXPOSURE BY:
SWALLOWING: If victim is conscious, immediately induce vomiting by giving 2 glasses of water and sticking a finger down the throat. GET
MEDICAL ATTENTION IMMEDIATELY. CALL A PHYSICIAN OR CHEMTREC (POISON CONTROL) IMMEDIATELY.
After patient has vomited, have patient drink milk, water, or solution of bicarbonate in water (1 tsp./1 qt.). Do not give
anything to an unconscious or convulsing person.
INHALATION: Immediately remove victim to fresh air. If victim has stopped breathing, give artificial respiration, preferably mouth-tomouth.
GET MEDICAL ATTENTION IMMEDIATELY.
CONTACT WITH
EYES: Immediately flush affected area with plenty of cool water. Eyes should be flushed for at least 15 minutes, lifting the upper
and lower eyelids. GET MEDICAL ATTENTION IMMEDIATELY.
CONTACT WITH
SKIN: Immediately wash skin with lots of soap and water. Remove contaminated clothing and shoes; wash before reuse. GET
MEDICAL ATTENTION if irritation persists after washing.

SECTION V – PHYSICAL DATA

BOILING POINT: 148º - 148.5º F
FREEZING POINT: -144º F
VAPOR PRESSURE: 96 mm Hg @ 68º F
SPECIFIC GRAVITY: 0.79
VAPOR DENSITY (AIR = 1): 1.1
SOLUBILITY IN WATER: Complete
APPEARANCE AND COLOR: Clear and colorless

SECTION VI – FIRE AND EXPLOSIVE HAZARDS

FLASH POINT: 54º F ASTM D-56 (Tag Closed Cup)
AUTO-IGNITION TEMPERATURE: 867º F
FLAMMABLE LIMITS IN AIR, % BY VOLUME: LOWER: 6.7 UPPER: 36.0

NFPA (National Fire Protection Association) RATING: HEALTH (1) FIRE (3) REACTIVITY (0)
(Does not apply to exposure hazards other than during a fire.)
Page 1 of 2
EXTINGUISHING MEDIA: Use water spray, dry chemical, CO2, or alcohol foam. Do not use a direct water stream
SPECIAL FIRE FIGHTING: Firefighters should wear self-contained breathing apparatuses and full protective clothing. Use water spray to
cool nearby containers and structures exposed to fire.
UNUSUAL FIRE & EXPLOSION HAZARDS: Extinguish all nearby sources of ignition. This product may burn with a flame which is invisible in daylight.
Mixtures with water and as little as 21% Methanol are flammable.

SECTION VII – REACTIVITY

STABILITY: Stable.
HAZARDOUS POLYMERIZATION: Will not occur.
CONDITIONS & MATERIALS TO AVOID: Heat, sparks, and open flames. Strong oxidizing agents, aluminum, zinc, any metal that displaces hydrogen,
certain plastics, rubbers, acids, and alkalis.
Hazardous Decomposition: May liberate carbon monoxide, carbon dioxide, formaldehyde and unidentified organic compounds in black.

ACTION TO TAKE FOR SPILLS OR LEAKS: Wear protective clothing including rubber boots, rubber gloves, rubber apron, and a self-contained breathing
apparatus in the pressure demand mode or a supplied-air respirator. If the spill or leak is small, a full face-piece
air purifying cartridge respirator equipped for organic vapors may be satisfactory. In any event, always wear eye
protection. Extinguish all ignition sources and ensure that all approved handling equipment is electrically
grounded. For small spills of drips, mop or wipe up and dispose of in D.O.T. approved waste containers. For
large spills, contain by diking with soil or other non-combustible absorbent material, place residue in D.O.T.
approved waste containers; or absorb with non-combustible absorbent material, place resident in D.O.T.
approved waste containers. Keep out of sewers, storm drains, surface waters, and soil. Comply with all applicable government regulations on spill reporting, and handling and disposal of waste

DISPOSAL METHODS: Dispose of contaminated product and materials used in cleaning up spills or leaks in a manner approved for this material. Consult appropriate Federal, State, and Local regulatory agencies to ascertain proper disposal procedures.

NOTE: Empty containers can have residues, gases and mists, and are subject to proper waste disposal, as above.

SECTION VIII – EMPLOYEE PROTECTION

VENTILATION: Approved local mechanical exhaust ventilation capable of maintaining emissions at the point of use below the PEL.

RESPIRATORY PROTECTION: Wear a NIOSH-approved self-contained breathing apparatus in the pressure demand mode, or a supplied-air respirator if use conditions generate vapors or mists. Approved air purifying respirators may be used if sufficient oxygen is available.

PROTECTIVE CLOTHING: Long-sleeved shirt, trousers, safety shoes, rubber gloves, and rubber apron.

EYE PROTECTION: Chemical goggles unless a full face-piece respirator is also worn. It is generally recognized that contact lenses should not be worn when working with chemicals because contact lenses may contribute to the severity of an eye injury.

CONTROL MEASURES: An eyewash and safety shower should be nearby and ready for use.

SECTION IX – ENVIRONMENTAL PROTECTION

ENVIRONMENTAL PRECAUTIONS: Avoid uncontrolled releases of this material. Where spills are possible, a comprehensive spill response plan should be developed and implemented.

SPILL OR LEAK PROCEDURES: Wear appropriate respiratory protection and protective clothing as described in Section VIII. Contain spilled material. Transfer to secure containers. Where necessary, collect using absorbent media. In the event of an uncontrolled release of this material, the user should determine if the release is reportable under applicable laws and regulations.

WASTE DISPOSAL: All recovered material should be packaged, labeled, transported, and disposed of, or reclaimed in conformance with applicable laws and regulations and in conformance with good engineering practices.

SECTION X – REGULATORY CONTROLS

DEPARTMENT OF TRANSPORTATION (DOT):

DOT CLASSIFICATION: 3 (Flammable Liquid) **For Pint Packages Domestic Shipments Only**

DOT PROPER SHIPPING NAME: Methyl Alcohol ORM-D

OTHER DOT INFORMATION: Identification No. UN1230 Consumer Commodity ORM-D

P.G. II

Emergency Response Guide No. 131

TOXIC SUBSTANCE CONTROL ACT (TSCA): This product is listed in the TSCA Inventory of Chemical Substances.

SECTION XI – PRECAUTIONS: HANDLING, STORAGE, AND USAGE

Protect container against physical damage. Detached or outside storage is preferred. Inside storage should be in an NFPA approved flammable liquid storage
room or cabinet. All ignition sources should be eliminated. Smoking should be prohibited in the storage and usage areas. Electrical installations should be in
accordance with Article 501 of the National Electrical Code. NFPA 30, Flammable and Combustible Liquids Code, should be followed for all storage and
handling. Frequent careful leakage inspections should be done. An automatic sprinkler system should be provided. Isolate from oxidizers, chemicals capable
of spontaneous heating, materials reacting with air or moisture to liberate heat, ignition sources and explosives. Consult local fire codes for additional storage
information.

When contents are being transferred, the metallic container must be bonded to the receiving container and grounded to avoid static discharges. Never use
pressure to empty. Replace closure securely after each opening.

Keep material packaged in drums or bottles out of sun and away from heat. Remove closure carefully; internal pressure may be present. Keep closure on to
prevent leakage.

Container hazardous when empty. Since emptied containers retain residual product (vapor and liquid), all precautions described on this MSDS must be
observed.

CAUTION: For manufacturing, processing, repackaging, or industrial use. Not for household use.

SECTION XII – SARA TITLE III

Components present in this product at a level that could require reporting under the statute (section 313) are:

Chemical	CAS Number	Concentration
Methanol	67-56-1	99%

The information contained herein is furnished without warranty of any kind. Employers should use this information only as a supplement to other information
gathered by them and must conduct testing and/or make independent determinations of suitability and completeness of information from all sources to assure
proper use of these materials and the safety and health of employees.
AAPER ALCOHOL AND CHEMICAL COMPANY Methanol
May 2005 Page 2 of 2

Material Safety Data Sheet: Sodium Hydroxide

(http://www.proscitech.com.au/catalogue/msds/c200.pdf)

Date of Issue: 21 Sept 06

STATEMENT OF HAZARDOUS NATURE

Hazardous according to criteria of Worksafe Australia

COMPANY DETAILS

Company: ProSciTech

Address: PO Box 111, Thuringowa Central Qld. 4817 Australia

Street Address: 1/11 Carlton Street, Kirwan Qld, 4817 Australia

Telephone Number: (07) 4773 9444

Fax Number: (07) 4773 2244

IDENTIFICATION SECTION

Product Name Sodium Hydroxide

Other Names Not available

Product Code C200, C2005

U.N. Number UN1823

Dangerous Goods Class 8

and Subsidiary Risk None allocated

Hazchem Code 2X

Poison Schedule S6

Use Common caustic solution

Physical Description and Properties

Appearance White, deliquescent, odourless pellets

Boiling Point/Melting Point BP 1388oC; MP 318oC

Vapour Pressure 0

Specific Gravity 2.1

Flash Point Not applicable

Flammability Limits Not determined

Solubility in water 1111g/L, approx.54% @ 200C

Other Properties

Ingredients

Chemical Name CAS Number Proportion

Sodium hydroxide 1310-73-2 99 – 100%

NaOH

HEALTH HAZARD INFORMATION

Health Effects:

Acute

Swallowed: Will cause severe irritation and chemical burns to the gastrointestinal tract. Symptoms include severe abdominal pain, vomiting and diarrhoea.

Eye: Corrosive. Can cause permanent eye damage and blindness. Severe pain and tearing.

Skin: Will cause severe irritation and chemical burns in contact with the skin, which can result in tissue destruction.

Inhaled: Dusts and mists will cause severe irritation and chemical burns to the respiratory tract.

First Aid:

Swallowed: Do not induce vomiting. Immediately wash out mouth with water and then give plenty of water to drink. Seek immediate medical attention.

Eye: Immediately flush eyes with plenty of water for approximately 20 minutes holding eyelid open. Call a doctor immediately.

Skin: Remove all contaminated clothing. Wash gently and thoroughly with water for 15 minutes. Ensure contaminated clothing is washed before re-use or discard. If contact is more than of minor nature, seek medical attention.

Inhaled: Remove the source of contamination or move the victim to fresh air. Ensure airways are clear and have a qualified person give oxygen through a face mask if breathing is difficult. If victim has stopped breathing begin artificial respiration, or if heart has stopped, cardiopulmonary resuscitation.

First Aid Facilities: Safety showers, eye wash and normal washroom facilities.

Advice to Doctor: Corrosive. May cause stricture. If lavage is performed, endotraceal and/or esophagoscopic control is suggested. Material is strong alkali. If skin burns are present, treat as any thermal burn after decontamination. Eye irrigation may be necessary for extended period of time to remove as much alkali as possible. Duration of irrigation and treatment is at the discretion of attending medical personnel. No specific antidote. Supportive care suggested. Treatment based on judgement of attending physician and reaction of patient.

PRECAUTIONS FOR USE

Exposure Standards: TWA 2mg/m3. Permissible exposure limit (PEL) 2mg/m3

Engineering Controls: Where dust is generated the use of a mechanical exhaust ventilation system is recommended.

Personal Protection: Protection of hands: the use of Nitrile or Neoprene gloves is recommended.
Eye protection: The use of face shields, chemical goggles or safety glasses with
side shield protection complying with AS/NZS 1337 is recommended.
Body protection: The use of plastic apron, sleeves overalls and rubber boots is
recommended.
Where ventilation is inadequate the use of a Class P1 or P2 respirator
complying with AS/NZS 1715 and 1716 is recommended.
Flammability: Not flammable under conditions of use.

SAFE HANDLING INFORMATION

Storage and Transport: Requirements to be met by storerooms and containers: Provide alkali-resistant
floor. Unsuitable material for container: aluminium, zinc, tin, lead, glass. Do
not store together with acids, oxidisers and chlorinated organic compounds.
This product is hydroscopic. Protect from humidity and keep away from water.
Protect for carbon dioxide. Store upright in cool, dry well ventilated area in
well sealed containers. Remove closure carefully to release possible internal
pressure. **UN1823 Hazard group: 8 Packaging group: II Correct
shipping name: Sodium hydroxide, solid**. This material is a Class 8
Corrosive Substance according to the Australian Code for the Transport of
Dangerous Goods by Road and Rail. Class 8 – Corrosive Substances are
incompatible in a placard load with any of the following: Class 1, Explosives.
Page 3 of 3
Sodium Hydroxide
Class 4.3, Dangerous when wet substances. Class 5.1, Oxidising agents and
Class 5.2, Organic peroxides. Class 6, Toxic substances (where the toxic
substances are cyanides and the corrosives are acids). Class 7, Radioactive
substances.
Class 8 substances are incompatible with food and food packaging in any
quantity.

Spills and Disposal: Wear protective equipment. Keep unprotected persons away. Do not allow to enter drainage system, surface or ground water. Do not allow to enter the ground/soil. Sweep or vacuum material avoiding dust generation. Ensure adequate ventilation. Dispose of contaminated material as waste. Must not be disposed of together with household garbage. Do not allow product to reach sewage system. Dispose in accordance with local, state and federal EPA waste regulations. Neutralisation is the preferred method of disposal.

Fire/Explosion Hazard: Solutions may react with aluminium and other soft metals to generate hydrogenwhich is flammable and/or explosive if ignited.
Suitable extinguishing agents: Carbon dioxide; fire-extinguishing powder; dry
sand; cement.
Wear self-contained breathing apparatus. Wear full protective suit.

Hazardous Reaction Heat generated upon dilution with water. Dilute only by adding to water with agitation. Do not add water to sodium hydroxide.

OTHER INFORMATION

Incompatibilities

(Materials to avoid)

Incompatible with strong oxidising agents and strong acids, organic materials,
aluminium, tin, zinc and nitro compounds. Absorbs CO2 from air. Can react
with moisture from air.

Animal Toxicity Data: Skin (rabbit): severe irritation 500mg/24H. Eyes (rabbit): severe irritation 1mg/30sec rinse.

The information published in this Material Safety Data Sheet has been compiled from data in various technical
publications. It is the user’s responsibility to determine the suitability of this information for adoption of necessary
safety precautions. We reserve the right to revise material Safety Data Sheets as new information becomes available.
Copies may be made for non-profit use.

Material Safety Data Sheet: Magnesol

(Absorbent Filter Powder)

(Conforms to CFR 1910.1200)

(http://www.gfs.com/content_us/msds/files/310268.pdf)

1 IDENTIFICATION OF SUBSTANCE

TRADE NAME: MAGNESOL®

GRADES: XL

SUPPLIER: The Dallas Group of America, Inc.

374 Route 22

P.O. Box 489

Whitehouse, NJ 08888 Tel: 908-534-7800 FAX: 908-534-0084

Information department: Product Safety Department

2 COMPOSITION/DATA ON INGREDIENTS

CAS No.	Description	% Min.
1343-88-0	Magnesium Silicate	97

3 HAZARDS IDENTIFICATION

MAGNESOL® products are not explosive, flammable, or combustible.

Mild irritant to eyes, skin, and respiratory system.

HMIS ratings (scale 0-4)

Health = 0

Fire = 0

Reactivity = 0

4 FIRST AID MEASURES

Inhalation: Drink water to clear the throat, blow nose to clear respiratory passages.

Ingestion: Incidental ingestion of this product does not require first aid.

Skin Contact: Wash exposed area thoroughly with soap and water.

Eye Contact: Flush eyes with plenty of water. Call a physician if irritation persists.

5 FIRE FIGHTING MEASURES

EXTINGUISHING MEDIA: Select the proper media to extinguish a surrounding fire.

6 ACCIDENTAL RELEASE MEASURES

SPILL CLEANUP METHODS: Sweep or vacuum spilled material; the use of a sweeping compound/dust suppressant is suggested. Make sure that all personnel involved in housekeeping and spill clean-up follow good industrial hygiene practices and wear proper personal protective equipment.

7 HANDLING AND STORAGE

USAGE PRECAUTIONS: None in designated use.

STORAGE PRECAUTIONS: None in designated use.

STORAGE CRITERIA: No special requirements.

8 EXPOSURE CONTROLS AND PERSONAL PROTECTION

American Conference of Government Industrial Hygienists (ACGIH) - The 1998-99 issue does not list magnesium silicate in the substance index. A threshold limit value - time weighted average (TLV-TWA) of 10 mg/m^3 of total dust is recommended for substances for which no specific TLVs have been assigned.

PROTECTIVE EQUIPMENT:

VENTILATION: No special requirements.

RESPIRATORS: If the airborne concentration exceeds the ACGIH recommended TLV, an approved dust mask should be worn.

PROTECTIVE GLOVES: Not required.

EYE PROTECTION: Not required.

OTHER PROTECTION: Not required.

HYGEINIC WORK ROUTINES: No special requirements.

9 PHYSICAL AND CHEMICAL PROPERTIES

Normal Physical State @ 20° C (68° F): White, odorless powder

pH (1 in 10 slurry) 7.0 to 10.8

Melting Point: 1910° C (3470° F)

Absolute Density (H_20 = 1) 2.10 – 2.20

Solubility in Water: Insoluble

Vapor Pressure: N/A*

Viscosity: N/A*

Boiling Point: N/A*

Vapor Density: N/A*

% Volatile: N/A*

Evaporation Rate: N/A*

Ignition Temperature: N/A*

*N/A - Not applicable

10 STABILITY AND REACTIVITY

Stability: Stable

Polymerization: Will not and cannot occur

Conditions and Materials to Avoid - None in designated use. In sufficient quantity, a filter cake composed of a flammable organic liquid absorbed on MAGNESOL® or other filter materials such as diatomaceous earth, perlite, or natural clays may be pyrophoric.

11 TOXICOLOGICAL INFORMATION

Hill Top Biolabs, Inc. a) Albino male rat: Acute oral - LD50 > 5.0 g/kg

Cincinnati, OH, 1989. b) Albino rabbit: Acute dermal - LD50 > 2.0 g/kg Primary Irritation Index 0.80

0 = No erythema (skin redness)

1 = Very slight erythema

c) Albino rabbit: Eyes-Mild irritation and conjunctivitis.

The above study was specific to MAGNESOL® with the formula $MgO:2.6SiO_2 \cdot H_2O$. The conclusions of this test were:

A. MAGNESOL® is classified as non-toxic by oral administration.

B. It is not a primary skin irritant or a corrosive by dermal application.

C. It is not classified as toxic by dermal administration.

D. It is classified in Toxicity Category III by ocular administration.

This product does not contain any ingredient designated by IARC, NTP, ACGIH, or OSHA as probable or suspected human carcinogens.

12 ECOLOGICAL INFORMATION

WATER HAZARD CLASSIFICATION: Not a known pollutant.

13 DISPOSAL CONSIDERATIONS

DISPOSAL METHODS: MAGNESOL® products are not regulated under RCRA landfill requirements. However, under RCRA, it is the responsibility of the user of products to determine, at the time of disposal, whether the product falls under RCRA as a regulatory waste. This is because product uses, transformations, synthesis, mixtures, etc., may render the resulting end-product subject to regulation.

14 TRANSPORT INFORMATION

DOT CLASS: Not Regulated

UN/NA NO.: Not Classified

FREIGHT CLASSIFICATION: NMFC - 48210 Column 55

IMO CLASS: Not Classified

15 REGULATORY INFORMATION

This material is not listed in Sections 302, 312, or 313 of SARA III.

It is reported in the TOSCA Inventory, 1986.

16 OTHER INFORMATION

APPROXIMATE CHEMICAL FORMULA: $MgO:2.6SiO_2 \cdot H_2O$

International Numbering System (INS) number 553i

European Union E number E553a(i)

EINECS number: 215-681-1

References A through D and F are specific to magnesium silicate with the approximate chemical formula $MgO:2.6SiO_2 \cdot H_2O$:

A. 21 CFR Part 182, Subpart C - Generally recognized as safe.

B. Chemical Toxicology of Commercial Products, Edition 4, 1976 - No acute toxicology recognized.

C. Chemical Abstracts, 1958, 6721 Referring to USSR Medical Prom.10, No.4, Moscow, USSR - The powder is well tolerated by white rats, dogs, and cats.

D. NIOSH Registry of Toxic Effects of Chemical Substances, Vol. 2, 1986 - Irritation data: Human skin-300 micro gram/3 days. Very mild.

E. American Conference of Government Industrial Hygienists - The 1998-99 issue does not list magnesium silicate in the substance index. A threshold limit value - time weighted average (TLV-TWA) of 10 mg/m^3 of total dust is recommended for substances for which no specific TLVs have been assigned.

F. Magnesium silicate with an approximate chemical formula of $MgO:2.6SiO_2 \bullet H_2O$ is not listed in:

1. IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man, 1988
2. Industrial Hygiene and Toxicology, F. A. Patty
3. Industrial Toxicology, Alice Hamilton and Harriet Hardy
4. Toxicology of the Eye, W. Morton Grant
5. Dangerous Properties of Industrial Materials, Sax and Lewis
6. Government Publications:

a. NIOSH/OSHA Pocket Guide to Chemical Hazards
b. Registry of Toxic Effects of Chemical Substances
c. The Industrial Environment - It's Evaluation and Control

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The data contained herein is being supplied for the limited purpose of complying with the OSHA "Right-to-Know" Regulation, 29 CFR 1910.1200. The submission of this MSDS may be required by law but this is not an assertion that this substance is hazardous when used in accordance with proper safety practices and normal handling procedures.

Appendix 4

ITEMISED COSTS

QTY	CODE	PRODUCT DESCRIPTION		COST EX	COST INC	TOTAL
5	16179	ELBOW COMP BRS (NYLON OLIVE)	20C X 20C	9.14	10.054	50.27
6	18739	BALL VALVE LEVER HYFLO AGA	F&F NON DR 15MM	8.82	9.702	58.21
5	18119	TEE BRS 15MM		4.07	4.477	22.39
10	17509	ELBOW F&F BRS 15MM		4.09	4.499	44.99
4	17734	NIPPLE ALLTHREAD BRS 15MM X	150MM	8.93	9.823	39.29
10	17818	NIPPLE HEX BRS 15MM		1.81	1.991	19.91
2	17415	BUSH BRS 25MM X 20MM		4.88	5.368	10.74
10	17867	NIPPLE HEX RED BRS 20M X15MM		3.10	3.41	34.10
10	17298	OLIVE NYLON 20MM		0.25	0.275	2.75
10	17238	NUT SERVICE KINGCO BRS 20MM		1.60	1.76	17.60
3	30716	TAPE PLUMBERS PNK TEFLON		3.73	4.103	12.31
1	22896	REDUCER CONCENTRIC CU	50MMX20MM	5.81	6.391	6.39
10	26174	SADDLE SUIT CU TUBE C/P LIGHT	20MM	0.84	0.924	9.24
2	10309	COUPLING DWV THREADED	PVC 100MM	3.70	4.07	8.14
2	10349	CAP PUSH ON DWV PVC 100MM		2.36	2.596	5.19
10	42750	COVER PLATE 15MM BSP X FLAT	S/S	0.40	0.44	0.44
5	16230	OLIVE COPPER 20MM		0.56	0.616	0.62
1	31399	STEEL WOOL ROLL 500GRM		6.38	7.018	7.02
1	22876	REDUCER CONCENTRIC CU	20MMX15MM	1.14	1.254	1.25
2	10206	BEND DWV M&F INTO FITTING	40MM X 90D	1.62	1.782	1.78
1	19333	CHECK VALVE SPRING BRS NON	NON S/M F&F 20MM	10.07	11.077	11.08
2	19331	CHECK VALVE SPRING BRS NON	NON S/M F&F 15MM	7.47	8.217	8.22
1	20677	CONNECTOR STR W3 20 X 15MI	(3/4X1/2")	2.49	2.739	2.74
1	20677	CONNECTOR STR W3 20 X 15MI	(3/4X1/2")	2.49	2.739	2.74
4	27240	BRACKET S/OFF COATED SUIT	PIPE 100MM	5.26	5.786	5.79
3	17562	ELBOW M&F BRS 15MM		6.19	6.809	6.81
2	10338	CAP THREADED ACCESS DWV	100MM	3.98	4.378	4.38
1	21484	BUSH TUBE BRS 15C X 15FI		1.25	1.375	1.38
1	20788	ELBOW CAP W12 20CX20C		1.95	2.145	2.15
10	17668	LOCKNUT FLANGED BRS 15MM		1.32	1.452	1.45
1	28001	SCREWS TEK BUTTON NO NEO CL	12MMX8G (100)	9.72	10.692	10.69
1	10945	SOLVENT CEMENT PRESSURE	P GRN 125ML	6.00	6.6	6.60
1	10913	PRIMING FLUID PVC RED 250ML		5.00	5.5	5.50
6	31109	SOLDER SILVER 2% PER STICK	750MM X2.5MM DIA	1.94	2.134	2.13
1	31334	FLUX EZI-WELD W1S602 250GRM		18.32	20.152	20.15
4	16282	UNION COMP BRS (NYLON OLIVE)	20C X 15FI	4.41	4.851	4.85

QTY	CODE	PRODUCT DESCRIPTION		COST EX	COST INC	TOTAL
1	35113	BALL VALVE 3-WAY L-PORT S/E	AGA NON DR 20MM	81.71	89.881	89.89
4	17945	SOCKET HEX BRS 15MM		1.90	2.09	2.09
4	17818	NIPPLE HEX BRS 15MM		1.81	1.991	1.99
2	26541	CLAMP HOSE STL 1A 22MM-30MM		1.27	1.397	1.40
2	83096	DIRECTOR MICRO IRRIGATION	20MM MI X 19MM	0.44	0.484	0.48
2	15041	ELBOW POLY THREADED BSP	FEMALE 3/4"F	2.54	2.794	2.79
2	42896	COVER PLATE 20MM BSP X FLAT	S/S	1.39	1.529	1.53
2	17867	NIPPLE HEX RED BRS20MMX15MM		3.10	3.41	3.41
2	82712	HOSE CLEAR PLASTIC 20MM (PER	MTR)	2.15	2.365	2.37
2	11353	CAP STORMWATER PUSH ON PVC	90MM	1.80	1.98	3.96
2	17734	NIPPLE ALLTHREAD BRS 15MM X	150MM	8.93	9.823	19.65
5	17818	NIPPLE HEX BRS 15MM		1.81	1.991	1.99
2	17867	NIPPLEHEX RED BR 20MM X15MM		3.10	3.41	3.41
1	21452	BUSH TUBE BRS 15C X 15MI		1.38	1.518	1.52
1	17474	CAP BRS 15MM		2.38	2.618	2.62
2	18119	TEE BRS 15MM		4.07	4.477	4.48
2	17409	BUSH BRS 20MM X 15MM		1.38	1.518	1.52
1	17564	ELBOW M&F BRS 20MM		5.68	6.248	6.25
3	17238	NUT SERVICE KINGCO BRS 20MM		1.60	1.76	1.76
4	17298	OLIVE NYLON 20MM		0.25	0.275	0.28
1	27330	BRACKET FIXING ONLY ADJ S/O	0080 ABEY	1.37	1.507	1.51
1	26253	CLIP HEAD SUIT CU TUBE N/C	0027 ABEY 20MM	0.84	0.924	0.92
2	26535	CLAMP HOSE STL 0 16MM-22MM		1.19	1.309	1.31
1	17734	NIPPLE ALLTHREAD BRS 15MM X	150MM	8.93	9.823	9.82
1	29081	RIVETS ALUM AS 4-2 (100)		7.47	8.217	8.22
4	14012	COUPLING PLASSON METRIC 25P	X 25P	7.74	8.514	34.06
1	83668	CARTRIDGE 5 MICRON WOUND	SEDIMENT	11.35	12.485	12.49
2	10347	CAP PUSH ON DWV PVC 65MM		1.69	1.859	1.86
2	26470	SADDLE S/OFF SUIT D.W.V. PIPE	N/C 1694 65MM	1.38	1.518	1.52
1	10346	CAP PUSH ON DWV PVC 50MM		1.62	1.782	1.78
1	10353	CAP DUST DWV PVC 50MM		0.80	0.88	0.88
1	18739	BALL VALVE LEVER HYFLO AGA	F&F NON DR 15MM	8.82	9.702	9.70
1	17346	ADAPTOR M&F BRS 15MM		1.86	2.046	2.05
1	17348	ADAPTOR M&F BRS 20MM		2.66	2.926	2.93
2	18194	UNION BARREL F&F LIGHT BRS	20MM	14.88	16.368	16.37
1	30490	BOND TITAN BOSTIK SYRINGE		18.18	19.998	20.00
1	324142	BIA INOX80PC 800W 240V	ELEC CONT FLOWS	303.12	333.432	333.43

QTY	CODE	PRODUCT DESCRIPTION	COST EX	COST INC	TOTAL
1		ISOPROPYL ALCOHOL	11.10	13.32	13.32
1		DEMINERALISED WATER`	1.20	1.32	1.32
1		ALCOHOL & ACID MIXING VESSELL	149.34	164.27	164.27
2		REACTOR VESSELL	28.18	31	62.00
1		OUTLET PUMP	41.20	49.44	49.44
1		MISC CONSTRUCTION MATERIALS	212.90	234.19	234.19
1		ELECTRICAL FITTINGS	68.00	74.8	74.80
1		FINISHING MATERIALS (PAINT, EDGING, SILICONE)	114.83	137.79	137.79
				TOTAL	**1868.11**

Appendix 5

SUPPORTING INFORMATION

"As the concentration of biodiesel increased, the oxides of nitrogen [NOx] emissions increased. The B20A20 fuel blend effectively reduced the oxides of nitrogen emissions below that of baseline diesel fuel. Retarding the timing was an effective way of reducing NOx emissions when fuelling with the biodiesel blends. Oxides of nitrogen emissions ... can be successfully reduced below that of baseline diesel fuel by either retarding injection timing or replacing 20 percent of the baseline diesel fuel of the B20 blend with heavy alkylate." -- "Engine Exhaust Emissions Evaluation of a Cummins L10E When Fueled with a Biodiesel Blend", William Marshall, Leon G. Schumacher, Steve Howell (1995), Society of Automotive Engineers, SAE Paper # 952363
[B20 = a blend of 20% biodiesel with 80% conventional low sulphur petroleum diesel fuelB20A20 = a blend of 20% biodiesel and 20% heavy alkylate with 60% conventional low-sulphur petroleum diesel fuel]

"Nitrogen Oxides (NOx) emissions from biodiesel increase or decrease depending on the engine family and testing procedures. NOx emissions (a contributing factor in the localized formation of smog and ozone) from pure (100%) biodiesel increased in this test by 13 percent. However, biodiesel's lack of sulfur allows the use of NOx control technologies that cannot be used with conventional diesel. So, biodiesel NOx emissions can be effectively managed and efficiently eliminated as a concern of the fuel's use." -- US National Biodiesel Board, Biodiesel Report, April 1998, "Biodiesel First Alternative Fuel to Meet EPA Health Effects Requirement -- Positive environmental and health effects results for Biodiesel" [Sulphur poisons catalytic converters. Sulphur content of low-sulphur conventional diesel fuel: 0.05 percentage weight. Sulphur content of methyl ester biodiesel: less than 0.001 percentage weight.]

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Evaluation of Magnesol R60 as an Alternative to Water Washing During Biodiesel Production

Final Report
to the
Dallas Group of America

Jon Van Gerpen
Kirk Menges

Department of Mechanical Engineering
Iowa State University

May 3, 2004

Objective

The purpose of this project was to compare a commercial product called Magnesol R60, produced by The Dallas Group of America, Inc., to water washing for removal of soap, free glycerin, and total glycerin from biodiesel produced from soybean oil and yellow grease. The biodiesel pilot plant located at the Biomass Energy Conversion Center (BECON) Facility in Nevada, Iowa was used to produce the biodiesel and conduct the experiments.

Biodiesel Production

Biodiesel is an alternative fuel for compression ignition engines that has many benefits over petroleum-based diesel fuels including lower emissions and the potential for reducing global warming. It can be made from many different oilseed feedstocks and animal greases along with different alcohols and catalysts. The pilot plant at the BECON facility can produce biodiesel from soybean oil, yellow grease, and restaurant grease, using methanol and sodium methoxide as the other two ingredients of the reaction.

Soybean oil or pre-treated grease (grease from the esterification process described below) is reacted for 1-2 hours with the appropriate amount of methanol and catalyst (sodium methoxide) to produce biodiesel in a process called transesterification. Heat and agitation help speed the process of transesterification, so the temperature of the reactor is held at 140°F. This temperature is slightly below the boiling point of the methanol. A condenser is located on the top of the sealed reactor for condensing methanol, which returns to the reaction. Agitation is provided using a constant speed mixing motor with a propeller on the top of the mixing shaft and a paddle on the bottom. Fixed baffles inside the reactor assist with mixing of the fluids. Sometimes the reaction is conducted in two steps. In the first step, approximately 80% of the methanol and catalyst are added and the mixture is agitated for an hour. Then, the free glycerin that has formed is allowed to settle and is removed. Then, the remaining 20% of the methanol and catalyst is added and the reaction is continued for another hour. Finally, additional glycerol that has formed is removed. This approach provides a very complete reaction while potentially using less methanol than the single step reaction. Upon completion of the reaction, the mixture is pumped from the reactor into the methanol recovery system for methanol removal from the fluid.

Biodiesel enters the methanol recovery system where it is pre-heated by an economizer heat exchanger before entering the main heater exchanger, which heats the fluid to 240°F. The fluid then enters the flash vessel where methanol is flashed from the fluid and drawn through a condenser. The liquid methanol is collected in a storage tank where it will be sent to a methanol purification system for reuse in the biodiesel production process. Biodiesel exiting the methanol recovery system is pumped into the separation tank where free glycerin settles to the bottom of the cone bottom tank. The glycerin is pumped from the separation tank into a storage tank and will eventually be sent to a glycerin purification system. The by-products of biodiesel production, soap and residual methanol and free glycerin, are removed from the fuel at the biodiesel pilot plant by washing with hot, softened water.

The washing process in the biodiesel pilot plant involves spraying hot, softened water through spray nozzles on to the top of the biodiesel so the droplets fall through the fuel until they collect at the bottom of the tank with the soap that each droplet was able to extract from the biodiesel. After dispensing an amount of water equal to 50 percent of the weight of the biodiesel fuel, the water, soap, and biodiesel mixture are recirculated in the tank by pumping the fluid from the bottom of the tank and spraying it through the nozzles in the top of the tank. This typically takes 15 minutes. Then 30-45 minutes is allowed for settling, which allows the separation of the water/soap (and some glycerin) mixture from the biodiesel. The water/soap mixture is pulled off the bottom of the tank and a fresh batch of hot, softened water is sprayed into the tank and the process of mixing and settling is repeated again for a total of 4 to 5 washes. The last step in the biodiesel production process involves the drying of the fuel.

The drying system consists of an economizer heat exchanger that preheats the incoming biodiesel before being heated in the main heat exchanger to 240°F. The biodiesel is then sprayed through a nozzle into a flash tank under vacuum (around 28 inches of mercury) where the water is flashed off while the dried biodiesel is pumped from the flash tank into a storage tank. It is then analyzed in order to determine if it meets the fuel specifications for use in a compression ignition engine (ASTM D 6751).

The esterification process, or the process for pretreating grease prior to making biodiesel, is needed for greases or oils containing free fatty acid (FFA) amounts that are higher than 1.5 to 2 percent. The yellow grease used at the pilot plant is usually between 8 and 10% FFA. The pretreatment process is needed to reduce the FFA and prepare the grease for the base catalyzed process (transesterification). Without this process, soap would be produced when adding the base catalyst to the high free fatty acid grease in the biodiesel production process.

Pretreatment consists of determining the FFA of the oil or grease and then adding an acid catalyst and alcohol, in amounts based on the FFA, and heating and agitating the mixture for 1-2 hours before allowing it to separate into two phases. The acid and alcohol used in the pretreatment process at the pilot plant are sulfuric acid and methanol. The upper phase consists mainly of a water/methanol mixture and some free fatty acids, while the bottom layer is made up mostly of lower FFA grease or oil, some esters, and methanol. The two phases must be kept warm in order to prevent the grease or oil from congealing and trapping the methanol/water mixture. The mixture is kept at a temperature of 140°F by heating coils inside the tank. The upper phase is removed and the lower phase is supplied to the main reactor for the transesterification reaction.

Experiment

In preparation for the comparison, biodiesel was made from soybean oil and yellow grease using the biodiesel pilot plant. The amount of soybean oil, methanol, and catalyst (sodium methoxide) used in the experiments is given in Table 1. The amount of yellow grease, methanol, and sulfuric acid for the pre-treatment (esterification process) along with the amount of pre-treated grease, methanol, and catalyst (sodium methoxide) used for the transesterification process is also given in Table 1. Note that a two-step transesterfication reaction was used for both feedstocks, but only the yellow grease required pretreatment.

Table 1: Biodiesel Reaction Material and Amounts

Soybean Oil	1st Reaction	2nd Reaction
	(80%)	(20%)
Biodiesel Reaction	Amount (lbs.)	Amount (lbs.)
Soybean Oil @ 0.70% FFA	520	520
Methanol	95.68	23.92
Sodium Methoxide	6.37	1.59
Yellow Grease		
Pre-treatment Reaction	Amount (lbs.)	
Yellow Grease @ 11.6% FFA	480	
Methanol	125.04	
Sulfuric Acid	2.78	
	80%	20%
Biodiesel Reaction	Amount (lbs.)	Amount (lbs.)
Yellow Grease @ 1.62% FFA	460	450
Methanol	84.64	21.16
Sodium Methoxide	8.21	2.05

For all reactions the temperature of the mixture of fluids was kept at 140°F with constant agitation in order to achieve as complete a reaction as possible. Each reaction was timed for an hour and a half after the reaction reached 140°F. After the reaction period, each batch of biodiesel was sent through the methanol recovery system, so methanol could be removed from the fuel before separation. Methanol must be removed from the fuel because it reduces the effectiveness of the Magnesol. The methanol also contributes to a lower flash point, which can affect the classification of the fuel as flammable or non-flammable. Each batch of biodiesel was tested in a Marten-Pensky Flashpoint apparatus in order to make sure the flashpoint of the fuel was well above 150°F. In each case, as the flashpoint of each biodiesel batch was determined, a graph was used to determine the percent of methanol in the fuel based on the flashpoint. For each case, the methanol percentage in the fuel was determined to be low enough that it would not skew the results of the experiment. Once it was determined that the methanol percentage was low enough in each batch of fuel, half was set aside for water-washing while the rest was used in the Magnesol experiment.

The batches of biodiesel that were set aside for washing were washed according to the process used at the biodiesel pilot plant. This involved 4 washes using hot, softened water along with agitation, with fresh water used for each wash. After separation, the biodiesel fuel was dried using a flash vacuum drying process. All batches sent through the drying system were heated to 240°F and then throttled from a pressure of 25 psig to a vacuum of 27-28 in Hg. A sample of fuel from each batch was tested for moisture in a Karl-Fischer Moisture Titrator to make sure the moisture level met the fuel specification required for biodiesel. Upon completion of the drying process and moisture determination, each batch of biodiesel was put in a 55 gallon barrel and labeled according to the feedstock that was used to produce the fuel.

To conduct the Magnesol tests, an agitated tank and its corresponding piping system were washed with hot water and caustic. As the hot water and caustic were being recirculated through the degumming piping system, heat was supplied to the fluid to help with the cleaning process. This involved multiple washes and disposal of the water caustic mixture. Then, the unwashed and methanol-free soybean oil and yellow grease biodiesel were each added separately to the tank along with the corresponding Magnesol for each separate experiment. The Magnesol and biodiesel mixture was heated to 180ºF and recirculated for approximately 30 minutes before being filtered using a 5 micron sock-type filter. It was determined that diatomaceous earth needed to be added to the Magnesol and biodiesel mixture in order to assist in the development of a layer of "cake" on the filter. Without a layer of "cake", the finer Magnesol particles tende to avoid being trapped in the filter and remained in the biodiesel. After each experiment the biodiesel was tested for soap level.

Results

Table 2 shows the properties of the biodiesel after being water-washed and dried compared wit the original unwashed biodiesel. While the washing process reduced the soap level from 651 ppm to 13 ppm, the data show that the amount of free and total glycerin actually increased. Th increase in free and total glycerin is unlikely to be correct and may indicate non-representative sampling of the biodiesel. The data also show a slight increase in the cetane number from 51.0 to 54.1. This is within the variability of the cetane test procedure.

Table 3 shows the effect of two different adsorbent treatments, Magnesol R60 and a compound identified as Sample B. Comparison to the unwashed biodiesel described in Table shows that the Magnesol reduced the soap level from 651 ppm to 4 and 5 ppm,

Table 2. ASTM D6751 Results for **Water-washed Soybean Biodiesel**

ASTM Specification	*ASTM D6751 specification*	*Unwashed, Untreated M.E.*	*Washed And Dried M.E.*
Free Glycerin, %	0.020 maximum	0.033	0.084
Total Glycerin, %	0.240 maximum	0.209	0.282
Flash Point, °C	130 minimum	>190	170
Water and Sediment, vol. %	0.050 maximum	0.10	0.15
Carbon Residue, %	0.050 maximum	<0.010	0.050
Sulfated Ash, mass %	0.020 maximum	0.000	0.005
Kinematic Viscosity, cSt@40°C	1.9 - 6.0	4.127	4.207
Total Sulfur, mass %	0.05 maximum	0.00006	0.00014
Cetane Number	47 minimum	51.0	54.1
Cloud Point, °C	Report	0.0	0.0
Copper Corrosion	No. 3 maximum	1a	1a
Acid Number, mg KOH/gram	0.80 maximum	0.32	0.31
Phosphorus, mass %	0.001 maximum	0.0007	0.0006
ppm Soap	No specification	651	13

Table 3. ASTM D6751 Results for **Adsorbent Treated Soybean Biodiesel**

ASTM Specification	***ASTM D6751 specification***	***1% MAGNESOL R60***	***1% DALLAS SAMPLE B***
Free Glycerin, %	0.020 maximum	0.005	0.003
Total Glycerin, %	0.240 maximum	0.191	0.168
Flash Point, °C	130 minimum	200	189
Water and Sediment, vol. %	0.050 maximum	0.04	0.10
Carbon Residue, %	0.050 maximum	<0.010	0.013
Sulfated Ash, mass %	0.020 maximum	0.000	0.003
Kinematic Viscosity, cSt@40°C	1.9 - 6.0	4.097	4.109
Total Sulfur, mass %	0.05 maximum	0.00002	0.00006
Cetane Number	47 minimum	51.3	50.9
Cloud Point, °C	Report	0.0	0.0
Copper Corrosion	No. 3 maximum	1a	1a
Acid Number, mg KOH/gram	0.80 maximum	0.27	0.38
Phosphorus, mass %	0.001 maximum	0.0005	0.0000
ppm Soap	No specification	4	5

and also reduced the free and total glycerol level. The acid value was decreased for the Magnesol R60 and increased for the Sample B. These changes in acid value are not believed to be significant and are probably within the range of error for the measurement.

Table 4 shows the corresponding results for the yellow grease-based biodiesel. Note that an important difference between the biodiesel from this feedstock and the soybean-based biodiesel is the high initial soap level of 2458 ppm. When this biodiesel was passed through the methanol recovery system, the removal of the methanol caused the soap to come out of solution and plug the screens used to protect the pumps. This prevented the methanol recovery system from working properly. To ensure that the methanol was removed, a portion of the biodiesel was processed through a batch-type solvent recovery still. Thus, the results presented in Tables 4 and 5 show data for samples of biodiesel that had not been through the still and a sample that had gone through the still.

In Table 4, the water-washed biodiesel showed a reduction in soap from 2458 to 91 ppm. There was also a reduction in free glycerin although still not to the level required by the biodiesel standard.

Table 5 shows the properties of the biodiesel samples that had and had not been treated with the still and then processed with the Magnesol R60 The sample that had not gone through the still was treated with 3% Magnesol R60 and the sample that had gone through the still was treated with 2% Magnesol R60. The results for the two cases are very similar with equal flash points, indicating similar methanol contents, and reductions in soap to 14 ppm for the sample that had not gone through the still and 4 ppm for the sample that had gone through the still. Both sample met the requirements for ASTM D 6751 except that the sample that had not been through the still was a little high on water and sediment. This may have been caused by Magnesol breaking through the filter.

Table 4. ASTM D6751 Results for **Water washed Yellow Grease Methyl Ester**

ASTM Specification	*ASTM D6751 specification*	*Unwashed, Untreated M.E.*	*Washed And Dried M.E. (not through still)*
Free Glycerin, %	0.020 maximum	0.063	0.037
Total Glycerin, %	0.240 maximum	0.220	0.185
Flash Point, °C	130 minimum	179	>190
Water and Sediment, vol. %	0.050 maximum	0.70	0.06
Carbon Residue, %	0.050 maximum	0.060	0.013
Sulfated Ash, mass %	0.020 maximum	0.007	0.004
Kinematic Viscosity, cSt@40°C	1.9 - 6.0	5.095	5.107
Total Sulfur, mass %	0.05 maximum	0.00146	0.00139
Cetane Number	47 minimum	57.8	60.3
Cloud Point, °C	Report	10.0	9.0
Copper Corrosion	No. 3 maximum	1a	1a
Acid Number, mg KOH/gram	0.80 maximum	0.21	0.27
Phosphorus, mass %	0.001 maximum	0.0009	0.0008
ppm Soap	No specification	2458	91

Table 5. ASTM D6751 Results for **Adsorbent treated Yellow Grease Methyl Ester**

ASTM Specification	*ASTM D6751 specification*	*3% Magnesol R60 (ME not through still)*	*2% Magnesol R60 (ME through still)*
Free Glycerin, %	0.020 maximum	0.009	0.004
Total Glycerin, %	0.240 maximum	0.151	0.147
Flash Point, °C	130 minimum	168	168
Water and Sediment, vol. %	0.050 maximum	0.10	0.005
Carbon Residue, %	0.050 maximum	0.000	0.000
Sulfated Ash, mass %	0.020 maximum	0.003	0.002
Kinematic Viscosity, cSt@40°C	1.9 - 6.0	5.089	5.060
Total Sulfur, mass %	0.05 maximum	0.00129	0.00133
Cetane Number	47 minimum	57.1	57.4
Cloud Point, °C	Report	10.0	9.0
Copper Corrosion	No. 3 maximum	1a	1a
Acid Number, mg KOH/gram	0.80 maximum	0.33	0.32
Phosphorus, mass %	0.001 maximum	0.0008	0.0008
ppm Soap	No specification	14	4

Conclusions

The Magnesol R60 provided a greatly improved reduction in soap and free and bound glycerin when compared to the traditional water washing process. Final soap and free and total glycerin levels were less for the Magnesol than for water washing. While the biodiesel producer has the additional costs of the Magnesol and disposal of the spent material, this should be justified by the reduction in water usage, wastewater treatment, and the additional processing steps needed to separate the emulsions that often form when water washing biodiesel containing high soap levels.

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	SPECIFICATIONS		RAPESEED METHYL ESTERS			SOYBEAN METHYL ESTERS			YELLOW GREASE METHYL ESTERS		
Parameter	ASTM D6751	EN 14214	Initial Sample	Washed & Dried	0.5% D-SOL D60	Initial Sample	Washed & Dried	0.5% D-SOL D60	Initial Sample	Washed And Dried	1.5% D-SOL D60
Soap, mg/kg	None	None	637	30	0	651	13	0	1900	91	0
Free Glycerin, %	0.020 max	0.020 max	0.053	0.000	0.005	0.033	0.002	0.000	0.063	0.037	0.002
Total Glycerin, %	0.240 max	0.250 max	0.217	0.162	0.162	0.209	0.196	0.186	0.220	0.185	0.143
Flash Point, °C	130 min	120 min	90	130	140	80	143	150	100	158	155
Metals I Na+K, mg/kg	5.0 max	5.0 max	53	3	0	61	5	0	67	3	0
Metals II Mg+Ca, mg/kg	5.0 max	5.0 max	6	5	0	4	0	0	8	0	0
Oxidation Stability @ 110°C, hours	3.0 min	6.0 min	0.61	0.65	2.25	0.5	0.6	3.7	0.5	0.6	4.3
Water, mg/kg	500 max	500 max	400	350	378	1000	150	300	7000	600	50
Sulfated Ash, mass %	0.020 max	0.020 max	0.056	0.002	0.000	0.060	0.005	0.000	0.08	0.010	0.002
Methanol Content, %	None	0.2 max	0.19	0.015	0.009	0.15	0.001	0.011	0.116	0.001	0.002

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