The Design and Construction of a Small-Scale Biodiesel Plant

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Mr. Handel Callender
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December 15th 2006

Dear Mr. Callender,

The team could not miss this opportunity to thank their mentor; the man who allowed this adventure to happen. It is only natural that the first page of this report be devoted to you.

This internship has been a tremendously invaluable experience on many levels. It has been an extraordinary opportunity to challenge ourselves through the application of all our knowledge, ingenuity, and creativity towards our goal: constructing a biodiesel plant. Through the challenges we have overcome during the process we acquired invaluable practical skills which cannot be taught inside the traditional university framework. This experience has provided us with essential tools which we know will be useful in all our future endeavors.

We thank you for trusting us with your project and for your perpetual support. Your devotion to promoting business in a framework which incorporates an inherent concern for the environment while integrating social realities of development will remain an inspiration to us. We are confident that this report will be helpful with the forthcoming expansion considerations, however if any problems persist it will be our pleasure to further assist you. Thank you for being an intrinsic part of what made Barbados such an interesting and fruitful experience.

Sincerely,

The team:

Wesley Fallon
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Nora Kirkpatrick
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Executive Summary

Construction of a small-scale biodiesel plant

The purpose of our internship was to design and construct a small-scale biodiesel plant for NativeSun NRG.

Biodiesel is a more sustainable and environmentally friendly fuel that is made with vegetable oil and methanol through a process known as transesterification. The fuel has superior combustion characteristics, and a lower emissions rating when compared to traditional, petrochemical diesel. NativeSun NRG, a local company, has been processing vegetable oil into biodiesel since 2004, with a small, but growing market. With a growing demand for biodiesel, and a government push for sustainable energy resources, NativeSun decided to upgrade production by constructing a new plant.

In order to plan our construction, we divided the operation into four stages: the vegetable oil pre-heat, the main processing stage, the biodiesel wash stage, and the wastewater treatment stage. As NativeSun is a one-person operation, the design of each stage focused on autonomous operation and minimizing the amount of work needed for each production stage. Due to financial constraints, the focus shifted to the main processing stage as it is integral to the process. With the main stage complete, work began on the oil preheat and wash stages. While it was not possible to build as per design, we shifted our focus to connecting the stages and setting them up on a provisional level to ensure that NativeSun could continue to produce biodiesel until funds became available for the full design implementation.

Even though we were unable to meet all of our desired objectives , we believe this internship was successful. The plant is nearly operational, and once funding becomes available, our designs will be there for NativeSun to implement. Furthermore, we have supplied Mr. Callender with a methodology for both construction and operation of the plant.

In conclusion, we have greatly helped NativeSun, and Mr. Callender, in the development of biodiesel production in Barbados. Along with Mr. Callender, we hope that the plant will ultimately serve as a template for other small-scale biodiesel production in the Caribbean, and beyond.

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We would like to thank Humphrey Broome, Business development officer at the Barbados Investment and Development Corporation (BIDC) for inviting us to the conference regarding the draft of a National Energy Plan, where we were able to gain some perspective on how environmental policy making is carried out in Barbados.

We are further grateful to Cheryl Collymore and Dr. Glyn Williams, consultants at C&G International, Inc. for sharing their expertise with us in working out specific complex issues in our design. We would also like to thank Brian Layne from the BIDC and Vincent MacLean of AquaSol for their technical input.

We also owe much of our success to Al at H&B Hardware for his immense assistance in choosing the right parts for our process, and the machine technicians at the Barbados Water Authority workshop and at Williams Steel who produced specialty parts for us free of charge.

Lastly, we wish to thank Susan Mahon for her guidance and suggestions all throughout the many aspects of this internship.

Background

Biodiesel

What is It?

Biodiesel is a liquid fuel obtained from the addition of alcohol to any source of complex fatty acids: vegetal oil or animal fat. The following describes how vegetable oil mixed with methanol yields biodiesel through the reaction of trans-esterification, whereby glycerin is separated from used vegetable oil via a caustic catalyst. The methyl-ester product, once purified, is known as biodiesel, while the glycerin by-product can be used as an environmentally friendly commercial degreaser.

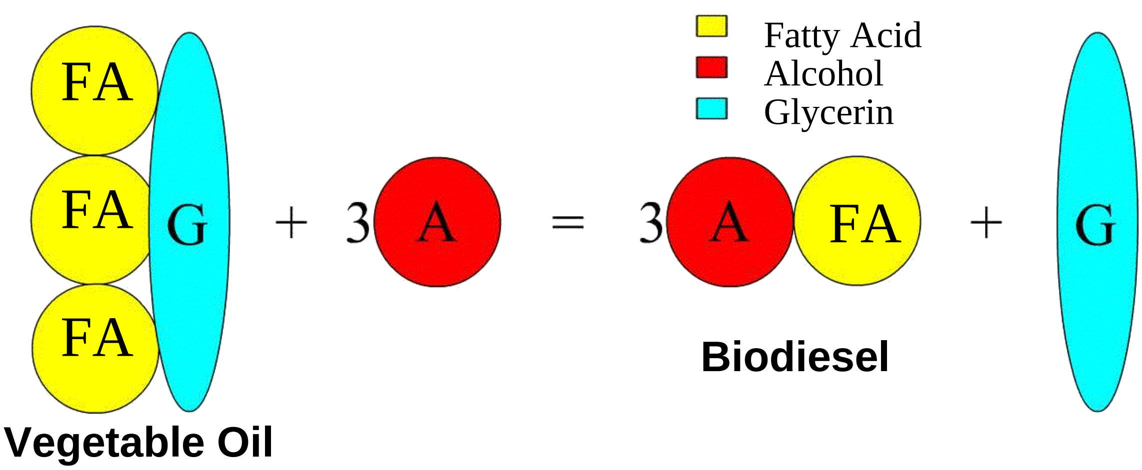


Figure 1 - Biodiesel Reaction

Environmental Benefits

Biodiesel has been produced since the mid 1800s, however the fuel itself was simply a by-product of soap production (glycerin)[1]. Although biofuels were developed and promoted by individuals such as Rudolf Diesel, the inventor of the diesel engine, and Henry Ford, the petroleum companies, who could offer lower prices, controlled the fuel industry from the early 1920s up to today. The oil crisis

[1] http://www.ybiofuels.org/bio_fuels/history_biofuels.html

of the 70's renewed an interest in alternative energy sources such as wind and solar power as well as alternative fuels. Biofuels include methanol, ethanol, biodiesel, and various diesel blends of the three. Biodiesel is environmentally superior to traditional diesel because it is renewable and emits lower emissions.

As populations expand, technology progresses, and cultures evolve humans create a setting where their relationship with their natural environment is incrementally complex. The continued existence of the species is dependant on the natural resources that sustain it. Hence the conservation and protection of our resource base must be a vital priority. In opposition to traditional fuels, finite resources extracted from the soil, biodiesel is renewable: it can be replenished at the same rate as it is being consumed. Biodiesel, when burned, releases less harmful emissions than diesel hybrid, B20 (20%biodiesel, 80% propane diesel), ethanol 85%, diesel or gasoline. In fact biodiesel has the following advantages when compared to traditional fuels:

Compared to gasoline:

- produces no SO_2;
- no net CO_2;
- up to 20 times less CO
- and more free oxygen

Compared to petroleum diesel fuel:

- Reduces net CO_2 emissions by 100%
- Produces no SO_2 emissions
- Reduces soot by 40-60%
- Reduces unburned hydrocarbon emissions by 10-50%
- Polycyclic Aromatic Hydrocarbons
- Slight increase of NO_X, by 5-10%

The combustion of biodiesel is more complete and efficient that that of diesel or gasoline hence the process releases less carbon monoxide (CO), the most prevalent air pollutant whose main source happens to be non-ideal combustion. While most emissions are in the form of NO for the nitrous oxides (NO_X), NO has no adverse health effects. However, NO_2, the result of oxidation of NO, is related to respiratory diseases, acid rain, algal blooms and fish kills, and photochemical smog. Soot and polycyclic aromatic hydrocarbons (PAHs, of which many are carcinogenic) enter the human system in the form of particulate matter and are associated with respiratory diseases. Sulfur oxides (SO_X), with combustion being their main source, have adverse effects on health, a synergistic effect with particulate matter, and can result in acid rain.

For human health as well as for environmental concerns, biodiesel is obviously a rational choice. It is a substantial step towards creation and diversification of energy sources therefore addressing the urgent and conflicting issues of rising energy demand and global warming

Socio-Economic Benefits

Biodiesel, given an adequate access to used vegetable oil exists locally, can be produced locally. It can reinforce livelihoods through the creation of new jobs and business opportunities in the community. It can reduce dependence on fossil fuel imports and vulnerability to fluctuation of fuel prices on the world market; a tremendous economic and political advantage for any country especially an import-dependant country like the island of Barbados.

Practical and Technical Advatanges

Biodiesel is safe to handle because it is biodegradable and non-toxic. According to the National Biodiesel Board, "neat biodiesel is as biodegradable as sugar and less toxic than salt." With a high flash point (or ignition temperature) of 300 deg. F, compared to petroleum diesel fuel's flash point of 125 deg F., biodiesel is safer in transport and in storage. Engines running on biodiesel run normally and have similar fuel mileage to engines running on diesel fuel. Auto ignition, fuel consumption, power output, and engine torque are relatively unaffected by biodiesel. When burned in an engine, the exhaust fumes have the pleasant aroma of popcorn or French fries. Furthermore, Biodiesel has a higher lubricity, reducing wear and tear and enhancing lifetime of components. As it is also a mild solvent it cleans the engine as it runs.

NativeSun NRG

The First Biodiesel Producer in Barbados

NativeSun NRG is Barbados' first commercial producer of biodiesel and converts a waste product into a resource. The company was originally a research project initiated by Mr. Handel Callender, while living in the Dominican Republic in 2002. After returning to Barbados, a decision was made, along with the future company's co-founder and fellow researcher, Julian Dautremont Smith, to investigate its commercial viability. The project has won a series of awards, namely:

- "Most Commercially Viable Exhibit" award and $3000 prize money provided by Senator Lynnette Eastmond during the 2004 NCST Expo.

- ‘‘The Central Bank of Barbados Award’’ during the National Innovations Competition in 2004, which provided a 20,000$ grant.

Current Production

The company has already started producing biodiesel in small volumes. Most of the equipment to produce an output of 100 to 300 gallons per week is already set up. Basic market research and public education activities demonstrate significant interest in using the fuel. Newspaper articles and expos have been crucial in education about the company’s oil recycling campaign. The company, as it is the only one collecting on the island, benefits from an array of sources for used vegetable oil. It is estimated that 3.2 million liters of oil are available for use annually through many sources including:

- Solid Waste Solutions and Services Ltd.
- Lonesome Hill disposal site
- Various restaurants
- Street vendors
- Lester Vaughan Secondary school oil recycling project
- Householders

Currently large volumes of used oil are either disposed of at the Lonesome Hill Site, dumped in the ocean, used in the production of animal feed, or end up down local kitchen drains which increases stress on water treatment processes. NativeSun NRG’s project offers a solution to many of these undesirable situations.

Projections for the Future

Mr. Callender wishes to expand his production to first meet local and national needs in Barbados. One of his main objectives is to build a prototype biodiesel plant for which the technology could easily be exported towards communities desiring to benefit from the many advantages of biodiesel production as stated earlier. Through his activities he would like to: establish networks with local farmers to develop oil producing crops (Barbados Nut, Castor Bean, Coconut); set up sister facilities in other island (franchise); and expand household recycling activities where over 1.5 million litres of oil are available per year. There are significant volumes of used vegetable oil on the many cruise ships visiting the island, creating another important potential source of oil for production.

Mr. Callender has identified a market through a few important potential users such as the fishing and farming industry, tour vehicles within the tourism industry (catamarans, tour buses, off road tours), and public service vehicles.

The long-term benefits of this project will be manifested in many domains: contribute to Barbados' economic independence; improve the use of resources in Barbados; diminish health and environmental impacts of fuel combustions; and promote sustainable energy sources.

The Engineering Team

Mr. Callender has done a notable job with developing his project; setting up a small but functional production unit and gaining visibility through community outreach. With his limited knowledge in engineering, he took the project as far as he could with the resources available. However, some support was necessary in order to get to the next stage: optimizing and upgrading his process in order to build a prototype biodiesel and achieve his plans for future expansions of his activities. Out team arrived in Barbados with impeccable timing.

The Internship: Goal and Objectives

The team embarked on this adventure inspired to work towards one pivotal goal:

The design and construction of a small-scale biodiesel plant.

This project was a unique opportunity to challenge ourselves and put our engineering skills to work towards this ambition. As future engineers, in each of our different domains: civil, chemical, and environmental, we see it as our professional, personal and ethical responsibility to demonstrate an underlying concern for the environment in all our endeavors and promote the integration of the environment in all decision making processes. Our goal was to be made more tangible by committing ourselves towards a more specific direction through setting the following objectives and tasks:

- Literature review of all pertinent subjects

- Improve the current bio-diesel production process
    - Review and understand the current process of bio-diesel production
    - Identify areas for improvement of the current process
    - Install new machinery and implement improvements

- Design an efficient water treatment system
    - Inventory of available resources for water treatment
    - Research potential water treatment systems
    - Design the water treatment system
    - Construct and implement the system, time permitting

- Explore alternative energies to reduce the need for propane to heat the system
    - Inventory of available resources for energy (i.e.: glycerin, solar)
    - Research existing designs for alternate heating of biodiesel
    - Design an appropriate heating system
    - Construct and implement the system, time permitting

- Write report summarizing all achievements, to be used as a resource for NativeSun NRG.

Process Design

Prior to our arrival, NativeSun had come to acquire new equipment, principally processing tanks, to be used to expand production. The aim of the process design was then to make use of this new equipment to expand production, while keeping in mind the limitations of NativeSun. The specific goals for the design are:

- Minimize manual labour
    - With only one employee, the more automation in the system the better. Pumping systems were designed to eliminate the need for manual handling of products from one stage to another.

- Minimize costs
    - With a tight budget, cost was always the top concern. While there was a need to purchase essential tools, simplicity and cost-prevention measures remained a constant concern.

- Flexibility
    - The piping system was designed for one possible processing method, but several other methods were also identified. It is important that NativeSun conserves the ability to experiment with different methods.

- Equipment limitations
    - Two pumps were purchased for the process. Meeting all pumping needs using only 1 or both of the pumps thus became a significant hurdle to overcome. Piping and valve systems were designed to ensure the two pumps could perform all required tasks without needing to be moved or reconnected.

The process for making biodiesel is summarized a follows:

- Preheat used vegetable oil to remove water
- Determine oil pH and measure appropriate quantity of NaOH and methanol
- Mix reactants
- Allow glycerin to settle out, drain glycerin and send to methanol recapture
- Wash biodiesel to remove trace contaminants
- Set in the sun to drive off traces of water

The process design is divided into 4 stages; the pre-heat, the processing and the wash stages that were previously part of the NativeSun process, as well as a methanol recapture stage which is a new addition. Also explored were a water treatment stage and solar heating system. The overall process layout can be found in the appendix.

Preheat Stage

The role of the preheat stage s to remove any water that might be mixed with the used vegetable oil. Water is detrimental to the transesterification process and must be removed as much as possible. Heating the oil to 50-54 ^{o}C is enough to cause the water to settle out.

There are two preheat tanks, both are used tanks purchased from the Bico ice cream factory in St. Michael. The tank volumes are 150 gal each and were both purchased for $BBD 600. Using two tanks allows for the continual receiving of used vegetable oil. Hot water flows from a propane heater and through a heating coil to heat the oil, the cooled water is then returned to the heater.

The valve system is designed such that hot water will flow through only one tank at a time, likewise the vegetable oil will be pumped out of the tanks sequentially. While one tank is pre-heating, the other is available for receiving used oil.

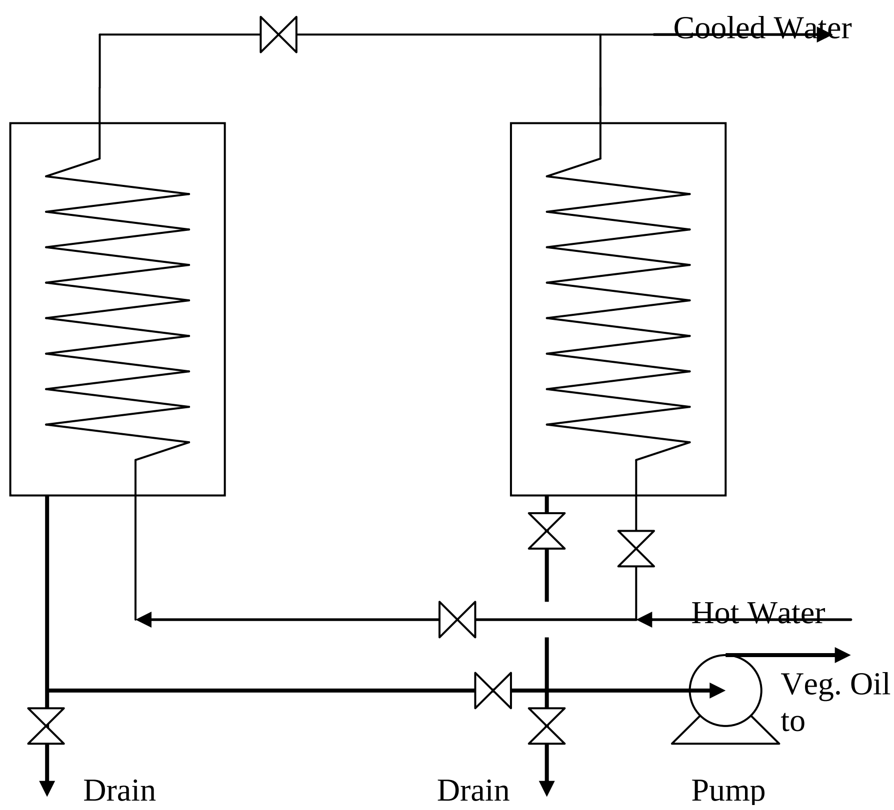


Figure 2 - Schematic of Preheat Stage

Processing Stage

The processing stage consists of two reactor tanks, each connected to its own pump for recirculating and mixing of the reactants. The first tank, reactor A, is tall and narrow with a conical bottom. This reactor shape provides adequate mixing of the fluid when recirculated by the pump. The second tank, reactor B, is bulkier and rounded on the bottom, which would create dead zones if mixed by simple recirculation. To overcome this problem and ensure adequate mixing in both processing tanks, a mechanical mixer with impellers was purchased. Static mixers were also purchased to increase mixing within the pipes.

The goal of the processing piping system is to ensure flexibility of the system while maximizing use of only two pumps. The primary feature of this system is that it allows for the transfer between the two reactors. Used vegetable oil can be pumped into either tank via pump A, and then recirculated with the reactor tanks via their respective pumps. Contents can be transferred between the two tanks via this piping scheme. The proposed processing method is outlined as follows:

- Used vegetable oil is pumped from the preheat stage into reactor B.
- Mixed methoxide is added to reactor B and circulated to provide initial mixing.
- Half of the mixture is then transferred to reactor A, and both tanks are recirculated for the required reaction times.
- Following the reaction, the tanks are allowed to settle and glycerin is drained out for eventual methanol recapture.
- The biodiesel product is pumped out towards the washing stage.

Initially mixing all of the reactants in one container ensures homogeneity of the oil:methoxide ration within both reactors. This removes one measuring step. Using both reactors for processing allows for eventual expansion. According to the business plan, NativeSun projects to initially process 150 gal /week increasing production towards 300 gal/week. The system also maximizes the use of the two pumps, which perform all the required transferring and recirculating.

Pump A is significantly larger than pump B. It also has more power and the additional feature that it can run dry without damaging. These two features make pump A the best choice for pumping used vegetable oil into the reactor, as it doesn't require the operator to monitor the level in the preheat tanks.

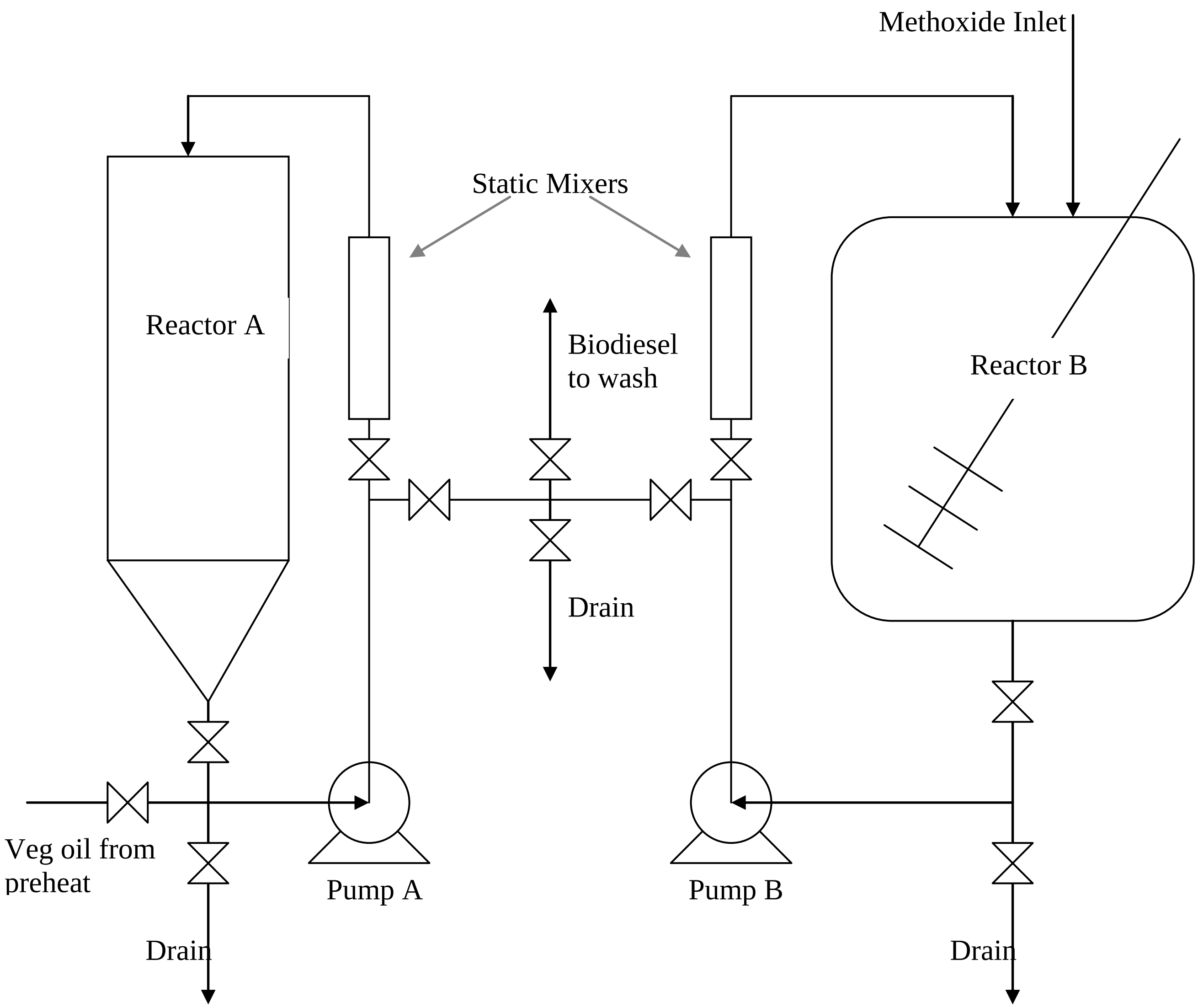


Figure 3 - Schematic of Processing Stage

Washing Stage

There are many methods of washing available when processing biodiesel. An ideal washing method maximizes interaction between the fresh biodiesel and washing water, while minimizing the risk of emulsifying[2]. Previously, NativeSun had simply mixed water and biodiesel manually. This works well for small batches, however the manual aspect makes it increasingly time-consuming with increase in batch size, and more difficult to control to avoid emulsification if automated.

The most commonly recommended method of washing biodiesel is aeration, whereby air is bubbled through layers of water and biodiesel. The bubbles rising into the biodiesel carry with them a thin film of water. The biodiesel contaminants dissolve in the water. When the bubble bursts, this water falls out of the biodiesel layer and returns to the water layer, brining the contaminants with it. This method yields a very high water-biodiesel surface area and minimizes the risk of emulsification. It also has a lower water requirement than the method previously used by NativeSun.

The wash tank design makes use of the following items we had at our disposition:

- A 1 m^3 plastic tank donated by a paint company.
- The compressor required for the operation of the pneumatic pumps.
- Lengths of ½" PVC piping for the aerator.

The aerator was constructed by drilling small holes along the PVC pipe at 3" intervals. Four lengths of tubing, running parallel along the bottom of the tank, are connected to a single shaft extending to the top of the tank. The compressor connects to a regulator and then to the shaft. The rate of air flow through the aerator, and thus the rate of bubbles, is controlled by the regulator.

For each batch, an amount of water equal to half the volume of biodiesel is added to the wash tank, followed by the biodiesel. The product is bubble-washed for 6 hours and then let to settle for 1 hour. This wash is repeated three times, each time the water is drained from the bottom and new water is added.

[2] http://journeytoforever.org/biodiesel_bubblewash.html

One identified problem with the aerator system is that biodiesel degrades PVC glue over time. As such, it is important to minimize the interaction between the aerator and the biodiesel. The paint tank has a built-in drain located at the bottom, but an additional tap was installed a few inches higher, which is the tap that will be used to drain the water to ensure that a certain volume of water will remain above the aerator at all times, protecting the PVC piping.

The total volume of the wash tank is 350 gal. Given that some airspace is required at the top, and 1/3 of the tank's volume must be water, this wash tank cannot wash biodiesel batches greater than 200 gal. Should NativeSun choose to increase production, a second wash system would be required.

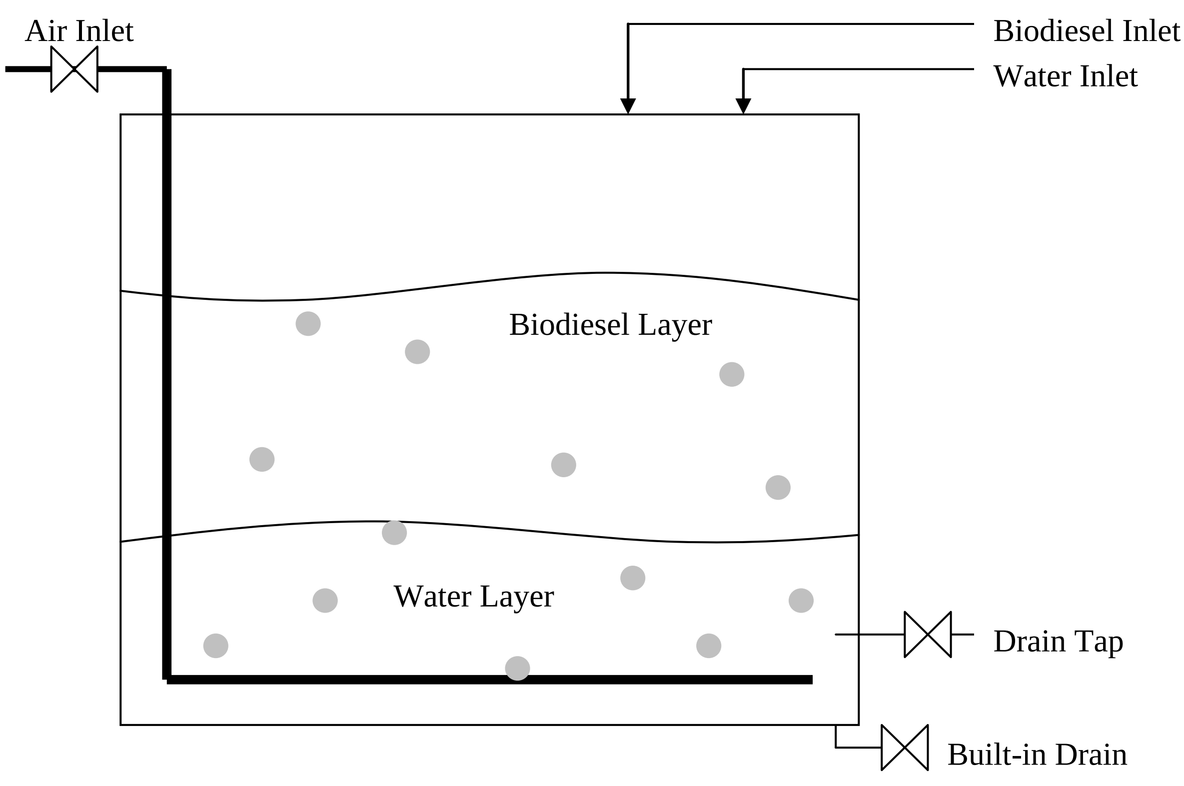


Figure 4 - Schematic of Wash Tank

Methanol Recapture

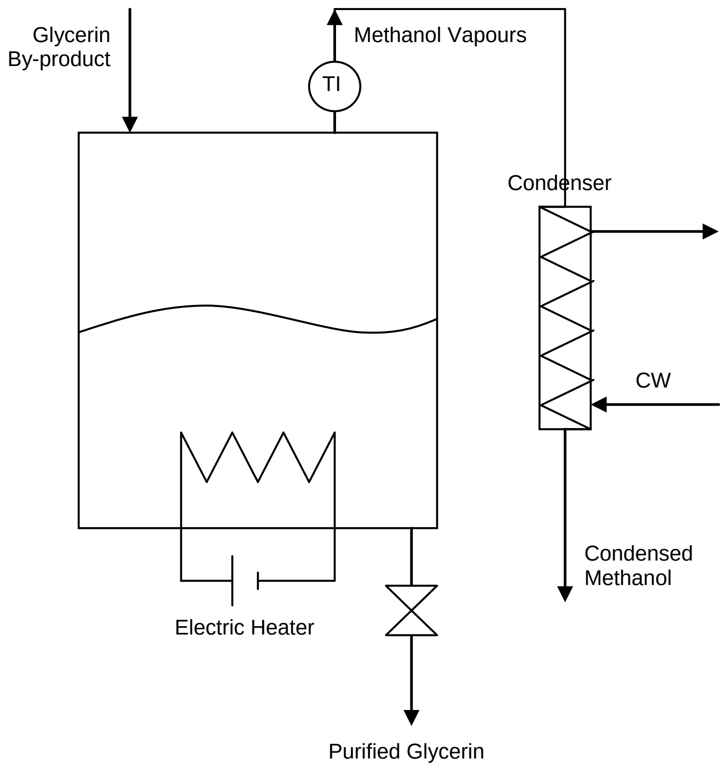
Methanol is the most expensive input for the biodiesel process. As methanol is derived from petroleum, it must be imported in Barbados resulting in an inflated cost. The price is also tied to the price of oil, and as such is at risk of instability as crude prices rise.

In order to ensure that the reaction consumes all of the vegetable oil, methanol is added in excess to force the equilibrium to the right. This excess methanol ends up in the glycerin by-product and represents a significant loss. Methanol in the glycerin also limits the potential for marketing it as a product, as the combination is deemed unsafe and flammable.

Given the relatively low boiling point of methanol, it is possible to recapture the methanol via a simple still. The mix of glycerin and methanol, still liquid following the reaction stage, can be heated to vaporize the methanol. These vapors can then be condensed and recycled, maximizing use, reducing waste, and lowering overall processing cost.

For the design of a methanol recapture system, a company based out of Quebec, FuelIt[3], has published their design for a simple methanol condenser system. The system can be constructed of items that can be found easily at any hardware store in Barbados.

[3] http://www.b100wh.com/recovery1.html#condenser



Source b100wh.com

Figure 5 - Schematic of Methanol Recapture Unit

Figure 6 - Photograph of a Methanol Recapture Unit

The glycerin by-product is poured in to a chemical container through a funnel in the lid. The container must be sturdy and air-tight. An electric heater heats the glycerin to the methanol boiling point of 66°F. The vapors rise through the bucket and into a length of copper tubing. The copper tubing then coils as it enters a condenser. Cold tap water passes through the condenser, cooling the methanol vapors to a liquid. The liquid falls through the copper tubing where it is collected at the bottom. Once the liquid methanol stops flowing, the process is complete and the glycerin is drained from a tap while still liquid.

Water Treatment

In an effort to reduce the overall impact of biodiesel production, water consumption and recycling were considered. Three wash stages are required for biodiesel production, the first stage taking out the most contaminants and each subsequent wash containing significantly less. Water recycling then becomes an ideal method for reducing overall water consumption within the process.

Each wash stage, at maximum production capacity uses 100 gal of water. The first wash produces water too dirty for reuse, but the water from the second and third washes are fairly clean. To reuse the water, two interim storage tanks of 100 gallons each will be placed near the washing station. The water from the second and third washing stages will be pumped into the storage tanks and then reused in t he following wash process. The general recycling process is outlined Figure 7. The water from wash 3 will be reused for wash 2, and the water from wash 2 reused in wash 1. Once the loop is established, the required water consumption for washing will be reduced by 2/3, requiring only half a gallon of water per gallon of biodiesel instead of 1.5.

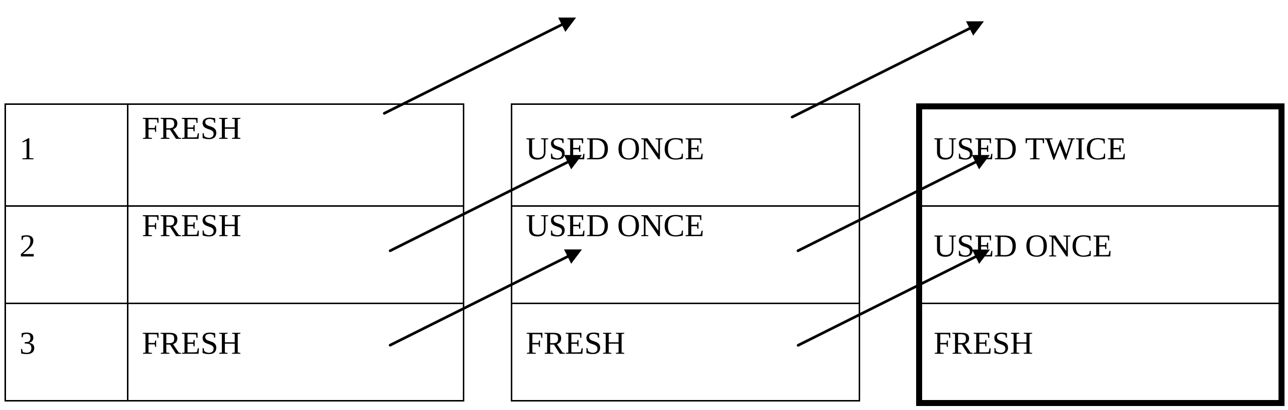


Figure 7 - Outline of Water Recycling Process

In addition to water recycling, the following water treatment options was also explored, with the hopes of bringing the process water demand to nearly zero.

Solar Distillation

This method of water purification produces almost perfect distilled water and would remove all of the glycerin, methanol, and dissolved solids. Solar distillation, however, is highly inefficient and would require an extremely large surface area in order to treat the amount of water needed by NativeSun for biodiesel production. Through some research and testing, it was determined that a solar still covering an area of $4m^2$ could only treat about 30 gallons a week, simply not enough to meet the needs of NativeSun, and anything larger would take up too much space and be too costly to implement.

Slow Sand Filtration

Slow sand filters are very efficient at removing organic solids and quite inexpensive to construct. The problems with this type of system are that it may clog up if the waste water is too turbid, and it will not remove dissolved solids. This means that the waste water from the washing stage of biodiesel production might have to be pre-treated to decrease turbidity in order to pass it through a sand filter. Furthermore, it remains unclear exactly how much dissolved caustic soda would remain in the treated water and its effects on whether the water would be acceptable for re-use. Finally, there may be a problem with using a slow sand filter since most of the actual water treatment is performed by the microorganisms living in the top layer of the sand and it is still unclear how these organisms would fair with the filter not in constant use. Unfortunately, there were no funds available to construct a test sand filter.

Both treatment methods were thoroughly researched and were presented to representatives of the BIDC and engineering consultants from C&G Inc. but no funds were made available to perform any further testing. It is still the opinion of the internship group, however, that an on-site water treatment system is an option worth further consideration in the future.

Methanol Evaporation

In some of the literature examined for the biodiesel internship there was mention of heating the unwashed biodiesel to boil off the methanol and cause the suspended solids to precipitate out. The theory is that methanol evaporates at a much lower temperature than biodiesel (only 60C) and thus could safely be evaporated out which would release the suspended solids leaving clean, useable biodiesel. This step would, in theory, altogether eliminate the need for a wash stage and thus eliminate the need for clean water. The internship group was able to perform some basic tests on this theory which were however inconclusive. Due to time constraints there was no further experimentation but this process definitely merits more thought and testing.

Solar Heating

In further attempts to reduce the environmental impact of biodiesel production, solar heating was investigated. The energy requirements for the oil pretreatment stage could easily be met using a solar heating system. We have met with Mr. Vincent MacLean, CEO of AquaSol, who generously offered technical support in designing such a system.

The system is a very simple one where a solar unit installed on the roof at the Future Centre would be connected to the heating coil of the preheating tank. The design requires a pump to allow the working fluid to circulate through the element up towards the solar panel. A debate emerged between two possible options: indirect or direct solar heating. Direct heating involves having the used vegetable heat directly as it flows through the coil of the solar panel. However, this option was eliminated as it causes tube-side fouling hence resulting in higher maintenance needs. We opted for indirect heating where water flows through the system.

Due to time and financial constraints this system could not be implemented, however it would be easily implemented once the necessary funds are made available to NativeSun.

Progress

Literature Review

In order to understand the process and the potential improvements for NativeSun, a review of literature was performed. While some research papers were of great use regarding new innovation in biodiesel production, the most useful sources were online websites, particularly forum pages. Thesee resources were immensely useful and were regularly referred to throughout the design and implementation process.

Improve Current Process

Initially it was felt that improving upon the initial process would occupy roughly half of our time with NativeSun. Ultimately, due to a variety of unforeseen obstacles, this took the bulk of our time. The process consists of four stages, the preheat, the processing, the washing and the methanol recapture. Our goal was to implement the design as much as possible, but where limitations existed we aimed to get the plant in working order so that NativeSun can resume production while awaiting funding.

Processing Stage

Our first focus was the processing stage, as it is the heart of the production line and the stage that required the most improvement and the most manual labour. The construction phase took significantly longer than expected, due to problems with acquiring funds, finding appropriate equipment, and sourcing outside work for tasks like pipe threading and welding.

By December, the piping for the processing stage was essentially complete, with the exception of one piece of pipe joining the two reactors together that was cut too long and is in need of rethreading. This was dealt with temporarily by using flexible PVC pipe to join the gap where the pipe would otherwise be. A compressor is still needed in order to operate the plant, but with the help of Williams Equipment we were able to acquire one for a day in order to test our pumps and piping system and identify leaks.

Completed:

- Purchased all required plumbing fixtures.
- Constructed a supports platform to elevate tanks and pumps.
- Measured, cut and threaded lengths of galvanized steel piping.
- Connected processing tanks and pumps with all required piping and valves.
- Connected sight gauges
- Tested the plumbing for leaks by running water through the system.
- Repaired leaks.

Still to do:

- Complete cross-pipe connection where pipe was cut too long.
- Install drain tap and outlet to wash stage on cross-pipe connection.
- Install the mechanical mixer on reactor B.
- Acquire a compressor.

Preheat Stage

Our next focus was the preheat stage. The two preheat tanks were acquired from Bico in November. One of the tanks has no built in heating coil and was lined with a fiberglass lining that was in poor condition. This lining was easily removed and the tank is in otherwise excellent condition. The second tank has a built-in heating coil but is extremely fouled with lime scale. This scale will inhibit heat transfer across the coil and may contaminate the vegetable oil.

Due to lack of both funds and time, only one of the preheat tanks was connected in a temporary fashion, using flexible tubing where threaded pipe was unavailable and without the recommended valves and drains.

Completed:

- Constructed a support platform to elevate the tank above the pump.
- Drilled an access hole in the wall to allow for pipe connections between the outdoor preheat and the indoor processing stages.
- Began cleaning out the scaled preheat tank.
- Installed piping to connect the first preheat to the processing stage.

Still to Do:

- Complete the piping to the processing stage. It currently only connects to one of the preheat tanks, is missing most of the suggested valves and drains, and is constructed largely of flexible tubing supported by cinder blocks.
- Clean out as much of the lime scale as possible in the first preheat tank.
- Install a heating coil in the second preheat tank.
- Purchase and install hot water heater.

Washing Stage

Our final task in setting up the process was the washing stage. This was the most simple of the steps, as it required only cleaning out the tanks and constructing the aerator. The wash tanks itself if ready for operation, but the connections to and from the tank are not constructed. The interim storage tanks for water reuse are also not constructed. The system in its current state can be used with temporary flexible pipe to make the required connections until funds are available for a permanent solution.

Completed:

- Cleaned tank to remove the bulk of the paint remnants.
- Constructed aerator.
- Installed drain tap.

Still to Do:

- Construct a supporting platform to ensure wash tank is level.
- Install aerator.
- Purchase and install regulator for the aerator.
- Set up storage for final washed biodiesel product and for water to be recycled.
- Install connecting piping.

Design Water Treatment System

With the water recycling methods, consumption of water for washing is significantly reduced. Also, a rainwater collection system has been installed on the grounds of the Future Centre which would provide the required wash water. It then becomes questionable whether treatment is required, and if enough water would be produced to ensure the continuous flow required in slow sand filtration. This system would be more useful following an increase in production when water use may become more intensive. However, since the wash water is relatively benign it can be used for watering the grounds at the Future Center.

Design Alternative Heating System

Given time and financial constraints, this objective became a low priority for the success of the project. Solar heating methods were investigated, including how to build a "Do It Yourself" solar water heating panel. Following meeting with Vincent MacLean of AquaSol, it was decided that most likely a pre-made solar heating unit would be purchased, as opposed to the "DIY" option.

Completed:

- Explored options for solar heating.
- Met with Vincent MacLean.

Still to Do:

- Determine required size of the water heater.

- Fix the plant’s roof.
- Purchase and install heater, once funds become available.

Gantt Charts

Table 1 - Initial Gantt Chart

Task	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec	15-Dec	
Literature Review																ALL
Improve Current Process																
Understand Current Process																ALL
Identify Problems and improvement potential																Nora, Kyrke
Install new equipment and implement improvements																ALL
Design Water Treatment																
Inventory available resources																Wes
Research potential systems																Wes, Kyrke
Design treatment system																Wes, Kyrke
Construct and implement system																ALL
Design Alternative Heating																
Inventory available resources																Isa
Research existing designs for heating of biodiesel																Isa, Nora
Design an appropriate system																Isa, Nora
Construct and implement system																ALL
Write Report																ALL

To Be Completed	
Completed	
Unable to Complete	

Table 2 - Midterm Gantt Chart

Midterm Gantt Chart

Task	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec	15-Dec	
Literature Review																ALL
Improve Current Process																
Understand Current Process																ALL
Identify Problems and improvement potential																ALL
Install new equipment and implement improvements																ALL
Design Water Treatment																
Inventory available resources																Wes
Research potential systems																Wes, Kyrke
Design treatment system																Wes, Kyrke
Construct and implement system																ALL
Design Alternative Heating																
Inventory available resources																Isa
Research existing designs for heating of biodiesel																Isa, Nora
Design an appropriate system																Isa, Nora
Construct and implement system																ALL
Write Report																ALL

To Be Completed	
Completed	
Unable to Complete	

Table 3 - Final Gantt Chart

Task	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec	15-Dec	
Literature Review																ALL
Improve Current Process																
Understand Current Process																ALL
Identify Problems and improvement potential																Nora, Kyrke
Install new equipment and implement improvements																ALL
Design Water Treatment																
Inventory available resources																Wes
Research potential systems																Wes, Kyrke
Design treatment system																Wes, Kyrke
Construct and implement system																ALL
Design Alternative Heating																
Inventory available resources																Isa
Research existing designs for heating of biodiesel																Isa, Nora
Design an appropriate system																Isa, Nora
Construct and implement system																ALL
Write Report																ALL

To Be Completed	
Completed	
Unable to Complete	

Obstacles and Problem Solving

This section will detail some of the major obstacles that were encountered throughout the semester and the attempts to resolve them. The obstacles are loosely divided into technical, equipment, and non-technical. While the list is not exhaustive, it does serve to highlight some of the major issues dealt with. This list is not in chronological order, as a thematic approach is easier to follow.

Technical obstacles

Installing the Electric Mixer

Adequate mixing of the vegetable oil with the methoxide is very important in the biodiesel process. As mentioned above, Reactor B, with its ellipsoid shape does not provide the vortex required for adequate mixing. To alleviate this problem, an industrial strength electric mixer was purchased from the United States. The plan was to have this mixer mounted on Reactor B. When the mixer finally arrived, several weeks late, it became apparent that this would be no small feat. The mixer itself weighs approximately forty pounds, and is very awkward to handle.

The proposed solution is to weld two brackets to the tank and secure the mixer to them with a steel bolt. These brackets would need to be steel, at least ¾ inches thick, and would also need to follow the curvature of the top of the Reactor. To accomplish this, a cardboard outline of the curvature was created and the brackets were cut by Williams Steel on a CNC machine at no charge using steel also donated to NativeSun by Williams Steel. Figure 8 shows one of the brackets in its intended position on Reactor B.

Figure 8 – The electric mixer with the mounting brackets

The brackets have yet to be welded to Reactor B, as we require a welder to come to perform this welding.

Leaking Pipes

One of the major concerns with the main reaction stage was pipe leakage. Using a compressor on loan from Williams Industries, we tested for leaks by pumping water through the network. Leaking was observed in several nodes of the network. Since oil is more viscous than water, the amount of leaking in the piping will be far less when the oil is being processed. Nonetheless, it is desirable to eliminate all possible leaks.

Many of the leaks were removed by tightening the connections and sealing them with plumbers tape. However, the unions (a pipe connection that allows pipes to be connected in situations where tightening one connection loosens another one) proved very resistant to sealing. These connections are prone to leaking because the interface between the two halves of a union is a metal on metal connection. It is impossible to add plumbers tape to this interface because there is no surface to wrap the tape around. Instead, unions are usually sealed by tightening them to such an extent that the steel surface on one face bites into the softer surface on the opposite face. However, our purpose for the unions was to allow easy disassembly of the pipes for cleaning and maintenance, and to repeatedly tighten and loosen the unions would quickly damage the metal-on-metal seal.

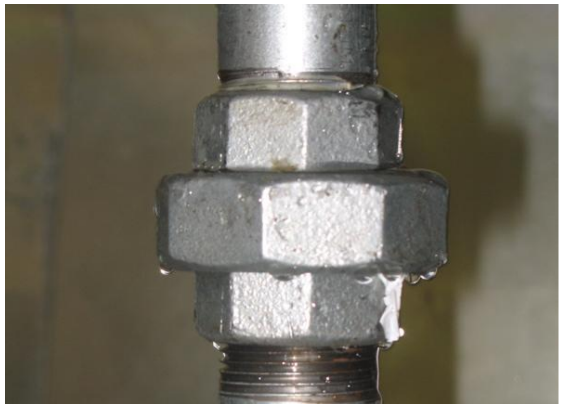


Figure 9 – A leaky union in the network

An alternate method of sealing unions is through the use of rubber O-rings. These O-rings act as gaskets and, when squeezed between the two metal surfaces of the union, provide an effective seal. O-rings, available at the hardware store, were installed in the 1” unions. However, the 2” unions, located at the entrance and exit of Reactor B, are too large for standard O-rings. To remedy this, gaskets were constructed out of cork sheet. Both gaskets were effective at removing leaks in the network.

The only remaining source of leaking is at the exit of Reactor B. Reactor B does not have standard pipe threading on it, but it is possible to connect it with a 2” thread. Plumbers tape has been unable to seal the connection. Silicon caulking was applied to attempt to eliminate the links, but the effect has yet to be verified.

Measuring Flow and Fluid Levels

One of the difficult aspects of the main reactor stage is that it is essentially a black box. Once the reactants are in the reactors, there is no viable way of measuring what is happening. Knowing the flow rate through the mixers is very important for process control. Furthermore, a flow-meter would also be helpful in determining how much fluid is left in the tanks when pumping out of the reactors and into the wash stage. Transparent flexi-piping has been installed which gives a visual approximation of fluid flow, but not actual quantifiable measurement. The four-way valve with the plastic tubing is shown in Figure 10. A flow-meter would be a useful tool should funds become available.

Figure 10 - The 4-way valve with the height-gage attachment

With regards to monitoring fluid levels in tanks, sight gages were installed for both tanks. Clear PVC tube is connected to the bottom of the each tank via a valve. By opening the valve, the level inside the tank is indicated within the tubing. This will help ensure that the pumps will not run dry when draining the tank, as well as help when pumping roughly half the biodiesel reaction mixture from reactor B to reactor A. It was felt that this was a cost-effective solution to the problem.

Equipment Obstacles

Pumps

Due to economic constraints, the two main reactors differ in both shape and size. These differences impact the mixing abilities of the tanks. Whereas the conical bottom of Reactor A causes a vortex that mixes the biodiesel, Reactor B has an ellipsoid shape and does not form the vortex. To compensate for the reduced mixing, Reactor B will have an electric mixer as well.

Figure 11 - The two Reactors

In the current piping network, each reactor is coupled with a pump. Both pumps that were purchased run on compressed air. This is a safety consideration as electrical pumps sometimes spark, which could ignite the biodiesel. Furthermore, NativeSun NRG chose a larger, more powerful pump for Reactor A. The reason for the larger pump is that Reactor A is higher, and since the critical mixing in Reactor A is due to the vortex, it is imperative that the pump be powerful enough to create one.

The first obstacle encountered concerned the pump connected to Reactor B. The pump did not arrive with an exit flange. Pumps rarely come with a flange because each flange can only accommodate one size of pipes, and there are too many pipes sizes for the manufacturer to supply flanges for. Instead, flanges are usually purchased at specialty stores. Without a flange the pump could not be connected into the network. We were unable to find any stores on the island that had the required flange. Fortunately, we were able to have flanges machined for us by technicians working for the Barbados Water Authority.

A second obstacle was encountered upon examining the documentation supplied with the pumps. Both pumps are more powerful than required. This is problematic as pumps are designed to operate at a certain capacity. If they run too far below capacity, there is a risk they will stall. To ensure that they would not stall, the pumps were tested by with water in the network. Both pumps operated satisfactorily; however, there is still concern that operating the pumps outside of their design range will have long-term consequences.

Compressor

As has been previously mentioned, a compressor is required to operate the pumps and the bubble washer. Before purchasing a compressor, however, it needed to be sized. The sizing process was difficult due to two different, and over-designed, pumps running concurrently on one compressor.

To help size the compressor we contacted the pump manufacturers, as well as Williams Industries, and two consultants from the BIDC. Eventually a gasoline-powered compressor was chosen. This compressor was tested for a day by running water through the network. There was not enough water in the tanks to run both pumps simultaneously, so only one pump was tested at a time. The compressor was able to fulfill the pressure requirements of each pump. It is believed that the compressor storage tank will be capable of supplying enough airflow for both pumps to run simultaneously, and NativeSun NRG intends on confirming this before purchasing one.

The lack of a compressor caused a serious delay in the project. Without one, no tests on the piping could be preformed and no processing could be attempted. Much time and energy was invested in finding a compressor to borrow for a day in order to test the equipment.

Static Mixers

To help with the mixing process in the main reaction, static mixers were purchased. However, the mixers are made from PVC and they may not be able to withstand the strain of pumping biodiesel. For example, the threading on Mixer B was cracked when Pump B accidentally fell over. While new threading was installed, this highlights the safety concern for the mixers.

Figure 12 shows the mixer attached to Reactor A. As can be seen, both ends of the mixer are connected to steel piping components. Since steel is far stronger than PVC, any stresses placed on the network will deform the mixers first.

Figure 12 – The static mixer connected to Reactor A

Two different methods were proposed to secure the mixers. The first solution involved creating a cage around each static mixer by welding bars onto the unions that connect the mixers at both ends. There was concern that the heat from the welding would melt the mixer. Furthermore, once welded, it would be impossible to remove the mixer from the cage. A second proposal involved running a parallel pipe next to each static mixer. This pipe would be closed off to fluid, the only purpose being to bear the stresses place on the structure. It would not require much extra plumbing equipment to implement such a parallel system. Due to financial constraints the solution was never implemented, however this can be performed quite easily in the future.

Pipe Threading

One obstacle that arose during our work was the threading of the pipes. In the past, NativeSun NRG used both PVC and flexible pipes in the operation. Neither PVC nor flexi-pipe requires threading as the PVC is glued and flexi-pipe is bracketed. However, for long-term durability in the plant, steel pipes were chosen as the primary mode of piping.

Steel pipes are purchased in a standard length of twenty feet. Before they are used they must be cut and threaded. Cutting the pipes poses no problem, as they can be cut with a hacksaw. Threading the pipes requires special equipment that we lacked. Fortunately, the technicians for the Barbados Water Authority were willing to thread the pipes at their station in Bowmanston. While their help was appreciated, there was a significant time factor involved, as it would sometimes take several days before the pipes could be threaded.

Non-Technical Obstacles

The non-technical problems were generally chronic, rather than acute, problems. They persisted throughout the entire semester, and often set the tone for the internship.

Lack of Finances – Private Investors and the BIDC

The lack of finances is by far the most difficult issue facing NativeSun's biodiesel project on the island. Without money, the equipment required cannot be purchased, nor can any services, which need to be outsourced, be performed.

Over the summer, NativeSun was approached by the Barbados Investment Development Corporation (BIDC) to apply for a business loan. The BIDC is a government agency that provides funding and consulting to small businesses with potential for growth on the island. They were interested in the company because it was the only biodiesel producer on the island, and they felt that there is a growing market for this product. NativeSun was eligible for the Special Technical Assistance Program, which pays for equipment purchases and consulting services.

Even though an application for funding was made and granted in principle, there has as of yet been no money from the BIDC. By September, the McGill interns had arrived and money was needed for work to begin. Fortunately, the BIDC was not the only source of funding for NativeSun. A friend of Mr. Callender, Mrs. Laura Farnum, was willing to loan him some money on the condition that it would be repaid when the BIDC funding came in. With this funding some equipment for the plant was ordered from the US (this will be discussed in greater detail in a later section.

NativeSun's main contact with the BIDC was Bryan Layne, an engineer working in the business development sector of the BIDC. Mr. Callender and the McGill internship group met with him on several occasions, and even presented design layouts of the planned processes to him. Mr. Layne corresponded often with NativeSun concerning the designs, and the vision of the project.

With only three weeks left for the internship project, it was discovered that NativeSun was in fact not eligible for Special Technical Assistance, but rather Technical Assistance, from the BIDC. The difference being that within the Technical Assistance framework, equipment purchases are not covered. Thus all of the money spent on purchasing equipment would not be refunded.

These financial problems have dogged the project throughout the entire semester. This makes testing the equipment very difficult, as for example NativeSun does not currently own an air compressor to run the pumps that were installed. However, the lack of funding has not stopped the project completely and simply forced Mr. Callender and the McGill interns to come up with creative and innovative ways of working around the problems faced.

Equipment Arrival and Port Problems

Aside from lacking sufficient funds to purchase equipment, there were also several delays in obtaining the equipment that was purchased from overseas - Barbados does not manufacture heavy machinery and pumps locally. Many of the equipment orders were delayed in shipping or temporarily lost along the way. When equipment did arrive, it was delayed at the port for long periods of time. This was partly due to port problems, but also because NativeSun had not obtained a port visa, and thus was forced to wait for the processing of the visa to finish before getting the equipment.

Physical State of the Plant

One of the concerns the BIDC raised was the physical condition of the biodiesel plant. The plant is in a shed behind the Future Center and security is an issue as there is no lock on the front door. This lack of security meant that nothing valuable could be left in the plant overnight, as theft is not uncommon in the area. Thus every night all of the equipment which was not securely bolted to the floor had to be brought into the Future Center overnight. At the end of each day of work, the work-in-progress was dismantled and carried indoors, only to be re-assembled the following day. There are plans to upgrade the security of the plant, but once again they are contingent on funding from the BIDC and thus have still not been implemented.

Final Remarks on the Obstacles

The obstacles described above should give a good feel for how the internship progressed. Some of the problems encountered were the result of inexperience but, at the root, most were caused by the lack of funding. The added constraint that the solutions to problems had to be implemented for very little or no money was the hardest thing to overcome. The no-cost solutions were by necessity somewhat more complex and extremely time-intensive. Even though some of the project objectives were not met, the internship is still qualified as a success by all parties involved. The reality of this kind of work is that things rarely go as planned and the problem solving and innovation skills developed by all members during the internship will prove to be more valuable than any classroom experience could ever be.

Conclusions

During our four months with NativeSun, we have seen an enormous transformation of the plant and the process itself. Upon our arrival, the plant was disorganized and the process very labour intensive. Now, the process is streamlined, making use of pumps and valves to limit the manual input requirements.

While it was not possible to implement all of our designs, we feel that we are leaving NativeSun with a valuable document that will assist the company in further expansions and requests for funding. The plant has reached near functionality, and with only a few finishing details NativeSun will be able to resume processing biodiesel, with a much higher capacity than before.

This internship project has been an immensely valuable experience for the four interns. It has been a practical, hands-on experience that has allowed us to apply our engineering skills. The highlight of the internship has been seeing the plant come together, bit by bit, actually seeing the results of our hard work.

We hope that our work over the past four months will continue to benefit NativeSun in further expansions.

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APPENDIX

Appendix A – Overhead Plant Layout

Appendix B – Biodiesel Proposal

Appendix C – Biodiesel Presentation for the BIDC

Appendix D – Biodiesel Progress Report for the BIDC

Appendix E – Bill of Materials for the BIDC

Appendix F – Suggestions for an Ethanol-Based Biodiesel Process

Appendix G – Optimization of a Batch Type Ethyl Ester Process

Appendix H – A Novel Pumping Setup

Appendix I – Internship Reflections

Appendix J – Final Presentation