1-1-2003

Investigation of transesterification reaction rates and engine exhaust emissions of biodiesel fuels

Jeffery Gail Rothermel
Iowa State University

Recommended Citation

Rothermel, Jeffery Gail, "Investigation of transesterification reaction rates and engine exhaust emissions of biodiesel fuels" (2003). *Retrospective Theses and Dissertations*. 20017.
https://lib.dr.iastate.edu/rtd/20017

Investigation of transesterification reaction rates and engine exhaust emissions of biodiesel fuels

by

Jeffery Gail Rothermel

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE

Major: Mechanical Engineering

Program of Study Committee:
Jon H. Van Gerpen, Major Professor
Kenneth Bryden
Brent Shanks

Iowa State University
Ames, Iowa
2003

Graduate College
Iowa State University

This is to certify that the master's thesis of

Jeffrey Gail Rothermel

has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The objective of this study was to determine the effect of increased temperatures on atmospheric pressure transesterification reaction rates, reaction rate changes due to the possible mixing benefits of a cyclonic separator, and to perform emission level comparisons between petroleum-based diesel fuels and methyl esters. In order to facilitate these tests, the capabilities of the biodiesel pilot plant in the BECON energy center were expanded to include on-site soybean oil production and processing, temperature-controlled transesterification reactions, recirculating cyclonic separation capabilities, on-site diesel electric power generation, and NOx and smoke emissions testing. The results of the reaction rate temperature tests indicate that atmospheric pressure transesterification reactions can be driven to completion in less than 22 minutes using a sodium methoxide catalyst. The preliminary investigation of the cyclonic separator mixing effect showed increased reaction temperatures resulted from recirculating through the separator during transesterification. Further investigations into the separating characteristics and optimum mixing schedules are necessary in order to better use this technology. Exhaust emissions comparisons between biodiesel and petroleum-based diesel fuels showed an average 10% increase in NOx for biodiesel-based fuels at 80% of maximum engine power but an 11% decrease in NOx emissions at 100% of maximum engine power. Smoke tests showed significantly reduced particulate emissions for biodiesel at all operating conditions with an average 27% reduction at 80% of maximum engine power and a 54% reduction at 100% of maximum engine power. Exhaust gas temperatures were reduced under all operating conditions for the biodiesel-based fuels as compared to the petroleum-based fuels.

1. INTRODUCTION

The main objective of this project was to expand the capabilities of the existing biodiesel pilot plant at the BECON research facility. In addition to being able to produce pilot plant scale batches of methyl esters, the BECON biodiesel facility had the potential of becoming an effective demonstration tool both to other researchers and to the public. Planned biodiesel seminars could include tours of an operational plant showing existing techniques, works in progress, and future technologies. By expanding its capabilities, it would be possible to transform the existing pilot plant into a valuable biodiesel demonstration facility.

In recent years, biodiesel fuels have received significant attention both as a possible renewable alternative fuel and as an additive to existing petroleum-based fuels. Beyond simply representing an additional fuel supply, biodiesel exhibits several advantages when compared to existing petroleum fuel. Many researchers have shown that exhaust particulate matter, unburned hydrocarbons, carbon monoxide, and sulfur levels are all significantly reduced when using biodiesel fuels [1,2]. The same research has shown increases in the levels of oxides of nitrogen, primarily as a result of advanced injection timing. Considerable research has been undertaken to understand the performance characteristics of biodiesel fuels as well as the methods used to produce them [3,4,5,6]. Having the BECON pilot plant operate both as a research facility and as an effective demonstrator of biodiesel technologies would allow new and existing biodiesel information to be passed along to other researchers, biodiesel producers, and the public.

The existing BECON biodiesel pilot plant was constructed primarily through the efforts of Mustafa Canakci in an effort to test various methyl ester production methods using high free-fatty-acid feed stocks such as yellow and brown grease [6]. The facility consisted of storage tanks for commercially purchased soybean oil and animal fats, a 9-gallon pretreatment reactor and recirculating heat pipe used for esterification of animal fat, two open top settling tanks for pretreated oil, an open top 75-gallon main reactor for the transesterification process, a 120-gallon cone-bottom tank for gravity separation of glycerin and washing, two finished fuel storage tanks, and the necessary plumbing.

The work represented by this thesis was undertaken in order to be able to better use the pilot plant as an effective biodiesel technologies demonstration facility. The following tasks were established in order to reach this goal.

- Construct an on-site soybean processing facility for the production of soybean oil feedstock.
- Improve the operation, safety, and dependability of the pilot plant in order to provide reliable demonstrations.
- Install a new main reactor system capable of exhibiting the effects of high temperature, atmospheric pressure transesterification reactions.
- Set up a recirculating cyclonic separator to investigate potentially increased mixing during transesterification reactions and the effect on product quality.
- Install a diesel-powered generator capable of producing electrical power from biodiesel fuels produced onsite and characterize the effect of biodiesel on the emissions from this generator.

The addition of these new facilities allowed several experimental opportunities. The effects of transesterification of soybean oil over a range of temperatures on reaction rates and total glycerol levels were explored. The addition of the cyclonic separator allowed a preliminary exploration into possibly enhanced mixing action and real time glycerin removal during the transesterification process. The diesel powered generator provided an opportunity to compare the smoke levels, NOx emissions, and engine performance of soybean and yellow grease methyl esters produced at BECON to commercially purchased #1 and #2 diesel fuels.

2. BACKGROUND

This chapter provides background information on biodiesel fuels as well as the BECON biodiesel pilot plant facility. The first section discusses the definition, production, and specifications of biodiesel fuels as well as important differences between biodiesel and its raw oil feedstocks. The second section of this chapter details the existing pilot plant and its capabilities as previously used.

2.1 Biodiesel Transesterification

The monoesters commonly known as biodiesel are usually produced through the transesterification of vegetable oils or animal fats. Both oils and fats are triglycerides or fatty esters of glycerin. Fat usually refers to the triglycerides which are solid at room temperature while oils are liquid at room temperature. The triglyceride molecule has the chemical structure shown in Figure 2.1, where R_1, R_2, and R_3 represent long chain fatty acids [7,8].

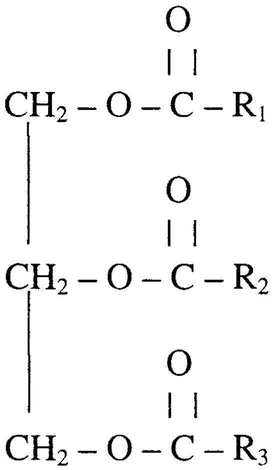


Figure 2.1 Triglyceride Chemical Structure.

Molecules having three fatty acid chains are referred to as triglycerides, while those with two fatty acid chains are diglycerides, and those with one fatty acid chain are monoglycerides.

Raw triglyceride vegetable oils have properties similar to those of petroleum-based diesel fuels and can be used as a direct replacement without engine modification for a limited operating duration. Long-term diesel operation on raw vegetable oils causes numerous problems including injector coking, contamination of lubrication oil, engine deposits, and increased emissions [9,10,11]. These problems are primarily the result of the high viscosity of the triglyceride oils as compared to petroleum-based diesel fuels. Increased viscosity adversely affects fuel injection duration, pressure, and atomization [11,12,13]. The increased injection line pressure can lead to advanced injection timing, increasing combustion pressures and temperatures, and increased NOx formation in the exhaust [14].

The transesterification process is one useful method of reducing the high viscosity of triglyceride oils. In this process, the long fatty acid chains are removed from the glyceride molecule by reacting with alcohol and a catalyst. Common catalysts are potassium hydroxide, sodium hydroxide, and sodium methoxide. The reaction produces fatty monoesters and free glycerin. Any remaining unreacted monoglycerides, diglycerides, or triglycerides make up the bonded portion of the remaining glycerol in the fuel. Together, the free and bonded glycerols make up the total glycerol percentage remaining. This total glycerol percentage is used to determine the completion of the reaction. The transesterification process is shown in Figure 2.2

Esters resulting from reaction with methanol, as shown in Figure 2.2 are referred to as methyl esters. Other alcohols may be used, such as ethanol or butanol, resulting in ethyl

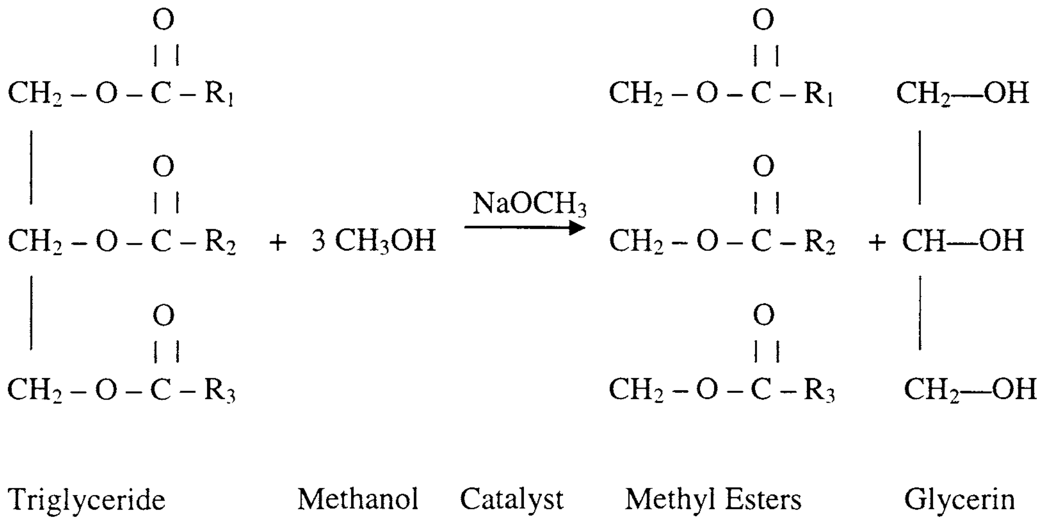


Figure 2.2 Transesterification of Triglyceride with Alcohol.

esters and butyl esters, accordingly. The American Society for Testing and Materials has developed standardized specifications for biodiesel fuels, ASTM D 6751.

These specifications were created in such a way as to allow biodiesel to be made from various feedstocks using a variety of processes so long as the finished monoesters comply with the specifications. These specifications can be found in Table 2.1[15].

Table 2.1 ASTM Specifications for Biodiesel [15].

ASTM D 6751 Specification for Biodiesel (B100)
12/1/2001

Biodiesel is defined as the mono alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, for use in compression-ignition (diesel) engines. This specification is for pure (100 %) biodiesel prior to use with diesel fuel.

Property	**ASTM Method**	**Limits**	**Units**
Flash Point	D93	130 min.	Degrees C
Water & Sediment	D2709	0.050 max.	% vol.
Kinematic Viscosity, 40 C	D445	1.9 - 6.0	mm2/sec.
Sulfated Ash	D874	0.020 max.	% mass
Sulfur	D5453	0.50 max.	% mass
Copper Strip Corrosion	D130	No. 3 max.	
Cetane Number	D613	47 min.	
Cloud Point	D2500	Report	Degrees C
Carbon Residue 100% Sample	D4530**	0.50 max.	% mass
Acid Number	D664	0.80 max.	mg KOH/gm
Free Glycerin	D6584	0.020 max.	% mass
Total Glycerin	D6584	0.240 max.	% mass
Phosphorus Content	D4951	0.001 max	% max.
Distillation Temp, Atmospheric Equivalent Temperature, 90 % Recovered	D1160	360 max.	Degrees C

* To meet special operating conditions, modifications of individual limiting requirements may be agreed upon between purchaser, seller, and manufacturer.

** The carbon residue shall be run on the 100% sample.

A considerable amount of experience exists in the US with a 20% blend of biodiesel with 80% diesel fuel (B20). Although biodiesel (B100) can be used, blends of over 20% biodiesel with diesel fuel should be evaluated on a case-by-case basis until further experience is available.

2.2 Existing pilot plant capabilities

The existing pilot plant, as built by Canakci [6], was constructed in order to test pilot plant scale transesterification reactions of soybean oil and high free fatty acid animal fats. This section details the equipment and capabilities offered by the existing plant.

Feedstock materials were stored indoors in two heated, insulated, 500-gallon tanks. One tank was used for the storage of yellow grease while the other contained soybean oil. Both feedstocks were purchased commercially. The heated tank was required for the storage of yellow grease, which is a solid at room temperatures. The storage tanks contained gear-type recirculation pumps, which were also used to pump the feedstocks into the main reactor in the case of the soybean oil, or into the pretreatment system in the case of the yellow grease. Figure 2.3 shows a flow schematic of the yellow grease pretreatment system [6].

The 9-gallon pretreatment reactor shown in Figure 2.3 was capable of processing 44 lbs of yellow grease per batch. Methanol and sulfuric acid were added to the reactor and the mixture was recirculated using a centrifugal pump through a 1200 W heater for the one-hour esterification process. The resulting low free fatty acid oil could then be pumped into either a 100-gallon or 120-gallon unheated, open top, settling tank where the pretreated oil was allowed to settle out over a 24-hour period. This procedure needed to be repeated ten times in order to produce enough feedstock for one transesterification batch. After the 24-hour settling period, the lower oil phase was pumped off and the upper water / methanol phase was removed. The pretreated oil was tested for free fatty acid levels. If these levels were acceptable, that is below 1.0%, the pretreated oil could be pumped over to the main reactor unit using a centrifugal pump and reacted in the same manner as soybean oil.

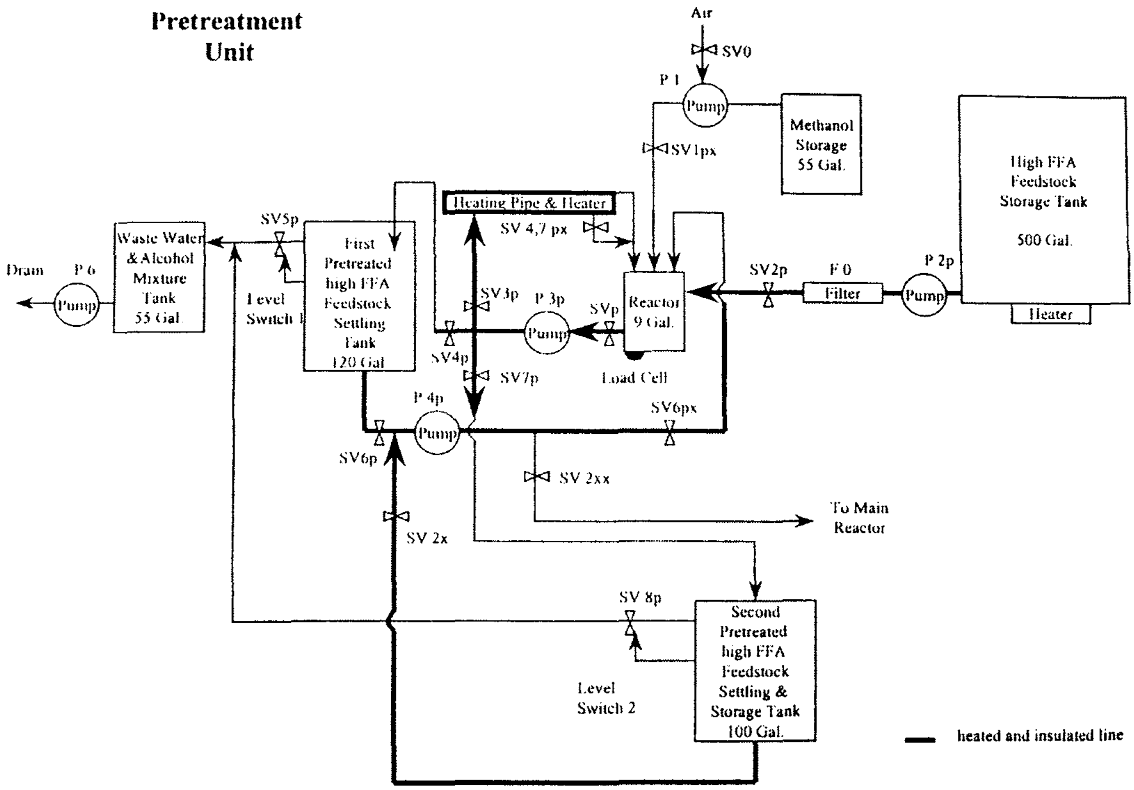


Figure 2.3 Pre-existing Pretreatment Equipment Schematic[6].

Figure 2.4 shows a flow schematic of the pre-existing main transesterification reactor system [6]. A 70-gallon, open-topped, unheated main reactor with an agitator and internal baffles was used for transesterification. Oil from either the soybean oil storage tank or the pretreatment system could be pumped into the main reactor along with methanol from a 55-gallon drum. The KOH catalyst was manually measured and added to the methanol before the start of the reaction. The room temperature transesterification reaction took eight hours to reach acceptable total free glycerol levels of less than 0.24%. A centrifugal pump was used to transfer the mixture into a 120-gallon cone-bottom separation and washing tank where free glycerin was pumped off and soaps were washed out.

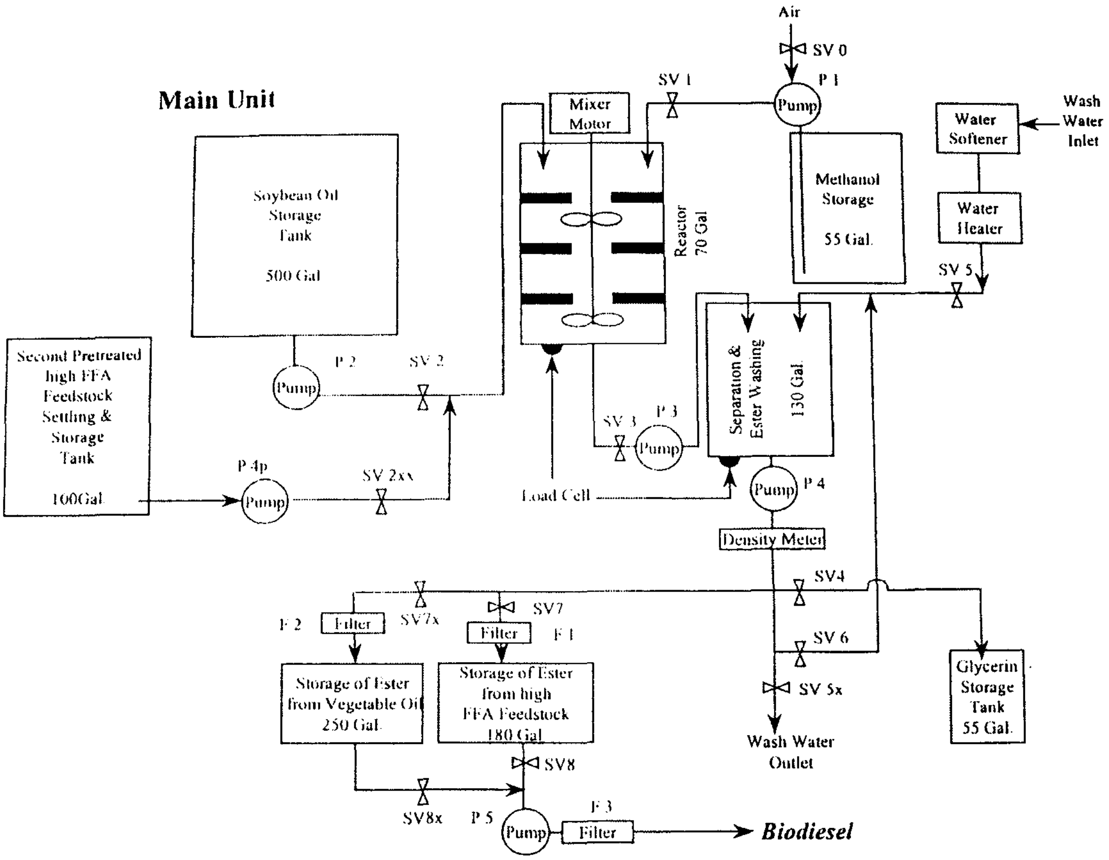


Figure 2.4 Pre-existing Transesterification Equipment Schematic [6].

A water softener and electric hot water heater provided wash water to four showerheads above the cone-bottom tank. Another centrifugal pump delivered the finished methyl esters into either a 250-gallon or a 180-gallon finished fuel storage tank.

This pilot plant was primarily constructed for the purpose of serving as a test bed in the production of biodiesel fuels from high free fatty acid (FFA) feed stocks. While capable of performing limited-run research test reactions, certain aspects of the plant's design and construction were ill-suited for more conventional use and demonstration purposes. A portion of the work represented in this thesis was directed at improving these areas of the BECON biodiesel pilot plant.

3. EQUIPMENT

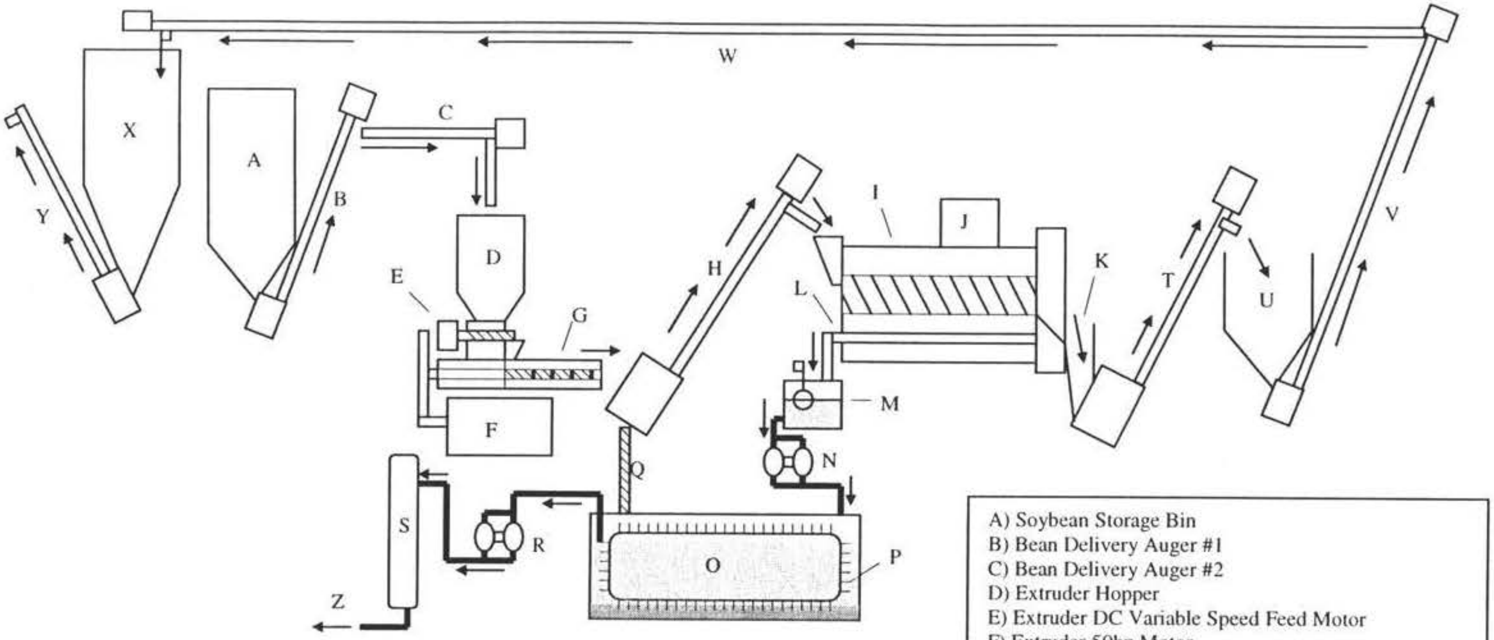
In this chapter, the additions and modifications made to the BECON biodiesel pilot plant are reviewed. The chapter is divided into three sections. The first section details the addition of the soybean processing equipment which allows on-site soybean oil production. The second section describes the various modifications made to the pilot plant itself. The third section deals with the diesel generator and fuel delivery system.

3.1 Soybean Processing Equipment

Previously, soybean oil had been delivered to the pilot plant by commercial suppliers or purchased locally in smaller batches. This method made the production of large quantities of soybean-based biodiesel impractical and provided a poor example of how the pilot plant could operate as a demonstration tool to others. The addition of the soybean processing equipment allowed continuous on-site soybean oil production with the intent to use this oil as a feedstock for the pilot plant. The soybean processing equipment consists of a bean delivery system, the oil extraction equipment, a fine material screening system, and a crushed meal removal system. A flow schematic of this equipment is shown in Figure 3.1.

3.1.1 Soybean Delivery System

The soybean delivery system starts with an outside 1000-bushel bin. This bin has been modified with a front side-loading door allowing easy filling access for auger-equipped trucks. The beans gravity feed from this bin into the first of two automatically controlled flexible augers. The first flexible auger brings beans into the main BECON high bay building and conveys them to the second ceiling-mounted flexible auger.



A) Soybean Storage Bin
B) Bean Delivery Auger #1
C) Bean Delivery Auger #2
D) Extruder Hopper
E) Extruder DC Variable Speed Feed Motor
F) Extruder 50hp Motor
G) Extruder Barrel
H) Conveyor Auger #1
I) Expeller Continuous Horizontal Screw Press
J) Expeller 20hp Motor
K) Expeller Soybean Meal Exit
L) Expeller Soybean Oil Exit
M) Soybean Oil Sump
N) Soybean Oil Sump Diaphragm Pump
O) Screening Tank
P) Screening Tank Scrapper Paddle Conveyor Belt
Q) Screening Tank Fine Material Exit Auger
R) Screened Oil Diaphragm Pump
S) Bag Filter
T) Conveyor Auger #2
U) Soybean Meal Hopper
V) Meal Removal Auger #1
W Meal Removal Auger #2
X) Soybean Meal Storage Bin
Y) Soybean Meal Unloading Auger

Figure 3.1 Soybean Processing Equipment Flow Schematic.

This second auger continues carrying the beans to the biodiesel pilot plant and terminates directly over the extruder bean hopper. The layout of the soybean delivery system is shown in Figure 3.2. The two flexible augers are controlled automatically by two capacitive proximity level switches inside of the extruder bean hopper. When the extruder bean hopper level falls low, the two flexible augers are engaged and begin delivering additional soybeans. When the extruder bean hopper has filled, a timer circuit disengages the first flexible soybean auger while the second auger continues to run for 90 seconds. This allows the second auger to fully empty avoiding possible material jams when the system restarts.

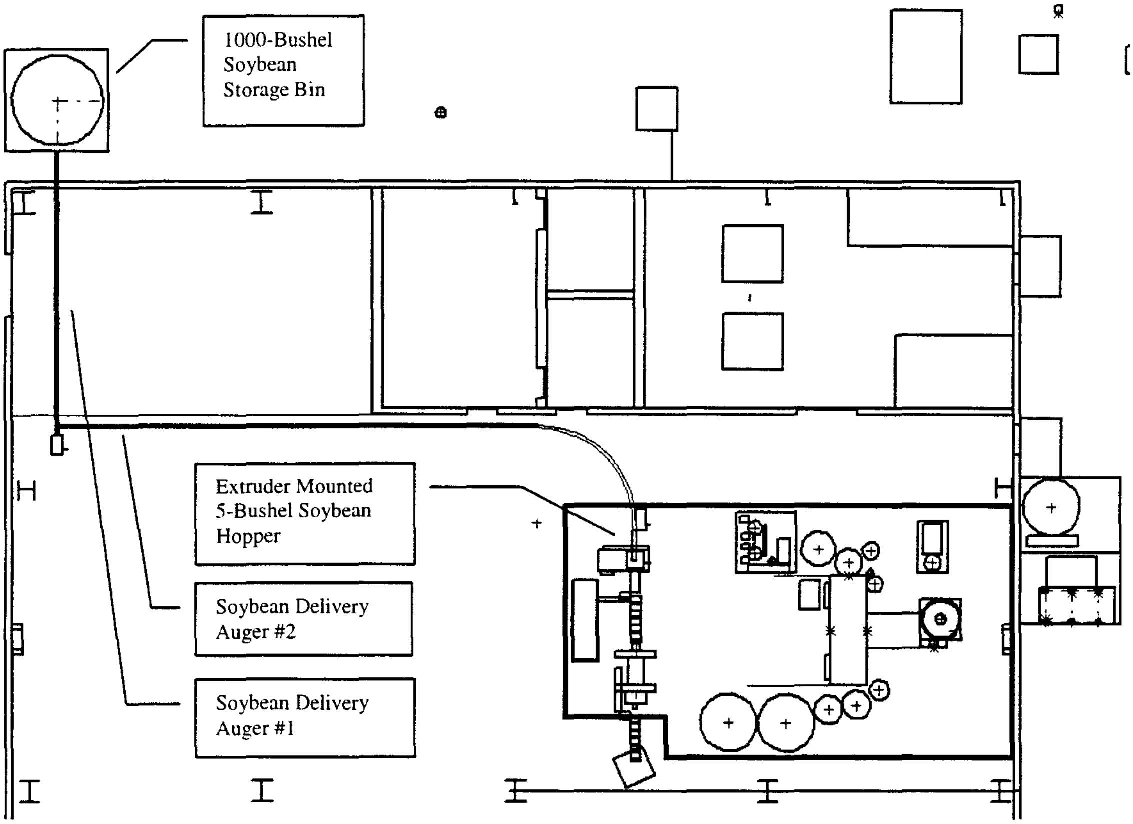


Figure 3.2 Soybean Delivery System Layout.

In the event of a jam or stoppage due to over-feeding the system, foreign objects, or frozen beans in the wintertime, both flexible augers are equipped with automatic overload protectors that stop the system until the problem is cleared.

3.1.2 Soybean Oil Extraction Equipment

The second overhead flexible auger gravity feeds soybeans into a small five bushel hopper mounted directly above an Insta-Pro Model 600 Extruder as seen in Figure 3.3. The extruder is rated to operate at 600 lbs/hr, though rates in the 400-500 lbs/hr range are more typical. At these rates, the small five-bushel bin will feed the oil extraction equipment for approximately 45 minutes between delivery system cycles. The delivery system is capable of filling this bin in less than ten minutes, depending on the extruder rate setting.

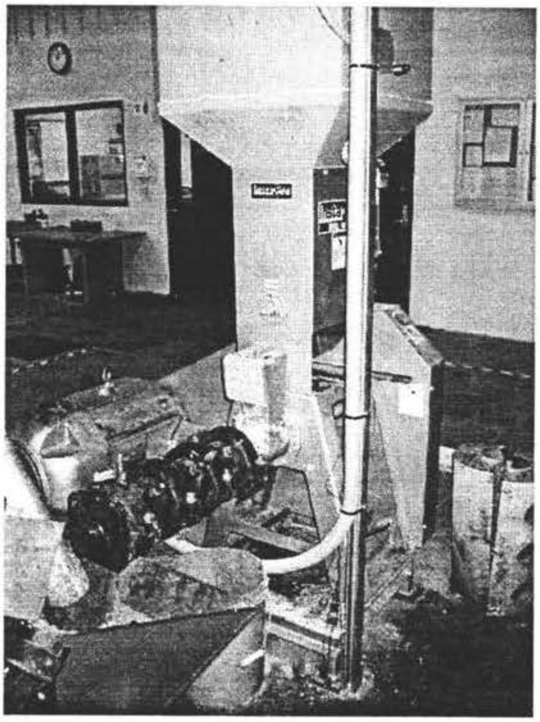


Figure 3.3 Insta-Pro Model 600 Extruder.

The Model 600 extruder features a small variable speed DC auger that feeds the soybeans into the extruder barrel and is used to control the system's rate. The extruder barrel crushes the soybeans and mechanically forces the bean material past a series of steam lock restrictions via a screw press as shown in Figure 3.4 [16].

The temperature and pressure exerted on the soybean material rises at each steam lock until the beans are expelled through a variable sized orifice at 310°F and 40 atm of pressure. By adjusting the DC feeder motor rate and the exit orifice size, the exit temperature can be controlled. When the bean material exits the extruder barrel, the rapid pressure change causes the cell walls to burst and any water present in the bean material to flash off as steam. A steam handling system was constructed to ventilate this water vapor away from the work area. The pilot plant ventilation fan was connected by a series of ductwork and pipes to the extruder outlet. The pipes also contain a 50-foot long chilled water condensing coil. The water vapor condenses on this coil and is gravity drained into a water trap while the

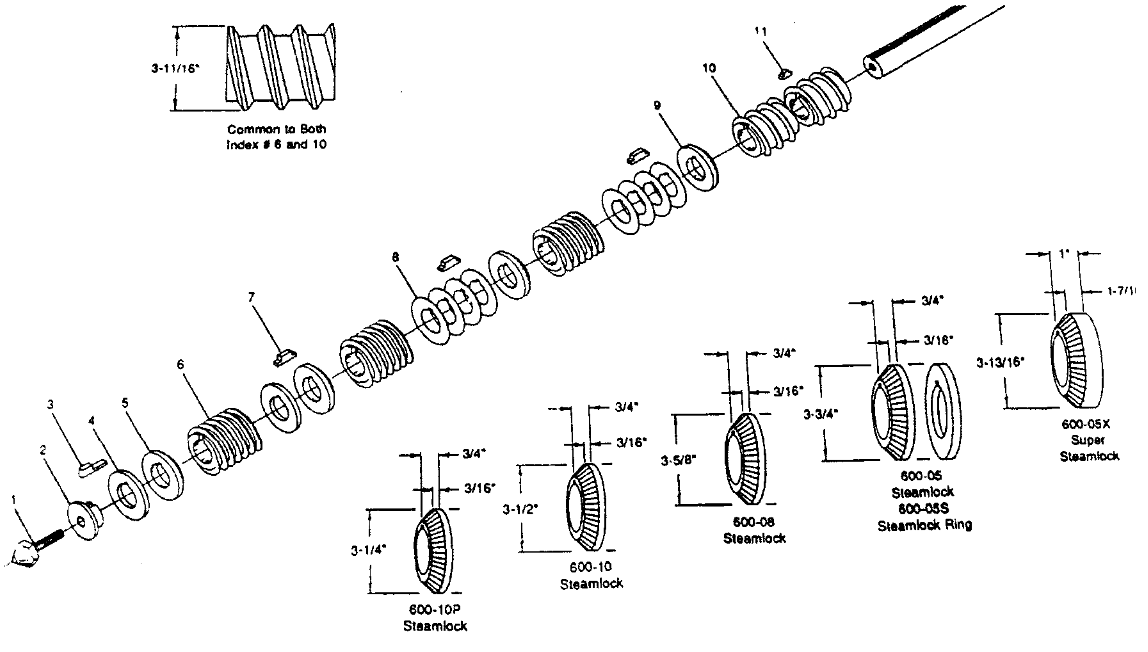


Figure 3.4 Extruder Internal Diagram [16]

ventilation fan exhausts the remaining air outside.

The burst cell walls allows for mechanical oil extraction via a normal screw press as contained in the Insta-Pro Model 1000 Continuous Horizontal Press shown in Figure 3.5. The mechanical oil extraction of this screw press is capable of removing 56-67% of the total soybean oil, by weight, contained in the raw soybeans. The oil constitutes about 18% of the weight of the soybean, resulting in 6-7.2 lbs of oil extracted for each 60 lb bushel of beans processed.

The soybean oil expelled from the screw press flows by gravity into an 11-gallon sump reservoir. Once filled, an automatic float switch engages an air-operated diaphragm pump capable of passing both the soybean oil and any suspended solid particulate matter into the screening tank. Figure 3.6 illustrates the oil sump, float control, and diaphragm pump.

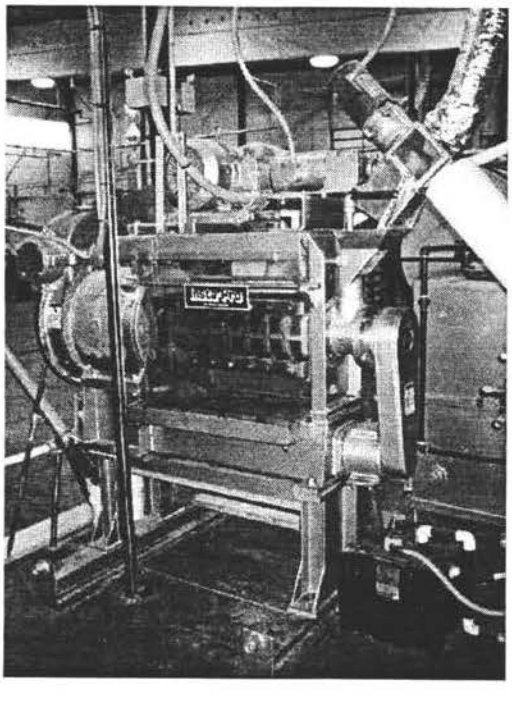


Figure 3.5 Insta-Pro Model 1000 Continuous Horizontal Press

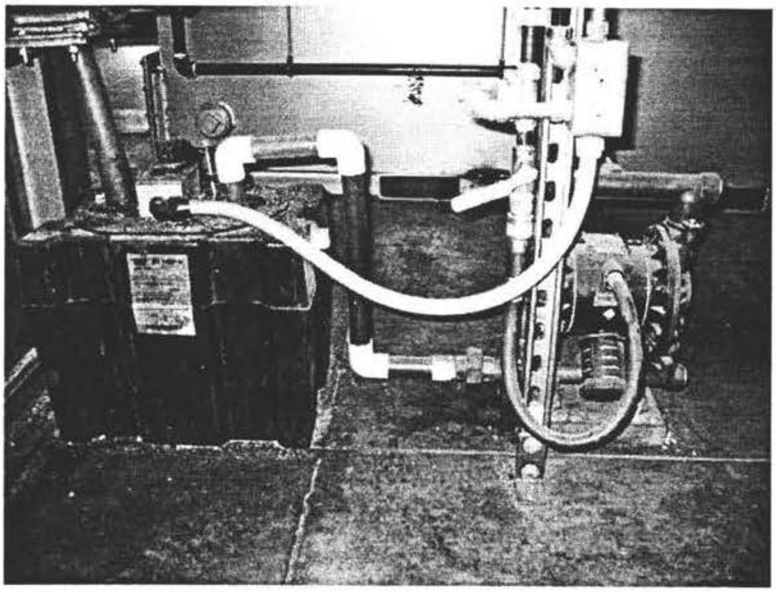
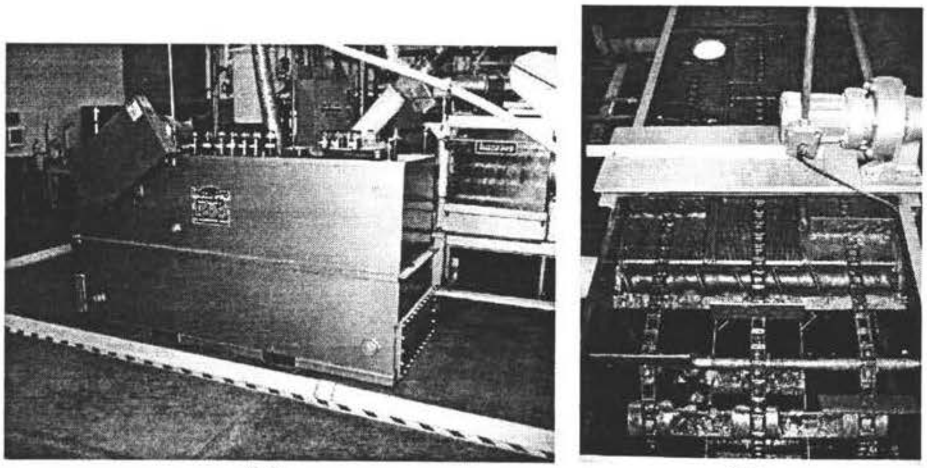


Figure 3.6 Soybean Oil Sump System

3.1.3 Soybean Oil Screening Equipment

The expelled soybean oil contains many fine particles, or *foots*, from the soybean meal. These are removed by means of the Insta-Pro Model 1500 screening tank shown in Figure 3.7 (a). This 400-gallon tank consists of three separate chambers divided by internal baffles as shown in Figure 3.7 (b). The oil flows from the first chamber to the next in a cascade fashion. The large volume and cascade flow ensures a lengthy resonance time of at least 40 hours while running at full rated capacity. Over this time period the fine material settles to the bottom of each chamber, where it is picked up by a conveyor screen system. This material is then augered back into the horizontal screw press ensuring all fine material eventually leaves with the soybean meal. When the screening tank approaches its high level mark, an automatic float switch engages another air-operated diaphragm pump that draws from the top of the last screening tank chamber. This screened oil is passed through a 50-micron bag filter before entering a degumming tank for further processing.



(a) (b)

Figure 3.7 Soybean Oil Screening Tank

3.1.4 Soybean Meal Removal System

A second 5-bushel hopper was constructed to collect the crushed and expelled soybean meal. A series of two flexible auger units, similar to those used in the soybean delivery system as seen in Figure 3.1, were arranged to empty the small 5-bushel bin. Two capacitive proximity sensor level switches installed in the meal bin automatically engage the augers as the bin becomes full. The first flexible auger conveys the crushed meal up to the ceiling of the main BECON high bay and away from the biodiesel pilot plant. The second flexible auger carries the soybean meal to a second 1000-bushel bin located outside. Both augers are controlled by a staged timer and have overload protection systems as described in the soybean delivery system Section (3.1.1). An 8 inch auger attached to the cone bottom of the 1000-bushel meal bin empties the soybean meal into waiting trucks. The layout of the soybean meal removal system is shown in Figure 3.8.

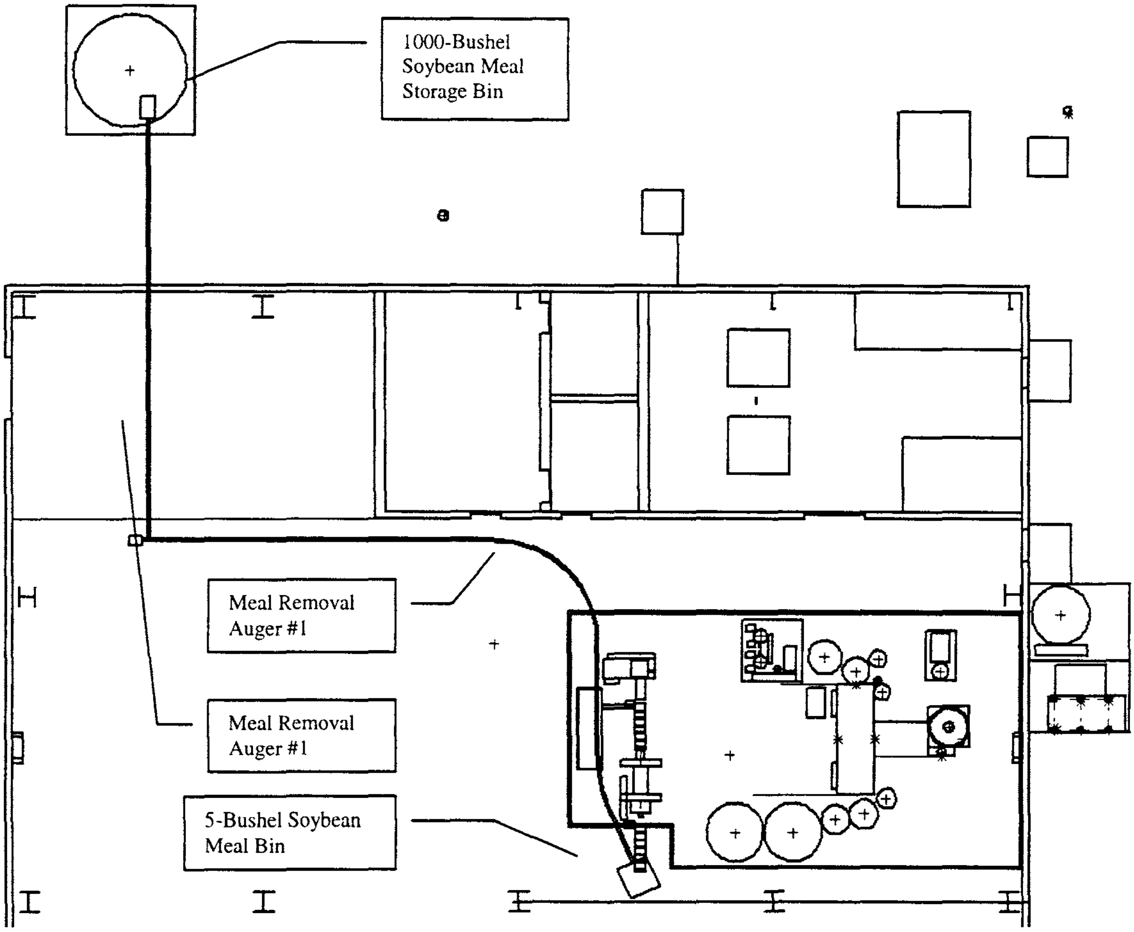


Figure 3.8 Soybean Meal Removal System Layout.

3.2 Pilot Plant Equipment and Modifications

In order to more effectively use the pilot plant as a demonstration tool for biodiesel research and production, a number of modifications and improvements were undertaken. The yellow grease pretreatment system was modified to allow easy startup, shorter cycle times, and safe all-season operation. The main reactor system was replaced with a larger unit that allowed variable reaction rates, greater batch sizes, and safe high- temperature operation. A diaphragm pump-driven, recirculating, cyclonic separator system was constructed and connected to the main reactor in order to explore alternate glycerin separation techniques and continuous glycerol removal.

3.2.1 Yellow Grease Pretreatment Equipment

Several issues had to be addressed with the existing yellow grease pretreatment system. These included nonfunctioning valves, unsuitable pumps, yellow grease solidification in the settling tanks, and possible methanol vapors escaping the open-top tanks. Additionally, the original operation technique and plumbing configuration required a ten-hour period of operator attention in order to produce the feedstock for one batch of fuel.

It was determined that the previous solenoid valves contained wetted materials that were unsuitable for use with both sulfuric acid and methyl esters. The same rubber seal valves were used throughout the rest of the pilot plant. All of these valves were replaced with GC Valves Model S21 Diaphragm valves constructed with stainless steel bodies and Teflon seals. These valves are compatible with all liquids used in the pilot plant as well as being less expensive than the original valves. These valves are depicted in Figure 3.9.

The stainless steel centrifugal pumps used throughout the pilot plant were found to be incapable of pumping the thick viscous yellow grease, particularly in colder weather. These pumps were replaced with positive displacement air-operated diaphragm pumps from Graco. The Graco Husky line of pumps was used with either polypropylene or aluminum bodies and Teflon seals throughout. These pumps were not only capable of pumping even the unheated yellow grease but are also explosion-proof due to their air-powered design. The same pump was also used to replace the previous air-operated centrifugal methanol delivery pump. The centrifugal unit delivered methanol to both the pretreatment and main reactors at too low of a rate for practical fuel production. These pumps are depicted in Figure 3.10.

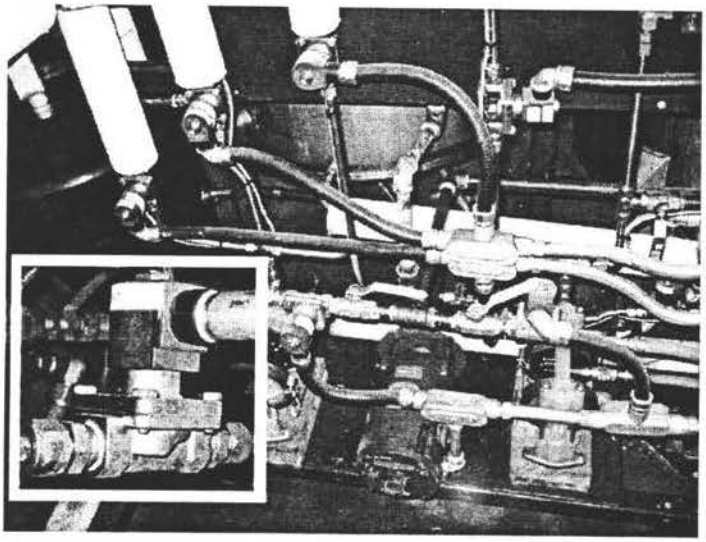


Figure 3.9 GC S21 Diaphragm Valves.

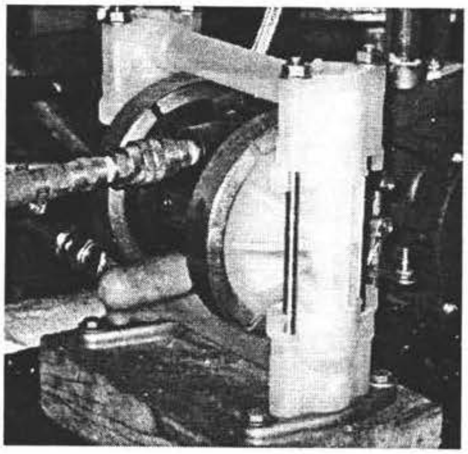


Figure 3.10 Graco Husky Diaphragm Pumps.

The original pretreatment tanks were used for unheated settling of the yellow grease after the esterification process. The required 24 hour settling period could only be observed during summer months, as the yellow grease would solidify at the ambient temperatures typical of winter months. After the installation of the building's glycol heating system, a hot glycol line was run through heating coils in both tanks. The tank temperature could be easily controlled with the addition of an Omega CN9000A series temperature controller and thermocouple. These heating coils are depicted in Figure 3.11.

These same tanks were originally unsealed, open-topped tanks. The pretreatment process utilizes a significant amount of methanol at elevated temperatures. In order to minimize the chance of methanol vapors escaping, the tanks were sealed air-tight and vented through a water bubbler trap. The ventilation line and trap allows the tanks to be filled and empted while remaining at atmospheric pressure, yet the make-up air volume always passes through the water trap. Any methanol vapors in this air end up in the trap water. The pretreatment water trap is depicted in Figure 3.12.

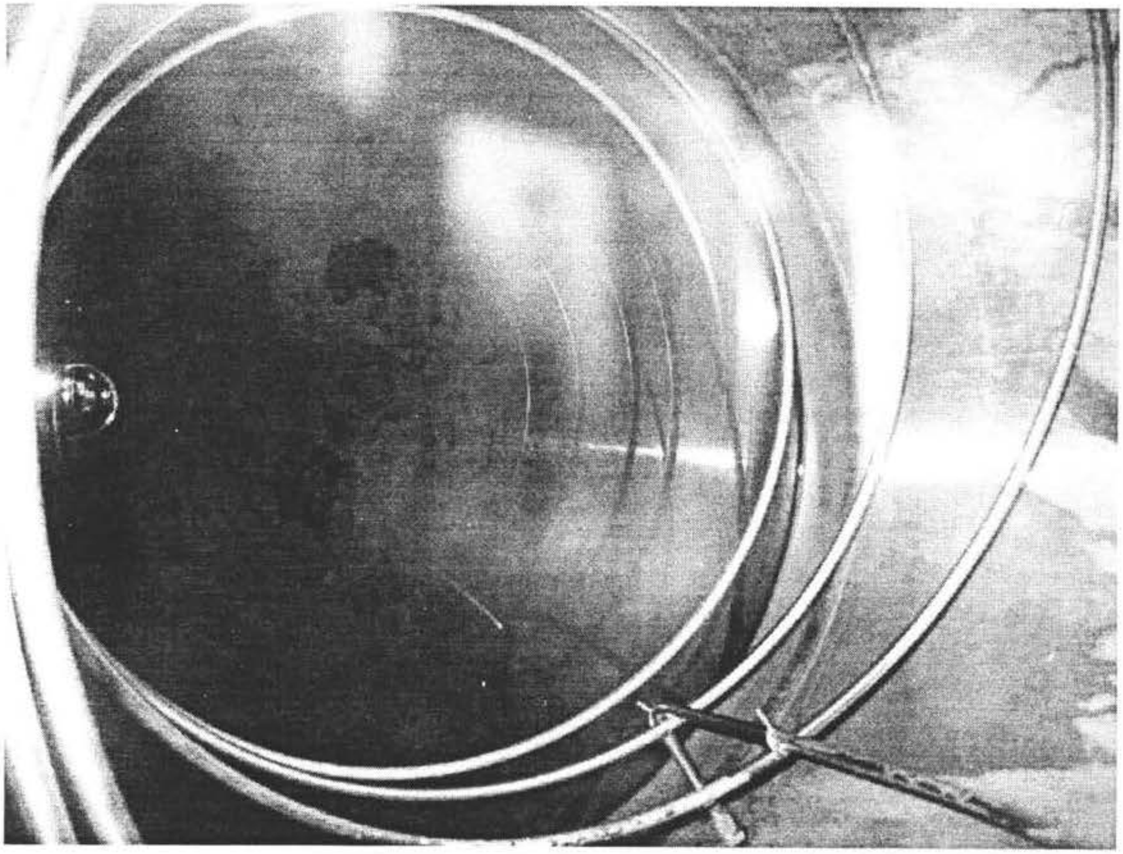


Figure 3.11 Pretreatment Settling Tank Heating Coils.

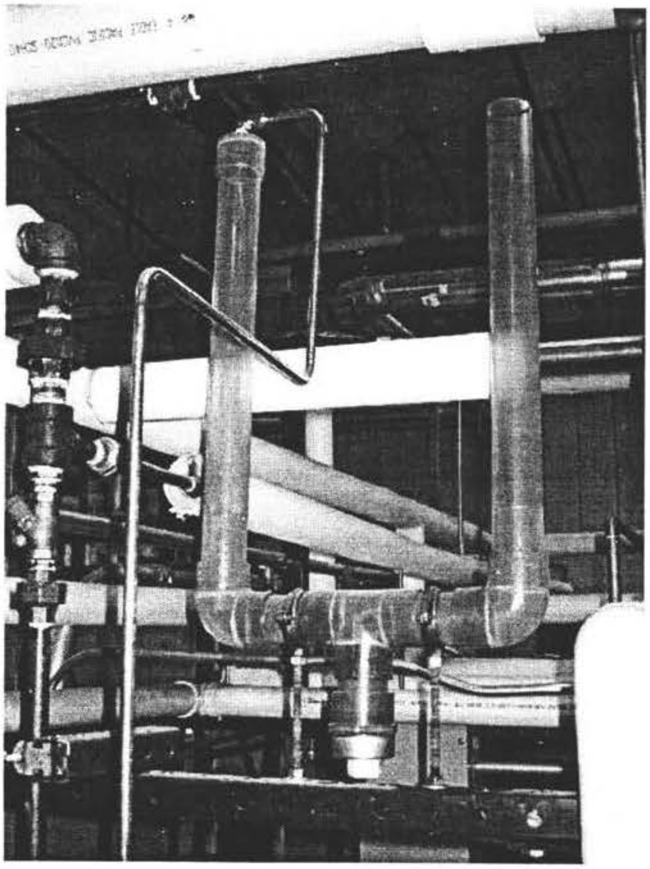


Figure 3.12 Pretreatment System Water Trap.

The previous esterification process was started by the addition of sulfuric acid to the mixture. This acid was manually measured out and poured into the open 9-gallon pretreatment reactor. In order to eliminate the manual handling of sulfuric acid, a calibrated peristaltic pump was used to time and deliver the correct amount of acid into the pretreatment reactor. Having eliminated the need for manual access to an open reactor, the pretreatment reactor was also sealed air-tight and vented through a methanol vapor water trap. The peristaltic acid delivery system is depicted in Figure 3.13.

The previous esterification technique involved reacting small batches in the pretreatment reactor while recirculating through a heating tube at 140F. After the one-hour

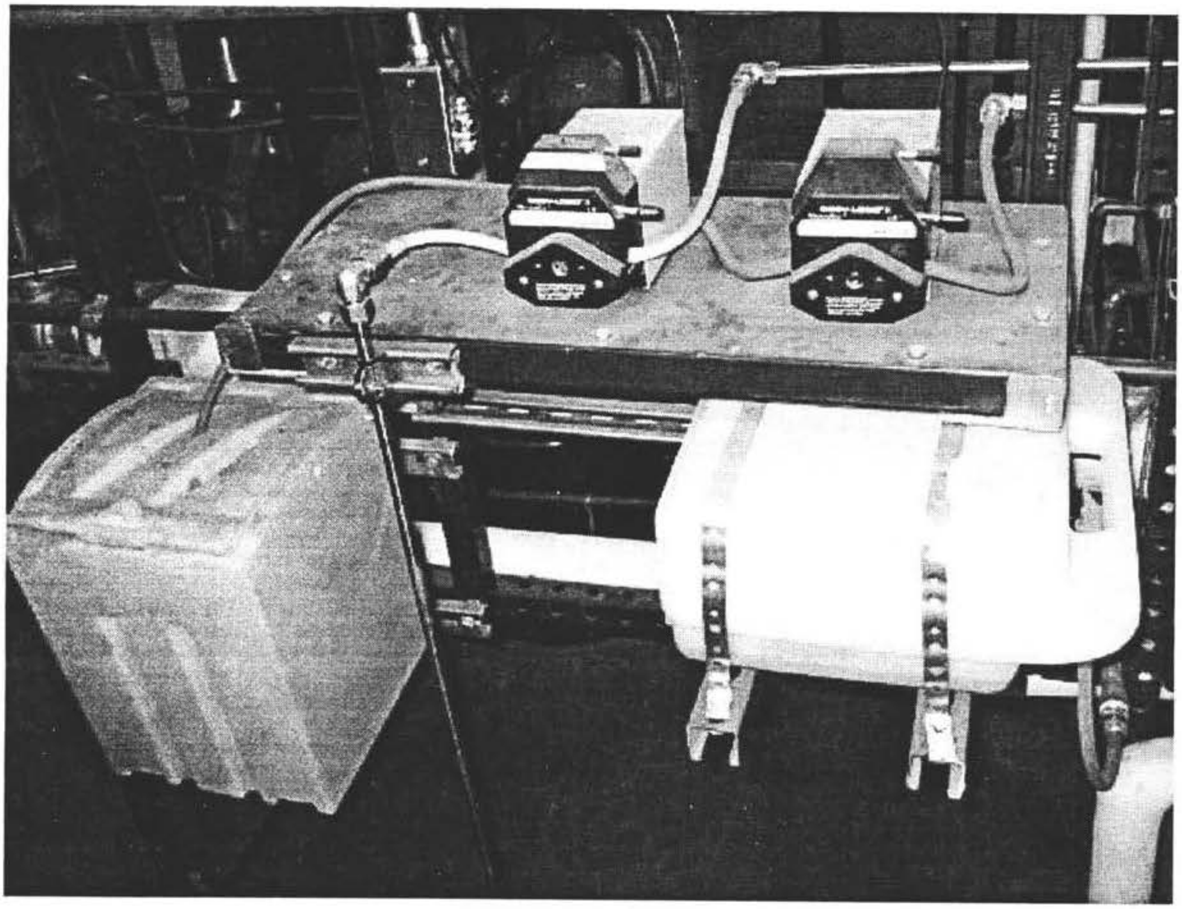


Figure 3.13 Peristaltic Acid Delivery System.

reaction was complete, the pretreated mixture was allowed to settle for 24 hours in the settling tanks. Ten such reactions were required for one 70-gallon batch and the total time per batch exceeded ten hours when pumping and mixing times were included. With the ability to heat the entire settling tanks, the reaction could now take place inside the settling tanks themselves. A rerouting of the pretreatment plumbing allowed recirculating through the same heating tube. These changes allowed the pretreatment reaction for an entire batch to take place in one step over a one-hour period. The plumbing routing required is depicted in Figure 3.14.

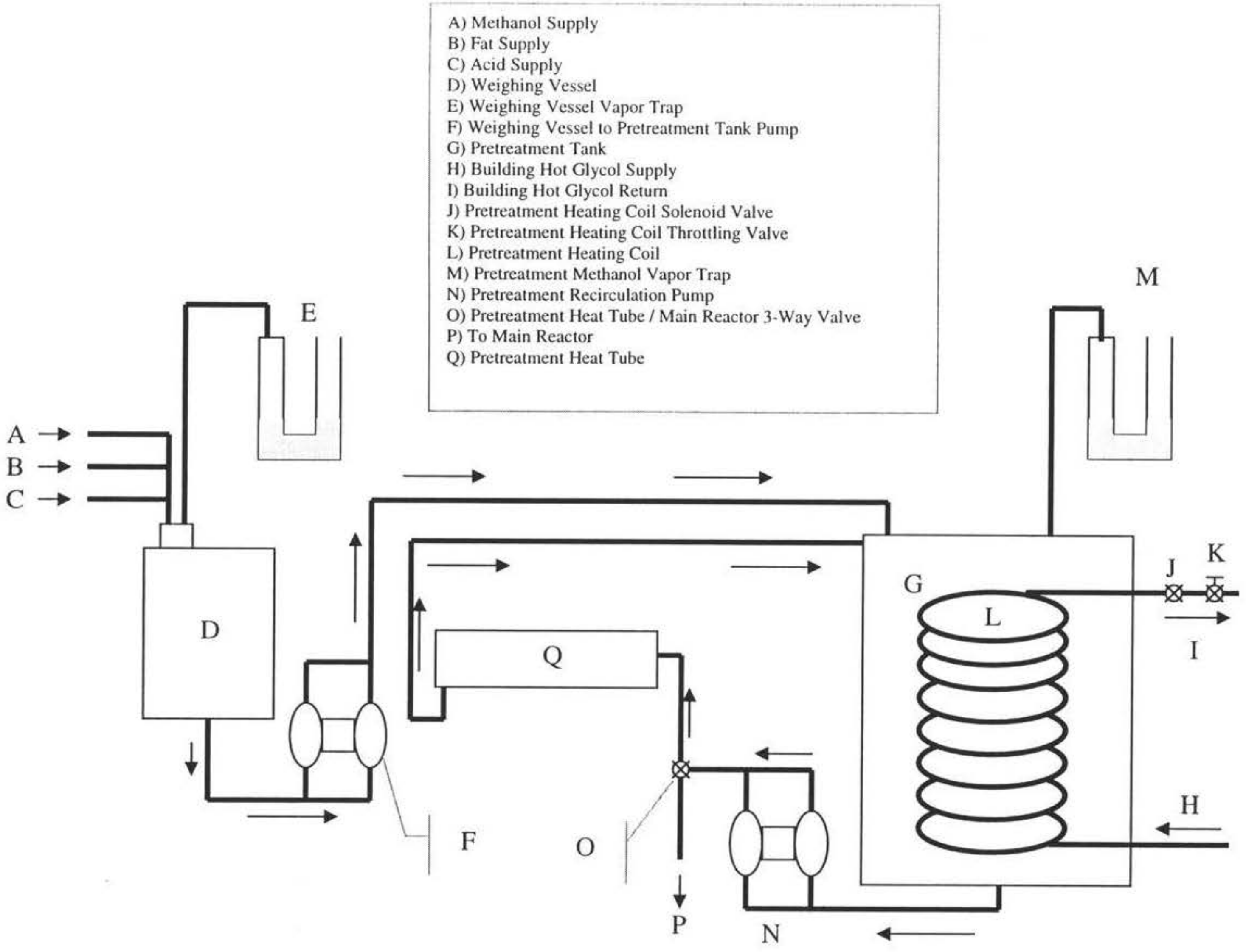


Figure 3.14 Pretreatment Process Flow Schematic.

3.2.2 Main Reactor System

The original main reactor was a small open-top, unheated 70-gallon tank. In order to conduct larger main reaction experiments at elevated temperatures, a new tank was needed. The original tank was replaced with a larger 100-gallon jacketed reactor and is depicted in Figure 3.15. The new tank was cleaned, sand blasted, shortened, and powder-coated gray. This tank also has a carbon steel heating jacket that could be used to control the tank's temperature. The main reactor heating jacket was connected to a recirculating centrifugal pump and filled with a water glycol mixture. A heat exchanger in this recirculating loop connects to the building's hot glycol system as shown in Figure 3.16. An in-tank thermocouple provides temperature information to an Omega CN9000A series temperature controller. The temperature controller can easily regulate the main reactor temperature

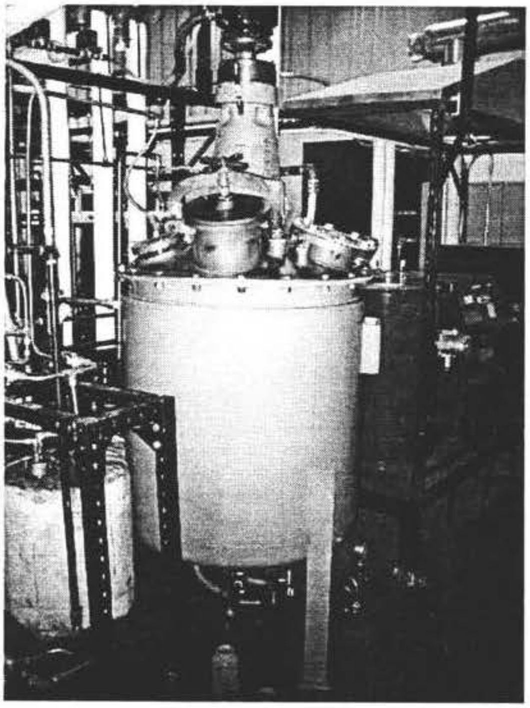


Figure 3.15 Main Reactor.

through use of a solenoid valve on the heat exchanger's hot glycol supply line. This separate glycol system provides even heating around the entire main reactor jacket and allows the jacket to operate at atmospheric pressure. This was required as the building hot glycol system operates at pressures well above the maximum allowed heating jacket pressure. The main reactor heating system allowed the transesterification process to be driven at different rates at temperatures ranging from room temperature up to the boiling point of methanol (148.46°F).

In order to prevent the release of methanol vapors during the main reaction, this airtight sealed tank was fitted with a water-cooled condenser column. Makeup air entering or leaving the tank during volume changes must go through this column, condensing and returning any methanol vapors to the main reactor. Furthermore, the condensing column breathes through a second water bubbler trap that operates on the same principle described in Section 3.2.2. A flow schematic of the main reactor system is shown in Figure 3.16.

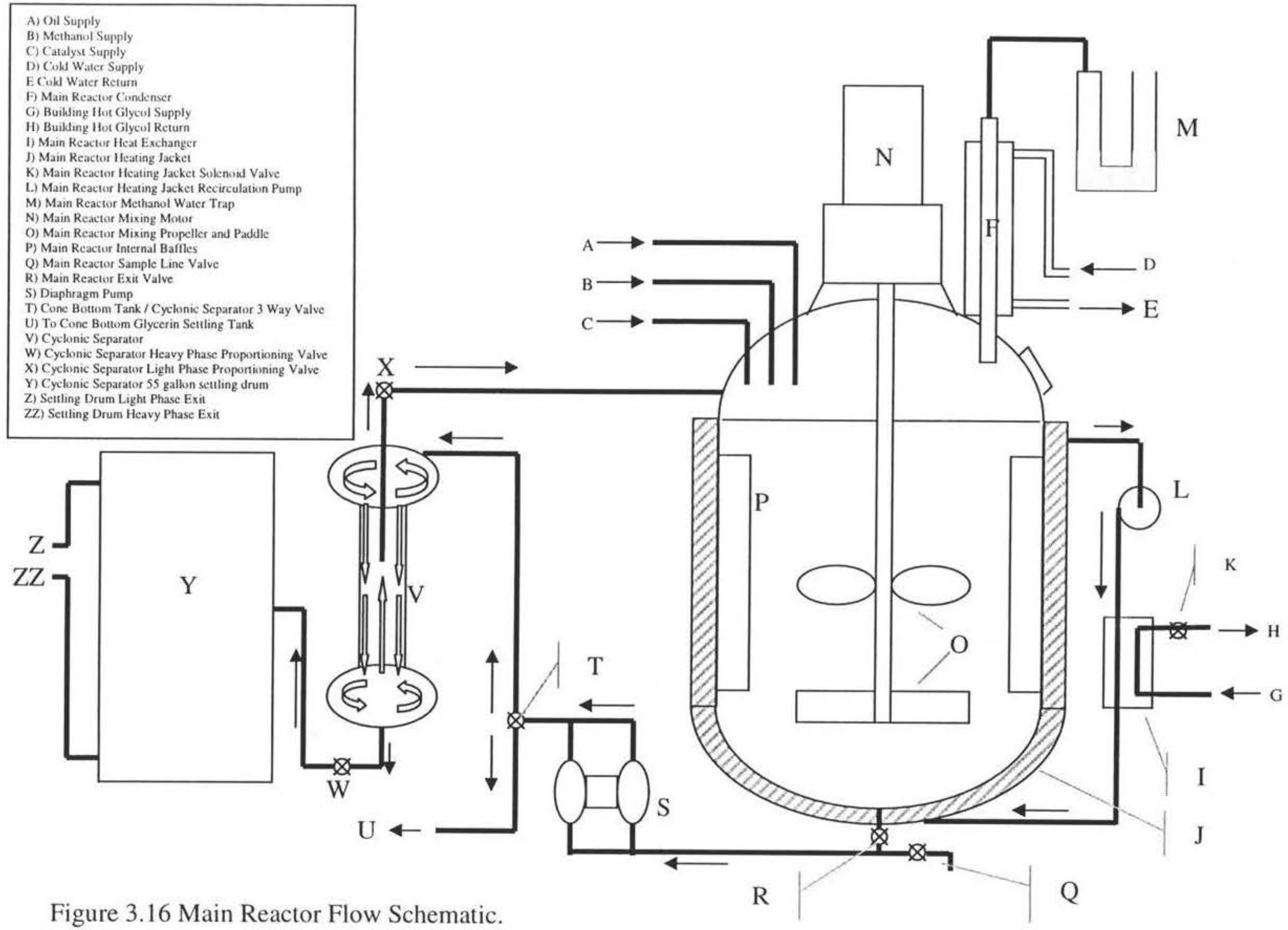


Figure 3.16 Main Reactor Flow Schematic.

3.2.3 Cyclonic Separator

In addition to higher reaction rates at higher temperatures, the addition of a cyclonic separator allowed the effects of possibly enhanced mixing and real time glycerol removal to be studied. The heavy glycerol phase can be separated by gravity, however very large tanks are necessary for the residence time required to do this during the main reaction. Similar results could be achieved with an appropriate centrifuge, however these are very expensive. A similar centrifugal separation process takes place in the much simpler cyclonic separator. The cyclonic separator itself has no moving parts and is powered by an external explosion-proof, air-operated diaphragm pump. The cyclonic separator system is depicted in Figure 3.17.

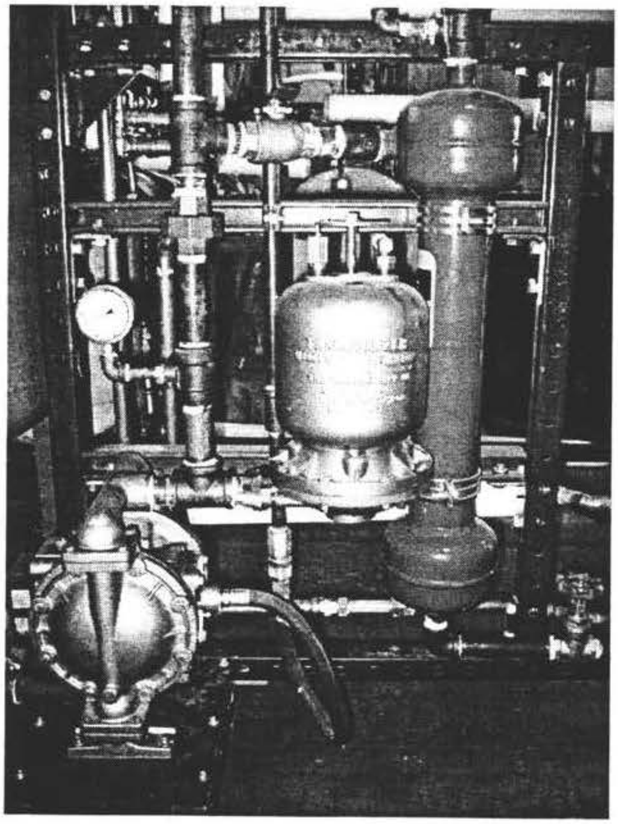


Figure 3.17 Cyclonic Separator.

The agitated contents of the main reactor are pumped out of the main reactor bottom exit valve and into the top of the cyclonic separator. The fluid enters tangentially at a high velocity and induces a strong rotational flow. Any heavier phases tend to gather at the outside of the upper chamber until their volume fills this chamber and they flow down the inner wall of the main body tube. At the bottom end the heaviest phases will again collect on the outer walls while the lighter phases exit up the center of the main body tube and out of the separator. The light stream is recirculated to the main reactor. The heavy phase in the bottom of the cyclonic separator can be emptied through its central bottom drain. Proportioning gate valves on the light and heavy phase exits determine the flow rates and separation strength.

Early ideas involving the use of the cyclonic separator centered around the concept of removing glycerin during the transesterification process. Initial tests also indicated the possibility of a very strong mixing action taking place within the separator. This early investigation into the uses for the cyclonic separator focused on the enhanced mixing's effect on reaction rates.

3.3 Diesel Generator

The final phase of the current pilot plant goals as a demonstration tool was the installation of a diesel generator. With on-site power generation, biodiesel production technologies could be demonstrated all the way from raw soybeans to kilowatts of electricity. To this end, an Olympian D40P3 40kW generator set was installed outside the main BECON high bay building. A fuel supply shed situated next to the generator handles fuel delivery of both diesel and biodiesel fuels. The instrumented generator and fueling system can be used to both power the building and provide information on the fuel's performance and emissions. The generator and fuel shed are depicted in Figure 3.18.

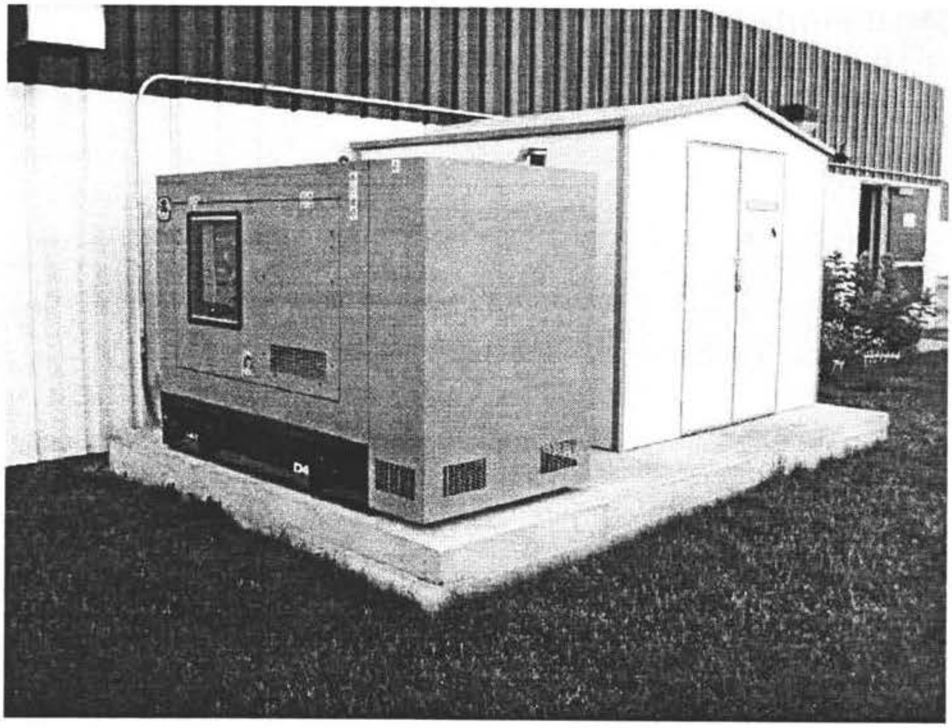
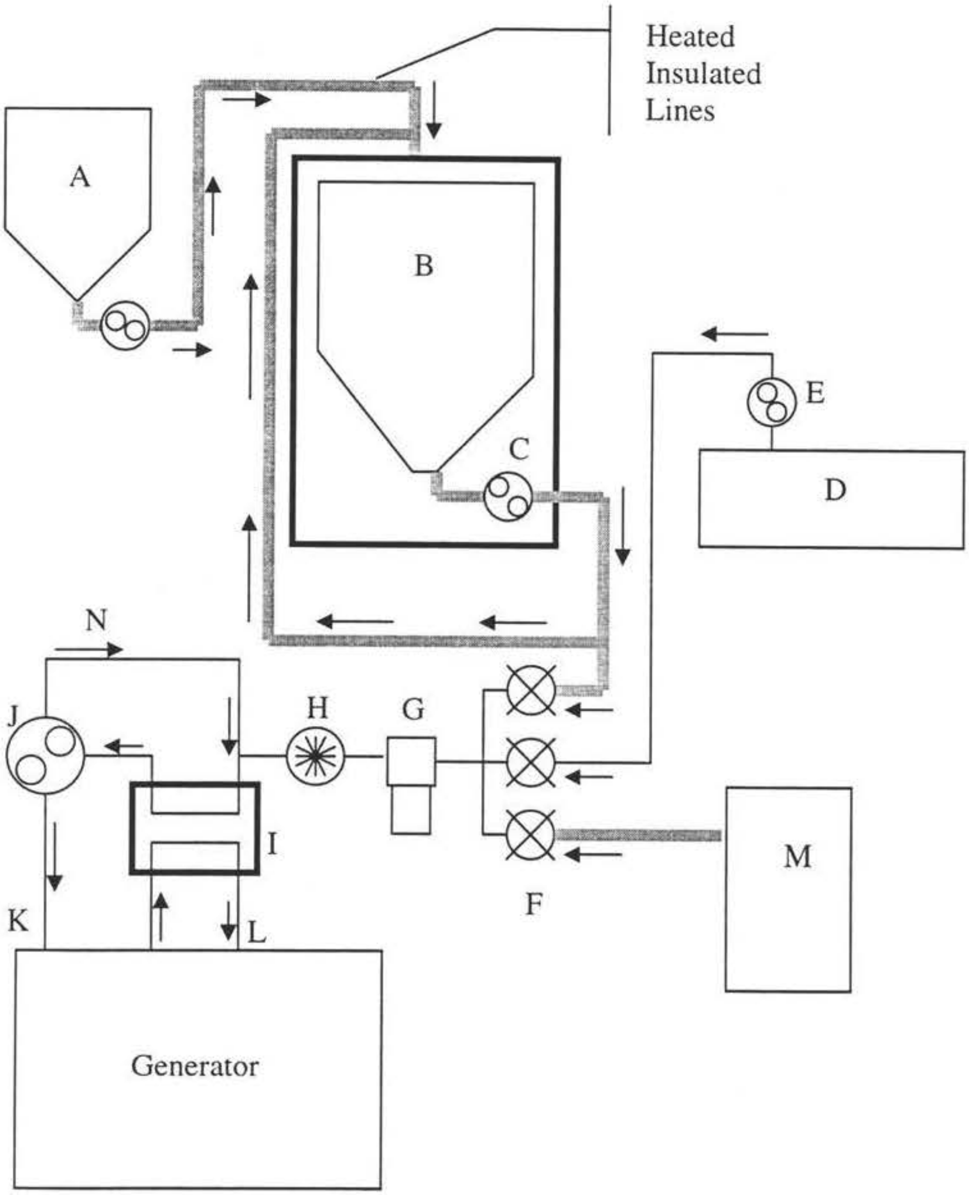


Figure 3.18 Generator and Fuel Shed.

3.3.1 Fuel Delivery System

The fuel delivery system consists of a biodiesel storage tank and a small diesel day tank, both located in the fuel shed, heated and insulated piping running from the building to the generator itself, a remote controlled source switching solenoid manifold, a final fuel filter, an AW Company JVM-10KL flow meter, and a heat exchanger. A flow diagram for the fuel delivery system can be found in Figure 3.19.

After the final wash and drying process, the finished biodiesel can be pumped to the outside tank through an overhead line. In order to keep the biodiesel from gelling during the



A) Dried finished fuel storage.
B) 500 Gallon Biodiesel storage tank.
C) Biodiesel fuel supply and recirculation pump.
D) 36 Gallon #1 Diesel storage tank.
E) Diesel fuel supply pump.
F) Solenoid valve fuel selection manifold.
G) Fuel filter.
H) Flow meter.
I) Fuel / engine coolant heat exchanger.
J) Engine fuel pump.
K) Engine fuel supply line.
L) Engine coolant line.
M) Sample fuel barrel.
N) Engine fuel pump bypass / return line.

Figure 3.19 Fuel Delivery System.

colder winter months, these lines were wrapped in temperature-controlled heating tape and insulated. The overhead lines empty into the outside heated, insulated 500-gallon biodiesel tank. A heated, insulated line was run from the tank's exit pump to the generator and back into the top of the tank. This line not only allows the biodiesel to be recirculated but also supplies pressurized fuel to the selection manifold. A fuel selection manifold was assembled out of the same solenoid valves used throughout the pilot plant. This manifold allows the generator fuel supply to be switched from the biodiesel storage tank to a smaller 36-gallon #1 diesel tank that is also stored in the fuel shed. The third port in the fuel selection manifold leads to a heated, insulated line allowing the generator to be run off of small test samples or barrels of fuel. The fuel selection manifold is depicted in Figure 3.20. Immediately after the fuel selection manifold, a final fuel filter was installed just ahead of the AW flow meter. This positive displacement flow meter provides accurate volumetric flow data displayed

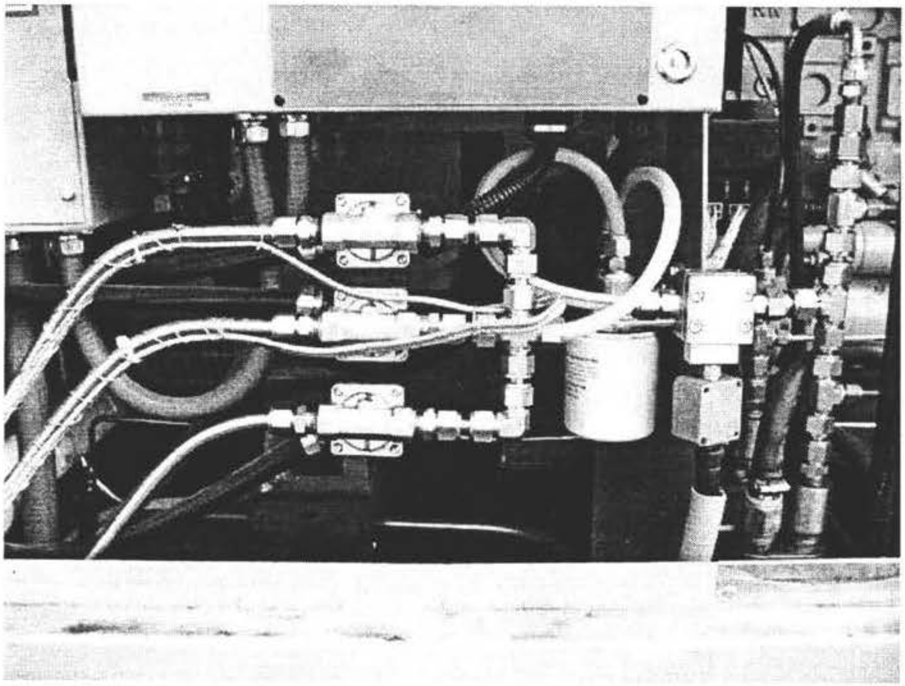


Figure 3.20 Fuel Selection Manifold.

on a readout panel inside. A heat exchanger was installed between the flow meter and the engine fuel intake. The other side of the heat exchanger was connected to the engine cooling system. The engine's fuel-pump bypass cannot return excess flow past the flow meter. The heat exchanger prevents any high temperature buildup in the return fuel loop at low engine duty. The second function of this heat exchanger was to provide a constant fuel intake temperature. Since the engine regulates its cooling system to a constant temperature, the heat exchanger similarly regulates the incoming fuel supply to a constant temperature near 120°F. The fuel selection manifold control, flow meter output, and thermocouple temperature output are all routed to the indoor fuel control panel shown in Figure 3.21.

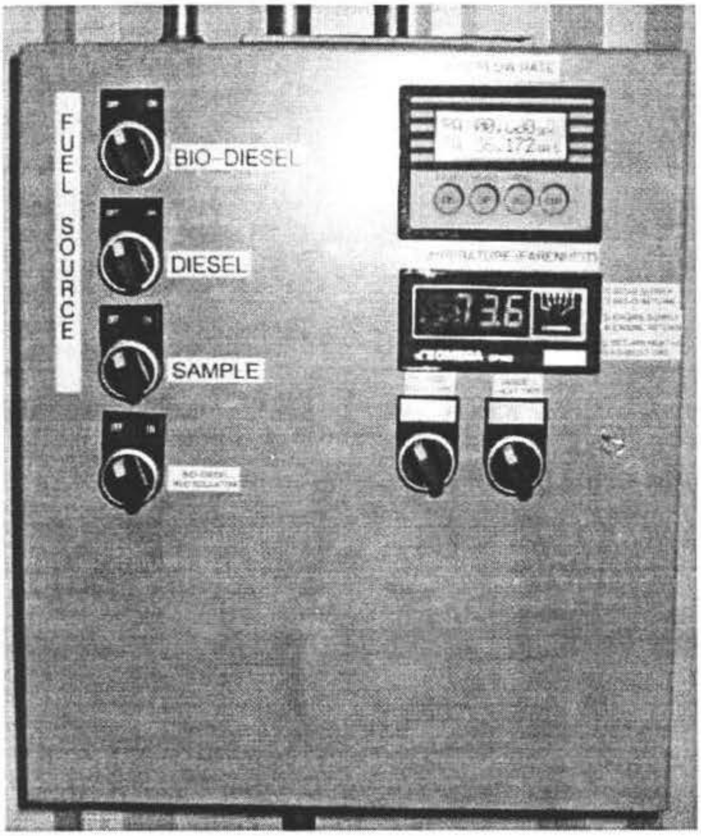


Figure 3.21 Fuel Control Panel.

3.3.2 Generator Equipment and Instrumentation

The generator itself is an Olympian D40P3 diesel generator set. This consists of a 40 kW three phase 277/480 V alternator rated at 89.4% efficiency at full load driven by a Perkins 4 cylinder diesel engine. The engine has a displacement of 3.99L with a 100 mm bore and a 127 mm stroke. The engine is naturally aspirated with a compression ratio of 16.0:1 and is electronically governed to 1800 rpm.

The engine has been fitted with thermocouples that read fuel intake temperature, bypass fuel return temperature, heat exchanger supply and return temperatures, and exhaust gas temperature. The engine's exhaust system has also been fitted with a stainless steel sampling line for exhaust gas emissions analysis. A small filtering and drying unit was constructed for this line. The line first passes through a particulate filter and into a diaphragm pump. The remainder of the emissions testing equipment operates under the pressure of this pump allowing for the lowest chance of contamination from outside air. After the diaphragm pump, a DryRite column was installed for water vapor removal from the exhaust sample. A final particulate filter catches any DryRite dust before the emissions line runs out to the test instruments. This filtering and drying unit is depicted in Figure 3.22.

For the purposes of this study, the emissions sampling line was routed to a Beckman Industrial Corp. model 955 chemiluminescent NO/NOx analyzer. The NO/NOx analyzer also requires a source of compressed air or oxygen, compressed nitrogen, and compressed nitric oxide. A safety stand was constructed for these gas bottles next to the emissions bench. The NO/NOx analyzer system is depicted in Figure 3.23. A Robert Bosch GMBH model DTD02050 smoke meter was used for the purpose of examining smoke emissions in this study. The smoke meter was attached directly to the generator housing near the exhaust pipe.

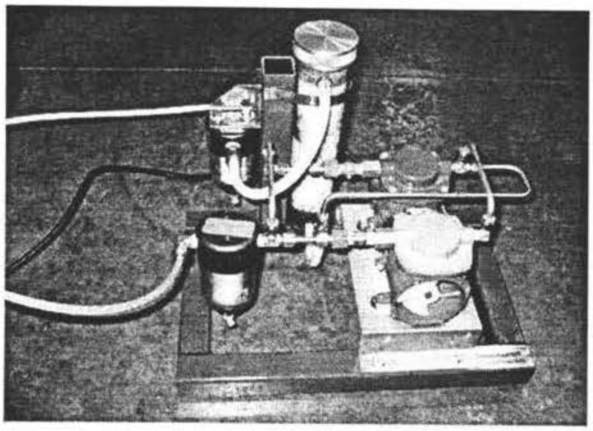


Figure 3.22 Exhaust Sample Filtering and Drying Unit.

Figure 3.23 NO/NOx Analyzer System.

This allowed the smoke meter's probe to be positioned directly in the center of the exhaust pipe flow. A schematic diagram of the entire exhaust emissions measurement system is shown in Figure 3.24.

The Olympian D40P3 diesel generator set used for these experiments has a maximum output of 40kWe. This generator normally powers only the building lights and electrical

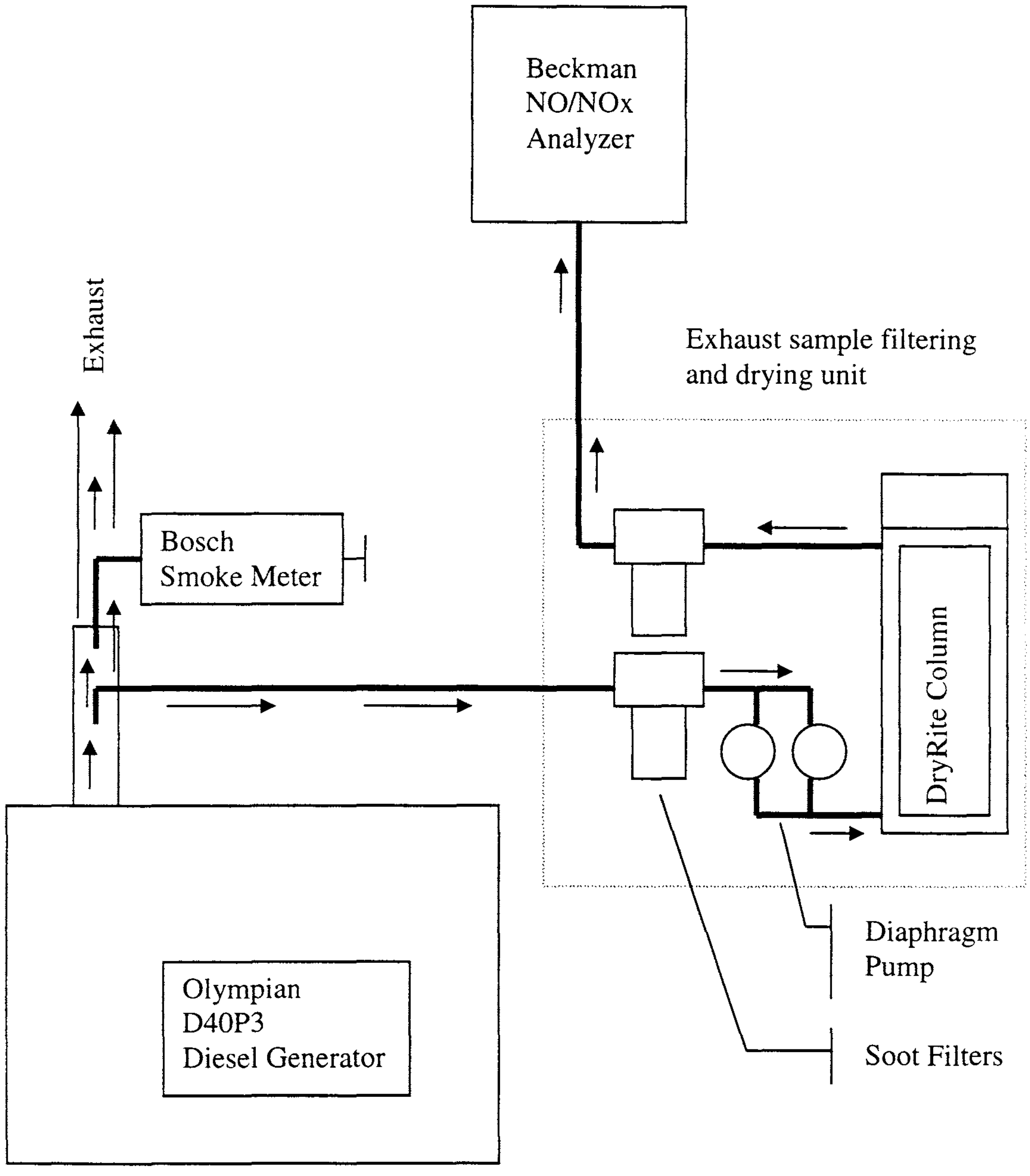


Figure 3.24 Exhaust Emissions Flow Schematic.

outlets, providing an approximate 12kW load. In order allow the generator to operate at all of the desired loadings, a load tester was constructed. A schematic diagram of the load tester system is shown in Figure 3.25.

The load tester is comprised of a series of 6000W electric water heater elements run inside of a cooling water jacket. Individual circuit breakers connect each heater element to the to the generator power. By switching a circuit breaker on or off, the load on the generator can be varied. Smaller load variations were made using a 1000W heat gun as well as several banks of 500W lights.

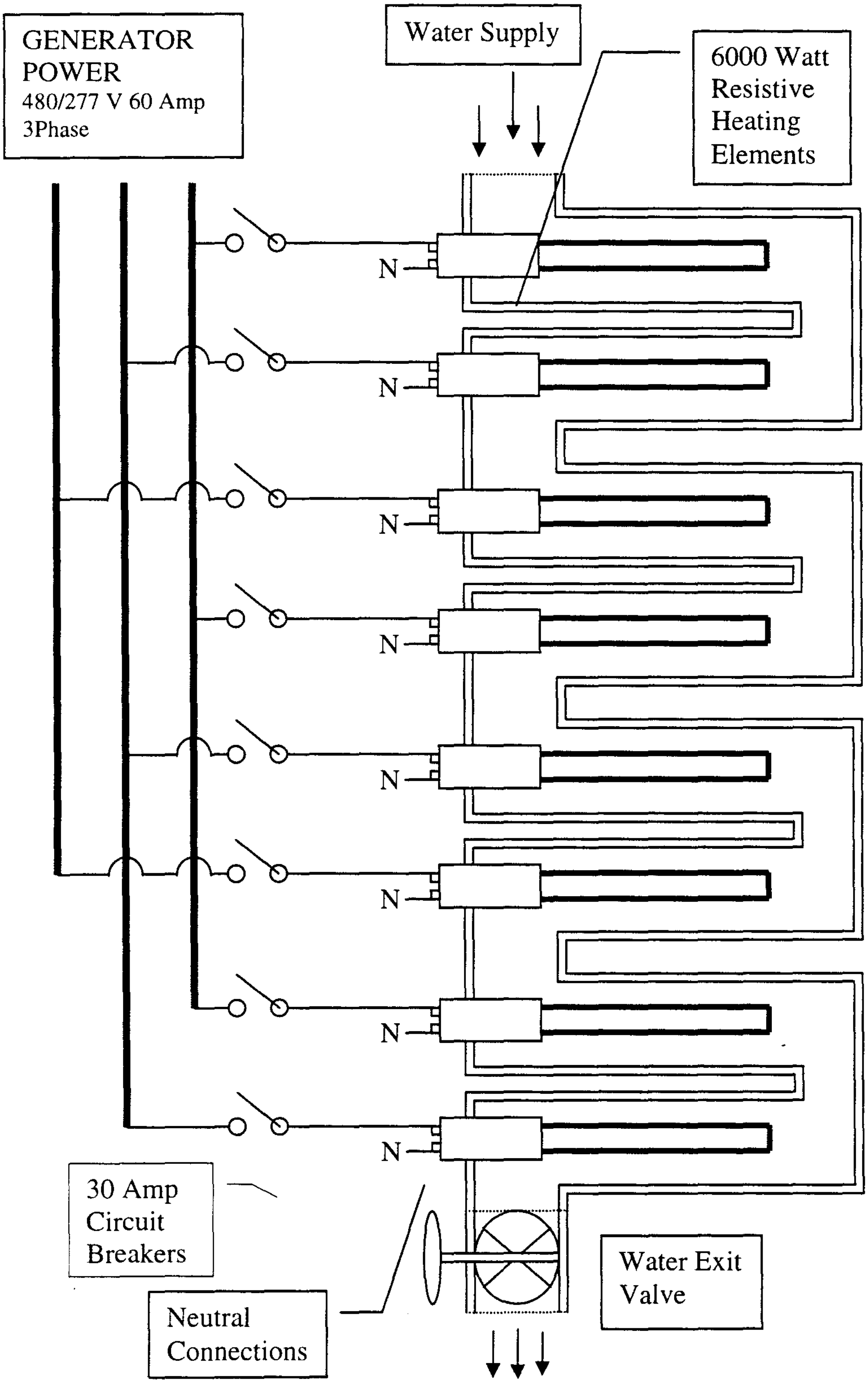


Figure 3.25 Generator Load Tester Schematic.

4. PROCEDURES

In this chapter, the experimental procedures followed for the fuel production rate testing and generator emissions testing are reviewed. The chapter is divided into two sections. The first section details the reaction rate tests for both the heated main reactor and the cyclonic glycerin separator. The second section goes over the NO/NOx and smoke emissions testing performed using diesel and biodiesel fuels in the diesel generator.

4.1 Fuel Production Rates

The following section describes the test procedure for the fuel production reaction rate experiments. The reaction rate test program consisted of a series of eight transesterification reactions. Four of the eight tests were run with the recirculating cyclonic separator and four were run without the separator. The four tests in these two groups were run at main reactor temperatures of 80°F, 100°F, 120°F, and 140°F. All eight tests were prepared using a 6:1 molar ratio of methanol to oil, 0.25% sodium methoxide catalyst by mass, and an additional 1:1 molar ratio of catalyst to free fatty acid for acid neutralization. The reactants are shown in Table 4.1.

Table 4.1 List of Reactants for Transesterification Reactions.

100.00 lbs	1.0% FFA Soybean Oil
21.69 lbs	Methanol
1.76 lbs	25% Sodium Methoxide Solution in Methanol

4.1.1 Pilot Plant Preparation

Before each reaction, the pilot plant and supporting equipment were prepared in the following manner. The pilot plant exhaust system was turned on. The main reactor condenser column cold water supply was opened. The main reactor was checked to be sure it was empty and its drain valve was closed. The building's hot glycol heating system was turned on and set to a temperature that was 20°F higher than the desired main reaction temperature.

Soybean oil was pumped from the soybean oil storage tank into the main reactor. Once the main reactor load cell showed that 100 lbs of oil had been delivered, the main reactor temperature controller was set to the desired temperature. The main reactor heating recirculation loop pump was turned on causing the glycol filled main reactor jacket to exchange heat with the building's hot glycol system. Once the 100 lbs of oil had reached a steady state at the desired temperature, 21.25 lbs. of room temperature methanol were pumped into the main reactor. The main reactor agitator was then engaged and the two reactants were allowed to mix and heat. When the soybean oil-methanol mixture in the main reactor had reached the desired steady state temperature, 1.76 lbs. of sodium methoxide solution catalyst were poured into the main reactor through its top access port. In order to minimize high local concentrations of catalyst, the sodium methoxide solution was slowly introduced over the course of a one-minute time span while the agitator was running. The stopwatch timing this reaction was started at the beginning of the one-minute time span. The main reactor drain valve was opened at this time, allowing access to the contents of the main reactor via the sampling valve. The diaphragm pump immediately following the drain valve prevented any further flow or emptying of the main reactor.

4.1.2 Cyclonic Separator Preparation

In the case of reactions utilizing the cyclonic separator, the following additions were made to the above preparations. Once the main reactor load cell showed 21.25 lbs. of methanol had been pumped into the main reactor, the main reactor drain valve was opened. The three-way valve leading to the cyclonic separator was opened and the two-way valve preventing flow to the cone bottom separation tank was closed as seen in the main reactor flow schematic, Figure 3.16. The cyclonic separator heavy phase gate valve was fully closed while the light phase gate valve was fully opened. With the cyclonic separator now set up to separate and recirculate the contents of the main reactor, the air supply to the cyclonic separator diaphragm pump was fully opened. The diaphragm pump then recirculated the main reactor mixture through the room temperature cyclonic separator and its various plumbing then back into the top of the main reactor, slowly heating this system. When the soybean oil-methanol mixture in the main reactor and separator system had reached the desired steady state temperature, 1.76 lbs. of sodium methoxide solution were poured into the main reactor through its top access port over the course of a one minute time span. The stopwatch timing this reaction was started at the beginning of the one-minute time span. The cyclonic separator heavy phase gate valve was opened at this time. During each transesterification reaction, approximately 10.5 pounds of glycerin would be produced. The heavy phase gate valve was set to the smallest opening that would allow at least 11 lbs of product to be pulled off over the course of the reaction. This heavy stream could be observed entering the glycerin separation drum. This rate of heavy phase removal was kept constant over the course of the reaction.

4.1.3 Reaction Rate Samples

For both cases with and without the cyclonic separator, once the reaction was underway samples were taken as follows. Five hundred milliliters of hot softened water were poured into a one-liter Nalgene bottle. In order to assure a fresh sample was being taken, the sample line was flushed before every collection. A second empty one-liter Nalgene bottle was placed under the main reactor sample line. The main reactor sample valve was opened and one liter of the mixture inside the main reactor was allowed to escape into the empty Nalgene bottle. The sample valve was closed, the one liter sample was set aside, and the Nalgene bottle containing water was placed under the sample line. Having flushed the sample line with a fresh mixture, the sample valve was opened again and 500 milliliters of mixture were allowed to mix with the hot softened water in the first Nalgene bottle. Adding such a large amount of water to the mixture sample effectively stopped the reaction [17,18]. The water sample mixture was thoroughly shaken over the course of one minute and set aside. The second Nalgene bottle containing the undiluted main reaction mixture was returned to the main reactor via its top access hatch. In the test cases utilizing the cyclonic separator, the air supply to the diaphragm pump had to be temporarily closed in order to allow the main reactor mixture to flow out of the sample line.

The time and main reaction temperature were noted on the sample label and the sample was set aside. Samples were taken at four different temperatures, ranging from room temperature to just below the boiling point of methanol. These samples were taken every 15 minutes for the first hour, then at half-hour intervals for the next two hours, and at one-hour intervals for the remainder of the test. These tests were done for each case both with and without the cyclonic separator. This resulted in the test matrix shown in Table 4.2.

Table 4.2 Reaction Rate Test Matrix.

	Temperature (Fahrenheit)							
Time (Hours)	80°F w/o	80°F w/sep.	100°F w/o	100°F w/sep.	120°F w/o	120°F w/sep.	140°F w/o	140°F w/sep.
0:15	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol
	Temp	Temp	Temp	Temp	Temp	Temp	Temp	Temp
0:30	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol
	Temp	Temp	Temp	Temp	Temp	Temp	Temp	Temp
0:45	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol
	Temp	Temp	Temp	Temp	Temp	Temp	Temp	Temp
1:00	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol
	Temp	Temp	Temp	Temp	Temp	Temp	Temp	Temp
1:30	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol
	Temp	Temp	Temp	Temp	Temp	Temp	Temp	Temp
2:00	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol
	Temp	Temp	Temp	Temp	Temp	Temp	Temp	Temp
2:30	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol
	Temp	Temp	Temp	Temp	Temp	Temp	Temp	Temp
3:00	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol
	Temp	Temp	Temp	Temp	Temp	Temp	Temp	Temp
4:00	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol	% Glycerol		
	Temp	Temp	Temp	Temp	Temp	Temp		
5:00	% Glycerol	% Glycerol	% Glycerol	% Glycerol				
	Temp	Temp	Temp	Temp				
6:00	% Glycerol	% Glycerol	% Glycerol	% Glycerol				
	Temp	Temp	Temp	Temp				
7:00	% Glycerol	% Glycerol						
	Temp	Temp						
8:00	% Glycerol	% Glycerol						
	Temp	Temp						

The shorter sample times of the higher temperature runs reflect the faster reaction rates observed at those temperatures.

4.1.4 Sample Separation and Washing

In all cases, the water-sample mixtures were allowed to settle overnight. The heavy water phase was pumped off of the bottom of each sample using a peristaltic pump. The suction side of the peristaltic pump was connected to a short piece of stainless steel tubing. This tubing was dipped to the bottom of the sample bottle and the pump was engaged. The heavy water phase was pumped to a drain, leaving the lighter phase behind. This light phase was again mixed with hot softened water and thoroughly shaken. The mixture was allowed to settle out over a one-hour period and the wash process was repeated for a total of four washes. A small sample was taken from each Nalgene bottle after the final washing. This sample was used to determine the completeness of the transesterification process.

4.1.5 Glycerin Testing

The washed samples were run through a gas chromatograph to determine the amount of unreacted oil remaining. The resulting data includes the percentage concentration of monoglycerides, diglycerides, and triglycerides in each sample, as well as total free and total bonded glycerol.

The Varian model CP-3800 gas chromatograph consists of a 15-meter-long 0.32mm inner diameter capillary tube with a helium source at one end and a hydrogen flame at the other. The inner diameter of the capillary has a polyimide coating which attracts the glyceride molecules to varying degrees dependant on their species. The helium carrier gas transports a sample injected in one end of the tube down its length to the hydrogen flame.

The coating will cause different molecular species to traverse the 15-meter capillary at different rates, in proportion to the strength of attraction to the polyimide coating. When the individual species exit the capillary and are burned, the resulting ions cause a charge to build up on two near-by electrode plates. The magnitude and duration of each voltage peak across the plates can be integrated and corresponds to the concentration of each species present. The time at which the peaks occur indicate which species is being counted.

4.2 Generator Power Production and Emissions

The following section describes the test procedure for operating the diesel generator and performing the exhaust emissions tests. An Olympian D40P3 40KW four-cylinder, naturally aspirated diesel engine was used for these tests. Modern emissions regulations regulate several exhaust including carbon monoxide, unburnt hydrocarbons, nitric oxides and particulate matter. Of these engine exhaust emissions, carbon monoxide and unburnt hydrocarbon emissions are always well below regulated levels. The primary exhaust emissions of interest for these tests were NOx levels and smoke number. Four different fuels were used in these tests, two petroleum based diesel fuels and two 100% biodiesel, B100, fuels. The #1 and #2 diesel fuels were purchased from a local supplier while the soybean-based B100 biodiesel and yellow grease-based B100 biodiesel were made on-site. These fuels were tested in a random order. The test matrix is shown in Table 4.3.

Table 4.3 Fuel Types and Engine Test Conditions.

	Percent Total Engine Load				
	20%	40%	60%	80%	100%
#1 Diesel	NOx Smoke	NOx Smoke	NOx Smoke	NOx Smoke	NOx Smoke
#2 Diesel	NOx Smoke	NOx Smoke	NOx Smoke	NOx Smoke	NOx Smoke
Soybean B100	NOx Smoke	NOx Smoke	NOx Smoke	NOx Smoke	NOx Smoke
Yellow Grease B100	NOx Smoke	NOx Smoke	NOx Smoke	NOx Smoke	NOx Smoke

Calibration of all equipment was performed before each test. The following equipment was used to collect the emissions data:

- Beckman Industrial Corp., model 955 chemiluminescent NO/NOx analyzer
- Robert Bosch BMBH, model ETD02050 smoke meter
- AW Company, model JVM-10KL flow meter
- FG Wilson Engineering Ltd., GenAccess 1.1 generator monitoring software

4.2.1 Emissions Equipment Preparation

Before any emissions data could be taken, some preparation to the equipment used was necessary. This included warming up the NO/NOx meter, smoke meter cleaning, and calibration of both. These processes are described below.

The Beckman NO/NOx meter contains both a small refrigeration unit and a small oven unit. Applying power to the meter and switching it to any sampling position turns on the internal temperature regulators for both units. As their temperatures and any fluctuations therein will affect the meter reading, the temperatures must reach a steady state before readings can be accurately taken. As such, the NO/NOx meter was turned on and allowed to reach a steady state of operation for 24 hours in advance of the testing. In order to prevent excessive ozone buildup from attacking the internal stainless steel ozone generation chamber, the meter's oxygen source was left on, metering out a small supply of 5 psi oxygen.

The Bosch smoke meter slowly accumulates soot in its plumbing and internal parts through normal use. This soot can contaminate fresh samples and was removed before each test run. The smoke meter and associated plumbing was completely disassembled and blown clean using compressed air. Upon reassembly the meter was tested to confirm a smoke number reading of 0 from the atmosphere.

Immediately before each test run, both the NO/NOx meter and smoke meter were calibrated. These processes are briefly described below.

The NO/NOx meter consists of an oxygen-fed ozone generation chamber, a photocell, and an alternate plumbing route through a small oven reaction chamber. When a sample gas is introduced into the oxygen supply, any NO in the sample will react in the ozone chamber producing NO_2, oxygen, and releasing a photon of light. The photocell detects these photon emissions and produces a measurable voltage in proportion to the concentration of NO. If the sample gas is first routed through the heated reaction oven, any NO_2 present in the sample will be converted to NO before entering the ozone generator. In this way, both NO and NOx can be counted.

Assuming steady state operation, three factors affect the photocell output: the oxygen source partial pressure, the sample partial pressure, and the quantity of NO present. In order to eliminate any variance due to partial pressures, the oxygen supply was regulated to a constant 40 psi and the sample was regulated to a constant 5 psi as per Beckman's recommendations. With the NO/NOx meter thus configured and operating in its NOx setting, a 5 psi sample of 2500 ppm NO supply was introduced. A digital multimeter was used to confirm full-scale deflection on the 2500-ppm setting. Next, a 5 psi sample of nitrogen was introduced and the multimeter was used to confirm a zero reading on the 2500-ppm setting. Finally the NO/NOx meter was switched to its NO mode, the 2500-ppm source of NO was reconnected at 5 psi, and the internal flow restrictor was used to match the previous full-scale deflection. If any changes were required in full-scale settings, zero settings, or restrictor settings, the process was repeated.

The smoke meter consists of a calibrated light source and a photocell contained in a probe and a voltage display for the photocell, as well as a spring-loaded sampling syringe of known volume and filter disks. Calibrating the smoke meter involved holding its probe against a clean sample filter disk and confirming this produced a zero reading. In operation the sampling syringe is connected to an exhaust probe by a short piece of plumbing. After loading a clean filter disk into the syringe, the spring is released and a sample of clean air was taken from the generator's exhaust. The filter disk was removed and tested using the smoke meter's probe. With the engine not running, this resulted in a 0.0 smoke number when the equipment was properly cleaned and calibrated.

4.2.2 Load Tester Preparation

The generator load tester was connected using the following steps. The load tester was placed in position near its connection box below sub panel PA in the high bay maintenance room. Two 50-foot water hoses were connected to the water jacket intake and exit. The intake hose was connected to a water faucet and the exit hose was inserted into a floor drain. Both the water faucet and water jacket exit valve were fully opened. Once the load tester had been observed to have zero leaks, the electrical connections were made. With the diesel engine control and the 60 amp main load tester circuit breaker in sub panel PA switched off, the electrical connections were made to the load testers main power leads matching the generators neutral, leg 1, leg 2, and leg 3 lines. The extraneous building light and wall outlet circuits were switched off, the load tester circuit breaker was switched on, and the load tester was ready to receive the generator's full power.

4.2.3 Generator Operating Procedure

The generator is always started and shut down on the diesel fuel supply stored in the fuel shed. Switching ON the diesel fuel pump at the fuel control connects this fuel source to the engine's fuel intake. With the fuel source ready, the generator was switched to the on automatic position and started. Once the diesel engine comes up to speed, the automatic transfer switch routes power from the generator through sub panel PA and to the load tester. The generator was allowed to run in this configuration until its radiator water temperature had reached a steady state as indicated by the GenAccess software.

Once the engine had reached steady state operation, the fuel source was changed from the fuel shed diesel supply to the fuel sample being tested. The test fuel was allowed to flow through the plumbing and generator until the flow meter reported that two gallons of fuel had been consumed. Once the engine was operating in steady state and the entire fueling system had been flushed with the sample fuel, the emissions testing could begin.

4.2.4 Emissions Testing Procedure

To measure the engine exhaust emissions, the exhaust sampling line was connected to the NO/NOx meter and the sampling pump was turned on. The meter was switched to the NO position. For each fuel sample, the lowest power load case was examined first. Using the load tester heating elements and the smaller auxiliary loads, the generator power was brought up to the desired level as indicated on the GenAccess software. The exhaust gas temperature was allowed to reach steady state at the requested power level before any emissions readings were taken. Once at steady state, EGT, fuel intake temperature, engine temperature, engine power, engine RPM, and fuel flow rate were all noted.

The exhaust smoke number was taken next using the following procedure. The smoke meter zero was checked on a fresh filter before each run. The spring-loaded syringe was made ready to sample and a filter disk loaded. The spring was released and this first disk thrown away. This was repeated two more times to insure fresh exhaust was being sampled. The sampling syringe was made ready again and loaded with a new filter. After pulling the exhaust gas through this filter, the disk was removed and checked using the smoke meter. The smoke number was recorded and this procedure was repeated two more times.

The NO readings were then taken off of the digital multimeter attached to the NO/NOx meter's output leads. Once these readings were taken, the meter was switched over to the NOx sampling position. This reading was allowed to reach steady state and then noted. With all of the emissions readings for the current power level taken, the engine operating conditions were rechecked against the pre-testing values to verify steady state operation.

This procedure was repeated for the remainder of the engine operating conditions, using the load tester to achieve higher power levels up to the engine's maximum output. Despite the generator set's advertised rating of 40kWe, this power level was never obtained. Depending on fuel supply, the highest loads possible were between 35kWe and 38kWe. Further load increases resulted in low voltage alarms and automatic generator shutdown. For the test case requiring 100% of maximum engine power, the generator was run as near its maximum output as possible.

5. RESULTS AND DISCUSSION

In this chapter the results of the transesterification reaction rate and generator emissions tests are discussed. This chapter is divided into two sections. The first section deals with the main reaction rate results. The temperature dependency on the reaction rates of the fuel, the main reaction temperature trends, and the performance effects of the cyclonic separator on the main reaction are discussed. The raw data for these tests can be found in APPENDIX A. The second section goes over the results of the generator emissions testing. The NOx levels and smoke levels present in the emissions of the test fuels are all discussed as well as differences in generator power output. The raw data for these tests can be found in APPENDIX B.

5.1 Main Reaction Rates

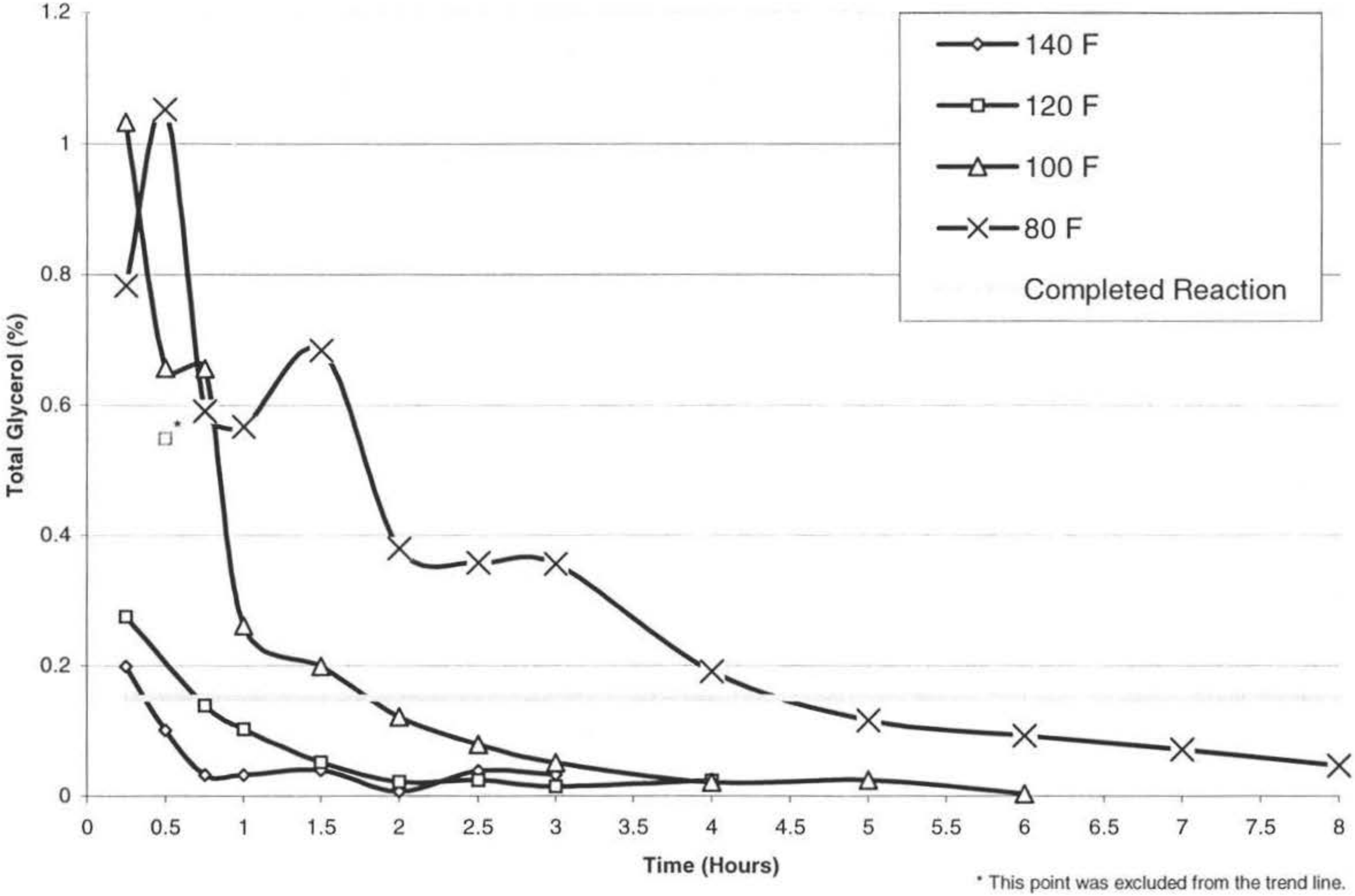
The samples taken from the main reactor during the tests described in Section 4.1.3 were mixed with equal volumes of hot, softened water and allowed to settle. The addition of a large percentage of water to the reaction stops the transesterification process [17,18]. By separating out the water, and further washing out soaps, solvents, and other impurities, the progress of the reaction at each sample can be checked by looking at its total glycerol percentage. The ASTM standard for maximum allowable total glycerol in biodiesel is 0.24% by mass. The biodiesel fuel produced at the BECON facility is held to a tighter 0.15% tolerance in order to assure reaction completion and standard compliance. The reaction is said to have gone to completion when the total remaining triglycerides, diglycerides, and monoglycerides available to be broken down for production of additional methyl esters is less than 0.15%. This value also includes any free glycerin, which normally is removed through the separation and wash process. This section examines both the effects of conducting the reaction at different temperatures and the cyclonic separator mixing effects on the rate of the main reaction.

5.1.1 Reaction Rates of the Fuel

The original pilot plant main reactor had no means of temperature control or any external heat source. As such, all prior biodiesel work at the BECON facility had been done at room temperature and atmospheric pressure. The main reactor and heating system installed as part of the work presented in this thesis allows for high temperature atmospheric pressure reactions. The results of driving the transesterification reaction at various temperatures on the main reaction rates are shown in Figure 5.1.

The constant horizontal line representing a completed reaction lies at the 0.15% total glycerol mark. The series of data points taken at a nominal reaction temperature of 80°F represents the reaction rates possible at room temperature at atmospheric pressure. This reaction met the 0.15% total glycerol requirement near the four hour and thirty minute mark. The reaction was allowed to continue for the previously recommended 8-hour period during which the percent total glycerol slowly declined.

Heating the same reaction to 100°F pushes the time to completion back to less than two hours. This 100°F follows a similar trend as the percent total glycerol approaches zero asymptotically. The higher temperature 120°F and 140°F degree runs follow much the same trend with the time to completion being driven ever shorter. The 120°F batch of fuel met its total glycerol requirements in fewer than 45 minutes while the 140°F batch completed near the 22-minute mark. Higher temperature runs using an atmospheric pressure reactor are not possible due to the relatively low, 148.5°F, boiling point of methanol.



* This point was excluded from the trend line.

Figure 5.1 Percent Total Glycerin vs. Time Without Cyclonic Separator.

These high reaction rates using atmospheric pressure reaction vessels suggests very high production rates are possible with a batch process as used here. A process operating at these temperatures and rates could produce as much as 4900 gallons a day or 1.8 million gallons per year, using a relatively small 100-gallon main reactor.

It is important to note that the 30-minute data point for the 120°F reaction was excluded from the trend line. This point is atypical of the reaction trends seen here and in other similar runs. The discrepancy is likely due to human error in the sample collection, testing, or data analysis process.

The same matrix of reaction rate tests was conducted using the cyclonic separator as described in Section 4.1. The results of driving the transesterification reaction at various temperatures on the main reaction rates while using the cyclonic separator to continuously remove a heavy stream from the reaction are shown in Figure 5.2.

Elevated temperatures had much the same effect on the reactions using the separator as those without. The room temperature (80°F) reaction proceeds the most slowly and takes the full eight hours to approach completion. Further increased reaction temperatures caused increased reaction rates. The fastest reaction of this group took place at 120°F and reached completion in just over an hour.

There are notable exceptions to this trend. The highest temperature reaction at 140°F does not follow the same trends and does not reach completion. Also, the 100°F and 80°F reactions are at best borderline complete. Possible reasons for this are discussed in Section 5.1.3, and appear to be caused by the cyclonic separator. These reactions which did not reach final total glycerol levels below 0.15% would normally be separated, washed, and returned to the main reactor for a second transesterification reaction.

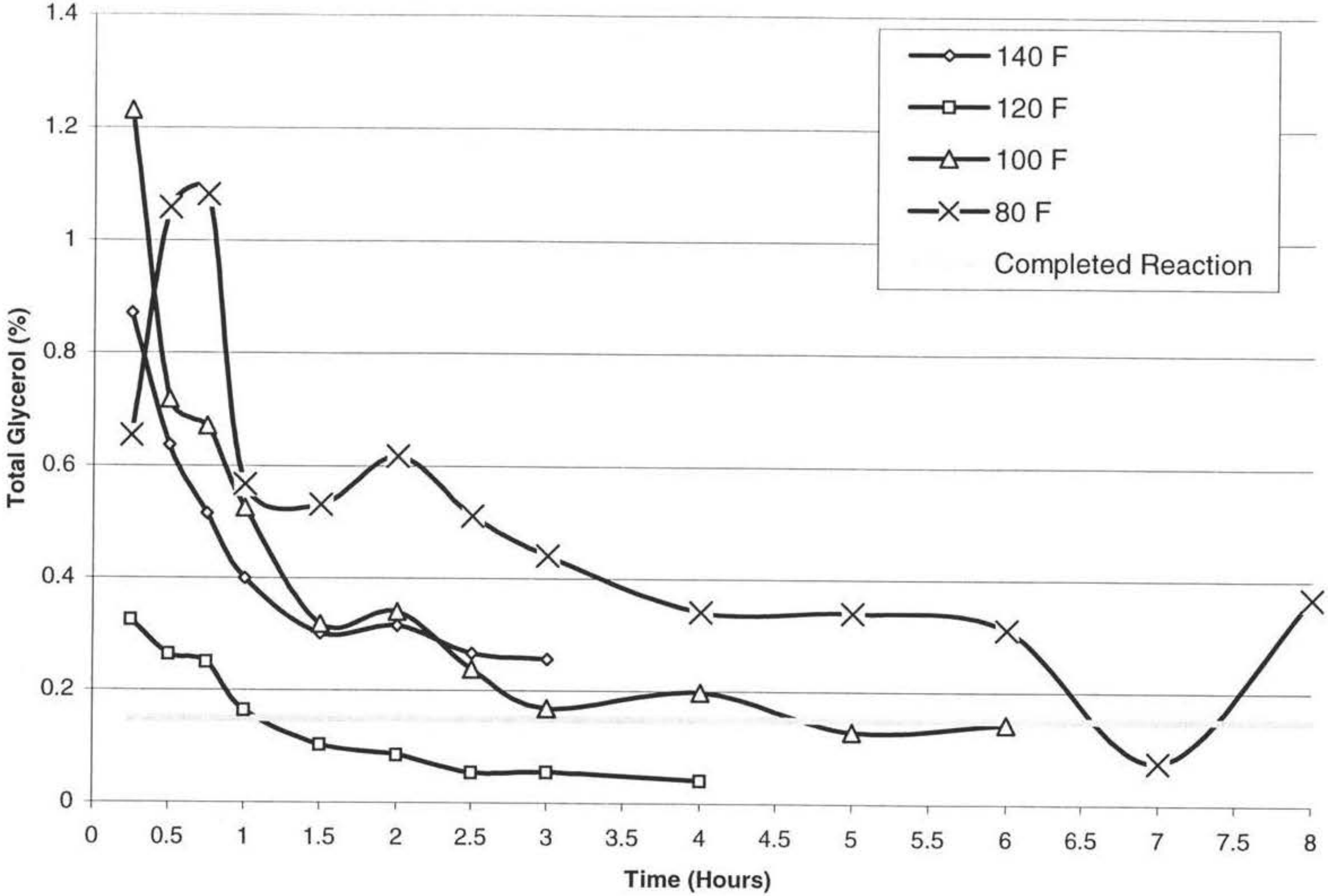


Figure 5.2 Percent Total Glycerin vs. Time With Cyclonic Separator.

5.1.2 Main Reaction Temperature Trends

In addition to heating the main reaction to a nominal starting temperature, the actual temperature of the reaction was monitored and noted at every sample collection time. The results of the temperature readings for these main reactions are shown in Figure 5.3.

Each of the transesterification reactions represented in Figure 5.3 were brought up to a stable nominal temperature before the catalyst was added and the reaction started. As Figure 5.3 shows, in each case the main reactor temperature quickly rose between three and eight degrees Fahrenheit. As the main reactor heating system is not fitted with a chiller of any type, free convection heat transfer to the environment slowly brought the temperatures back down to the controller's set point. In the cases of the lower temperature runs, this temperature return occurred more slowly. In the case of the room temperature run, the main reactor had so little temperature differential with its environment, it never returned to room temperature over the course of the eight hour reaction.

The rapid increase in main reaction temperature followed by the gradual return to nominal temperature is highly characteristic of an exothermic reaction. The previous room temperature transesterification work done at BECON did not observe this result [19]. Most likely this was due to the relatively small temperature rise and very gradual reduction seen for room temperature runs combined with the previous lack of proper monitoring equipment. The results shown here strongly suggest an exothermic transesterification process.

The same main reaction temperature data was taken during the transesterification runs utilizing the cyclonic separator system. The results of the temperature readings for the main reactions with the cyclonic separator continuously mixing and removing a heavy phase are shown in Figure 5.4.

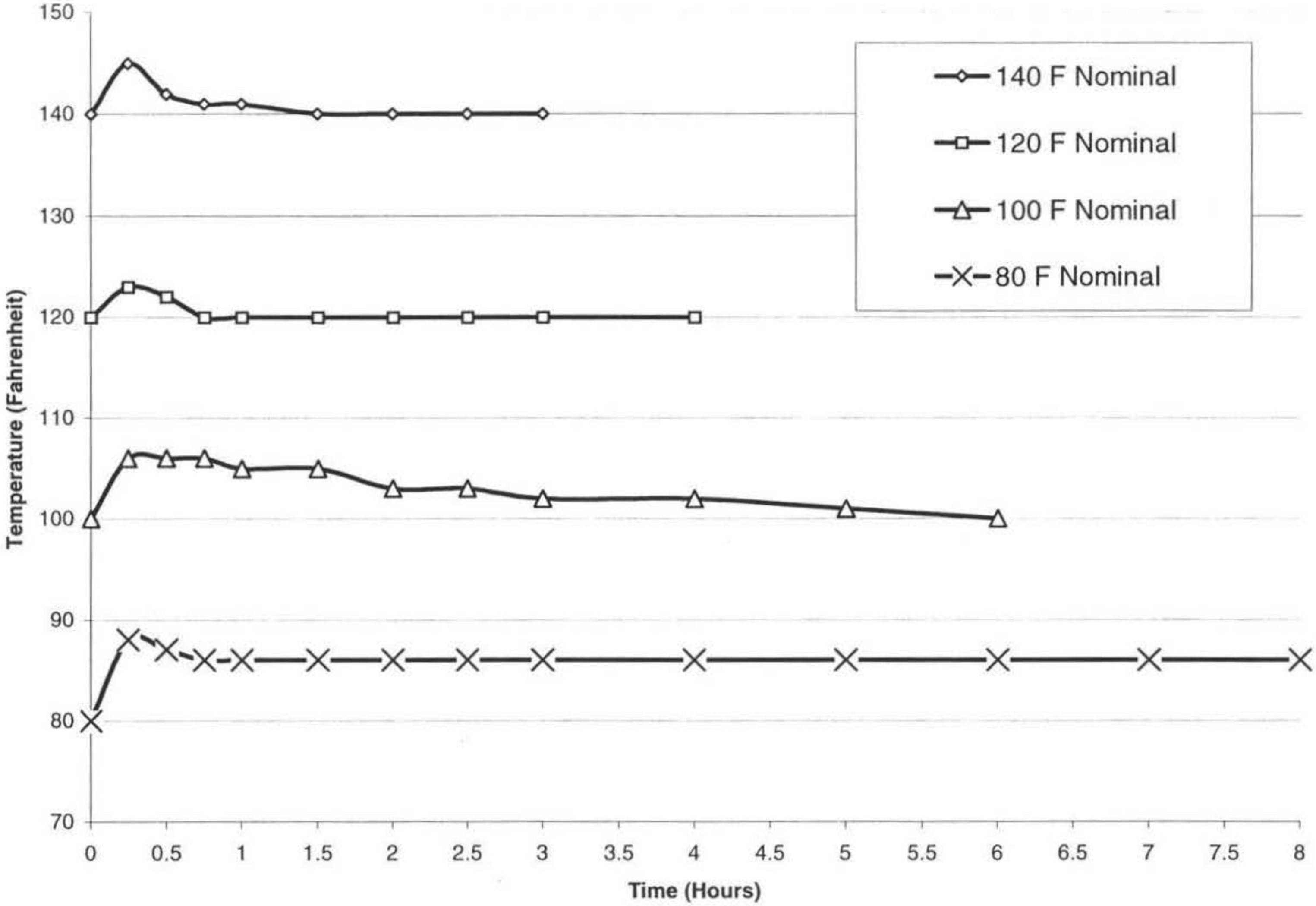


Figure 5.3 Temperature vs. Time Without Cyclonic Separator.

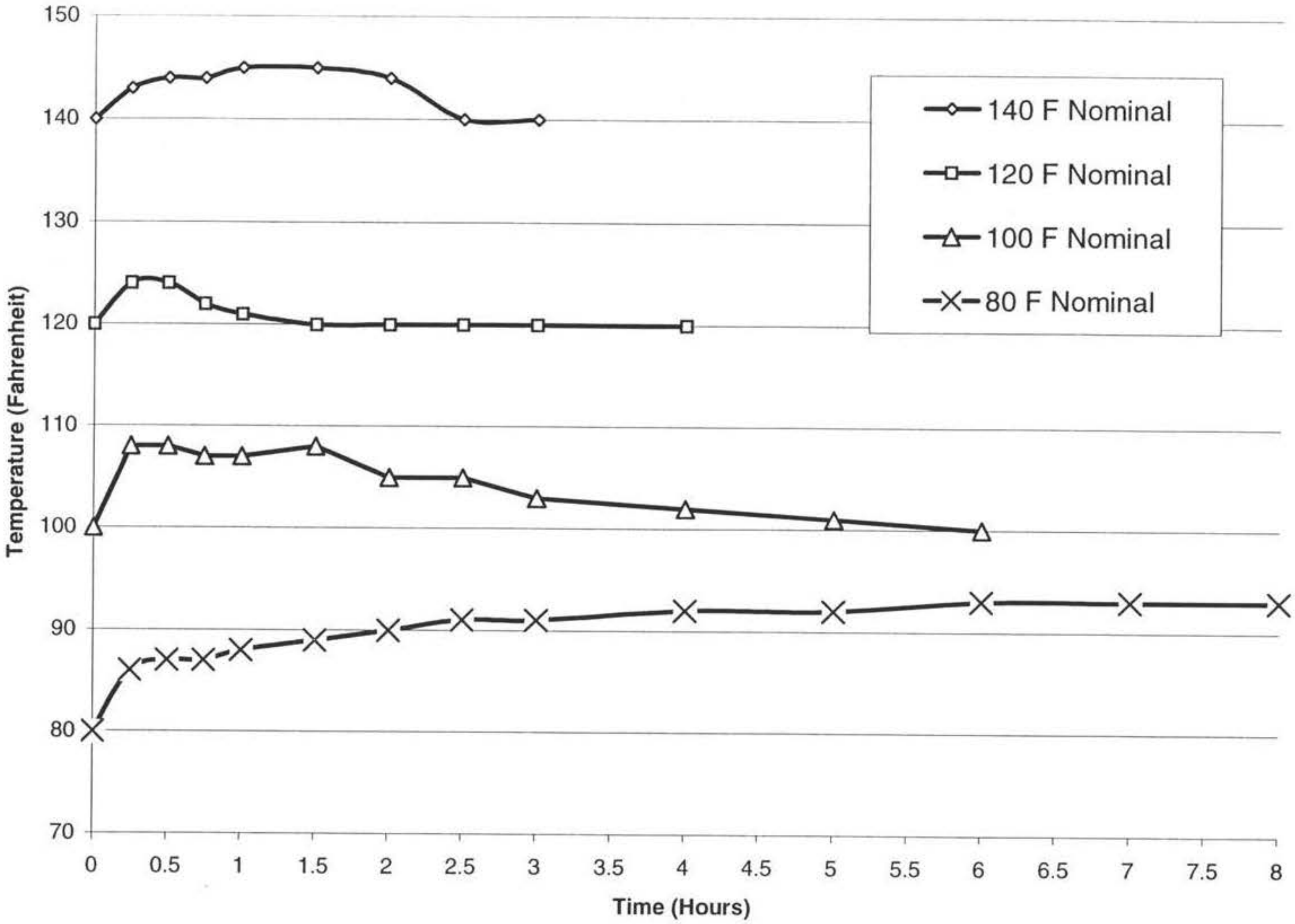


Figure 5.4 Temperature vs. Time With Cyclonic Separator.

The temperature data taken from runs using the cyclonic separator follow similar trends. The main reactor starts off at a steady state nominal temperature controlled by the heating system. After the catalyst is introduced and the reaction started, the temperature immediately climbs between three and eight degrees Fahrenheit before slowly returning to the nominally controlled set point temperatures. Again, no active cooling system was used and the rate of temperature decrease represents heat loss to the environment through passive convective cooling.

Some important exceptions to this trend should be noted. The room temperature reaction, nominally at 80°F, never returns to its set point temperature. While this result is similar to that seen in the 80°F reaction without the cyclonic separator, the reaction seen here in Figure 5.4 continues to increase in temperature over the course of the entire eight hour period. Possible explanations for these differences are discussed in the next section.

5.1.3 Performance of the Cyclonic Separator

This thesis, in part, represents a preliminary look at cyclonic separators as a possible real time glycerin removal technology for use in the production of biodiesel fuels. It was thought that this low cost alternative to centrifuge separation techniques might increase the reaction rates through several means. These include removing the unwanted heavy phase glycerin byproducts as they are produced, possible improved mixing performance, and noted temperature increases. Real-time free glycerin separation has several possible advantages. Not only would decreasing the concentration of the products of transesterification drive that reaction further forward, but the reaction catalyst also tends to go into solution with the glycerin preventing its close contact with the triglyceride molecules. The transesterification reaction depends heavily on this close contact between the catalyst and the other reactants.

This is normally accomplished through mixing. The sodium methoxide catalyst tends to associate with glycerin formed during the transesterification reaction. Without strong mixing, gravity separates the higher density glycerin and the associated catalyst from the remaining glycerides.

Previous work showed that increased mixing offers substantial increase in reaction rates and lower total glycerol in the final product [19]. The method of operation of the cyclonic separator induces large shear forces on the reactants as they pass through the device. In this way the cyclonic separator could function in much the same manner as a micro mixer, offering substantially increased mixing capabilities. Initial trial runs utilizing the cyclonic separator showed higher reaction temperatures. It was hoped these higher temperatures may have indicated that a higher rate of reaction was taking place. The results of the reaction rate tests bear out some but not all of these ideas. Figure 5.5 illustrates the temperature vs. time differences seen in paired reactions with and without the separator.

As can be seen in Figure 5.5, utilizing the cyclonic separator resulted in higher overall temperatures in each case. The temperature peaks in the separator runs, however, occur late in the reaction and persist over a longer period than trials without the separator. These later peaks are typical of reductions in reaction rates. Higher rate exothermic reactions should result in a higher temperature peak that also occurs earlier in the reaction. The flattened temperature peak seen in the 140° F separator run most likely indicates localized methanol boiling near the heating jacket. The atmospheric pressure of the main reactor vessel effectively limits the highest possible reaction temperatures to the boiling point of methanol, 148.5°F. The continued rise in temperature for the 80°F separator run most likely reflects an increase in ambient temperature that was near or above 80°F at the time of the experiment. Steady heat input due to pump work is another possibility.

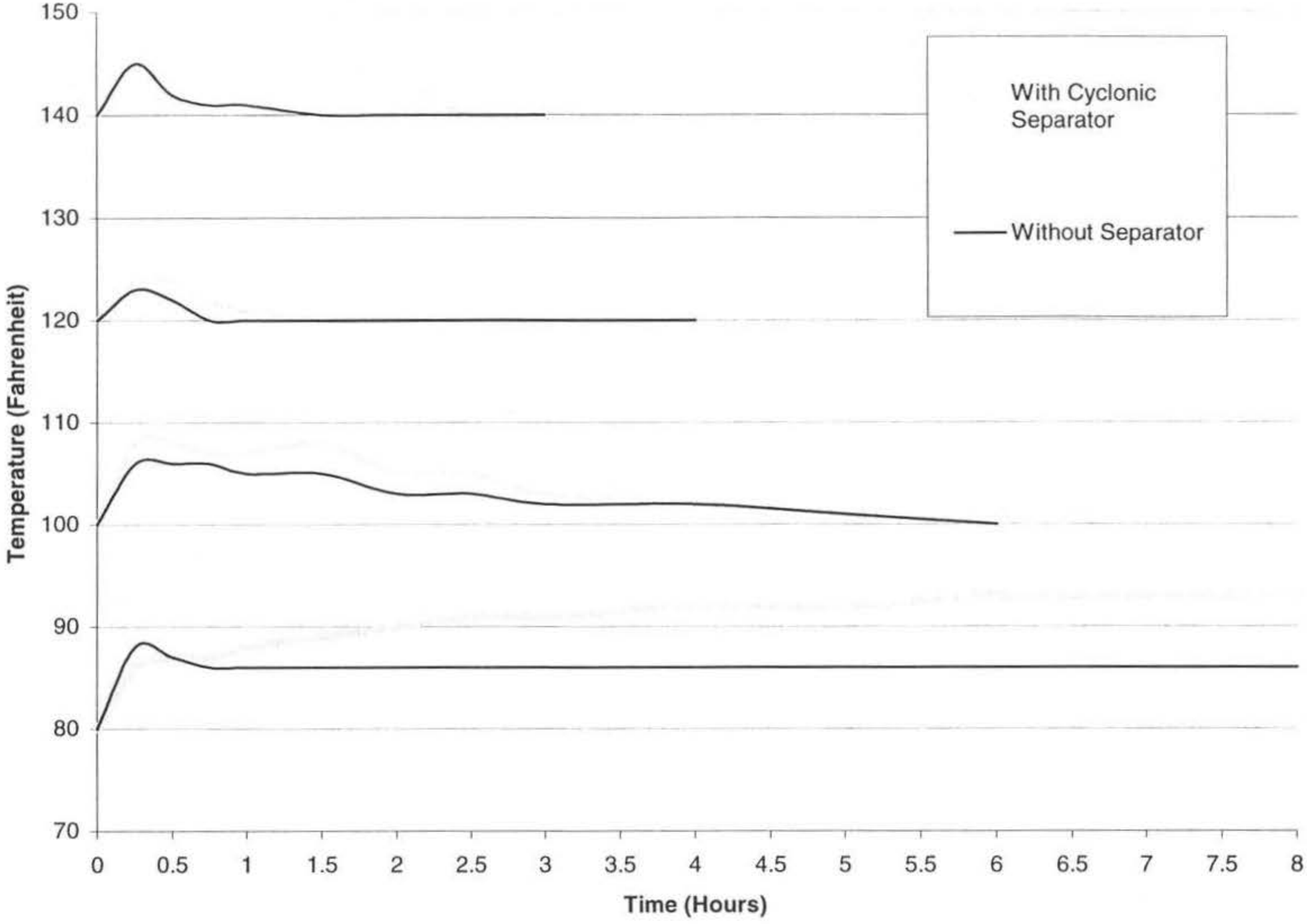


Figure 5.5 Temperature vs. Time With and Without the Cyclonic Separator.

It was hoped that the higher temperatures seen during initial trial runs would be reflected in higher reaction rates and corresponding shorter reaction times. Those comparisons are shown in Figures 5.6, 5.7, 5.8, and 5.9.

As can be seen in this series of figures, all of the tests utilizing the cyclonic glycerin separator occurred at a slower rate of reaction. Further, these separator runs consistently resulted in higher total glycerol percentages. Notably, only one of the four runs using the separator, the 120°F clearly met the 0.15% total glycerol requirement. The remaining runs would all normally be rejected after this first main reaction and returned for a second stage transesterification. The 140°F run with the cyclonic separator in particular starts out at a comparatively high total glycerol count of 0.87% after the first 15 minutes of the reaction and never gets below 0.24% over the course of its reaction.

The results of the 140°F separator reaction are out of place with the trends born out through the lower temperature runs. A possible explanation for this would be too much heavy phase removal early on in the reaction. If a significant quantity of heavy phase is removed before much glycerol product has had a chance to form, other products and reactants will be inadvertently removed. It is also possible that the increased agitation of the cyclonic separator caused undesirable mixing of products during the latter portions of the otherwise short reaction times seen at 140°F.

These observations raise several additional points for discussion. The rate and quantity of glycerol production should most likely be taken into account when controlling the rate of heavy phase separation and removal. Specially, if low levels of glycerol exist during the early phases of the reaction, early heavy phase removal should be kept to a minimum or at zero. Further, the increased mixing effect desired from the cyclonic separator may not be advantageous late in the reaction. Once a significant amount of the reactants have

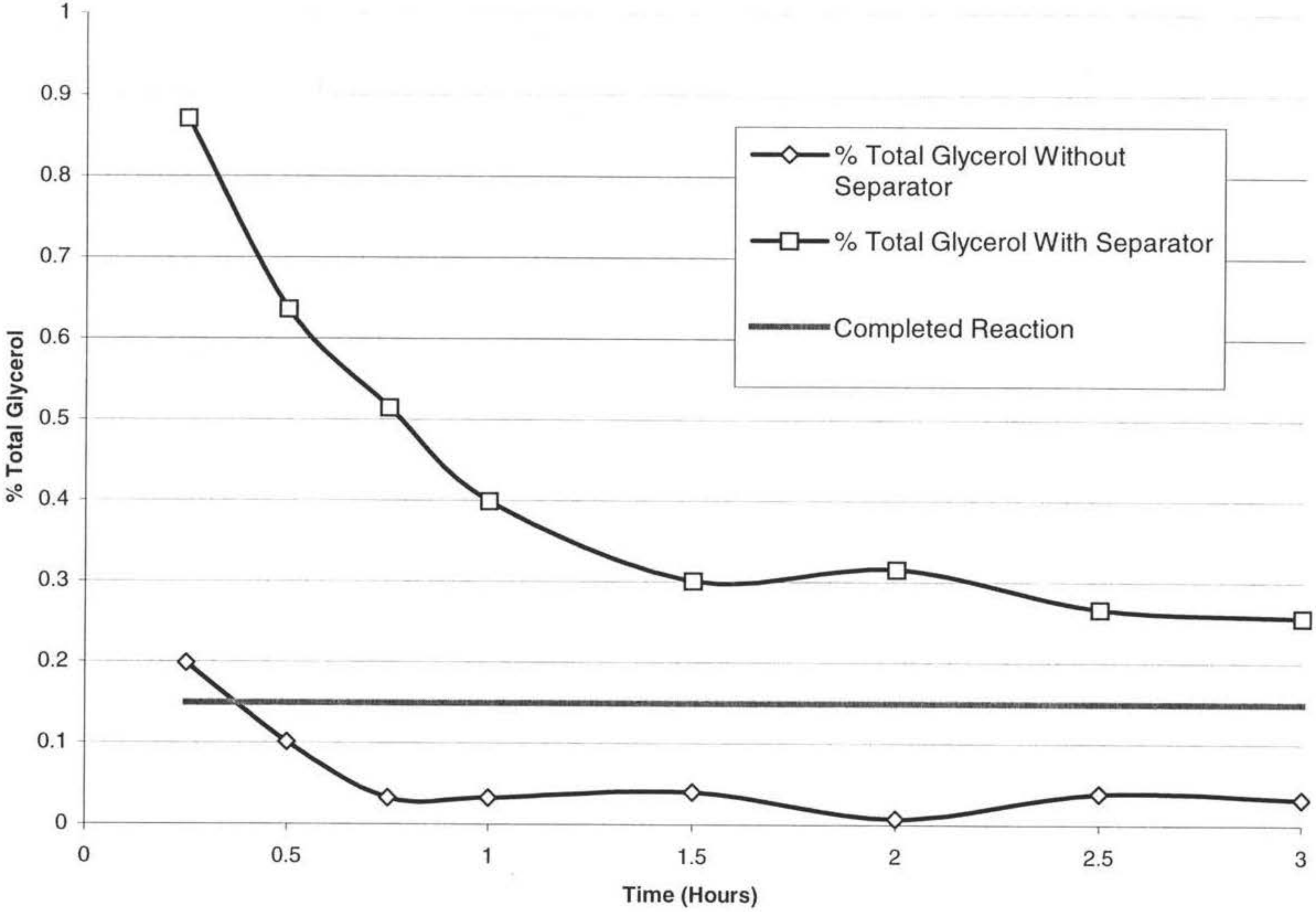
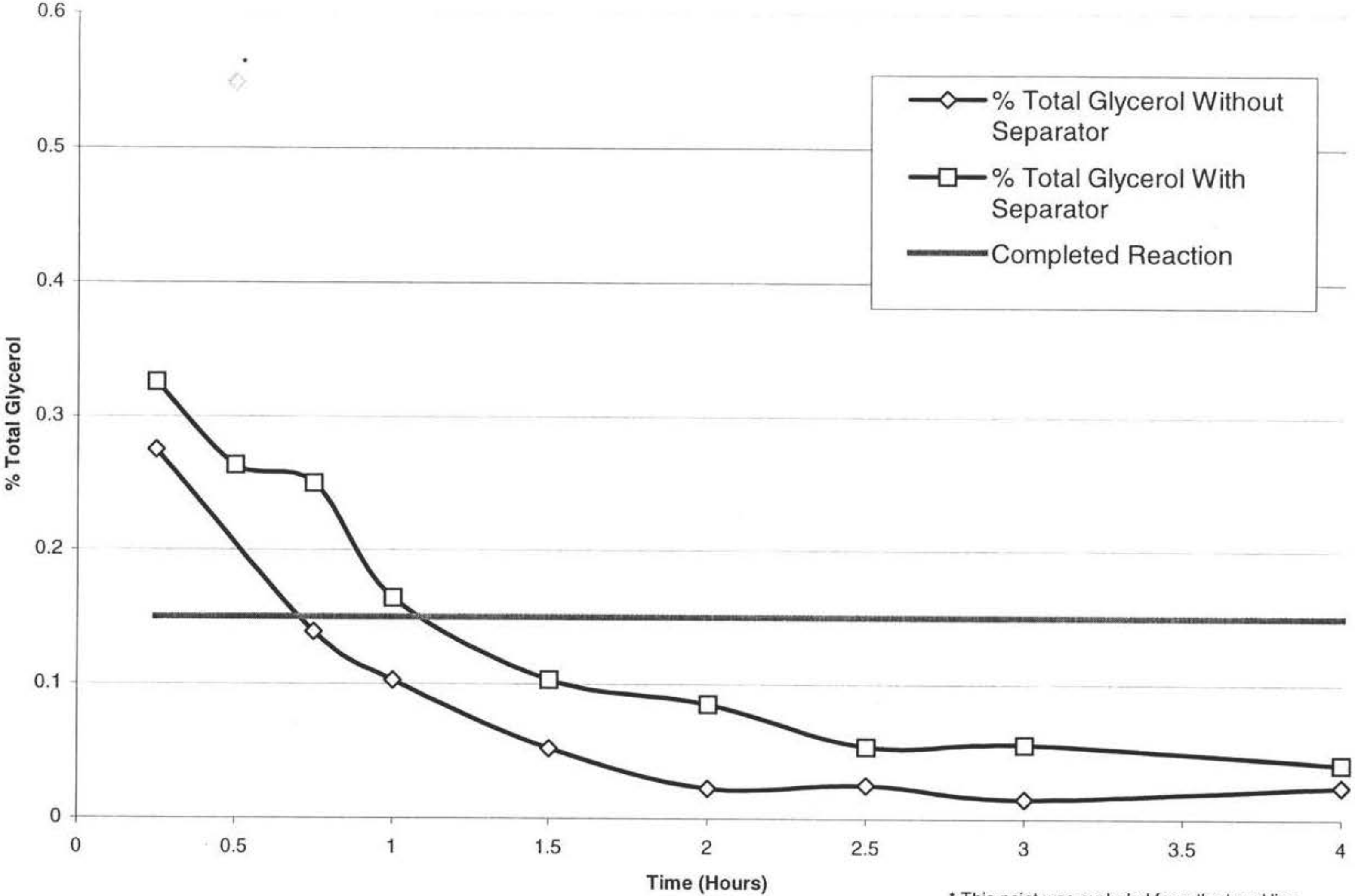


Figure 5.6 Total Glycerin Percent vs. Time at 140 F With and Without Cyclonic Separator.



* This point was excluded from the trend line.

Figure 5.7 Total Glycerin Percent vs. Time at 120 F With and Without Cyclonic Separator.

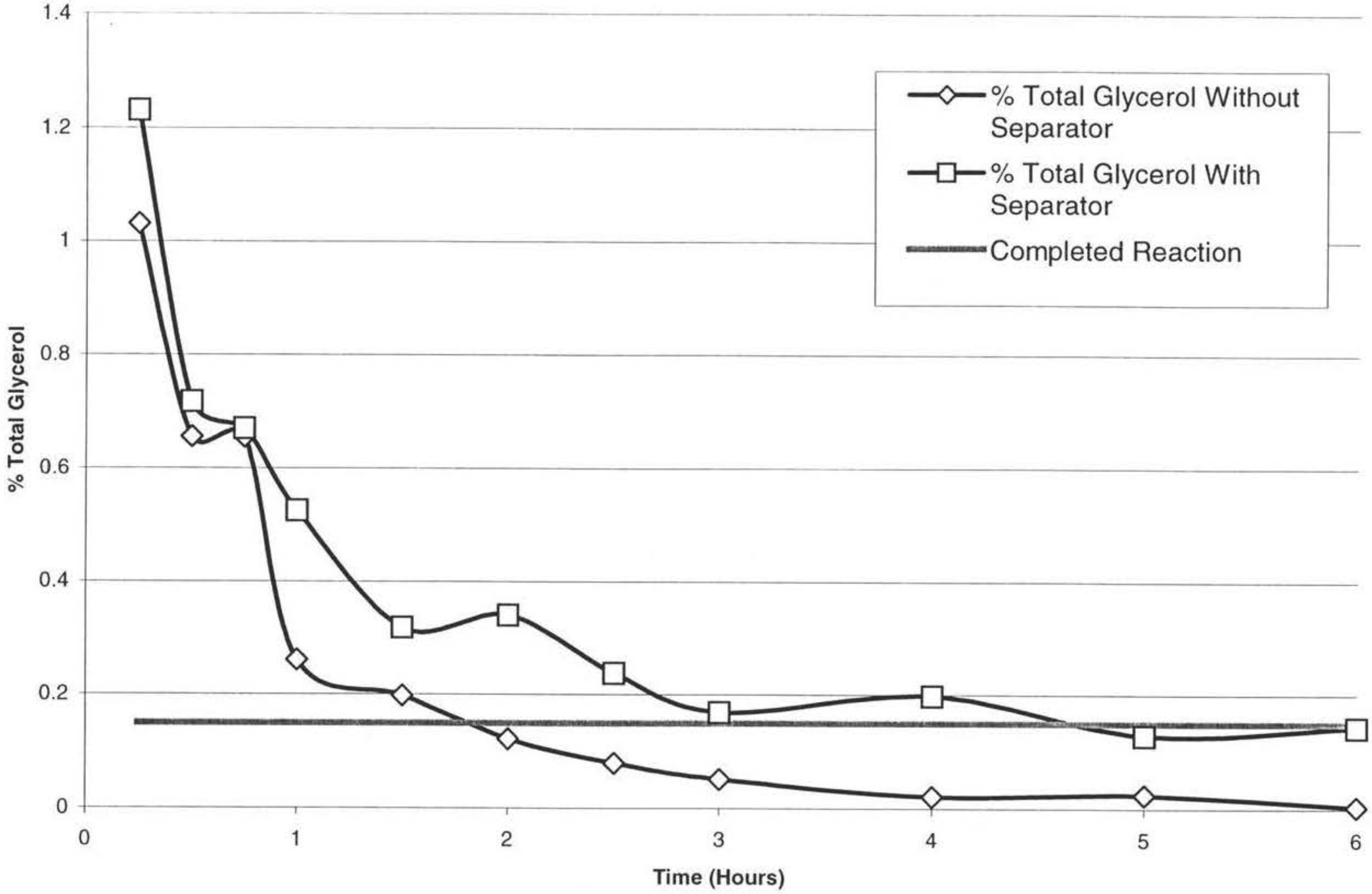


Figure 5.8 Total Glycerin Percent vs. Time at 100 F With and Without Cyclonic Separator.

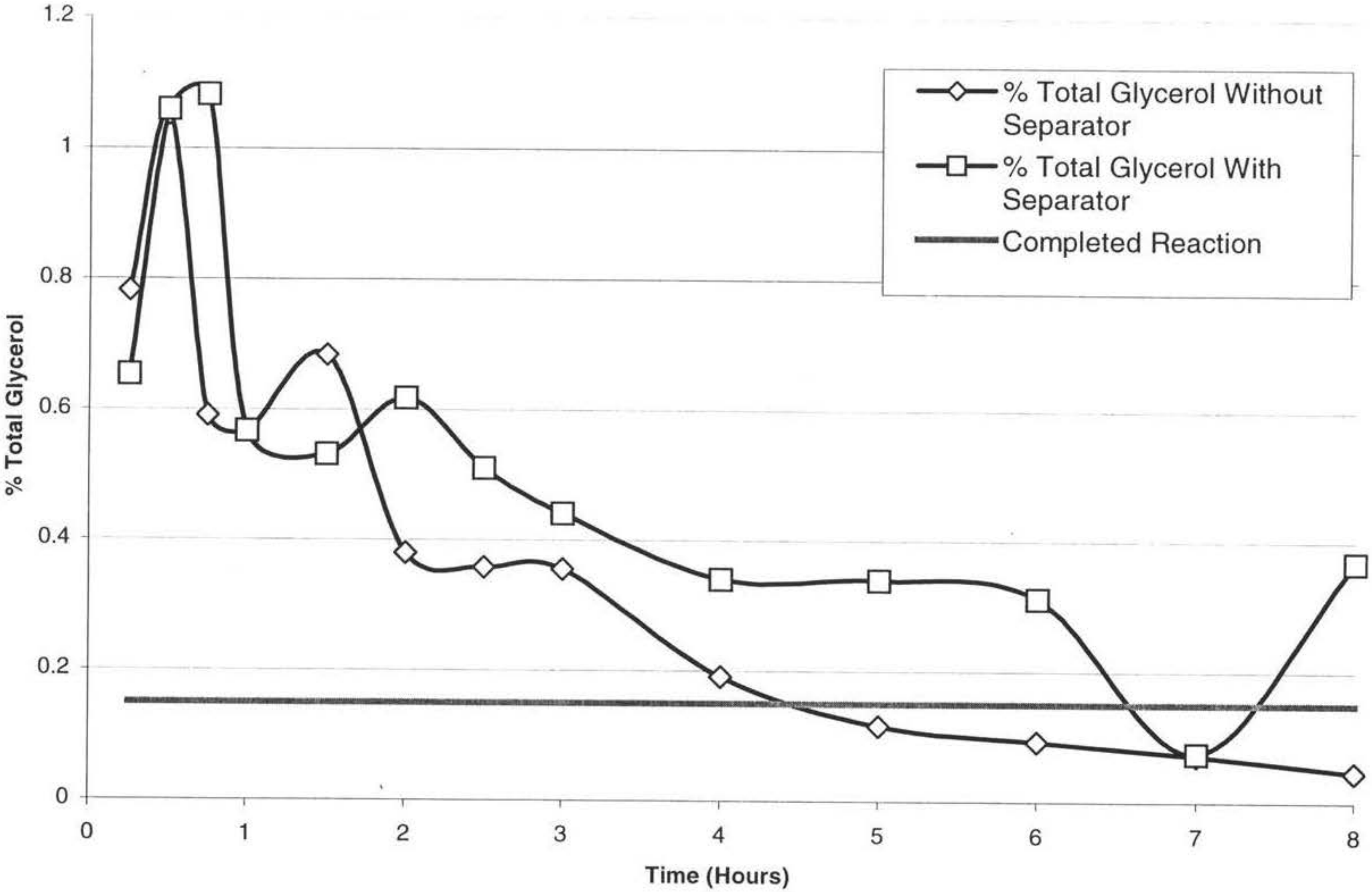


Figure 5.9 Total Glycerin Percent vs. Time at 80 F With and Without Cyclonic Separator.

undergone the transesterification process, bringing the resulting glycerol and catalyst in close contact with the methyl esters could bring about the reverse reaction and make the reaction less complete. This suggests some optimum separation schedule may exist during the central portion of the reaction.

Another byproduct of removing heavy phase material from the transesterification process is that significant portions of the reactant methanol and sodium methylate tend to go into solution with the product glycerin. By removing the glycerin during the main reaction, the cyclonic separator is also removing some portions of the reactants that drive the transesterification forward.

These reaction rate tests suggest that using the cyclonic separator for steady state heavy phase removal during the main reaction is counterproductive to the formation of methyl esters. The unanswered questions raised by this preliminary look at cyclonic separators suggest that further investigation is required before full advantage can be taken of this technology. Future efforts focused on analysis of the heavy phase material removed as the reaction progresses, as well as optimized schedules for controlled flow removal and mixing could show how to better utilize this system.

5.2 Generator Emissions and Fuel Performance

The numerical results of the generator tests described in section 4.2 were in part reported by the GenAccess software package that monitors the generator. It is important to note that these numbers reflect the power levels and outputs of the electrical generator as driven by the diesel engine. While in many ways this configuration operates as an electric dynamometer, the numbers reported were produced by monitoring the electrical generator and not the diesel engine itself. This results in power levels, and calculations involving the power levels, that include the efficiency losses inherent to the electrical generator.

Also note that the AW JVM-10KL fuel flow meter is a positive displacement volumetric meter. Volumetric fuel flow rates were converted to mass-based rates by calculation using the fuel's specific gravity. In order to take into account the elevated fuel intake temperature resulting from the fuel supply heat exchanger, the temperature specific gravity relationships outlined by Mustafa Tat [20] were used. This relationship is linear of the form:

$$SG = a + bt$$

Where: SG = Specific gravity
t = Temperature in °C

The constants for a and b are given in Table 5.1.

Table 5.1 Specific Gravity Correlation Constants [20].

Samples	a	b	R^2
#2 Diesel Fuel	8.53E-01	-6.41E-04	9.99E-01
#1 Diesel Fuel	8.40E-01	-6.63E-04	9.99E-01
Biodiesel	8.98E-01	-6.62E-04	9.99E-01

The following sections use these relationships to examine the results from the emissions tests. The discussion is divided into four sections dealing with the generator's exhaust gas temperatures, smoke levels, NOx levels, and finally its power output.

5.2.1 Generator Exhaust Gas Temperatures

In addition to the emissions levels of the engine exhaust, the exhaust gas temperatures were recorded at each power level. These results are illustrated in Figure 5.10. The exhaust gas temperatures for both soybean and yellow grease-based biodiesel fuels fall significantly below those of the reference #1 and #2 diesel fuels at every test point. Lower exhaust gas temperatures are one indicator of earlier combustion [14]. Earlier combustion allows more time and crank angle for the expansion process to remove energy from the hot combustion gasses. One of the strong factors affecting these temperatures is ignition timing. Much prior work has been done in this area on the comparison of biodiesel fuels to #2 and #1 diesel fuel [21,22,23,24]. Early ignition timing has the effect of increasing the combustion temperature while reducing the exhaust gas temperature due to a longer expansion period. Biodiesel has a higher cetane number which reduces the ignition delay after injection [14]. The fuel injection pump also begins injecting biodiesel earlier than with petroleum-based diesel fuels in order to make up for the lower energy content of the methyl esters when running at the same power levels [25]. This results in an artificially advanced timing and earlier ignition. All of these factors have the tendency to increase the combustion temperature of biodiesel fuels while decreasing the exhaust gas temperatures as shown here.

It is also of particular interest that the exhaust gas temperature for #1 and #2 diesel ramped up significantly for the highest load case verses the temperature trends seen in the two biodiesel fuels. For all of the tests cases, none of the fuels were able to achieve the highest rated power output of the engine. As the petroleum-based fuels neared this limit, the exhaust gas temperature began to rise significantly. This indicates an unfavorable combustion reaction was taking place and corresponds to the increased emissions levels seen in the following sections. At these maximum achievable power levels, all of the test fuels were flowing at the same volumetric flow rate.

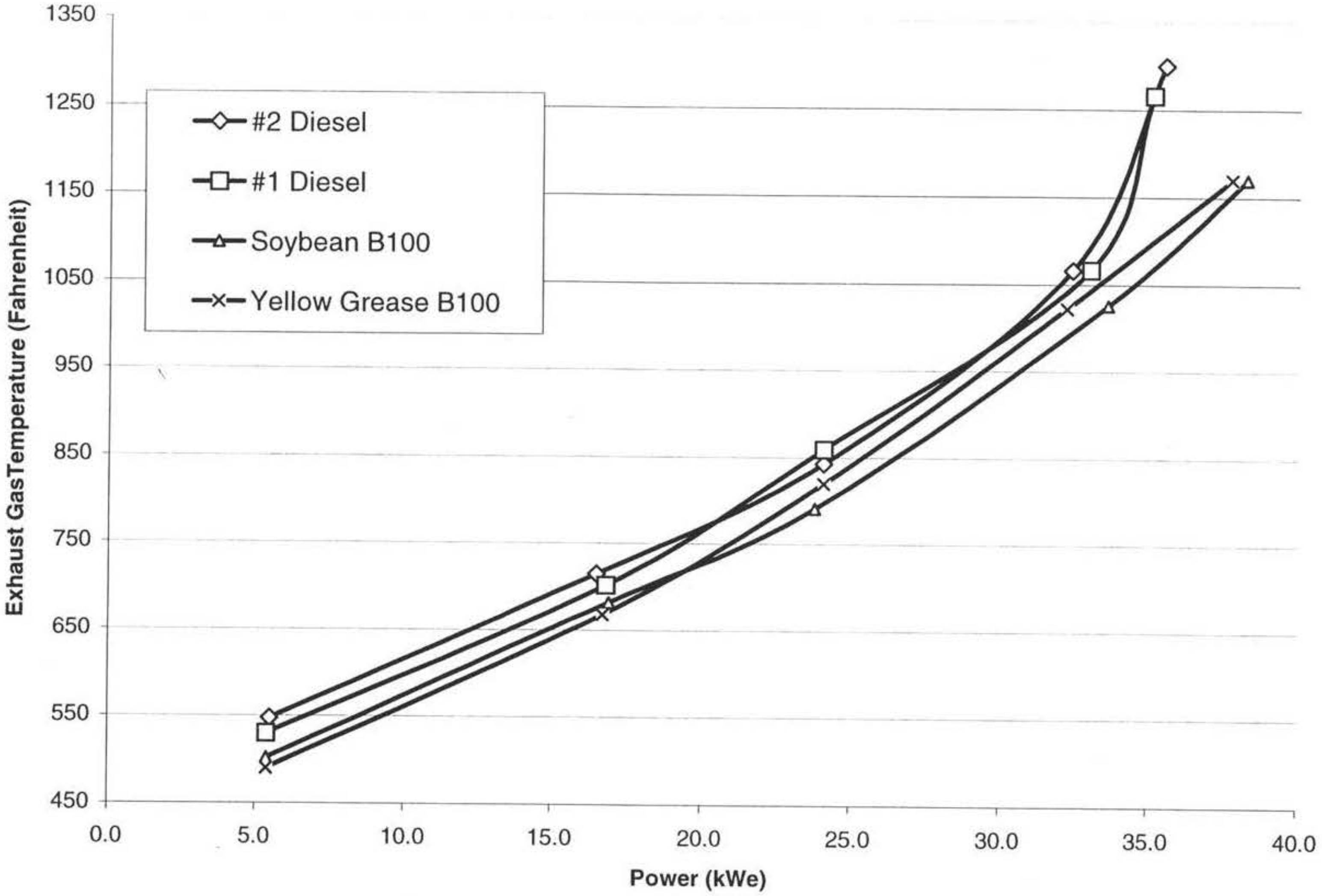


Figure 5.10 Exhaust Gas Temperature vs. Generated Power.

5.2.2 Generator Smoke Levels

One of the emissions of primary interest in this study was exhaust smoke. The results of the smoke tests at different loads are shown in Figure 5.11.

The smoke numbers for both soybean-based and yellow grease-based biodiesel fuels are significantly lower than those for #1 and #2 diesel fuels, matching the results found in several other studies [21,22]. As the power levels increased and correspondingly larger amounts of smoke were produced, the difference in smoke numbers between petroleum-based fuels and the biodiesel fuels became more substantial. As expected, the smoke emissions for the highest power level case showed a marked increase for the #2 and #1 diesel blends as they were pushed into an unfavorable combustion range. At this maximum power scenario, the biodiesel fuels produced so much less smoke that any trace of soot in the exhaust plume was difficult to see. Even though the #1 and #2 diesel fueled tests were restricted to lower maximum power levels, the smoke numbers for these runs were so high that the exhaust gas was nearly opaque.

5.2.3 Generator NOx Levels

The second emissions test of primary interest for the BECON pilot plant was NOx levels. This includes both nitric oxide (NO) and nitrogen dioxide (NO_2), NO being the predominate species of the two. The results of the NOx emissions at each test case are shown in Figures 5.12.

As can be seen from Figure 5.12, while the NOx emissions rise accordingly with load, the expected trend of higher NOx at each operating point with biodiesel as compared to #2 and #1 diesel fuels is not present. At low load conditions up through the 60% of maximum load tests, little difference was seen between the four fuels.

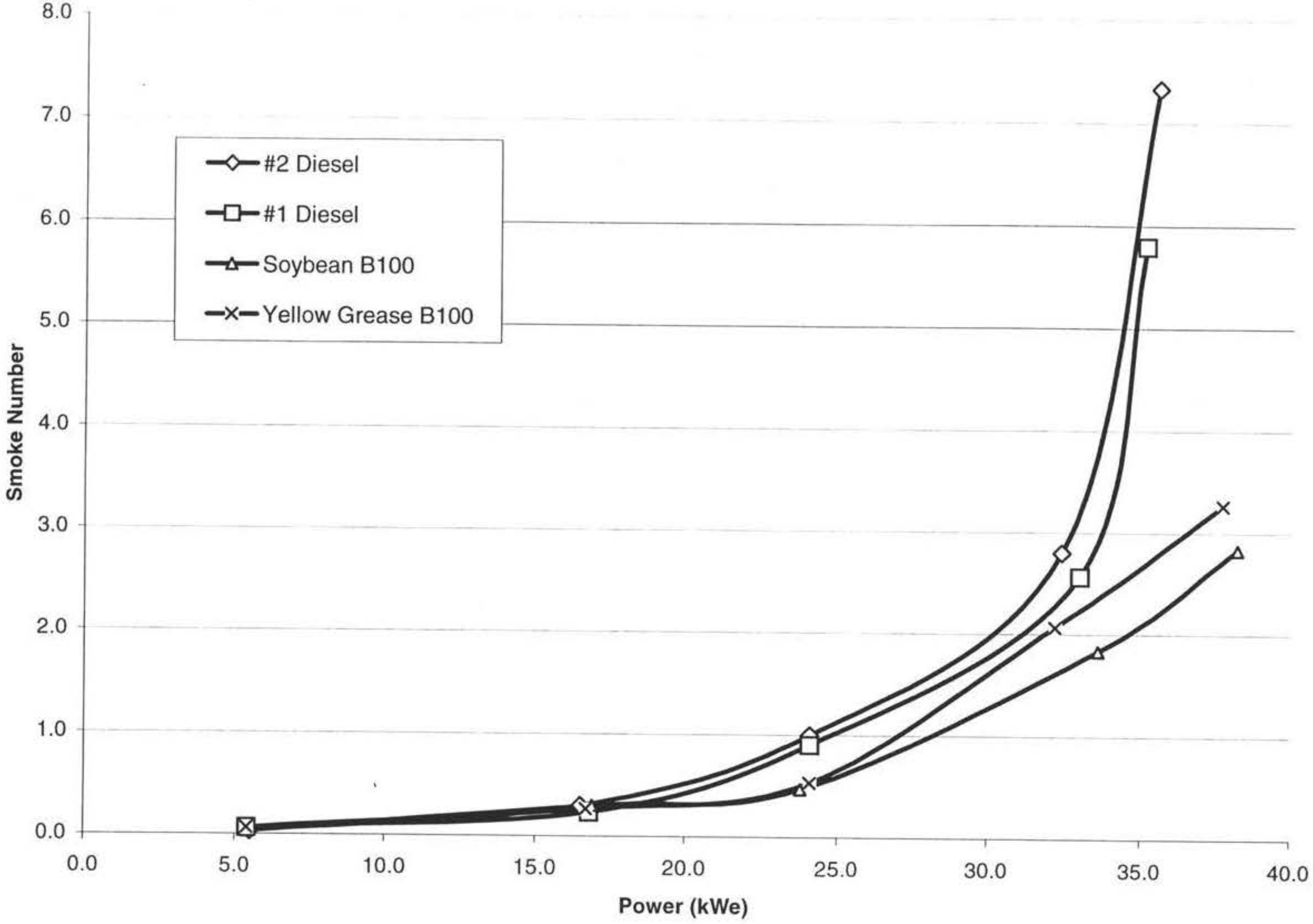


Figure 5.11 Smoke vs. Generated Power.

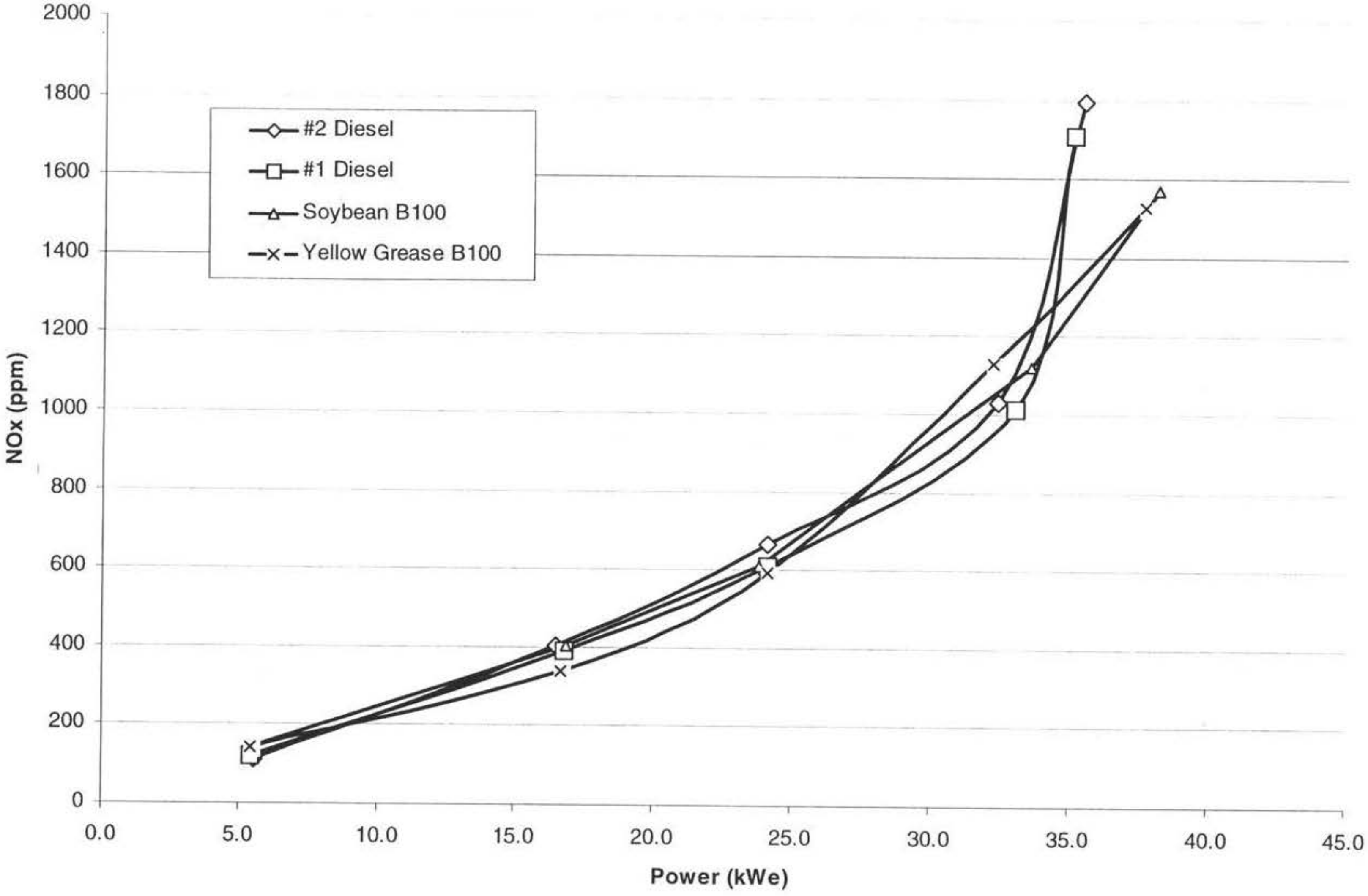


Figure 5.12 NOx vs. Generated Power.

At 80% of maximum engine load, the biodiesel fuels averaged 10% higher NOx while at the maximum possible load they averaged 11% lower NOx.

NOx formation is strongly dependant on combustion temperature. Higher combustion temperatures lead to significant increases in the formation of oxides of nitrogen. That the NOx levels of all four fuels fall within a narrow band over the low and mid power range operating points suggests that the fuels are achieving similar peak combustion temperatures.

As seen in the smoke emissions test results, the NOx emissions spike sharply for the highest power output case using #1 and #2 diesel fuel as compared to the yellow grease and soybean oil-based biodiesel. These peak values correspond to the peak exhaust gas temperatures discussed in Section 5.2.1. The high combustion temperatures could be caused by artificial advancement in injection timing due to the lower density and correspondingly higher volume of fuel required.

5.2.4 Generator Power Output

One of the more interesting results of these test runs was the maximum power output achievable with each of the four fuels. The heats of combustion for each fuel as tested by Phoenix Chemical Laboratory are shown in Table 5.2.

Table 5.2 Heats of Combustion (BTU/lb).

	#2 Diesel	#1 Diesel	Soy Biodiesel	Yellow Grease Biodiesel
Gross	19419	19773	17183	17252
Net	18235	18607	16072	16209

The lower heats of combustion for the biodiesel fuels require that a larger amount of fuel be injected into the engine to produce the same power. This results in the higher brake specific fuel consumptions often noted for biodiesel fuels [21,22]. Figure 5.13 shows the BSFC calculated at each of the load conditions for these tests.

It is important to remember that these figures include the inefficiencies inherent to the electrical generator driven by the diesel engine. The brake specific fuel consumptions for yellow grease and soybean oil-based biodiesel fall expectedly higher than the petroleum based-fuels at all part-load operating conditions. Attempts to run the generator up to its advertised full load capacity were unsuccessful. The 100% load conditions in these tests represent the highest possible load the generator could achieve before its governing software would cut out due to under-voltage alarms. It is notable that the highest possible loads were achieved with the biodiesel fuels, as shown in Table 5.3.

Table 5.3 Maximum Load Performance.

	#2 Diesel	#1 Diesel	Soy Biodiesel	Yellow Grease Biodiesel
Maximum Power (kWe)	35.5	35.1	38.2	37.7
Fuel Flow Rate (gal/min)	0.071	0.071	0.071	0.071
BSFC (g/kW-h)	372.7	370.9	364.9	369.9

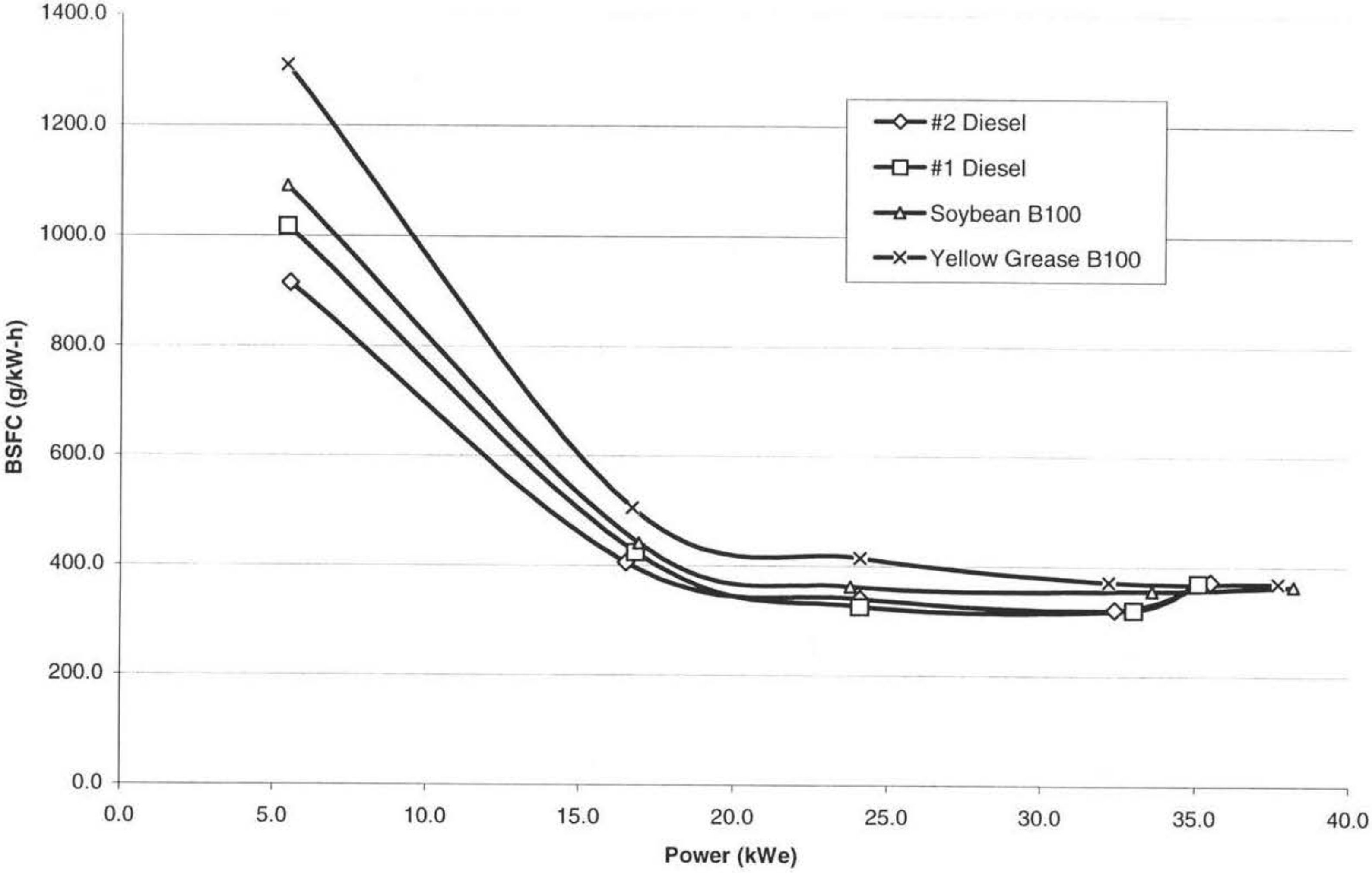


Figure 5.13 BSFC vs. Generated Power.

Table 5.3 also shows the volumetric fuel flow rates for these operating conditions and the corresponding brake specific fuel consumption. In each case it was found that the maximum possible power output occurred at a fuel flow rate of 0.071 gallons per minute. Further attempts to increase the load were unsuccessful and the fuel flow rate would not increase. It was determined that this is probably the highest flow rate the engine's fuel pump is capable of delivering. Given its slightly higher viscosity, and the increased effects of internal fuel pump leakage at these elevated temperatures, more fuel was likely able to stay on the pressurized side of the fuel pump with biodiesel. This allowed the engine to operate closer to its maximum advertised power output. The fact that all four fuels were being injected at the fuel pump's maximum output also indicates they all were injected with the same pump timing. This effectively reduced the net artificial advancement of combustion seen by the biodiesel fuels. The lower viscosity petroleum fuels could not reach as high a power level and were most likely forced into an undesirable state of combustion as evidenced by the marked increases in EGT and exhaust emissions. All of these density and viscosity issues were exaggerated due to the elevated fuel intake temperatures. The decreased fuel viscosity and the limitation of the fuel pump flow rate most likely caused the generator to be unable to achieve its maximum advertised power output.

In order to more fully utilize the generator as an effective demonstration tool of biodiesel technologies, a complete exhaust gas analysis bench would be of great use. Future work done with such an addition could more fully examine the emissions and engine performance offered by different fuels and technologies. Specifically, instruments measuring O_2, CO, CO_2, unburnt hydrocarbons, and intake airflow would allow determination of air fuel ratios, brake specific emissions, and provide an overall more complete picture of the combustion process.

6. Conclusions

The objective of this study was to expand the capabilities of the BECON biodiesel pilot plant into an effective demonstration facility. The following tasks were established to accomplish this goal.

- Implement a system for producing soybean oil onsite.
- Improve the operational capabilities and reliability of the pilot plant.
- Install a main reactor system capable of exploring high temperature atmospheric pressure transesterification processes.
- Construct a recirculating cyclonic separator system for preliminary examination of increased mixing effects on reaction rate and product quality.
- Set up a diesel generator capable of utilizing pilot plant produced fuel, providing electrical power to the BECON facility, and acting as an emissions test bed.

A complete soybean processing facility was constructed to provide on-site soybean oil feedstock for the pilot plant. The soybean facility consists of a 1000-bushel bean storage bin, bean extruder and oil extraction equipment, a fine material screening tank, the associated plumbing and conveying equipment, a 1000-bushel meal storage bin, and the required control systems for this equipment. The soybean facility can produce 46.75 gallons of soybean oil per 8-hour shift when operated at a nominal 450 pound per hour rate. At this rate, the bean and meal storage bins will supply the facility for over 16 8-hour shifts and 780 total gallons of soybean oil production.

The pilot plant was overhauled in order to be able to use its features as an effective demonstration tool for biodiesel production technologies. Valves, pumps, plumbing, wiring, and controls were replaced with equipment suitable for reliable operation. All open-top vessels involving methanol reactions were sealed or replaced with airtight units and ventilated through condensers and methanol vapor traps. The main reactor system was replaced with a larger 100-gallon, heated, temperature-controlled unit capable of demonstrating high temperature transesterification reactions. A recirculating cyclonic separator system was set up to provide a preliminary look at real time glycerin removal and enhanced mixing capabilities.

A diesel generator was set up to provide on-site electrical power generation from fuels produced in the pilot plant. The generator system includes an Olympian D40P3 40kWe diesel generator, a fuel storage building containing a 500-gallon heated insulated biodiesel storage tank and a 36-gallon petroleum diesel tank, a remote fuel selection manifold, a precision flow meter, the associated temperature-controlled plumbing required, the GenAccess control software, a filtered, dried, exhaust gas emissions sampling line and pump, and a load tester capable of fully loading the generator. The addition of the generator system to the BECON biodiesel facility allows demonstration of biodiesel technologies from raw soybeans to electricity, all at one site.

The following section summarizes the conclusions derived from the experiments performed as part of this research.

1. The reaction rate for the transesterification of methyl esters is inversely proportional to the reaction temperature. Reaction times as short as 22 minutes are possible at atmospheric pressure and temperatures of 140°F.
2. The transesterification of methyl esters is an exothermic reaction. All tests indicated a temperature rise after the reaction starts without additional heat input.
3. Separating a heavy phase stream from the transesterification process at steady state causes decreased reaction rates. All tests took longer to reach acceptable total glycerol levels of 0.15% as compared to reactions at the same temperature without separation. Some of the reactions using the separator never reached completion and those that did had higher total glycerol levels than reactions performed at the same temperature without separation.
4. Fuel selection between petroleum diesel and biodiesel was not a strong predictor of NOx levels at part-load conditions with this diesel engine.
5. Biodiesel reduced exhaust gas temperatures. The exhaust gas temperatures at all operating conditions for both soybean and yellow grease based methyl esters were lower than for both #1 and #2 diesel fuels.
6. Biodiesel fuels provide significantly reduced smoke when compared to petroleum-based diesel fuels. The smoke number at all operating conditions for both soybean-based and yellow grease-based methyl esters were lower than for both #1 and #2 diesel fuels. Further, the reduction in smoke number increases substantially with increased engine load.

The following section provides some suggestions for further work in these areas.

1. To better prepare the soybean oil feedstock and reduce filter clogging, the soybean oil production process should be followed by a degumming procedure. This would decrease the direct manual oversight required for the soybean processing facility as well as possibly reducing interphase material found in the methyl esters.
2. To further explore the cyclonic separator technology, the system should be fitted with an accurate flow control system. This would facilitate analysis of the heavy phase material removed and the formulation of a more effective glycerin removal schedule.
3. To more fully understand the exhaust emissions produced by the generator, a more complete exhaust emissions bench should be dedicated to use at the BECON facility. Specifically, instruments measuring O_2, CO, CO_2, unburnt hydrocarbons, and intake airflow would allow determination of air-fuel ratios, brake specific emissions, and an overall more complete picture of the combustion process. In addition to providing greater insight into the combustion process for different fuels, on-site exhaust testing of all relevant emissions would provide a more useful demonstration tool.

APPENDIX A

REACTION RATE DATA

140 Fahrenheit Without Cyclonic Separator

Time (hours)	0.25	0.50	0.75	1.00	1.50	2.00	2.50	3.00
Temp. (F)	145	142	141	141	140	140	140	140
% Free Glycerin	0.013	0.000	0.000	0.000	0.013	0.000	0.014	0.012
% Monoglycerides	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
% Diglycerides	0.122	0.070	0.026	0.026	0.021	0.000	0.019	0.013
% Triglycerides	0.060	0.031	0.007	0.007	0.006	0.007	0.005	0.007
% Total Glycerol	0.199	0.102	0.032	0.032	0.040	0.007	0.039	0.032

140 Fahrenheit With Cyclonic Separator

Time (hours)	0.25	0.50	0.75	1.00	1.50	2.00	2.50	3.00
Temp. (F)	143	144	144	145	145	144	140	140
% Free Glycerin	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
% Monoglycerides	0.006	0.006	0.007	0.007	0.001	0.006	0.004	0.005
% Diglycerides	0.481	0.361	0.290	0.236	0.163	0.188	0.160	0.152
% Triglycerides	0.385	0.270	0.219	0.157	0.137	0.122	0.103	0.099
% Total Glycerol	0.871	0.637	0.515	0.400	0.301	0.315	0.266	0.256

120 Fahrenheit Without Cyclonic Separator

Time (hours)	0.25	0.50	0.75	1.00	1.50	2.00	2.50	3.00	4.00
Temp. (F)	123	122	120	120	120	120	120	120	120
% Free Glycerin	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
% Monoglycerides	0.005	0.000	0.001	0.005	0.005	0.004	0.004	0.004	0.004
% Diglycerides	0.127	0.247	0.085	0.053	0.027	0.008	0.005	0.000	0.008
% Triglycerides	0.143	0.301	0.052	0.046	0.020	0.010	0.016	0.011	0.012
% Total Glycerol	0.275	0.549	0.139	0.103	0.052	0.022	0.025	0.015	0.024

120 Fahrenheit With Cyclonic Separator

Time (hours)	0.25	0.50	0.75	1.00	1.50	2.00	2.50	3.00	4.00
Temp. (F)	124	124	122	121	120	120	120	120	120
% Free Glycerin	0.006	0.005	0.005	0.005	0.005	0.004	0.006	0.007	0.006
% Monoglycerides	0.005	0.004	0.004	0.004	0.004	0.004	0.003	0.005	0.003
% Diglycerides	0.258	0.189	0.133	0.091	0.058	0.045	0.034	0.028	0.024
% Triglycerides	0.056	0.066	0.108	0.064	0.037	0.032	0.011	0.016	0.008
% Total Glycerol	0.326	0.264	0.250	0.164	0.103	0.085	0.054	0.055	0.041

100 Fahrenheit Without Cyclonic Separator

Time (hours)	0.25	0.50	0.75	1.00	1.50	2.00	2.50	3.00	4.00	5.00	6.00
Temp. (F)	106	106	106	105	105	103	103	102	102	101	100
% Free Glycerin	0.005	0.005	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.006	0.000
% Monoglycerides	0.009	0.006	0.006	0.003	0.004	0.004	0.005	0.004	0.000	0.004	0.004
% Diglycerides	0.507	0.289	0.228	0.145	0.100	0.060	0.037	0.029	0.012	0.009	0.000
% Triglycerides	0.513	0.356	0.421	0.106	0.095	0.057	0.038	0.018	0.009	0.005	0.000
% Total Glycerol	1.033	0.656	0.655	0.261	0.199	0.122	0.079	0.051	0.021	0.024	0.004

100 Fahrenheit With Cyclonic Separator

Time (hours)	0.25	0.50	0.75	1.00	1.50	2.00	2.50	3.00	4.00	5.00	6.00
Temp. (F)	108	108	107	107	108	105	105	103	102	101	100
% Free Glycerin	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.005	0.008	0.000	0.000
% Monoglycerides	0.010	0.009	0.007	0.000	0.002	0.000	0.005	0.004	0.003	0.003	0.003
% Diglycerides	0.534	0.340	0.324	0.272	0.169	0.180	0.168	0.126	0.138	0.084	0.081
% Triglycerides	0.688	0.369	0.339	0.254	0.148	0.160	0.061	0.034	0.049	0.041	0.058
% Total Glycerol	1.232	0.718	0.671	0.526	0.319	0.341	0.238	0.169	0.198	0.128	0.143

80 Fahrenheit Without Cyclonic Separator

Time (hours)	0.250	0.500	0.750	1.000	1.500	2.000	2.500	3.000	4.000	5.000	6.000	7.000	8.000
Temp. (F)	88	87	86	86	86	86	86	86	86	86	86	86	86
% Free Glycerin	0.011	0.000	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
% Monoglycerides	0.005	0.004	0.004	0.005	0.004	0.004	0.000	0.000	0.003	0.000	0.003	0.000	0.000
% Diglycerides	0.333	0.441	0.304	0.326	0.320	0.220	0.171	0.151	0.092	0.072	0.053	0.039	0.026
% Triglycerides	0.433	0.606	0.283	0.225	0.360	0.156	0.187	0.205	0.095	0.044	0.037	0.032	0.021
% Total Glycerol	0.783	1.052	0.591	0.567	0.684	0.380	0.358	0.356	0.191	0.116	0.093	0.071	0.047

80 Fahrenheit With Cyclonic Separator

Time (hours)	0.250	0.500	0.750	1.000	1.500	2.000	2.500	3.000	4.000	5.000	6.000	7.000	8.000
Temp. (F)	86	87	87	88	89	90	91	91	92	92	93	93	93
% Free Glycerin	0.010	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.010	0.000
% Monoglycerides	0.036	0.032	0.025	0.011	0.009	0.012	0.006	0.008	0.007	0.006	0.006	0.007	0.005
% Diglycerides	0.403	0.997	0.554	0.387	0.312	0.361	0.286	0.272	0.202	0.218	0.170	0.055	0.199
% Triglycerides	0.204	0.031	0.503	0.170	0.210	0.238	0.219	0.161	0.132	0.116	0.136	0.003	0.164
% Total Glycerol	0.654	1.059	1.082	0.567	0.532	0.618	0.511	0.441	0.341	0.340	0.312	0.075	0.369

APPENDIX B

EMISSIONS DATA

		Percent Generator Power (kW)				
Fuel	Test	20%	40%	60%	80%	100%
#2 Diesel	NOx (ppm)	110.3	402.5	665.3	1030.0	1792.5
	NO (ppm)	110.3	390.3	630.0	983.0	1765.0
	Smoke 1	0.1	0.3	1	2.8	7.3
	Smoke 2	0	0.3	1	2.7	7.5
	Smoke 3	0	0.3	1	2.9	7.2
	EGT (F)	548	715	843	1066	1300
	Fuel Temp (F)	120	121	120	123	122
	Fuel Flow (gpm)	0.027	0.036	0.044	0.056	0.071
	Power (kWe)	5.5	16.5	24.1	32.4	35.5
	RPM	1851	1836	1821	1807	1653
	Smoke (avg)	0.0	0.3	1.0	2.8	7.3
	Spec Grav	0.821	0.821	0.821	0.820	0.821
	Power (kW)	5.5	16.5	24.1	32.4	35.5
	Torque (NM)	28.4	85.8	126.4	171.2	205.1
	BSFC (g/kWe h)	915.7	406.8	340.6	322.0	372.7
#1 Diesel	NOx (ppm)	121.3	389.3	608.0	1015.0	1707.5
	NO (ppm)	0.0	381.3	575.0	937.3	1625.0
	Smoke 1	0	0.3	0.9	2.5	5.8
	Smoke 2	0.1	0.2	0.9	2.6	5.8
	Smoke 3	0.1	0.2	0.9	2.6	5.8
	EGT (F)	530	702	859	1067	1266
	Fuel Temp (F)	121	121	121	122	121
	Fuel Flow (gpm)	0.03	0.039	0.043	0.058	0.071
	Power (kWe)	5.4	16.8	24.1	33	35.1
	RPM	1855	1833	1823	1796	1678
	Smoke (avg)	0.1	0.2	0.9	2.6	5.8
	Spec Grav	0.808	0.808	0.808	0.807	0.808
	Power (kW)	5.4	16.8	24.1	33.0	35.1
	Torque (NM)	27.8	87.5	126.3	175.5	199.8
	BSFC (g/kWe h)	1018.8	425.7	327.2	322.2	370.9
B100 Soy Bio-Diesel	NOx (ppm)	143.3	402.0	607.5	1120.0	1572.5
	NO (ppm)	142.5	386.5	580.3	1045.0	1467.5
	Smoke 1	0	0.3	0.5	1.8	2.9
	Smoke 2	0	0.3	0.4	1.9	2.8
	Smoke 3	0.1	0.3	0.5	1.8	2.8
	EGT (F)	502	682	791	1026	1170
	Fuel Temp (F)	121	120	122	123	122
	Fuel Flow (gpm)	0.03	0.038	0.044	0.061	0.071
	Power (kWe)	5.4	16.9	23.8	33.6	38.2
	RPM	1850	1828	1820	1800	1785
	Smoke (avg)	0.0	0.3	0.5	1.8	2.8
	Spec Grav	0.865	0.865	0.865	0.864	0.865
	Power (kW)	5.4	16.9	23.8	33.6	38.2
	Torque (NM)	27.9	88.3	124.9	178.3	204.4
	BSFC (g/kWe h)	1091.2	441.8	363.0	356.3	364.9
B100 Yellow Grease Bio-Diesel	NOx (ppm)	143.0	338.5	591.3	1127.5	1530.0
	NO (ppm)	142.5	318.3	528.5	1053.3	1445.3
	Smoke 1	0.1	0.3	0.5	2	3.2
	Smoke 2	0.1	0.3	0.6	2.1	3.3
	Smoke 3	0	0.2	0.5	2.1	3.3
	EGT (F)	490	668	820	1022	1170
	Fuel Temp (F)	120	120	121	122	121
	Fuel Flow (gpm)	0.036	0.043	0.051	0.061	0.071
	Power (kWe)	5.4	16.7	24.1	32.2	37.7
	RPM	1851	1831	1823	1804	1782
	Smoke (avg)	0.1	0.3	0.5	2.1	3.3
	Spec Grav	0.865	0.865	0.865	0.865	0.865
	Power (kW)	5.4	16.7	24.1	32.2	37.7
	Torque (NM)	27.9	87.1	126.3	170.5	202.0
	BSFC (g/kWe h)	1310.0	505.9	415.6	371.9	369.9

APPENDIX C

FUEL PROPERTIES DATA

Test Property	**Commercial No. 1 Diesel Fuel**
Carbon (% mass)	86.83 *a
Hydrogen (% mass)	12.72 *a
Oxygen (% mass)	-
C/H Ratio	6.826
Sulfur (% mass)	0.045 *a
Cetane Number (ASTM D613)	45.3 *a
Gross Heat of Combustion (kJ/kg)	45,991 *a
Net Heat of Combustion	43,281 *a
Specific Gravity (@21 C)	0.8162 *c
Kinematic Viscosity (cSt, @40 C)	1.759 *c
Total Glycerin (%)	-
Free Glycerin (%)	-
*Disitllation (ASTM D86, F) *a*	
Initial Boiling Point	348
5%	373
10%	384
20%	394
30%	406
40%	416
50%	426
60%	440
70%	454
80%	474
90%	503
95%	535
End Point	580
Recovery (%)	98
Residue (%)	1.9
Loss (%)	0.1

a Measured by Phoenix Chemical Laboratory Inc., Chicago IL.
b Measured by Williams Laboratory Services, Kansas City, KS.
c Measured in the Department of Mechanical Engineering, Iowa State University, Ames, IA.
d Calculated using Universal Oil Products Method 375-86, Des Plaines IL.
e Calculated from Fatty Acid Distribution.

Test Property	**Commercial No. 2 Diesel Fuel**
Carbon (% mass)	86.66
Hydrogen (% mass)	12.98
C/H Ratio	6.676
Sulfur (% mass)	0.034
Cetane Number (ASTM D613)	42.2
Gross Heat of Combustion (BTU/Lb.)	19,419
Net Heat of Combustion (BTU/Lb.)	18,235
Hydrocarbon Types, FIA (ASTM D1319),	
Saturates	56.6
Olefins	1.6
Aromatics	41.8
Disitllation (ASTM D95, F)	
Initial Boiling Point	352
5%	389
10%	420
20%	449
30%	470
40%	490
50%	508
60%	527
70%	547
80%	571
90%	602
95%	629
End Point	660
Recovery (%)	98
Residue (%)	1.9
Loss (%)	0.1

Measured by Phoenix Chemical Laboratory Inc., Chicago IL.

Test Property	Biodiesel From Soybean Oil
Carbon (% mass)	77
Hydrogen (% mass)	12.18
Sulfur (% mass)	<0.005
Cetane Number (ASTM D613)	50.4
Gross Heat of Combustion (BTU/Lb.)	17,183
Net Heat of Combustion (BTU/Lb.)	16,072
% Free Glycerin	0.000
% Monoglycerides	0.025
% Diglycerides	0.122
% Triglycerides	0.045
% Total Glycerol	0.192
Fatty Acid profile, % Relative	Listed Below *
C08:0 Octanoic (Caprylic)	<0.10
C10:0 Decanoic (Capric)	<0.10
C11:0 Undecanoic (Hendecanoic)	<0.10
C12:0 Dodecanoic (Lauric)	<0.10
C13:0 Tridecanoic	<0.10
C14:0 Tetradecanoic (Myristic)	<0.10
C14:1 Tetradecenoic (Myristoleic)	<0.10
C15:1 Pentadecanoic	<0.10
C15:1 Pentadecenoic	<0.10
C16:0 Hexadecanoic (Palmitic)	10.81
C16:1 Hexadecenoic (Palmitolenic)	0.11
C16:2 Hexadecadienoic	<0.10
C16:3 Hexadecatrienoic	<0.10
C16:4 Hexadecatetraenoic	<0.10
C17:0 Heptadecanoic (Margaric)	0.1
C17:1 Heptadecenoic (Margaroleic)	<0.10
C18:0 Octadecanoic (Steric)	4.54
C18:1 Octadecenoic (Oleic)	24.96
C18:2 Octadecadienoic (Linoleic)	50.66
C18:3 Octadecatrienoic (Linolenic)	7.27
C18:4 Octadecatetraenoic	<0.10
C20:0 Eicosanoic (Arachidic)	0.37
C20:1 Eicosenoic (Gadoleic)	0.32
C20:2 Eicosadienoic	<0.10
C20:3 Eicosatrienoic	<0.10
C20:4 Eicosatetraenoic (Arachidonic)	<0.10
C20:5 Eicosapentaemoic	<0.10
C21:5 Heneicosapentaenoic	<0.10
C22:0 Docosanoic (Behenic)	0.42
C22:1 Docosenoic (Erucic)	<0.10
C22:2 Docosadienoic	<0.10
C22:3 Docosatriemoic	<0.10
C22:4 Docosatetraenoic	<0.10
C22:5 Docosapentaenoic	<0.10
C22:6 Docosahexaenoic	<0.10
C24:0 Tetracosanoic (Lignoceric)	0.12
C24:1 Tetracosenoic (Nervonic)	<0.10
Unknown Components	0.32
*Reported as methyl esters	
M I U	0.56
Moisture & Volatiles By Hot Plate	0.27
Insoluable Impurities	<0.10
Unsaponifiable Matter	0.29

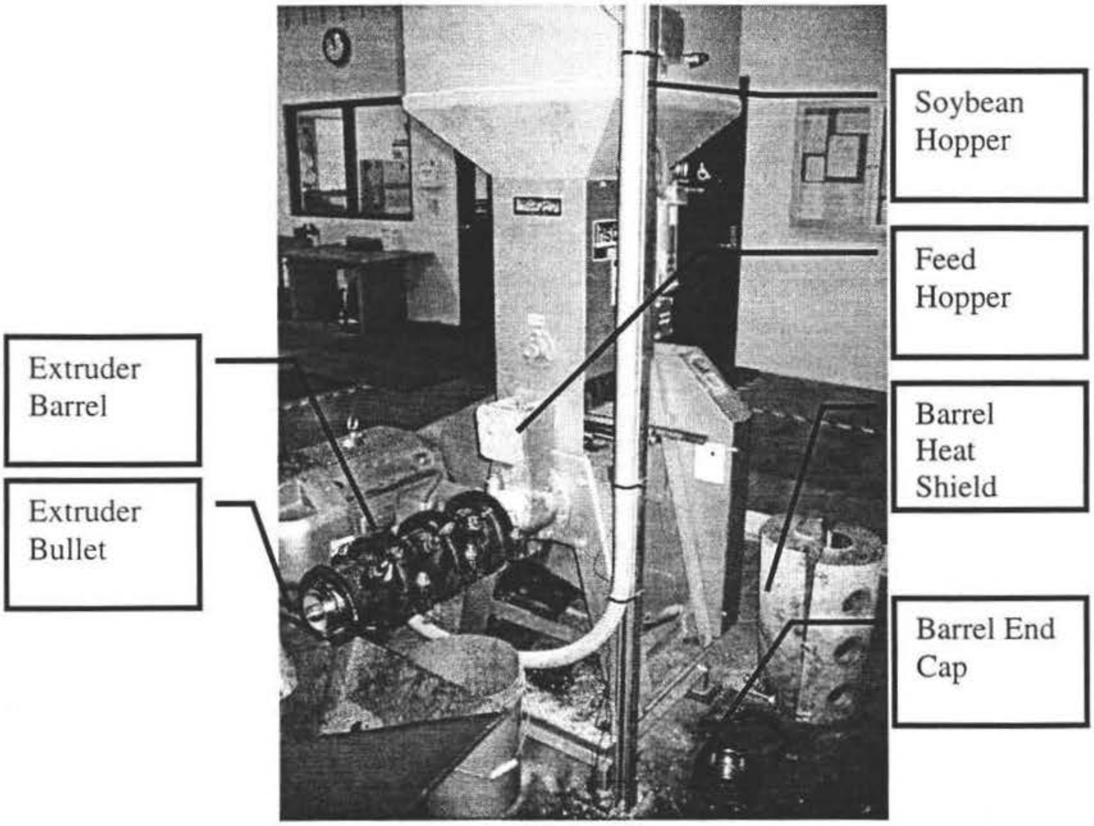
Test Property	Biodiesel From Yellow Grease
Carbon (% mass)	75.78
Hydrogen (% mass)	11.43
Sulfur (% mass)	<0.005
Cetane Number (ASTM D613)	62.6
Gross Heat of Combustion (BTU/Lb.)	17,252
Net Heat of Combustion (BTU/Lb.)	16,209
% Free Glycerin	0.000
% Monoglycerides	0.010
% Diglycerides	0.136
% Triglycerides	0.057
% Total Glycerol	0.203
Fatty Acid profile, % Relative	Listed Below *
C08:0 Octanoic (Caprylic)	<0.10
C10:0 Decanoic (Capric)	<0.10
C11:0 Undecanoic (Hendecanoic)	<0.10
C12:0 Dodecanoic (Lauric)	<0.10
C14:0 Tetradecanoic (Myristic)	1.27
C14:1 Tetradecenoic (Myristoleic)	0.43
C15:1 Pentadecanoic	0.18
C15:1 Pentadecenoic	<0.10
C16:0 Hexadecanoic (Palmitic)	17.44
C16:1 Hexadecenoic (Palmitolenic)	2.03
C16:2 Hexadecadienoic	<0.10
C16:3 Hexadecatrienoic	<0.10
C16:4 Hexadecatetraenoic	<0.10
C17:0 Heptadecanoic (Margaric)	0.51
C17:1 Heptadecenoic (Margaroleic)	0.41
C18:0 Octadecanoic (Steric)	12.38
C18:1 Octadecenoic (Oleic)	54.67
C18:2 Octadecadienoic (Linoleic)	7.96
C18:3 Octadecatrienoic (Linolenic)	0.69
C18:4 Octadecatetraenoic	0.13
C20:0 Eicosanoic (Arachidic)	0.25
C20:1 Eicosenoic (Gadoleic)	0.52
C20:2 Eicosadienoic	0.11
C20:3 Eicosatrienoic	<0.10
C20:4 Eicosatetraenoic (Arachidonic)	<0.10
C20:5 Eicosapentaemoic	<0.10
C21:5 Heneicosapentaenoic	<0.10
C22:0 Docosanoic (Behenic)	0.21
C22:1 Docosenoic (Erucic)	<0.10
C22:2 Docosadienoic	<0.10
C22:3 Docosatriemoic	<0.10
C22:4 Docosatetraenoic	<0.10
C22:5 Docosapentaenoic	<0.10
C22:6 Docosahexaenoic	<0.10
C24:0 Tetracosanoic (Lignoceric)	<0.10
C24:1 Tetracosenoic (Nervonic)	<0.10
Unknown Components	0.81
*Reported as methyl esters	
M I U	0.58
Moisture & Volatiles By Hot Plate	0.03
Insoluable Impurities	0.06
Unsaponifiable Matter	0.49

APPENDIX D

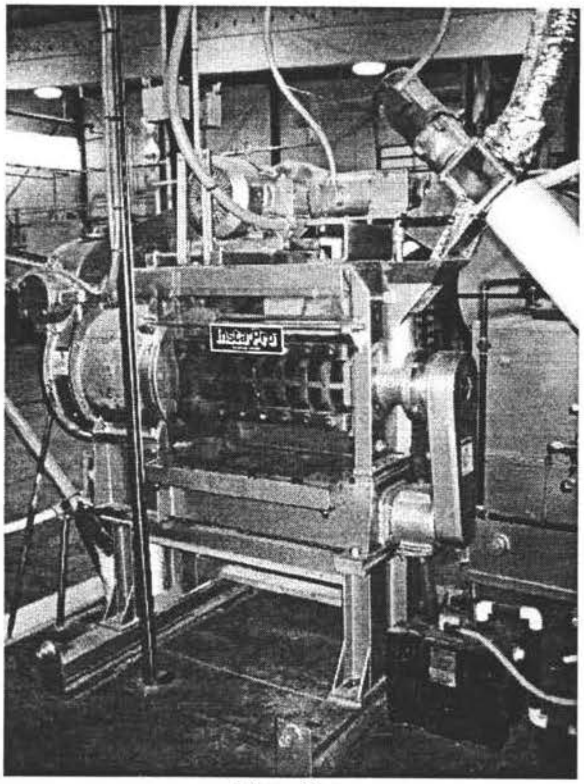
SOYBEAN OIL EXTRACTION EQUIPMENT STANDARD OPERATING PROCEDURE

Introduction

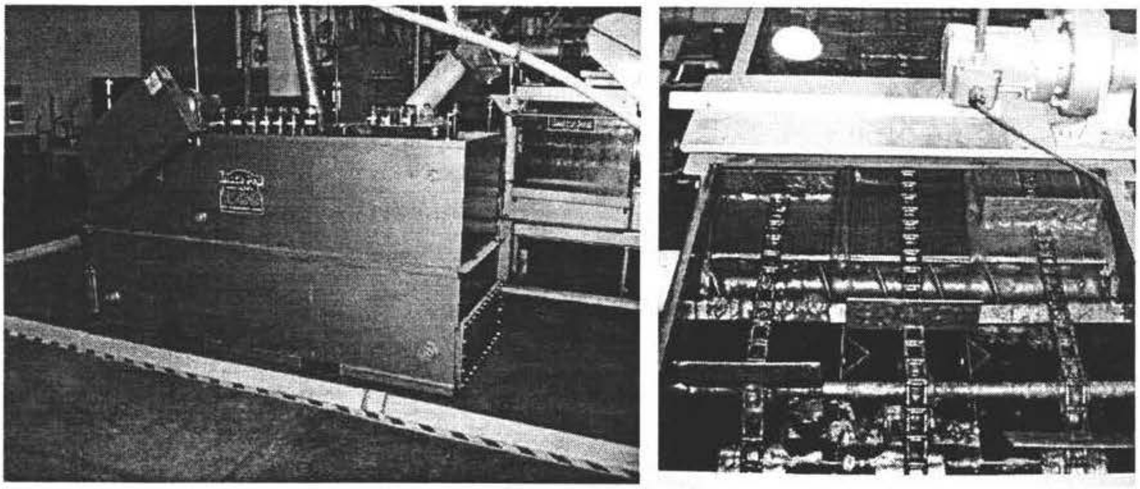
Before operating the soybean oil extraction equipment, read through this standard operating procedure manual completely. Be sure to familiarize yourself with the various previously encountered problems outlined herein. Should these problems happen to you, quick action will be required. Familiarize yourself with the following controls, equipment, and their respective parts.



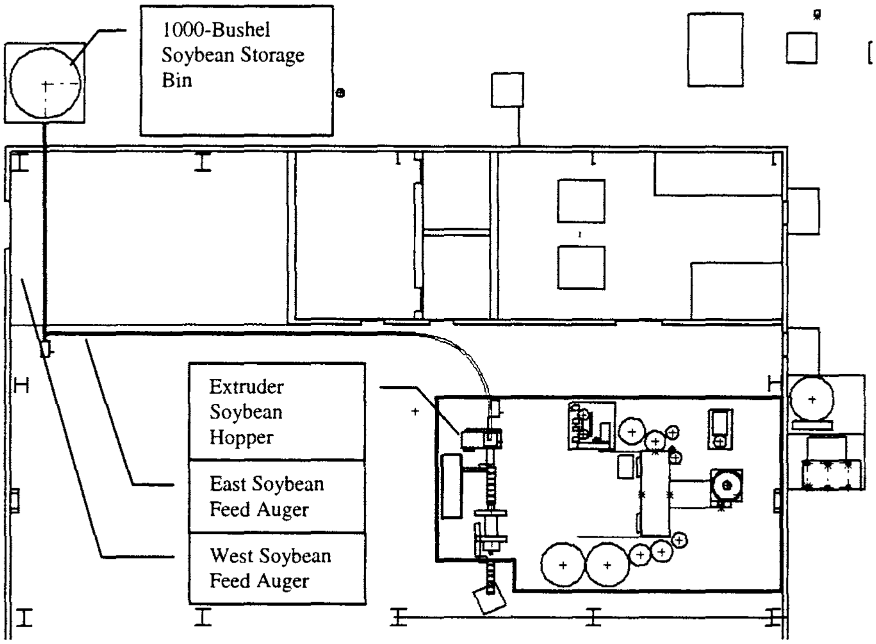
Extruder



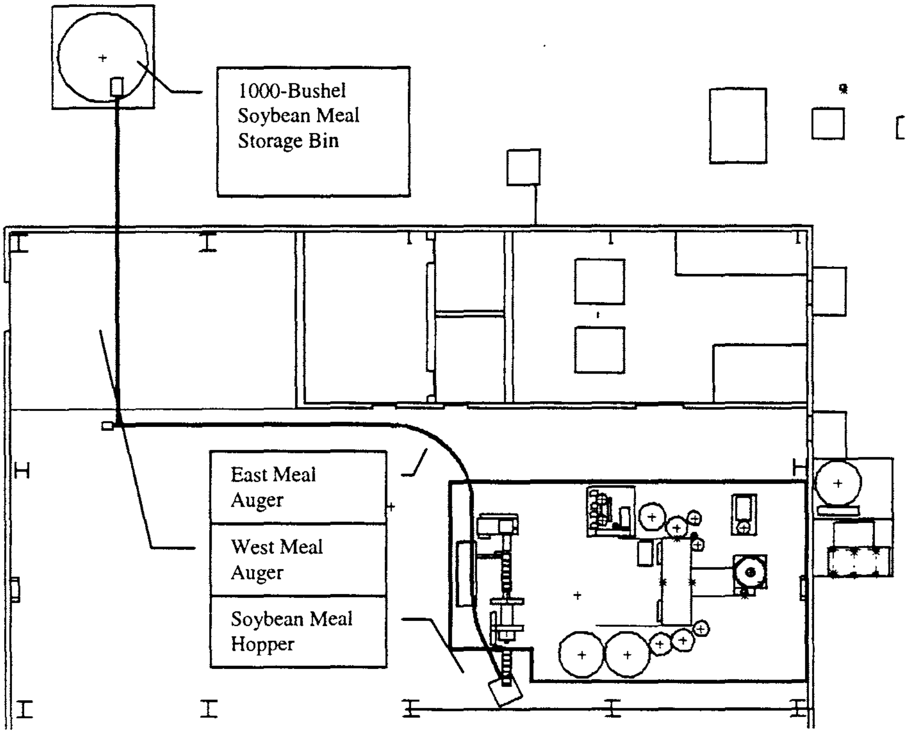
Expeller



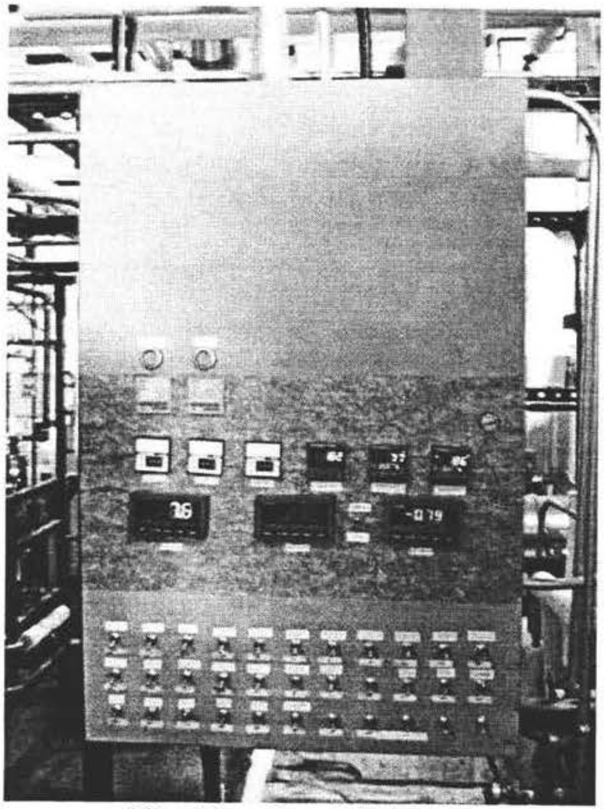
Screening Tank



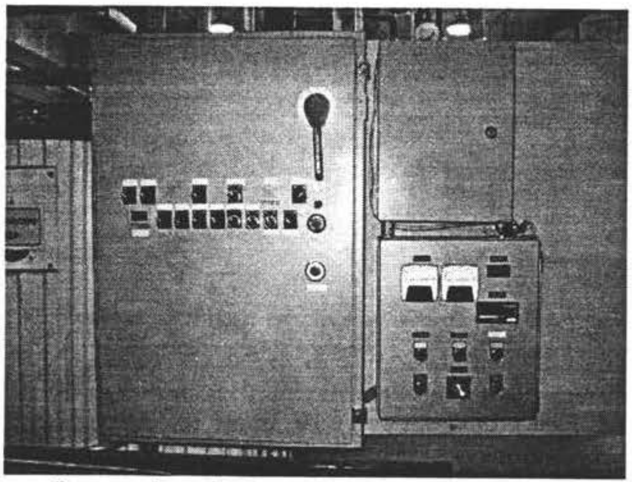
Soybean Delivery System



Meal Removal System



Pilot Plant Control Cabinet



Soybean Processing & Extruder / Expeller Control Cabinet

Inspecting these pieces of equipment beforehand will make them much easier to locate and work with when operating them for the first time.

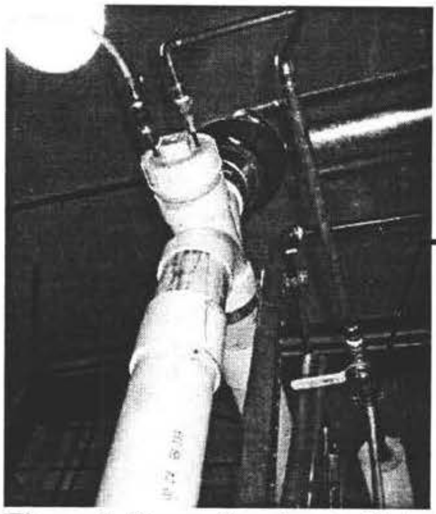
Startup Preparation

Equipment needed

- 15/16" wrench
- 10" x 20" cardboard sheet

Procedure

1. Ensure that all switches and controls on the main gray soybean processing cabinet and the small green expeller / extruder cabinet are in the off position.
2. Turn the water valve for the steam ventilation condenser to the completely open position. See Figure 1.



Condenser Water Valve

Figure 1. Steam Condenser Water Valve

3. Check that the pilot plant air supply is on. See Figure 2.

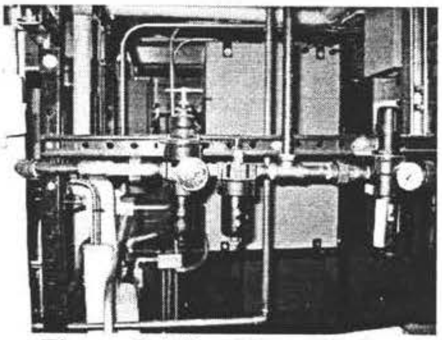


Figure 2. Pilot Plant Air Supply

4. Check to see that all of the appropriate circuit breakers are in the on position.

208 / 120 V Panel
#(1/2/3) Main
#9 Biodiesel Instrumentation
#11 Biodiesel 110V Relays
#25 Biodiesel Extruder Expeller 110V AC
#(24/26) Biodiesel Extruder Expeller Controls

480 V Panel
#1 Main
#3 Transformer
#10 Expeller
#16 Extruder
#21 Soybean Processing Cabinet

5. Turn the exhaust fan switch on at the pilot plant control panel.

6. Check to see that no foreign objects are in the conveyor auger system.

7. Check to see that the extruder bean hopper has beans in it.

8. Using the 15/16" wrench, check that all extruder barrel bolts are tight. See Figure 3.

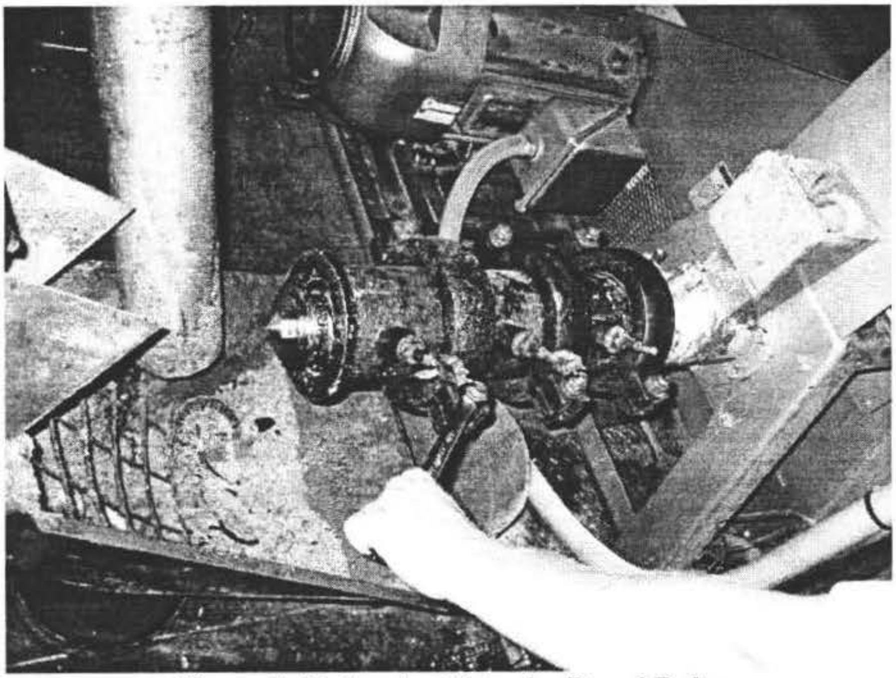


Figure 3. Tightening Extruder Barrel Bolts

9. Leaving the extruder end cap off, wrap the cardboard sheet around the extruder barrel end and lower the deflection shield to hold the cardboard in place. The cardboard sheet will help deflect most of the soybean material into the conveyor auger hopper. See Figure 4.

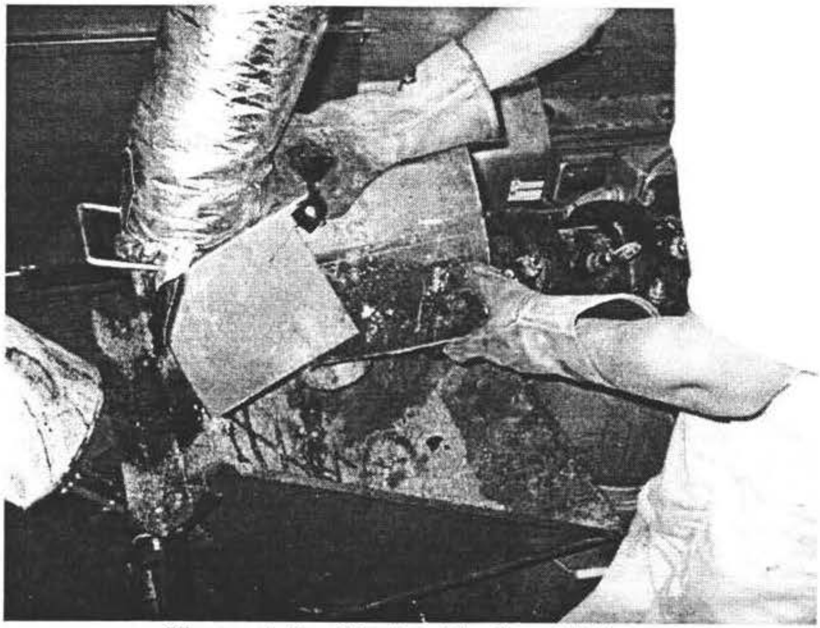


Figure 4. Positioning Cardboard Sheet

Startup

Equipment needed

- 15/16" wrench
- 1 1/4" wrench
- 10" x 20" cardboard sheet
- Heavy leather gloves
- Wire brush

Procedure

1. Turn the large power lever on the soybean processing control cabinet to the ON position and pull out the large red emergency stop button.
2. At the soybean processing control cabinet, turn the following switches to the ON position:
    - Feed augers automatic
    - Meal augers automatic
    - Expeller oil sump automatic
3. At the extruder expeller control panel, turn on the expeller.
4. At the soybean processing control cabinet, turn on the conveyor augers.
5. At the extruder expeller control panel, turn on the extruder.
6. At the extruder expeller control panel, set the feed rate to 35% and press the expeller feed auger start button.
7. Verify that soybeans are entering the extruder. If the soybeans are not feeding properly, immediately turn off the feed auger and all expeller and extruder systems. Dismantle the extruder barrel and clean out any blockage.
8. After approximately 30 seconds, crushed soybeans will exit the open end of the expeller barrel. Allow the system to operate for two minutes.
9. At the extruder expeller control panel, turn off the soybean feed and the extruder.

10. At the soybean processing control cabinet, turn off the conveyor augers.
11. At the extruder expeller control panel, turn on the expeller.
12. At the soybean processing control cabinet, turn off the large power lever and press the large red stop button.

Note: Be prepared to proceed through steps 13 – 23 quickly. The chance the extruder clogging or backing up is greatly reduced if the extruder is started warm and lubricated with crushed soybeans as has been accomplished in the preceding steps.

13. Once all equipment has stopped, put on the heavy leather gloves, remove the cardboard sheet, and use the wire brush to briefly clean off the end of the extruder barrel.
14. Using the 15/16" wrench, secure the end cap on the end of the extruder barrel.
15. Using the 1 1/4" wrench, snug down the large end cap exit screw. Once this screw has contacted the bullet at the end of the extruders main shaft, note the screw orientation and back the screw off two (2) full turns. See Figure 5.

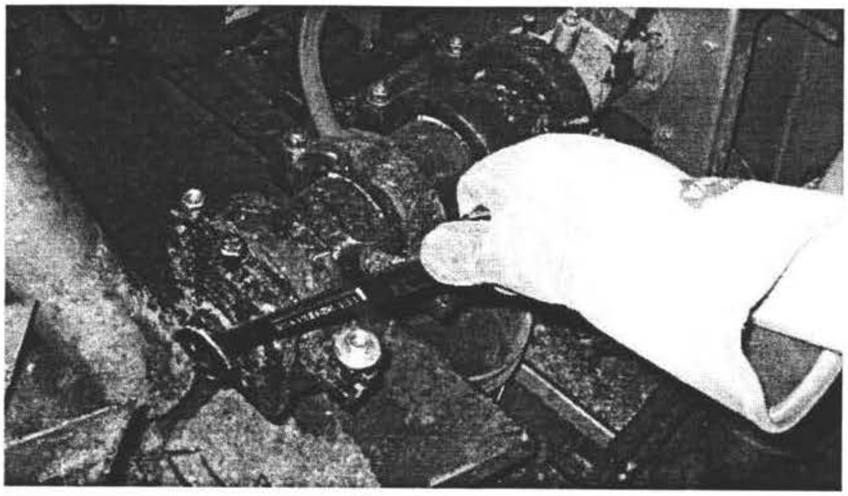


Figure 5. Adjusting End Cap Exit Screw

16. Secure the insulation heat shield over the extruder barrel and attach the three thermocouples. Thermocouple #1 is nearest the extruder barrel exit. Thermo couple #2 is in the center barrel section. Thermocouple #3 is nearest the extruder barrel feed hopper. See Figure 6.

Figure 6. Securing Extruder Barrel Heat Shield

17. Leave the extruder deflection shield up so that the extruded beans may be observed.
18. Verify that no foreign objects are in the conveyor augers.
19. At the soybean processing control cabinet, turn on the large power lever and pull out the large red stop button.
20. At the extruder expeller control panel, turn on the expeller.
21. At the soybean processing control cabinet, turn on the conveyor augers.
22. At the extruder expeller control panel, turn on the extruder.
23. At the extruder expeller control panel, set the feed rate to 35% and start the expeller feed auger.

24. Verify that soybeans are entering the extruder. Also, after approximately 30 seconds, crushed soybeans should begin to exit the extruder. See Figure 7.

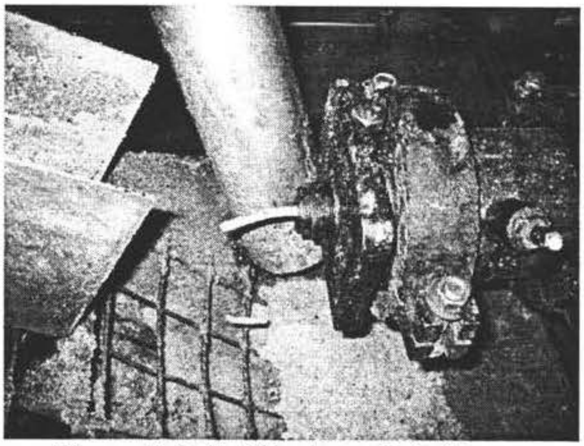


Figure 7. Initial Soybean Exit Stream

25. Within the first minute of expelling, the crushed soybeans will change in appearance from a slow moving paste to a high velocity steam jet. See Figure 8. At this stage, increase the soybean feed rate to 40% on the extruder expeller control cabinet.

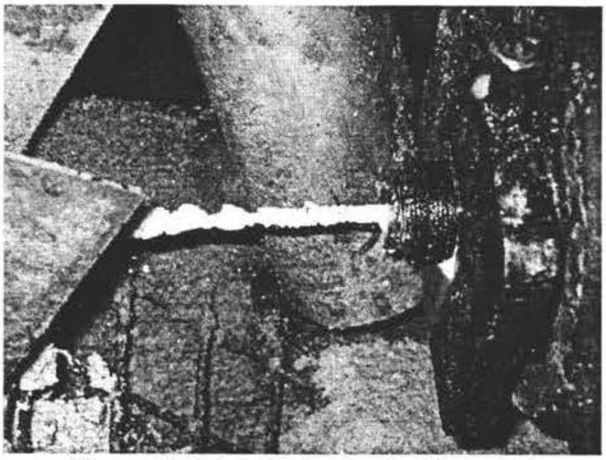


Figure 8. High Velocity Soybean Jet

26. Using the heavy leather gloves and 1 1/4" wrench, turn in the extruder barrel end screw one and a half turns, leaving it one half turn out.

27. When the extruder exit thermocouple, #1, reaches 260° F increase the soybean feed rate to 45% on the extruder expeller control cabinet.
28. When the extruder exit thermocouple, #1, reaches 290° F increase the soybean feed rate to 50% on the extruder expeller control cabinet.
29. Using the heavy leather gloves and the 1 1/4" wrench, turn in the extruder barrel end screw one-quarter turn, leaving it one-quarter turn out.
30. Lower the extruder barrel exit shield.
31. Over the next ten minute period keep a close eye on the extruder exit thermocouple #1. As temperatures approach 300° F slowly increase the soybean feed rate in 1% increments on the extruder expeller control cabinet. If the temperature does not approach 300° F, slowly decrease the feed rate in 1% increments until the temperature begins to climb.

The final steady state temperature should be 310° F for maximum oil extraction. Reducing soybean feed rate at the extruder expeller control panel increases temperature while increasing feed rate lowers temperature. If the temperature drops below 300° F, decrease the feed rate. If the temperature rises above 310° F, increase the feed rate.

Common steady state operating conditions are temperatures of 305 ° F at feed rates ranging from 50% to 65%. These conditions are highly dependant on ambient temperature and soybean moisture content. Steady state operation is usually reached in one to two hours, depending on ambient temperature.

Steady State Operation

Equipment needed

- Heavy leather gloves
- 15/16" wrench
- 1 1/4" wrench

Procedure

During steady state operation, the equipment needs very little attention. Once operating temperatures have been reached, feed rate adjustments are often not needed for the remainder of the day. The primary responsibilities of the equipment operator during steady state are:

- Verify that beans are feeding properly.
- Verify that the extruder feed hopper is clear of dust or foreign objects.
- Verify the conveyor augers are working properly.
- Verify the automatic soybean delivery system is keeping the extruder soybean hopper properly full.
- Verify the automatic soybean meal removal auger system is keeping the meal bin properly empty.
- Verify the automatic soybean oil sump pump is keeping the sump properly empty.
- Verify the extruder is operating in the appropriate temperature range.

During steady state operation, it is sometimes difficult to maintain the desired operating temperature. Reducing the extruder feed rate can increase the operating temperature, but this also reduces oil production rate. Turning the extruder end screw in closer to the bullet on the end of the extruder's main shaft will also increase operating temperatures, but this increases the likelihood of the extruder backing up. The standard operating procedure outlined here recommends setting the end screw at a quarter turn out and leaving it in this position, adjusting temperature by adjust feed rate. Operation with the screw turned in past ¼ is possible, but in the past this has significantly increased the occurrence of extruder backups while not offering worthwhile temperature increases. It is strongly recommended that the extruder be run with the end screw at ¼ turn out.

The specification for ideal steady state temperature is 310° F for maximum oil extraction efficiency. The feed rates required to achieve this will vary based on factors such as ambient temperature and soybean water content, but these feed rates will commonly be between 50% and 65%. In less than perfect conditions, it is difficult to maintain a temperature of 310°F. Common operating conditions are between 300 and 310°F at feed rates ranging from 50% to 65%

Occasionally due to oversight or equipment failure, the operator will have to deal with any number of problems. Below are some guidelines for dealing with problems that have happened in the past.

<u>Extruder not feeding properly</u>

Characterized by any of the following

- Beans not entering extruder barrel feed hopper.
- Burnt bean material being expelled from extruder barrel feed hopper.
- Crushed beans not exiting extruder barrel while soybeans are still entering the extruder barrel feed hopper.
- A rapid and uncontrollable temperature spike.

In any event proceed with the following actions:

1) Press the large red emergency stop button on the extruder expeller control cabinet.
2) Turn the large power switch and all other switches on the soybean processing control cabinet and the extruder expeller control cabinet to the OFF position.
3) While the expeller is still hot, use the heavy leather gloves and the 15/16" wrench to dismantle the extruder barrel and remove all soybean material inside.
4) Determine the cause of the problem. Common causes are:
    - Extruder barrel end screw turned in too far and contacting bullet, preventing soybean material exit
    - Soybean delivery system failed and the extruder hopper ran empty
    - Dust or foreign matter clogged the extruder barrel feed hopper
    - Operating temperatures or feed rates out of specification
5) Begin startup preparations again. After startup steady state conditions will be quickly reached since the machinery is already hot.

<u>Soybean delivery system failure</u>

Characterized by any of the following

- Beans entering extruder barrel feed hopper, but extruder soybean bin level below bottom level sensor
- Extruder soybean bin level overfilled past top sensor and up delivery auger tube

If a soybean delivery failure has caused beans to stop being fed into the extruder barrel feed hopper, follow the procedure outlined above under "Extruder not feeding properly."

In the case that automatic bean delivery to the extruder soybean bin has stopped, but beans are still being fed into the extruder barrel feed hopper, proceed as follows:

1) At the soybean processing control cabinet, turn on the Feed Auger East Manual and the Feed Auger West Manual switches.
2) After the bean deliver augers have started, turn both switches off again.
3) If bean delivery continues, allow the automatic system to turn off the bean feed when the extruder soybean bin is full. If bean delivery stops while the extruder soybean bin is still empty, it will be necessary to manually control the soybean feed switches until the problem can be found

In the case that the extruder soybean bin level is overfilled past the top sensor and up the delivery auger tube, proceed as follows:

1) At the soybean processing control cabinet, turn the Feed Augers Automatic switch off.

2) After the level in the extruder soybean bin has fallen below the top level sensor, turn the Feed Augers Automatic switch back on.
3) If the soybean delivery system immediately begins feeding again, manual control via the soybean feed manual switches on the soybean processing control cabinet will be necessary.

In either case, the problem with the automatic soybean delivery system will have to be found. Common causes are stuck level sensors. Keep a close eye on the soybean delivery system and the extruder soybean bin level for the remainder of the equipment's operation.

Soybean oil sump pump system failure

Characterized by any of the following

- Oil exiting the top of the sump pump
- Sump pump not pumping while air is supplied to it

In the case that the sump is full or overflowing, but the sump pump is not on, proceed as follows:

1) At the soybean processing control cabinet, turn the soybean oil sump pump manual switch on.
2) If the sump pump does not begin pumping, divert the incoming oil stream to a temporary bucket while the cause of the problem is determined.

3) After the level in the sump begins to fall, turn the manual switch off while leaving the automatic soybean oil sump pump switch on.
4) After the soybean oil level in the sump is under control, determine the cause of the problem.

In the case that the sump pump is not pumping despite air being supplied to it, proceed as follows:

1) At the soybean processing control cabinet, turn the soybean oil sump pump automatic switch off.
2) Verify the sump pump air valve is partially closed. The sump pump starts and operates best with its air valve closed to the approximate position shown in Figure 9.

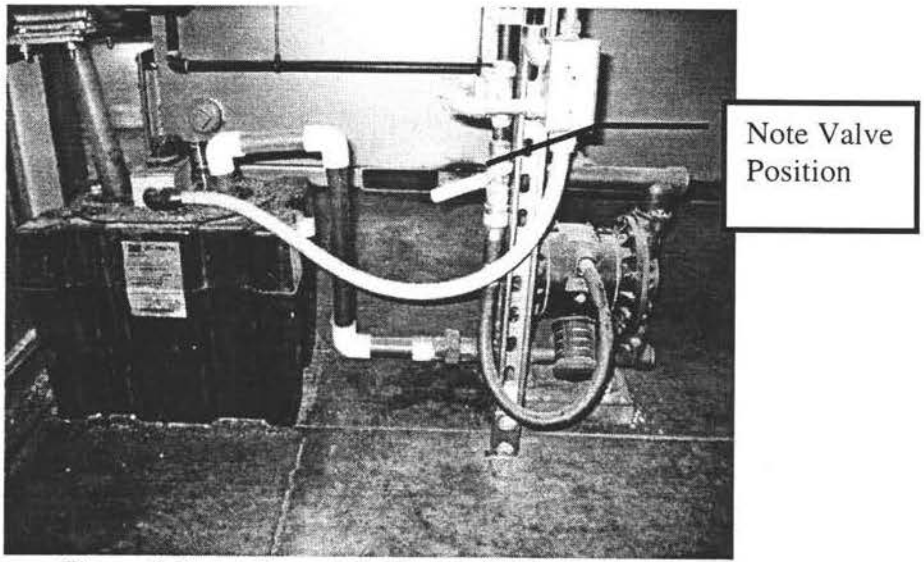


Figure 9 Sump Pump Air Supply Valve Position

3) At the soybean processing control cabinet, turn the soybean oil sump pump automatic switch on.

5) If the sump pump continues to fail to pump while air runs through it, attempt to repeat this procedure. If repeating the procedure does not free the pump, divert the incoming oil stream to a temporary bucket while the cause of the problem is determined.

Screening Tank Operation

Procedure

The screening tank is normally left with its motor off allowing the fine material suspended in the oil to settle. On those days when the drying system operator would like the screening tank to run, proceed as follows:

1. Achieve steady state operation of the entire soybean meal system.
2. On the soybean processing control cabinet, turn the screening tank motor switch on.

   NOTE: Do not accidentally turn the screening tank pump on by mistake.
3. Observe the operation of the screening tank. Within a few minutes a thick soybean material will begin to auger out of the screening tank.
4. Allow this material to enter the conveyor auger system for 30 seconds to one (1) minute, after which shut the screening tank motor off.

   NOTE: The thick soybean material augered out of the screening tank can quickly clog up the conveyor auger system. If the screening tank output begins to overwhelm the conveyor system before even 30 seconds have passed, turn the screening tank motor off. The output from the screening tank will mix with the extruded soybeans and cause them to become very thick and oily at first, but will diminish over the next few minutes of operation. If the screening tank motor is allowed to continue to run and excessive amounts of the thick soybean material clog up the conveyor auger, the expelled soybean meal will not be carried up the conveyor auger and the entire soybean oil extraction system will have to be shut down until the problem is corrected.

5. Allow the soybean processing equipment to run for two more minutes with the screening tank motor off.
6. After two minutes have passed, turn the screening tank motor back on for 30 seconds to one minute.
7. Repeat steps 5 and 6 until the screening tank has been sufficiently empted or the rate of material leaving the screening tank has dropped so low as to no longer pose a threat to the conveyor augers.

Shutdown

Equipment needed

- 15/16" wrench
- 1 1/4" wrench
- 10" x 20" cardboard sheet
- Heavy leather gloves
- Plastic Mallet

Procedure

1. Put on the heavy leather gloves and raise extruder bean meal deflection shield and using the 1 1/4" wrench back the extruder barrel end screw back out 2 full turns.
2. Unhook the thermocouples and remove the extruder barrel insulation shield.
3. Hook the thermocouple leads back up to the extruder barrel thermocouples after shield removal.
4. At the extruder/expeller control panel, increase feed rate up to 75% in 5% increments at 30-second intervals.
5. The temperature should begin to fall. Keep a close eye on temperature and continue to run the equipment for another 2 minutes.
6. At the extruder / expeller control panel, turn off the soybean feed switch.
7. At the extruder / expeller control panel, turn off the extruder.
8. At the soybean processing control cabinet, turn off the conveyor augers.
9. At the extruder / expeller control panel, turn off the expeller.
10. At the soybean processing control cabinet push the large red emergency stop button and turn off the large power switch.

11. After all of the equipment has stopped, use the heavy leather gloves, 15/16" wrench and plastic mallet to remove the end cap from extruder barrel. See Figure 10.

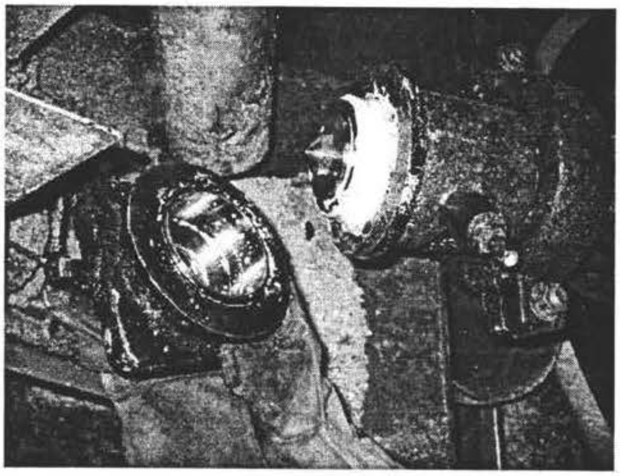


Figure 10 Extruder Barrel End Cap Removed

Note: The end cap will be hot and under pressure. Use the plastic mallet to tap the end cap off while standing clear and allow the end cap to fall into the hopper.

12. Place the 10" x 20" cardboard sheet around the end of the extruder barrel and lower the extruder bean meal deflection shield to hold it in place. See Figure 10.
13. With everyone clear of the extruder, pull the large red emergency stop button and turn on the large power switch at the soybean processing control cabinet.
14. At the extruder / expeller control panel, turn on expeller.
15. At the soybean processing control cabinet, turn on the conveyor augers.
16. At the extruder / expeller control cabinet turn on the extruder and the bean feed at a 75% feed rate.
17. Continue to operate for 1 minute.

18. At the extruder / expeller control panel, turn off the soybean feed switch. Continue to run until soybean material no longer exits the extruder barrel.
19. At the extruder / expeller control panel, turn off the extruder.
20. At the soybean processing control cabinet, turn off the conveyor augers.
21. At the extruder / expeller control panel, turn off the expeller.
22. At the soybean processing control cabinet, turn off all switches, push the large red emergency stop button and turn off the large power switch.
23. Turn the water valve for the steam ventilation condenser to the full off position.
24. At the pilot plant control cabinet, turn off the exhaust fan.
25. Sweep up any soybean material around the soybean processing equipment.

Complete Clean Out

Equipment needed

- 15/16" wrench
- 10" x 20" cardboard sheet
- Heavy leather gloves

Sometimes it is desirable to completely clean out the extruder. Often this is done if the machine will be sitting some time before its next operation or if there are blockage issues inside the extruder barrel.

Procedure

1. Ensure that all switches and controls on the main gray soybean processing cabinet and the small green expeller / extruder cabinet are in the off position.
2. Check to see that all of the appropriate circuit breakers are in the on position.

    <u>208 / 120 V Panel</u>
    #(1/2/3) Main
    #9 Biodiesel Instrumentation
    #11 Biodiesel 110V Relays
    #25 Biodiesel Extruder Expeller 110V AC
    #(24/26) Biodiesel Extruder Expeller Controls

    <u>480 V Panel</u>
    #1 Main
    #3 Transformer
    #10 Expeller
    #16 Extruder
    #21 Soybean Processing Cabinet

3. Using the leather gloves and a 15/16" wrench, remove the extruder barrel end cap.
4. Wrap the 10" x 20" cardboard sheet around the end of the extruder barrel and lower the bean meal deflection shield to hold it in place.
5. At the soybean processing control cabinet, turn on the large power lever and pull out the red emergency stop knob.
6. With everyone clear of the extruder turn on the extruder at the extruder / expeller control panel.

7. Run the extruder until no soybean material exits the barrel. If the extruder will not turn or is somehow jammed, immediately turn off the extruder and proceed with the "Unjamming the Extruder" section that follows the Complete Clean Out.
8. At the extruder at the extruder / expeller control panel, turn off the extruder.
9. At the soybean processing control cabinet, turn off the large power lever and push in the red emergency stop knob.
10. Using the 15/16" wrench, remove the next section of the extruder barrel and set aside.
11. Depending on the size of the cardboard sheet, it may not be possible to continue to use the cardboard on the end of the extruder barrel. If so, leave the soybean meal deflection shield raised and away from the main extruder shaft.
12. At the soybean processing control cabinet, turn on the large power lever and pull out the red emergency stop knob.
13. With everyone clear of the extruder turn on the extruder at the extruder / expeller control panel.
14. Run the extruder until no soybean material exits the barrel.
15. Repeat steps 8 through 14 for the remaining sections of the extruder barrel.
16. Once all of the barrel sections have been removed and cleaned out, at the soybean processing control cabinet, turn on the large power lever and pull out the red emergency stop knob.
17. Bolt all barrel sections back onto the extruder, using the 15/16" wrench to tighten all bolts. Leave the extruder barrel end cap off for the next startup.
18. Sweep up any soybean material around the soybean processing equipment.

Unjamming the Extruder

Equipment needed

- 15/16" wrench
- 1" wrench
- Heavy leather gloves

In the event that the Extruder has become jammed during a complete clean out, the extruder will have to be further disassembled.

Procedure

1. Ensure that all switches and controls on the main gray soybean processing cabinet and the small green expeller / extruder cabinet are in the off position.
2. Lock out the large power switch on the soybean processing cabinet, following BECON's safety lockout procedure.
3. Remove the soybean meal deflection shield from the red conveyor auger hopper. This will provide easier access to the extruder for the following operation.
4. Using the 15/16" wrench, remove the end cap from the extruder barrel.
5. Using the 1 1/4" wrench, remove the bullet from the end of the extruder main shaft.

   NOTE: This is a left hand threaded bolt and needs to be turned clockwise in order to loosen.

6. The last steam lock, key, and shim plates may or may not be easily removable from the main extruder shaft at this time. If so, remove them and set them aside.
7. Using the 15/16" wrench, remove the bolts and collars holding the next section of extruder barrel in place.

8. Slide the barrel section off of the main extruder shaft. The section of auger screw contained inside should also slide off with the barrel section. If the barrel section does not slide off easily, use the plastic pallet to loosen the barrel section. NOTE: Strike only the end flange of the barrel section with the mallet, and not the thermocouple.
9. Remove and set aside the barrel section. Remove and set aside the next steam lock, key, and shims.
10. Repeat steps 7 through 9 on the remaining sections of extruder barrel.
11. Once all extruder barrel sections have been removed, attempt to manually remove the screw flight from inside. If the screw flight can not be easily removed, proceed to step 12.
12. Take the barrel section over to the vertical hydraulic press and press the screw out of the barrel section. The hydraulic press should be able to very easily remove the screw flight. If excessive force is required, check to make sure the screw flight is free to pass out the bottom of the barrel section. NOTE: Do not allow the screw flight to fall to the floor.
13. Once all screw flights, barrels, steam locks, shims, and keys have been removed and cleaned, reassemble the extruder in the reverse order.

Some further notes:

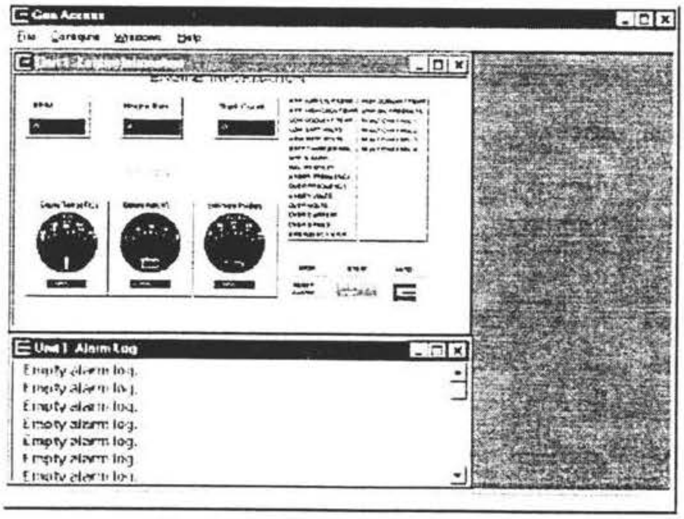
1. The placement of the shims ahead of or behind the steam locks is not critical and should be occasionally adjusted. The purpose of these shims is to adjust the location of the steam lock wear spot on the inside of the barrel sections.
2. The barrel sections are all the same size. Their order is not critical and should be occasionally rearranged in order to more evenly wear the inside of the barrel sections.
3. All of the steam locks, except the end bullet steam lock are of the same size and can be rearranged.
4. The first two screw sections deepest inside the extruder with a single screw flight must not be interchanged with the other screw flights. These two single flight screws can be interchanged with each other.
5. The remaining screw flights are all of the same size and their order is not critical. They should occasionally be reordered to more evenly spread the wear they receive.

APPENDIX E

DIESEL GENERATOR EQUIPMENT STANDARD OPERATING PROCEDURE

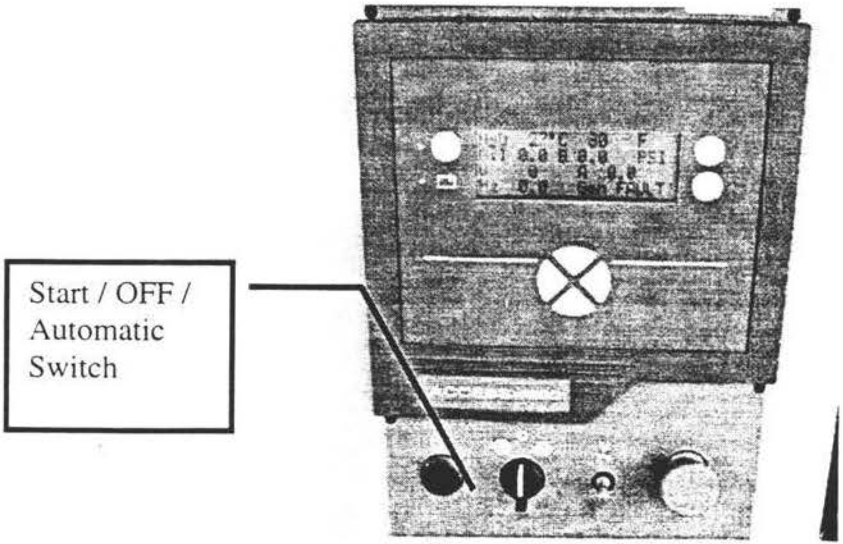
Introduction

Before operating the diesel generator, generator load tester, or fuel supply system, read through this standard operating procedure manual completely. Be sure to familiarize yourself with the various previously encountered problems outlined herein. Familiarize yourself with the following controls, equipment, and their respective parts.

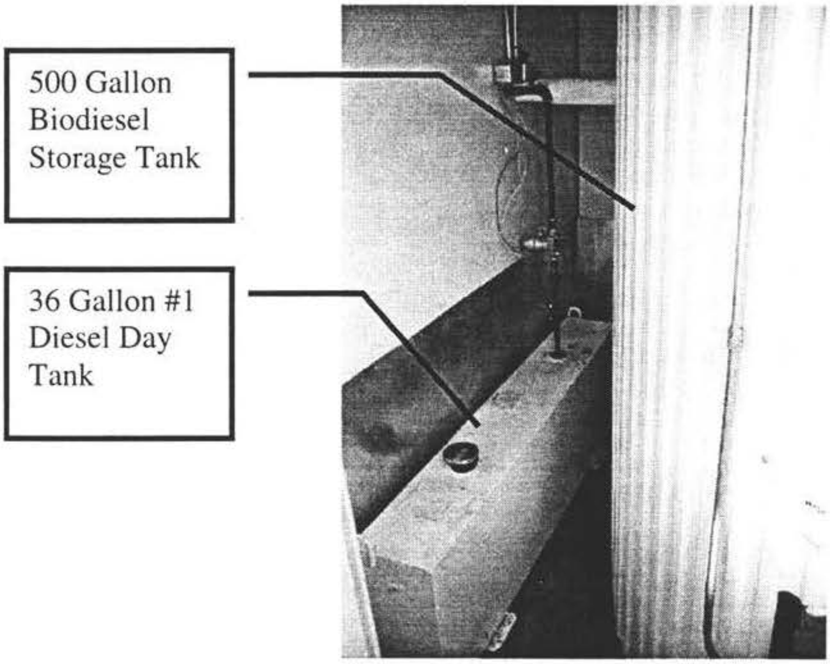


```
Empty alarm log.
Empty alarm log.
Empty alarm log.
Empty alarm log.
Empty alarm log.
Empty alarm log.
Empty alarm log.
```

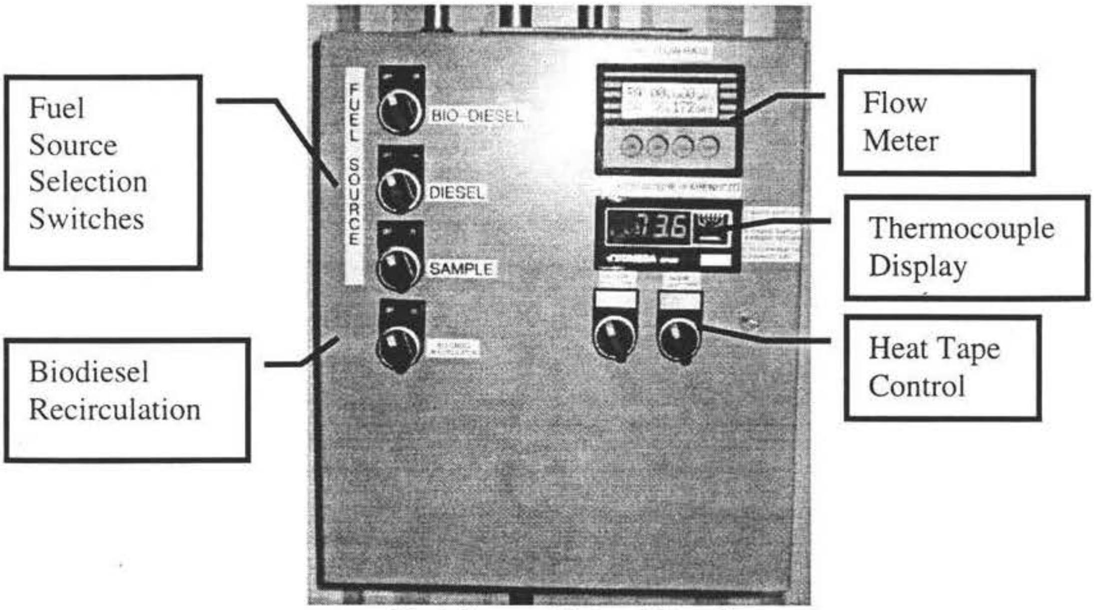
GenAccess Software Package



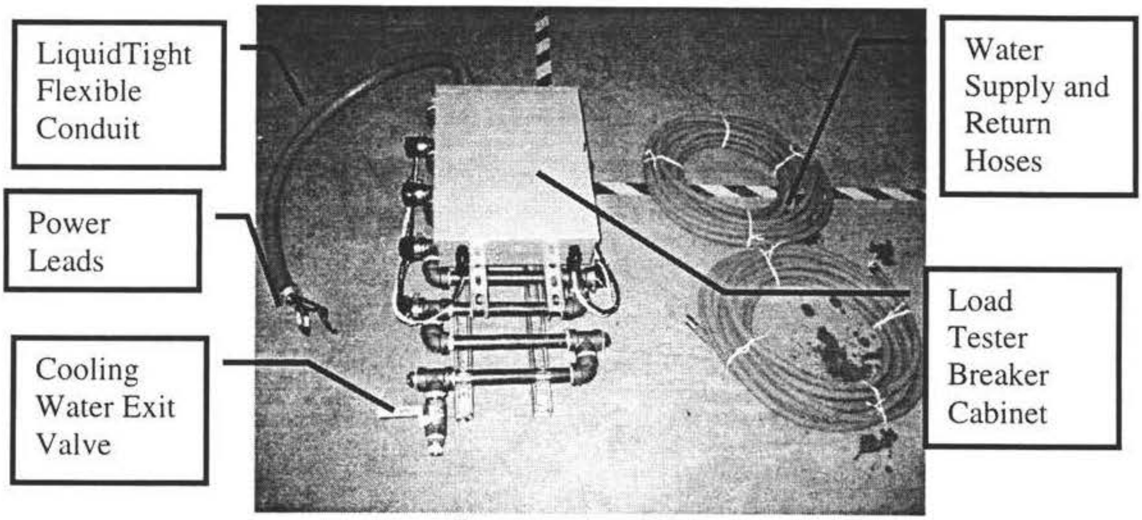
Generator Control Panel



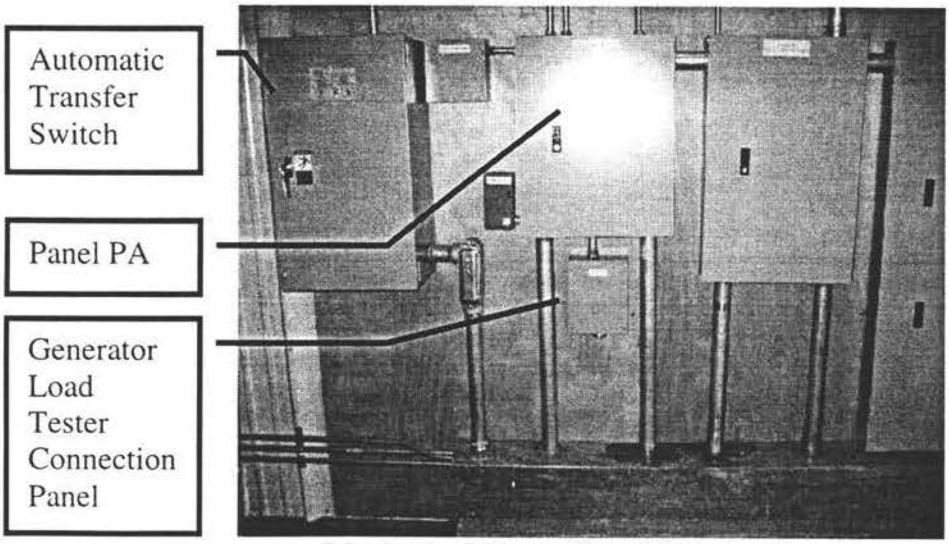
Fuel Supply Tanks



Fuel Source Control Panel



Generator Load Tester



Mechanical Room Circuit Breaker Panels

Inspecting these pieces of equipment beforehand will make them much easier to locate and work with when operating them for the first time.

Startup Preparation

Note: In cold weather conditions, below 0°C, it will be necessary to turn on the outside heating tape at least six hours before operating the engine on the biodiesel fuel supply. In these weather conditions, turning the outside heating tape on the night before is recommended.

Equipment needed

- Flat blade screwdriver

Procedure

1. At the fuel source control panel, switch ON the outside heating tape. This must be done at least one hour before generator operation on biodiesel fuel. Colder weather will require a longer warm-up period.
2. Fifteen minutes prior to starting the generator, switch ON the biodiesel recirculation pump.
3. Position the generator load tester near the load tester connection panel as shown in Figure 1.

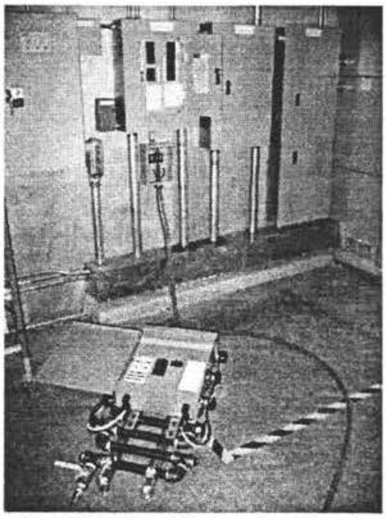


Figure 1: Positioning the generator load tester.

4. Connect a water supply hose from the wall faucet to the load testers water inlet.
5. Connect a second hose to the load tester's water exit.
6. Position the other end of the load tester exit hose down the floor drain.
7. Fully open the load tester cooling water exit valve.
8. Fully open the wall faucet water supply and observe that water exits the drain hose into the floor drain properly.
9. Close the load tester cooling water exit valve, while leaving the wall water supply on, and check for any leaks. If any water leaks are observed they must be corrected and dried before proceeding.
10. Open circuit breaker panel PA and ensure that the 60 A. generator load tester breaker is switched OFF. Follow BECON's lockout procedure to lock this circuit breaker off before proceeding.
11. Open the generator load tester connection panel using a flat blade screwdriver as shown in Figure 2.

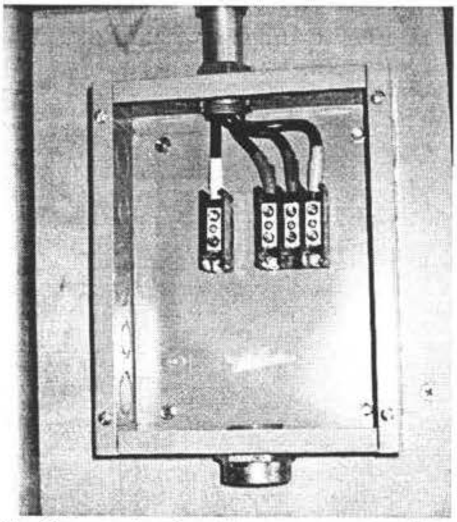


Figure 2: Generator load tester connection panel.

12. Connect the four color-coded power leads of the generator load tester to their respective color-coded terminals as shown in Figure 3.

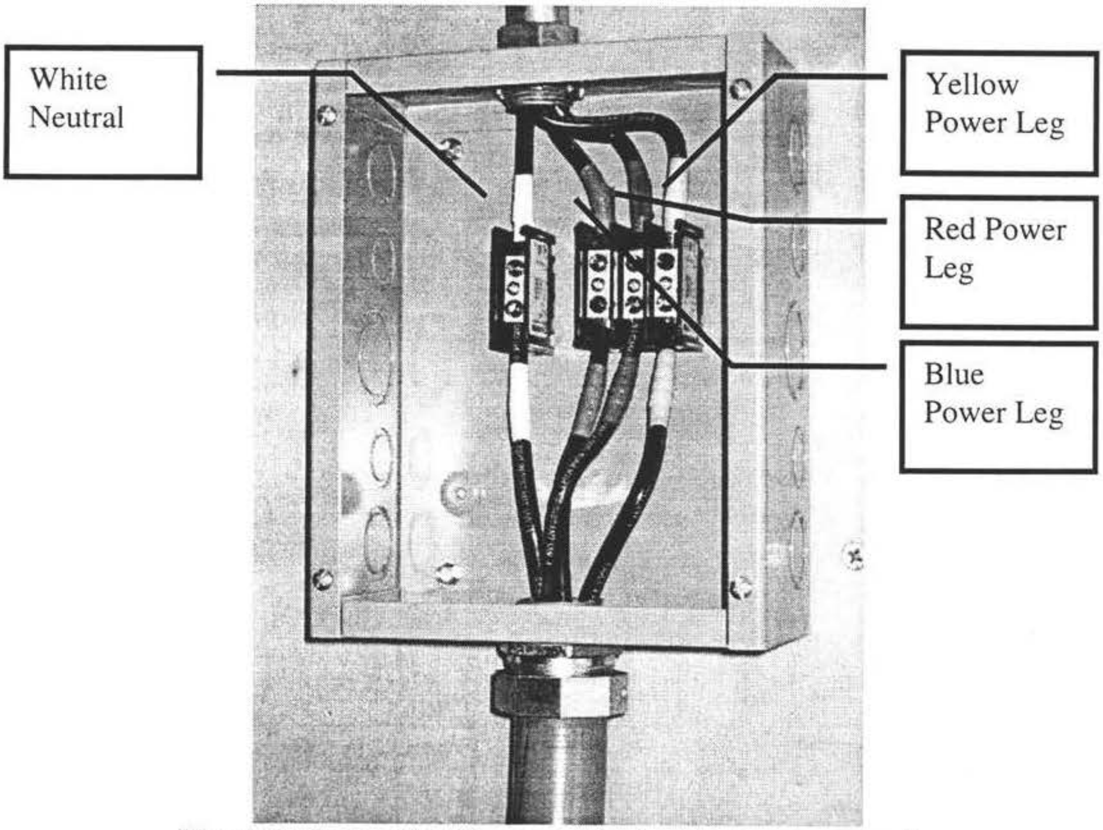


Figure 3: Connecting the generator load tester power leads.

Note: It is critical that the color-coded leads be properly matched. The white lead is neutral and must not be accidentally connected to the blue, red, or yellow power leads.

13. Check that each power lead has been securely tightened.
14. Tighten the large LiquidTight flexible conduit nut onto the generator load tester connection panel nipple.
15. Replace the cover on the generator load tester connection panel.

16. Switch all circuits on the generator load tester to OFF.
17. Fully open the generator load tester water exit valve and confirm that water is properly exiting into the floor drain.
18. Remove the safety lockout from the 60 A. generator load tester circuit breaker in panel PA and switch this breaker ON.
19. On the PC next to the fuel source control panel, launch the GenAccess software by clicking Start / Programs / GenAccess / GenAccess.
20. Once the software loads, select Connect from the File menu in the upper left window corner.
21. When prompted for an Access Password, enter the following password: 9999. Note: Do not attempt to change the password from 9999 to anything else. This password must be the same as the password configured in the generator. The generator password cannot be changed and any change in the software password will make generator communication impossible.
22. Select View DCP from the File menu.
23. When prompted for a Unit Number / DCP address, enter 1.
24. Select Engine Information from the Window menu to view bring up the current engine operating information.

Startup

Procedure

1. Switch OFF the biodiesel recirculation pump on the fuel source control panel.
2. Switch ON the diesel fuel source switch.
3. Unlock and open the generator control panel access door.

Note: The following step, 35, will actually start the generator's diesel engine. Make sure all operators and spectators are clear of the engine.

4. Rotate the START / OFF / AUTOMATIC switch counter clockwise to START as shown in Figure 4.

Start / OFF / Automatic

Figure 4: Starting the Generator.

5. Once the engine has started, the engine and electrical generator can be monitored from inside using the GenAccess software.

Note: Should the engine fail to start, refer to the Known Problems section at the end of this manual.

Generating Electricity

Procedure

1. From the GenAccess Window menu, select Generator Information as shown in Figure 5.

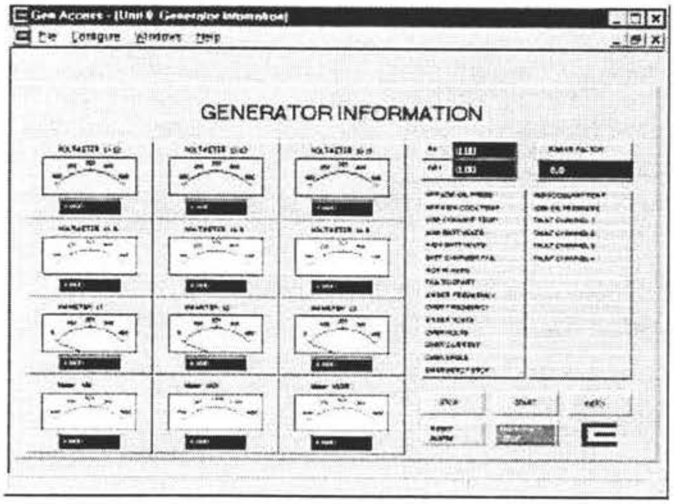


Figure 5: Generator Information Window.

Note: The Generator Information Window will allow monitoring of the generators electrical output, voltage and amperage on each of the three phases, and total power output. All of these values will be zero before completing the next step and putting an electrical load on the generator.

2. At the Automatic Load Transfer panel, turn the source select switch from Grid / Automatic to Generator.

Note: The high bay lights, office room outlets, and exterior wall outlets are normally connected to the generator circuit. Transferring the electrical load to the generator will cause a brief disturbance in these circuits. Please advise other workers as to the potential momentary disturbance on these circuits. Transferring this load to the generator will cause the high bay lights to shut off, warm back up, and then turn on within one to three minutes.

3. Observe the total power generated as well as the amperage load on each of the three phases. These readings represent the real time electrical load on the generator.

Changing the Electrical Load

Procedure

1. Observe which leg of the three phases is drawing the least current.
2. At the generator load tester, switch ON the corresponding circuit breaker. Example: If leg 1 had the lowest current draw, turn on circuit breaker #1. If leg 2 had the lowest current draw, turn on circuit breaker #2.

Note: The generator load tester circuit breakers are on the following power legs of the generator

- Leg 1: Circuit breakers 1, 4, 7
- Leg 2: Circuit breakers 2, 5, 8
- Leg 3: Circuit breakers 3, 6

3. Observe the new amperage and total power levels displayed in the GenAccess Generator Information window.

   Note: The generator is rated for 40kWe maximum output at 480V and 60Amps. Do not at any time exceed 40kW total generated power. Do not at any time exceed 60 amps on any single leg. Attempt to keep all three power legs equally loaded.

4. Observe which leg of the three phases is drawing the greatest current.
5. At the generator load tester, switch OFF the corresponding circuit breaker.
6. Observe the new amperage and total power levels displayed in the GenAccess Generator Information window. By turning generator load tester circuit breakers On and OFF, the total electrical load placed on the generator can be increased or decreased.

Switching Fuel Sources

To fuel from biodiesel:

1. Turn all generator load tester circuit breakers OFF.
2. Confirm the amperage and total power levels displayed in the GenAccess Generator Information window show only the building light and outlet loads.
3. Switch OFF the diesel fuel source switch on the fuel source control panel.
4. Switch ON the biodiesel recirculation pump.
5. Switch ON the biodiesel fuel source.

   Note: It will take several minutes for the Biodiesel fuel to purge out all of the diesel fuel from the engines filter, pump, and supply lines.
6. Once the engine is running on the new fuel source, return the generator load tester to the desired load level.

To fuel from the sample line:

1. Connect sample fuel source to generator sample line.
2. Turn all generator load tester circuit breakers OFF.
3. Turn the automatic transfer switch source select knob to Grid / Automatic.
4. Confirm the amperage and total power levels displayed in the GenAccess Generator Information window are at zero.
5. Switch OFF the diesel fuel source switch on the fuel source control panel.
6. Switch OFF the biodiesel recirculation pump.
7. Switch OFF the biodiesel fuel source.
8. Switch ON the sample fuel source.

Note: The engine may run roughly while the fuel pump purges air from the sample line. Manually purging this air in advance with a hand pump, siphon, or other means will reduce or eliminate any temporary poor engine performance. Do not reapply load to the generator until the engine is running smoothly.

9. Once the engine is running smoothly on the new fuel source, turn the automatic-transfer switch source-select knob to Generator.
10. Return the generator load tester to the desired load level.

Shutdown

Equipment needed

- Flat blade screwdriver

Procedure

1. Switch fuel source to diesel as outlined in Switching Fuel Sources.
2. On the fuel source control panel flow meter, note the total gallons of fuel delivered to the engine.
3. Continue to run the generator until the flow meter shows at least one additional gallon of fuel from the diesel fuel supply has been delivered to the engine.
4. Switch OFF all circuit breakers on the generator load tester.
5. Switch OFF the 60 A generator load tester circuit breaker in panel PA.
6. Turn the automatic transfer switch source select knob to Grid / Automatic.

Note: The following step, 7, will actually stop the generator's engine.

7. Turn the Start / OFF / Automatic switch to OFF on the generator control panel.
8. Close and lock the generator control panel access door.
9. Switch OFF the diesel fuel source switch on the fuel source control panel.
10. Switch OFF the outside heat tape switch on the fuel source control panel.
11. Turn off the wall faucet water supply to the generator load tester.
12. Lock out the 60 A generator load tester circuit breaker in panel PA following BECON's lockout procedure.
13. Open the generator load tester connection panel using the flat blade screwdriver.

14. Disconnect the four color coded generator load tester power leads from their respective lugs.
15. Loosen and remove the large LiquidTight flexible conduit nut.
16. Replace the cover on the generator load tester connection panel.
17. Remove the lockout device from the PA circuit breaker cabinet.
18. Disconnect the two hoses from the generator load tester and drain any water out of them.
19. Drain any water out of the generator load tester.
20. Coil and store the hoses along with the generator load tester.

Known Problems

Note: The generator level 1 password is: 1111

The generator level 2 password is: 2222

The generator communications password is: 9999

Do not attempt to change any of these passwords.

GenAccess Software

- Computer lockup during operation
    - No known solution.
    - Lockups are reduced, but not eliminated, by not running any other applications simultaneously.
    - Lockups do not affect the performance or operation of the generator, only the ability to monitor it.
    - Expect lockups to occur and save often.
    - Shut down and reboot the computer as needed.
- Cannot change communications password on generator control panel
    - No known solution
    - The password is: 9999
    - Use the same password, 9999, in the GenAccess software.
- Cannot change GenAccess password after new software installation
    - The GenAccess password is changed under the Configuration-Password menu.
    - The default password is 4001
    - When prompted for this password, do NOT click in the text entry box.

  - When typing the password, 4001, character markers will not appear in the text field however the password will be properly entered and accepted.
  - The password MUST be changed to 9999 in order to communicate with the generator.
- GenAccess starts, but cannot communicate with the generator
  - Verify the GenAccess password is: 9999, in the Configuration-Password menu.
  - Verify that GenAccess and the generator are set to the same 9600 baud rate in the Configuration-Network menu.

Generator

- Generator will not start
  - Verify generator fuel supply is switched on and fuel is present.
  - Verify electrical leads to engine fuel pump are not loose. See Figure 6.

Figure 6 Generator Engine Fuel Pump Electrical Leads

  - Loosen all four injector supply lines at the injectors and crank the engine to purge air from the system. If these lines spray fuel while cranking, air in the fuel system is not a problem. Retighten supply lines when finished. See Figure 7.

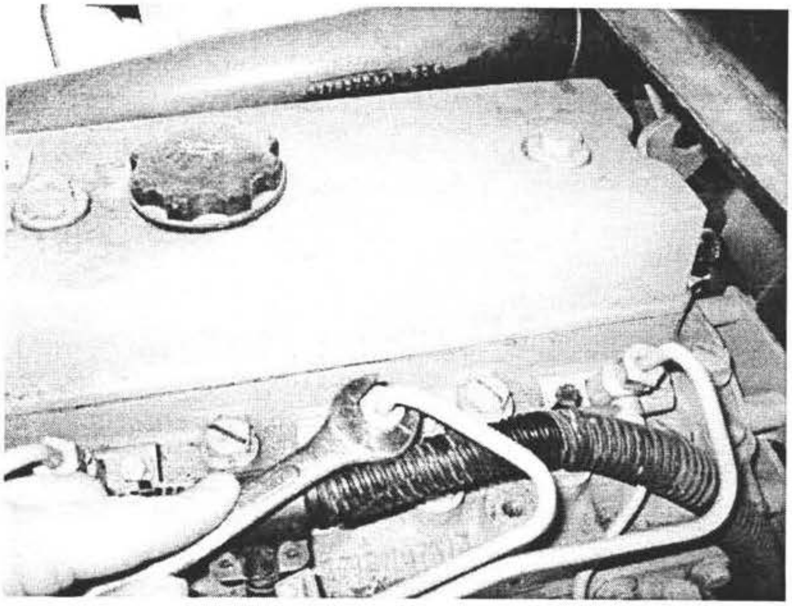


Figure 7 Diesel Engine Fuel Injector Supply Lines

- Generator shuts down due to "Over Temperature" error, despite low or normal temperatures
  - Verify the radiator level is full.
  - The low coolant level sensor shares the same error code as the over temperature sensor. The coolant level must be kept very full for proper operation.

REFERENCES

1. Graboski, M. S. and McCormick R.L. Combustion of Fat and Vegetable Oil Derived Fuels in Diesel Engines. Prog. Energy Comust. Sci. 24, 1998 125-164.
2. Zhang, Y. Emissions and Combustion of Fatty Acid Esters of Soybean Oil in a diesel Engine. M. S. Thesis, Iowa State University, 1994.
3. Chang, D. Y. Z. and J. H. Van Gerpen Fuel Properties and Engine Performance for Biodiesel Prepared from Modified Feedstocks. SAE Paper 971684, 1997.
4. Schmidt, K. and J. H. Van Gerpen The Effect of Biodiesel Fuel Composition on Diesel Combustion and Emissions. SAE Paper 961086, 1996.
5. Zhang, Y. and J. H. Van Gerpen Combustion Analysis of Esters of Soybean Oil in a Diesel Engine. SAE Paper 960765, 1996.
6. Canakci, M. Production of Biodiesel from feedstocks with high free fatty acids and its effect on diesel engine performance and emissions. Ph.D. Dissertation, Iowa State University, 2001 126-133.
7. Hill, J. W. Chemistry for Changing Times. Macmillan Publishing Company, New York, 1992.
8. O'Leary, M. H. Contemporary Organic Chemistry. McGraw-Hill Book Company, New Your, NY, 1978.
9. Ryan, T. W., Callahan, T.J. and Dodge, L.G. Characterization of Vegetable Oils for Use as Fuels in Diesel Engines. Vegetable Oil Fuels-Proceedings of the International Conference on Plant and Vegetable Oils as Fuels, Aug., 1982, 70-81.

10. Fort, E. F. and Blumberg, P. N. Performance and Durability of a Turbocharged Diesel Fueled with Cottonseed Oil Blends. Vegetable Oil Fuels-Proceedings of the International Conference on Plant and Vegetable Oils as Fuels, Aug., 1982, 374-382.

11. Walter, J., Aakre, P. and Derr, J. The 1981 "Flower Power" Field Testing Program. Vegetable Oil Fuels-Proceedings of the International Conference on Plant and Vegetable Oils as Fuels, Aug., 1982, 384-393.

12. Varde, K. S. Some Correlation of Diesel Engine Performance with Injection Characteristics Using Vegetable Oil As Fuel. Vegetable Oil Fuels-Proceedings of the International Conference on Plant and Vegetable Oils as Fuels, Aug., 1982, 303-311.

13. Radu, R. and Mircea, Z. The Use of Sunflower Oil in Diesel Engines. SAE Paper 972979, 1997.

14. Ferguson, C. R. Internal Combustion Engines. John Wiley & Sons, Inc., New York, 1986.

15. American Society of Testing and Materials ASTM D 6751. National Biodiesel Board, [online] December 2001, http://www.biodiesel.org/pdf_files/BDSpec.PDF (Accessed June 8 2003).

16. Insta-Pro Model 600 Extruder Manual. Insta-Pro International, Des Moines, IA, 1998.

17. Formo, M. W. Ester Reactions of Fatty Materials. JAOCS, Vol. 31, 1954, 548.

18. Gauglitz, E. J., and L. W. Lehman The Preparation of Alkyl Esters from Highly Unsaturated Triglycerides. JAOCS, Vol. 40, 1963, 197.

19. Canakci, M. Production of Biodiesel from feedstocks with high free fatty acids and its effect on diesel engine performance and emissions. Ph.D. Dissertation, Iowa State University, 2001.

20. Tat, M. Temperature Dependent Physical Properties of Biodiesel and its Blends with Diesel Fuel. M.S. Thesis, Iowa State University, 1998.

21. Monyem, A. The Effect of Biodiesel Oxidation on Engine Performance and Emissions. Ph.D. Dissertation, Iowa State University, 1998.

22. McDonald, J. F., Purcell, D. L., McClure, B. T., Kittelson, D. B. Emission Characteristics of Soy Methyl Ester Fuels in an IDI Compression Ignition Engine. SAE Paper 950400, 1995.

23. Last, R. J., Kruger, J., Durnholz, M. Emissions and Performance Characteristics of a 4-Stroke, Direct Injected Diesel Engine Fueled with Blends of Biodiesel and Low Sulfur Diesel Fuel. SAE Paper 950054, 1995.

24. Graboski, M. S., Ross, J. D., McCormic, R. L. Transient Emissions from No. 2 Diesel and Biodiesel Blends in a DDC Series 60 Engine. SAE Paper 961166, 1996.

25. Heisler, H. Advanced Engine Technology. Society of Automotive Engineers, Inc., Warrendal, PA, 1995.

ACKNOWLEDGMENTS

I would like to thank my major professor, Dr. Jon H. Van Gerpen, for sharing his knowledge and expertise in the biodiesel field. I would also like to thank him for all of his help and encouragement when I needed it most as well as for providing me with this opportunity to further my education. I would like to thank the members of my committee, Dr. Kenneth Bryden and Dr. Brent H. Shanks.

I would like to express my thanks to my colleagues, Kirk Menges, Paul Wang, Ben Collogan, Phil Soash, and Nate Johnson, for their help and assistance in all of my efforts.

I would especially like to thank my parents for all of their love and support. Without their motivation, I would never have come this far in life.