Biodiesel Processor Automation

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Abstract

An automated benchtop biodiesel processor was developed to simulate the operation of a processor and to implement a data acquisition and process automation approach.

1- Introduction

This project is to study the design and implementation of an automated biodiesel processor. A non-automated processor requires many man-hours for operation. An automation system can assist in adding further safety precautions while also reducing man hour time for processing. Automating the processor involves refining the processor design to make the operation more suitable for automation. The actual automation system has been studied using LabView software and a USB-NIDAQ (National Instruments Data Acquisition) interface. This arrangement is most suitable for a research environment to be used while changes in the process are being made. Based on this control system, a Programmable Logic Control (PLC) system can be developed for use with MBP's processors for customers. The PLC based systems are unique systems designed for continuous use in an industrial environment.

2- Project Goals/Objectives

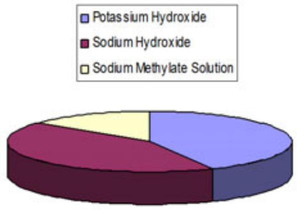
The goals of the project were to build a benchtop automated system that will simulate an existing processor design with modifications necessary to make it run by computer control. And to have the processor adaptable to test alternative and novel processing techniques in the lab on the benchtop scale. This project work includes design and assembly of an automated Biodiesel processing system. The automation is done using of a PC integrated data acquisition hardware and Labview software to monitor and control the operation.

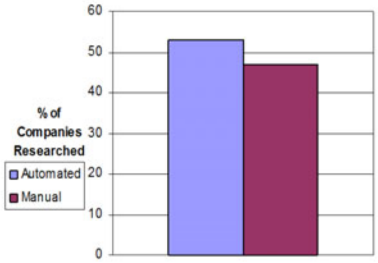
3- Methodology/Approach

The project started with a background research on manual and automated processors. Then an analysis was made of a manually operated processor design. Consideration was made for the aspects of the process that were easily adapted to automation equipment, such as replacing manual valves with solenoid actuated valves. Other parts of the design required modification of the existing system to be adaptable for automation hardware, such as the means of catalyst mixing. A flowsheet of the processor was generated detailing system design changes to accommodate automation technology. A benchtop prototype was developed. This required a chemical compatibility study. The introduction and implementation of computer control required a review of automation hardware and software. The prototype is useful in simulating a full scale automated system and in testing new processing technologies.

4- Background Research

It was important to learn the current industry practices of biodiesel production. Several organizations were contacted to find out their general processing methods including; feedstock requirements, reactor size, catalyst used, and whether the system was automated. Naturally some companies are reluctant to share information that they consider proprietary technology. The figures below show the results of our survey. The graph of percent of automated processors suggests that the industry is still maturing and there is a need for improvement in automation technology.





5- Chemical Compatibility

System design began with chemical compatibility research. Compatibility issues are severe in biodiesel processing. The oil and alcohol reactants are both very strong solvents, particularly the alcohol. The solvent nature of the reactants greatly limited the choices of acceptable polymers. In addition to the reactants, the finished product biodiesel also has the tendency to degrade many polymers. Furthermore, the strong alkaline catalyst is very reactive with many material options.

6- Preliminary System Design

The flowsheet of the design of the prototype processor system flow sheet is shown in figure 1. The final system apparatus is shown in the picture in figure 2.

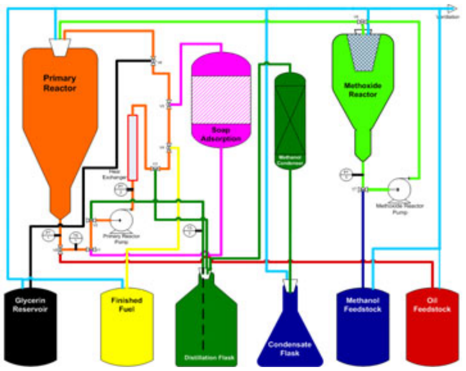


Fig 1; Prototype Automated Biodiesel Processor Flow Sheet

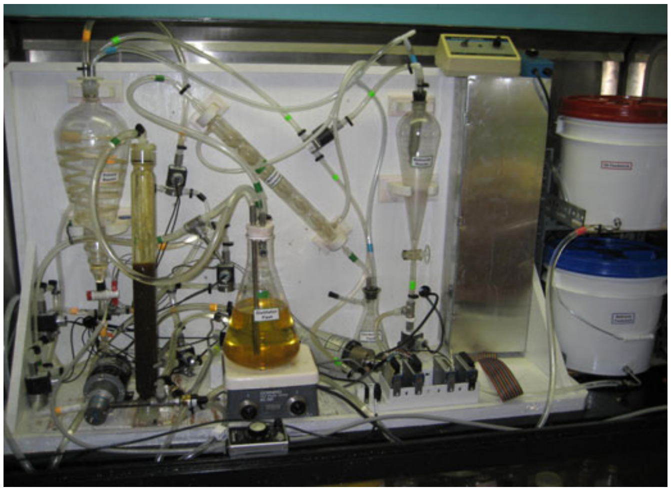


Fig 2; Prototype Automated Biodiesel Processor System

The steps in the process:

1. Oil Feed from the oil feedstock to the primary reactor by primary reactor pump.
2. Potassium Hydroxide manual addition
3. Methanol Addition from the methanol feedstock to the methoxide reactor by the methoxide reactor pump.
4. Methanol Circulation: Methanol and potassium hydroxide react and circulated.
5. Methoxide Transfer to the primary reactor to be mixed with the oil.
6. Oil and Methoxide Circulation by the primary pump. Glycerin and biodiesel are formed.
7. Drain Glycerin: Since glycerin is denser than biodiesel, it settles at the bottom of the primary reactor. Valve is opened and gravity drained glycerin into the glycerin reservoir.
8. Biodiesel Transfer to the distillation flask by the primary reactor pump.
9. Distillation and Condensation: Biodiesel is circulated with primary reactor pump and distillated to remove methanol.
10. Soap Adsorption &fatty acid removal in the soap adsorption unit
11. Finished Biodiesel Product is stored into the finished fuel tank.

The system design features two reaction vessels, a methoxide reactor and a primary reactor. Each is constructed of a Pyrex separatory funnel. The feedstock and finished product reservoirs are pails with re-sealable lids and fitted with drain ports on the bottom. The distillation flask is

Pyrex. A glass condenser column and small flask are used in the methanol recovery procedure. Two laboratory positive displacement pumps with magnetic drives are used. All of the flow streams are controlled by three way stainless steel solenoid valves. Clear tubing was used so that the process operation could be observed.

The valves are all controlled by mechanical relays and the pumps by solid state relays. Thermocouples are inline to read the temperature of the primary flow loop as well as the distillation loop. Pressure transducers are placed at the bottom of the primary reactor and the methoxide reactor vessels. These are calibrated to display the liquid level height in the vessels. The computer is interfaced with a National Instruments (NI) CompactDAQ 9172. The DAQ is outfitted with a 32 channel digital sourcing module NI9476, a 4 channel analogue input module NI9215 and a 4 channel thermocouple module with built in signal conditioning NI9211. The process control algorithm is written in NI Labview software.

7- System Design Considerations

The UNH prototype was built to use pumps as the method of mixing, instead of a stirrer mixer mounted through the tank with a mechanical seal. Mechanical seals are prone to leakage, which is particularly undesirable where volatile vapors are present as in biodiesel processing. The pump mixing system helps to improve overall safety of the processor.

Vent tubing is connected to all of the vessels such that the processor is a closed system other than the vent outlets. The vent tubing prevents siphoning and ensures no over pressuring. All stages of the system are operated at atmospheric pressure. For additional safety measures, the prototype processor is designed and built to fit inside the enclosure of a laboratory fume hood.

Pumps are expensive. The processor uses just two pumps for the whole system to minimize pumping capital costs. In order for two pumps to serve all of the mixing and fluid transfer purposes of the system, three way valves are used to direct piping streams. The system is designed to take advantage of gravity draining where possible.

The tubing diameter is chosen to slip over the glassware fitting ends. The pumping speed is designed to match the flow regime of the tubing. The fluid viscosity of oil is much greater than water and will of course affect the pumping rate. Once the oil is warmed and when reacted, the viscosity will drop and pumping performance improves. Valve options with the largest possible valve coefficient (Cv) values are specified. The three way valves used have a Cv of 0.17.

The primary reactor system is fitted with a heat cord apparatus fastened around the primary reactor to heat the oil and reaction mixture. The heat output of the heater therefore has to be limited in order to not fatigue the plastic fittings.

The methanol is reacted with catalyst to form methoxide solution. The alkaline catalyst used is potassium hydroxide (KOH) or sodium hydroxide (NaOH). Both catalysts come in crystalline flake form. The flakes dissolve in methanol solution and react to form methoxide. The methanol pump will not tolerate particulate through the impeller. To use the pump to mix the solution and dissolve the catalyst flakes, a screen catalyst trap is used at the top of the methoxide reactor. The methanol solution is pumped from the bottom of the methoxide reactor and into the top of the reactor. The catalyst trap is fitted to the end of the inlet tubing at the top of the reactor. The methanol flows through the trap, dissolving the catalyst while preventing any larger catalyst particulate from getting to the pump.

7- Automation Hardware

The sensing hardware are pressure sensors and thermocouples. The pressure sensors fitted to the bottom of the vessels are calibrated to display the fluid level in the vessels. To get an accurate pressure measurement, the system had to be both clear of bubbles and not circulating. The thermocouples used are type J thermocouples with a grounded pipe plug probe.

All of the valves are controlled by a Metrabyte mechanical relay board, with 24 relays. The relay board accepts digital 5 volt DC inputs from the DAQ and turns 120 volt AC power. The pumps and heater are controlled by solid state relays (SSRs). The SSRs switch 120 volt AC power with a 5 volt DC input. The advantage of SSRs is that they exhibit bounce-less operation which can be a concern when switch high power loads such as motor starters. The SSRs also features a larger heat sink for higher current load applications such as a heater. The variables measured, sensor and their use are indicated in the table below.

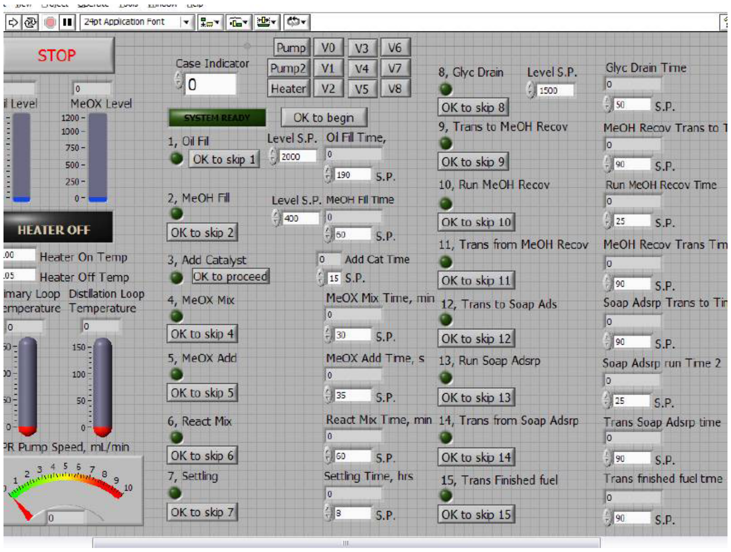
Variable Measured	How	Purpose/use
Pressure at bottom of reactor vessel	**Pressure transducer**	**Get/Display liquid level in tank Determine oil filling/product draining quantities Determine when Glycerin has been drained**
Pressure at bottom of Methoxide Tank	**Pressure transducer**	**Get/Display liquid level in tank Get methanol filling/ methoxide draining quantities**
Temperature..	**Type J thermocouple**	**- Read temperature measurement through DAQ in Labview**
Pump flow	**Pressure transducer**	**- Read Pressure head through DAQ in Labview - Calibrate program to show flow rate**

The Parameters controlled and the functions in the processing are indicated in the tables below.

Parameter Controlled	How/Purpose
Reactor filling and draining period	**The liquid level (or liquid volume) in the tank, as measured by the pressure transducer.**
Methanol filling and draining period	**The liquid level (or liquid volume) in the tank, as measured by the pressure transducer.**
Mixing times	**Dissolving/reacting/soap and methanol removal, as measured by labview timer.**
Temperature	**Reaction temperature and methanol removal temperature.**

7- Automation Software

Control logic is performed in PC software Labview. The computer is interfaced with the hardware components by the USB DAQ and modules. Labview was used to develop the automation program (see picture of front panel). Labview reads analogue voltage signals from the pressure sensors and thermocouples modules. The outputs are to a 32 channel sourcing module linked with the relay board. The Labview program continually monitors pressure, temperature and time; in addition to responding to user inputs.



8- Challenges /Difficulties

One of the most significant challenges of the project was to find appropriate materials that are compatible with the aggressive nature of the chemicals being used. For observational purposes the system was to have clear tubing that is also flexible to be easily fitted to laboratory glassware. The tubing also had to be able to withstand high temperatures encountered in the reacting and in particular the methanol recovery stages. After extensive research a Tygon formulation was decided on, based on the manufacturer's recommendations. However, in experimentation the tubing did not perform adequately. The solvent nature of the biodiesel, in combination with the concentrated alcohol and extremely alkaline catalyst, fatigued the tubing over time and developed leaks at the fittings. A future design should use a thicker walled tubing and if possible more chemical resistant polymer. The pressure sensors used are an expensive component. Much research was done to find sensors that could operate with the desired sensitivity at a reasonable price. Sensors that were made from chemical resistant materials such as stainless steel were overly expensive. Brass sensors were purchased and installed with oil filled tubing traps to isolate the sensors from the alkaline catalyst. All other components of the system were made of Pyrex glass, stainless steel or high density polyethylene.

Measurement sensitivity was a significant challenge for the pressure sensors. These are expensive and the price increases exponentially with the degree of sensitivity of the sensor. Pressure sensors for the processor are used to measure the height of fluid in the vessels. The sensors were calibrated in Labview to return the volume of fluid filling each vessel with±10mL. The operation of the sensors was sometimes erratic. In order for the sensor to give an accurate reading the fluid in the vessel had to be both stagnant and the lines containing the pressure sensor free of air bubbles.

Fluid resistances of the plumbing system caused significant back pressure on the pump and a slower than desired pumping rate. The achieved flow rate was about 70% of the desired flow rate. To compensate the reaction fluid was circulated for a longer period of time.

The Amberlite adsorbent used is a small particle polymer resin, and was placed in a fluidized bed. The bed had to accommodate the low fluidization velocity of the particles.

9- Results

A benchtop prototype automated system has been designed and built. It simulates typical industrial scale processing system, with automation. An automation loop is implemented using Labview and National Instruments hardware to control the core operations of the processor. The results of the system lay the ground work for design of an automated industrial scale processor.

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