Solar Thermal Energy for Biodiesel Process Heating

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ABSTRACT

A parabolic trough solar concentrator has been designed and tested in an attempt to offset the electric heating requirements associated with a commercial small scale biodiesel processor. The system design consisted of a parabolic trough with and area of 2.18 square meters and a 24 gallon batch biodiesel processing system. The processor was designed for processing temperatures in the range of 54-60 deg. C (129-140 deg. F). The internal system heater was removed from the processing system and replaced with a parabolic trough solar collector for process heating. The purpose of this study was to successfully produce biodiesel using concentrated solar energy as the primary source of process heat without the use of a heat exchanger.

An important cost associated with this method of biodiesel production is the use of electricity for process heating. It has been argued that using alternative energy for biodiesel production can reduce much of the electricity costs associated with process heat. Current system designs incorporate the use of solar collectors which follow designs similar to those used for electricity production. In most applications a heat transfer fluid is passed through a collector to absorb heat provided by concentrating solar radiation. These current designs rely on the use of a secondary heat exchanger as a method of heat transfer. Efficiency of a heat transfer system is reduced through the heat exchanger. This study has been conducted to provide concentrated solar heat without the use of a secondary heat exchanger to reduce energy losses during the process. This study has shown that inline process heat for a biodiesel production process can be offset by the use of a parabolic trough without the use of a heat exchanger.

1. INTRODUCTION

Research has been conducted to study the use of concentrated solar energy to meet the heating energy requirements for a small (24-50 gallon) batch biodiesel production system. Prior research has stated "total energy consumption in the production of the biodiesel fuel could be reduced by exclusively using renewable energy sources for the production of ester" [1]. Major materials for the project included an off-the-shelf batch biodiesel production system, parabolic trough, and instrumentation to conduct measurements for ac power, solar radiation, and fluid process temperature. The biodiesel was produced using waste vegetable oil (WVO) from a constant source restaurant, methanol as a reactant, and potassium hydroxide as a catalyst for the transesterification process. Testing was conducted by Donny Cagle, Research Technician for the Alternative Energy Institute/West Texas A&M University, Canyon, Texas at the facilities of the United States Department of Agriculture, Agricultural Research Service in Bushland, Texas. Testing took place during the spring of 2009.

2. Experimental Procedure

2.1 Overview

A 24 gallon, batch biodiesel production processor was utilized for the transesterification processing of waste soybean vegetable oil using utility electricity as a baseline. The chemicals used for the process included methanol, potassium hydroxide. True power and oil temperature were monitored during the heating and drying stages of the process. After collecting power and temperature data, the transesterification process was repeated using solar energy as the heat source. A parabolic trough was designed to replace the electrical heating element for process heat. Oil Temperature and solar radiation were measured to calculate the energy transfer using the trough. Due to uncertain values for specific heat of the feed stock, as well as washed and unwashed biodiesel, efficiencies were found for heating water as well.

2.2 Trough Design

A parabolic trough was designed to match the heating requirements of the process with respect to power. The equation used for constructing the final parabola of the trough was of the form:

$$Y = \frac{x^2}{4P} \quad \text{Equation 1.}$$

where P is the focal point of the parabola. Y coordinates where calculated for X in the range of -20 inches to + 20 inches and plotted in Excel for verification. **See Figure 1**. The resultant (X,Y) coordinates where then plotted in AutoCAD and transferred to a Torchmate© 2 program uses for controlling a CNC Plasma cutting table. A skeletal structure of the parabolic form was machined out of MDF board. The pieces were aligned and mounted in place using a separate sheet of MDF board, plywood, and all thread. The all thread served the purpose of spacing vertical alignment of the trough sections.
See Figure 2.

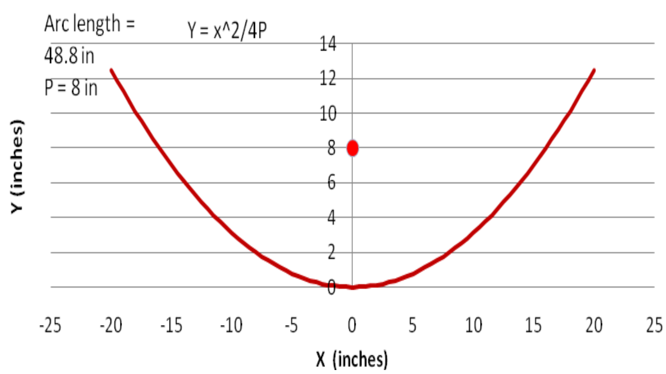

Fig 1 Plot of X and Y coordinates for parabola of the form Y = x^2/4P

Fig 2: Parabolic trough showing the final shape of the parabola, absorption tube, and rebar for alignment.

Formica was used as a backing material for the parabolic shape. A carnival mirror was used as the reflective material for the trough and was held in place using a spray mount adhesive. A steel pipe (1 in.) was used as the absorber tube. Valves, T-shaped pipe fittings, one flow meter and type-t thermocouples were placed at the ends of the absorber tube for flow rate control, circuit connection, flow rate and temperature measurement. The trough was painted with oil based paint and sealed with silicon for weather proofing. Adjustable legs were built to allow for manual pitch adjustment. **See Figure 3**. A picture of the final parabolic trough being used for inline process heat can be seen in **figure 4**.

Fig 3: Final Parabolic Trough

Fig 4: Parabolic trough being used for inline heat processing of biodiesel

2.3 Data Collection

Baseline data for temperature and power were taken by hand using a Northern Design Multicube©, two type-t thermocouples, one Apogee pyranometer, and one Hersey Flow Meter. Data was tabulated in Excel and plotted as Temperature versus sample number with respect to time. Temperature, flow rate, and solar radiation were collected as one minute averages. Manual samples were also monitored approximately once every ten minutes. Data, using the parabolic trough as the heat source for both heating and drying, was taken with a Campbell 3000 © data logger. Data was also taken for heating tap water, at 1 gallon per minute, with the parabolic trough to investigate the performance of the trough.

3. Results

The purpose of the project was not to investigate the process of producing biodiesel but to investigate the capability of offsetting electricity use by utilizing a renewable energy source to provide process heat to a system. The source of energy in this investigation was solar energy and was utilized by concentration. Data was collected for the biodiesel processor using electrical heating as the baseline and a parabolic trough for comparison. After analyzing the data collected, it became apparent that the key element for determining if the solar collector system would match the heating requirements set by the heating element was the rate at which the systems could heat the oil or biodiesel. In other terms the rate of change in temperature with respect to time is proportional to the energy provided to the system. This follows the equation of the form:

$Q = cm\Delta t$ Equation 2.

Where (Q) is the energy put into the system, (c) is the specific heat of the material being heated, and (Δt) is the change in temperature of the material. Only two tests were conducted using the trough for processing. The first test required heating the oil to a temperature between 120 and 140 deg. F. The latter was observed in this experiment. The second test required heating washed biodiesel, containing small amounts of residual water, to remove any water contained in the biodiesel after washing.

3.1 Heating Waste Vegetable Oil

A peak temperature of 140 degrees F was reached in this stage of the process however, the solar radiation varied throughout the time period for the first test. Reaction of the WVO with meth oxide occurred when the WVO temperature reached 130 to 140 deg. F. Manual readings were taken for this process due to incorrect wiring at the t-couple terminal block. Data taken for the second test was accomplished using the data logger at one minute averages for temperature and solar radiation. The variation of the solar radiation resulted in a smaller slope for heating the oil when compared to the electrical heating element. **See Figure 5**.

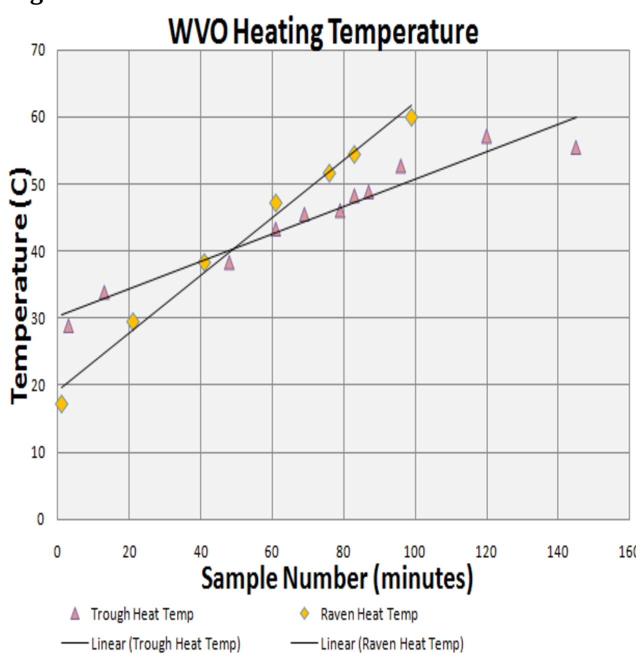

Fig 5: Plot of oil temperature versus time for parabolic trough versus electric heater element. Slope is smaller for trough due to cloud coverage.

At first glance it may seem as though the parabolic trough would not perform as well as the electrical heating element, however keep in mind the solar radiation varied in magnitude throughout the heating process due to cloud coverage. This mislead interpretation of the data became more apparent after analyzing the data collected for the second test. After the reaction was complete and all glycerin had been drained, the biodiesel received an initial rinse and a final aggressive wash. This was accomplished by blending 1part water to 5 parts biodiesel through the pump for 10 minutes and letting the water settle to the bottom of the reaction tank overnight.

3.2 Heating Washed Biodiesel

After settling and draining the wash water, the biodiesel had to be dried of any residual water still present in the biodiesel. This was accomplished by again heating the oil back up to 140 deg. F to evaporate the water. The heating times for this process for both the parabolic trough and the electrical heating element were very similar. The curves of temperature versus time are parallel in nature due to the starting temperature of the heating process as can be seen **Figure 6 and Figure 7.** The starting temperature of the biodiesel for the electrical heating element was lower than the starting temperature of the biodiesel for the parabolic trough. This was only due to the local climate on that day. When compared like this it can be seen that the parabolic trough almost matched the performance of the electrical heating element.

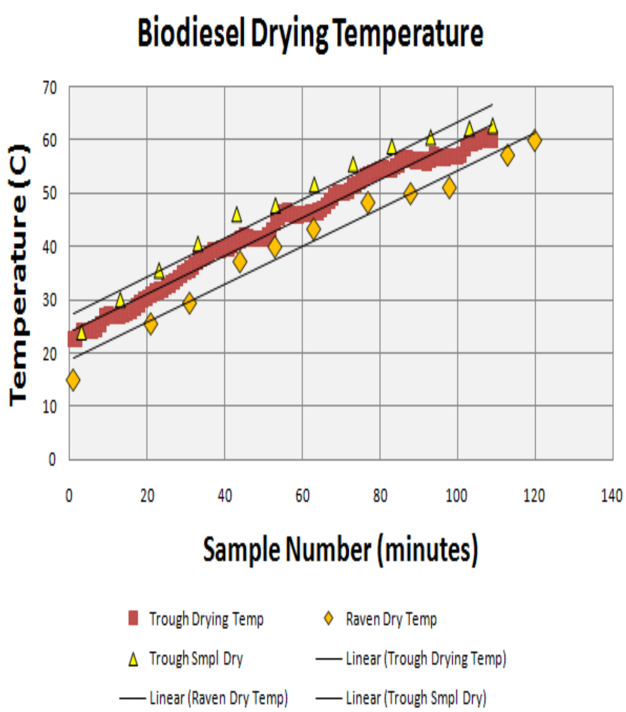

Fig 6: Plot of biodiesel drying temperature versus time for parabolic trough versus electric heater element. Slopes are alike indicating same heating characteristics.

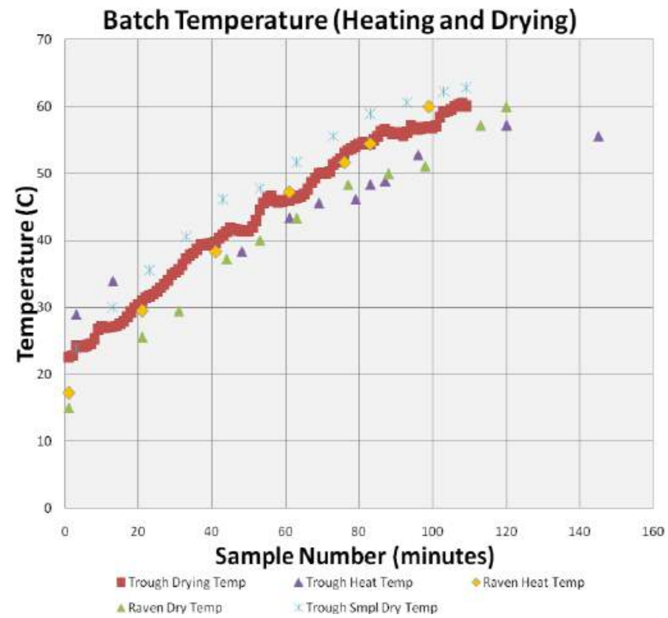

Fig 7: Plot of heating WVO and washed biodiesel using raven heater vs solar trough heat.

3.3 Trough Efficiency

An experiment for determining the efficiency of the parabolic trough was conducted. In this experiment, residential water was allowed to pass through the trough restricted to a flow rate of 1 gpm. Because the specific heat of water is known, the efficiency of the trough can be estimated using the energy formula of equation 2. The mass of the water is assumed to be the volume of water contained in the 1 inch pipe for the length of the trough mirror. A plot of the data is shown in **Figure 8.** The average efficiency of the trough was shown to 67 percent. Data was taken as one minute averages for 10 minutes. The middle eight minutes were used for the analysis. The efficiency ranged from 56 to 75 % efficiency.

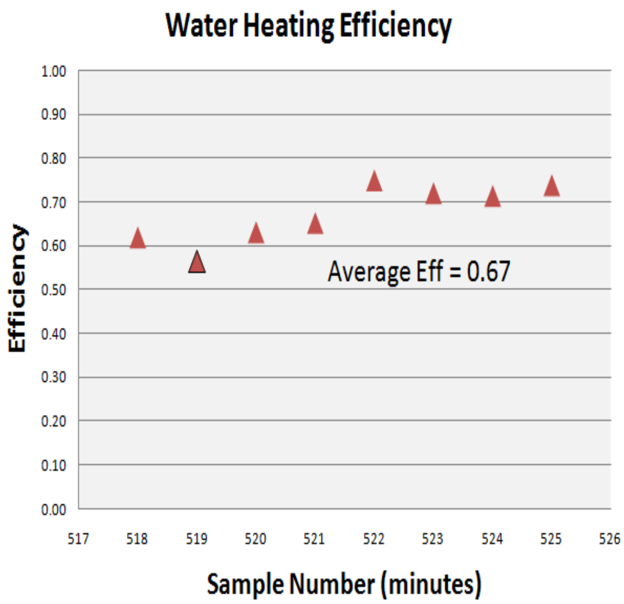

Fig 8: Efficiency of the parabolic trough while heating water. Flow rate = 1 gpm.

4. CONCLUSIONS

Based on the data collected and presented in this report, a parabolic trough solar concentrator provided enough energy to offset the energy requirements of an electric heating element. This would be the case for days throughout the year with low cloud coverage. Both the electric heating element and the parabolic trough showed to provide enough heat in similar amounts of time to complete the biodiesel production process of this study. It was determined that the slope of the curve for temperature versus time is a direct indicator of performance for the heating process. For a parabolic trough, the slope of the curve will be lower than that of the heating element, on a cloudy day but operating temperatures may be achievable if solar tracking is utilized. It should be noted the parabolic trough in this study was pointed directly at the sun and this relationship was maintained throughout the heating process. Efficiency of the parabolic trough in this study has been estimated to be within a range of 56-75% for heating water. Because of uncertain values for the specific heat of the WVO and washed biodiesel, efficiencies for this process were not given but estimates have been calculated. The system under investigation was not fully insulated therefore it is believed overall system efficiency could be improved by insulating the transfer lines to and from the parabolic trough. Further investigation of the system as it pertains to efficiency should be investigated with regards to specific heat values of the fluid being heated and how insulation of fluid lines will affect the overall performance.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

(1) Janulis, P., Reduction of energy consumption in biodiesel fuel life cycle. Renewable Energy, 29, 2004, pp 861-871