Biodiesel Production by Thermal Solar Heating in a Low Cost Plant Using Waste Cooking Oil

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Abstract—**Due to growing demand for fuel, for several goal, by the consumer market, the fatty acid alkyl esters appears as an alternative source to petroleum diesel, collaborating to the world energetic matrix and reduction of toxic gases in nature, enabling income to needy families on urban and rural areas. The most used chemical route to obtainment of this fuel is transesterification. In this, by the reaction of an alcohol with triglycerides present in vegetables oils, alkyl ester is produced. This paper proposes the utilization of low costs materials and technical application of temperature control in a laboratorial scale plant to alkyl esters production. The plant was composed by a stainless steel batch reactor, volumetric pump, solar thermosiphon system and temperature control system. The equipment proved to be feasible technically both in process temperature control as in the production of waste cooking at atmospheric pressure.**

Index Terms—**bio-fuel, low-cost, sun energy, ethyl ester**

I. Introduction

Simultaneously with the population and industrial growth, there is growing demand for energy. Currently, the power supply, derives in some cities, mainly from oil and coal. In large urban centers, diesel is used as fuel in power plants to produce electricity and in vehicles for cargo transportation [1]. Adding to this, due to lack of access to electricity in some communities, the use of diesel generators is common. This fuel is still used in equipment for planting, harvesting and transport of agricultural products. However, its use both in electricity production as for agricultural products, increases process costs due to the market value of oil and its burning corroborates to the emanation of polluting gases in nature [2].

Biodiesel is a bio-fuel, derived from biomass, such as ethanol, used as an alternative source to petroleum-based diesel, enabling cost reduction in fuel use and also reduction of pollutants in the environment, since the gases emitted in their use may return as energy source for plants, which are raw material for their production [3]. According to Kulkarni and Dalai *et al*. [4], among biofuels, biodiesel is an alternative source of energy, economically attractive, which can be produced using virgin vegetable oils or Wasted Cooking Oil (WCO) or animal fat. It is biodegradable, renewable, non-toxic, can be used to complement or replace the petroleum-based diesel and contribute to the reduction of pollution in the environment [5]. It may promote social inclusion through the use of oil crops produced by family farms or even through waste cooking oil cooperative collection, since in Brazil are recycled about 30 million of WCO to synthesize biodiesel, making this a potential feedstock

This bio-fuel can be obtained by transesterification reaction of triglycerides with an alcohol in the presence of a catalyst, resulting in ester and glycerol. In its synthesis, the control of process variables is required to maintain the process stable, ensuring product uniformity and favoring the increase of productivity, reduction of energy, while maintaining product quality [6]. Monitoring and control are generally done through a system containing electronic devices such as sensors, actuators and microcontroller. The Arduino is an electronic device, containing microcontroller, increasingly used in monitoring and process control systems due to its reliability and low cost [7]-[9].

Was applied a factorial design of experiments in order to study the interaction between the variables, using a smaller number of observations [10].

This paper proposes the use of low cost materials in the assembly, monitoring and control of a biodiesel production plant, through WCO, using ethyl alcohol and sun energy to heat the process reaction at atmospheric pressure.

II. Materials and Methods

A. Materials

The plant was assembled with a stainless steel jacketed batch reactor with 0.6-liter capacity, 0.91m^2 PVC roof sheet for thermosiphon, PVC hose, Styrofoam box 17L, windshield water pump, NTC 10K temperature sensor, Arduino UNO plaque, electric wires, power source of 110V and a chemical mixer. A schematic biodiesel plant, using low costs materials, is shown in Fig. 1. The WCO

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used in the experiments was collected from residences. Anhydrous ethyl alcohol (99,5%) was used in the reaction, NaOH as catalyst.

B. Methods

All transesterification reactions, for the production of Waste Cooking Oil Ethyl Esters (WCOEEs), were carried out in batch, employing WCO, with mechanical stirring at 300 rpm, under atmospheric pressure. All samples of WCO were filtered through filtration paper and silica-gel 60 mesh (10.0 g) to eliminate water and solid particles. Alkaline catalysis was adopted in these experiments due to lower reaction time and low temperature required for the conversion, as found in Froehner and Leithold [11] and ethanol was used due to be a less toxic and renewable fuel [12], [13]. The heating of water was carried out by a thermosiphon, and temperatures reaction was monitored by a NTC 10K temperature sensor. The Arduino controlled the water flow based on the comparison of temperature sensor information and set point temperature, enabling or disabling the water pump.

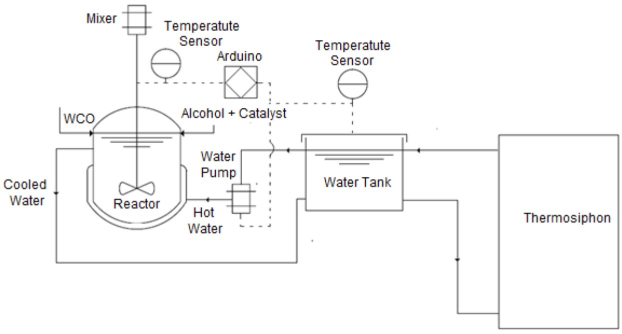


Figure 1. Schematic biodiesel plant.

C. Production o WCOEEs

For the transesterification reaction, the WCO was preheated at 35 ℃. To the WCO was added 80 ml of anhydrous ethanol (99.5%) premixed with 1.1 g of NaOH according to the methodology tested by Barbosa et al. (2013), maintaining a stoichiometric molar ratio oil/alcohol 1:6. Right after, were done experiments using samples of 200 mL of WCO, preheated to 35 ℃, and then added to WCO 120 ml of anhydrous ethanol (99.5%) previously mixed with 1.1 g of NaOH. All the experiments were repeated at 40 ℃. Then three experiments were performed using samples of 200 ml WCO preheated to 37.5 ℃, and then added to WCO 100 ml of anhydrous ethanol (99.5%) previously mixed with 1.1 g of NaOH, keeping a stoichiometric ratio oil/alcohol of 1:7.5, respectively. The experiments were performed during 1h, at atmospheric pressure, after the reagents being placed in the reactor and were carried out in duplicate for experimental error estimation.

D. Monitoring and Control

The process temperature was monitored by NTC 10K type temperature sensor in the reaction. Data acquisition and automatic temperature control was performed using Arduino, through the comparison of measured and desired temperatures, turning on/off the water pump. This, in turn, was withdrawing water from the reservoir, used in the jacketed reactor, warmed through the solar thermosiphon.

E. Biodiesel Post-Production Preparation

After the process of reaction, samples were placed in separatory funnel for decantation in a 24 hours period, allowing the separation of biodiesel produced from glycerol. Immediately after, the samples were preheated in laboratory, to a temperature between 50 - 60 ℃ and washed with a solution of 50 ml water, preheated to 60 ℃, containing 1 ml of phosphoric acid and then deposited in separatory funnel during 24 hours. After separation from water, the sample was heated to 105 ℃ for removal of excess moisture.

F. Characterization of Biodiesel Fuel

The samples of WCOEEs were characterized in the Technological Research Institute - TRI, Aracaju, Sergipe, SE, Brazil. The samples were tested to determine the biodiesel physical and chemical properties, according to American Society for Testing and Materials (ASTM), American Oil Chemists Society (AOCS) and Comité Européen de Normalisation (CEN). Table I summarizes the Standard Methods used, as well as the specification limits recommended by the regulation, and shows the results of analysis. The standard methods include physical and chemical parameters such as relative density (ASTM D4052), total acid number (AOCS Ca 5-40) and water content (EN ISO 12937). Also, total ester content (NBR 15764) was determined by Gas Chromatography Mass Spectrometer (GC/MS).

III. RESULTS

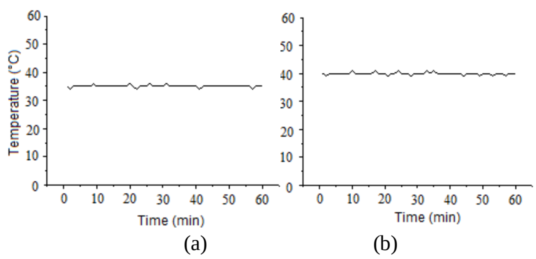
A. Physico-Chemical Characterization

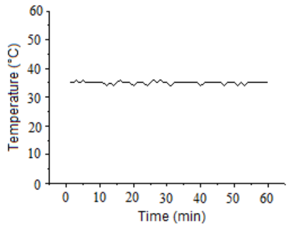
Table I shows the values of the physico-chemical characterization of the biodiesel produced at maximum yield within expected values [14].

TABLE I. BIODIESEL FUEL PHYSICOCHEMICAL PROPERTIES OF WCOEEs

Physical and Chemical Properties	**Units**	***Standard Methods***	***Results***
Relative Density (20 ℃)	kg/m ³	ASTM D4052	890.2
Water Content	mg/kg	EN 12937	440.0
Total Acid Number	mg KOH/kg	AOCS Ca 5-40	2.9
Total Content Esters	%mass	EN 14103	51.8

B. Monitoring





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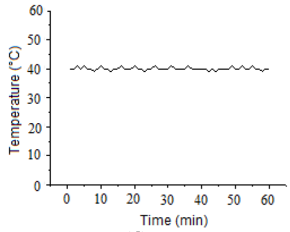

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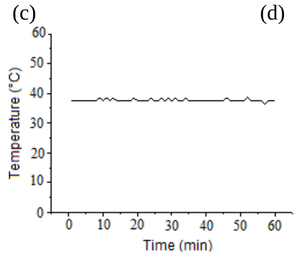


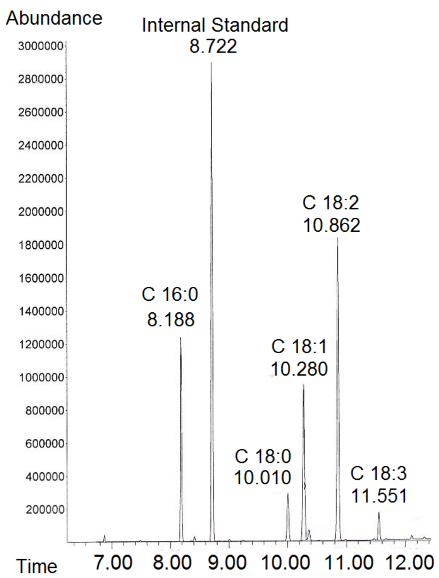
(e)

Figure 2. Data acquisition temperature, resulting from temperature control over the biodiesel manufacturing process at temperatures of 35 ℃ (a) and 40 ℃ (b) at a molar ratio oil/alcohol 1:6, 35 ℃ (c) and 40 ℃ (d) at a molar ratio oil/ethanol 1:9 and 37.5 ℃ (e) at molar ratio oil/alcohol 1:7.5.

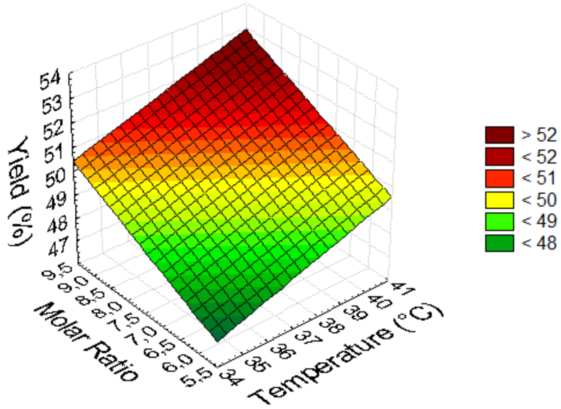
Data obtained by monitoring allowed to verify that the monitoring and control system designed was successful in maintaining the temperatures reactions stabled. The plant automatically made the necessary adjustments to reach the desired temperature when there were external disturbances. At all experiments, the variation of temperature was ± 1 ℃, as shown at Fig. 2.

C. *Chromatography and Statistical Analysis*

The conversion of WCO in ethyl esters could be followed qualitatively by GC/MS chromatographic analysis. The Fig. 3 (a) shows the chromatographic analysis of maximum yield among the experiments, highlighting the presence of linoleic acid (C 18:2) as the major component of bio-fuel [15], and Fig. 3 (b) the relation among temperature, molar ratio and yield.



(a)



(b)

Figure 3. Chromatographic analysis of biodiesel in maximum yield at temperature 40 ℃ and molar ratio of 1:9 WCO/ethanol (a) and surface response of temperature vs. molar ratio vs. reaction yield (b).

Table II shows the experimental matrix and the factors levels of temperature and molar ratio at all experiments. It also shows results collected through the chromatographic analysis. Low molar ratio and temperature resulted in a lower conversion factor, whereas the maximum yield, experiment 4, was obtained at maximum experimental temperature and molar ratio.

TABLE II. EXPERIMENTAL MATRIX AND BIODIESEL YIELD

Experiment Number	*Temperature (℃)*	*Molar Ratio (WCO/Ethanol)*	*Yield (%)*
Experiment 1	35	1:6	47.54
Experiment 2	40	1:6	48.94
Experiment 3	35	1:9	49.66
Experiment 4	40	1:9	51.85
Experiment 5	37.5	1:7.5	51.01
Experiment 6	37.5	1:7.5	50.29
Experiment 7	37.5	1:7.5	50.73

IV. CONCLUSIONS

The low cost designed plant was effective in production of WCOEEs. The monitoring and control processes kept the desired temperature conditions, demonstrating satisfactory results. It was produced biodiesel with an maximum yield of 51.85%. Characterization results showed physicochemical properties within the international standards.

The technology can be used to fuel production at low cost in rural as in urban areas, as agent of social inclusion and helpful in reduction of polluting gases at environment.

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