Biofuels from continuous fast pyrolysis of soybean oil: A pilot plant study

V.R. Wiggers a, H.F. Meier b,*, A. Wisniewski Jr. b, A.A. Chivanga Barros b, M.R. Wolf Maciel a

a Separation Process Development Laboratory, Chemical Engineering School, State University of Campinas (UNICAMP), SP, Brazil
b Chemical Engineering Department, Regional University of Blumenau (FURB), SC, Brazil

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A B S T R A C T

The continuous fast pyrolysis of soybean oil in a pilot plant was investigated. The experimental runs were carried out according to an experimental design alternating the temperature (from 450 to 600 °C) and the concentration of water (from 0% to 10%). The liquid products were analyzed by gas chromatography and by true boiling point (TPB) distillation. A simple distillation was used to obtain purified products such as gasoline and diesel. Physical–chemical analysis showed that these biofuels are similar to fossil fuels. Mass and energy balances were carried out in order to determine the vaporization enthalpy and the reaction enthalpy for each experiment. The thermal analysis showed that it is possible to use the products as an energy source for the process.

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1. Introduction

Approximately 80% of the main sources of energy come from fossil fuels like petroleum, coal and natural gas (Goldemberg, 2006). According to the United Nations Intergovernmental Panel on Climate Change (IPCC), climate change is due to the increase in the global average temperature caused by increases in greenhouse gas (GHG) emissions (IPCC, 2007). The main source of GHG emissions are the power generating plants running on fossil fuels (Kelly-Yong et al., 2007). Thus, the renewable energy sources, particularly biomass, offer an alternative for the reduction and gradual substitution of declining fossil fuel resources (Demirbas, 2007; Asadullah et al., 2008). Biomass is the only renewable source able to produce yields of solid, gaseous and liquid fuels (Bridgwater and Peacocke, 2000). Biomass can thus be considered as a natural reservoir of solar energy. Biomass can be used in a range of energy conversion technologies, such as direct combustion, thermochemical, biochemical and agrochemical processes (Wang et al., 2007), and pyrolysis and gasification are modern techniques for the conversion of biomass into useful liquid and gaseous fuels (Bridgwater, 2006). However, the gasification process has drawbacks related to biofuel storage, transportation and handling (Asadullah et al., 2008).

The utilization of biomass is centered on the fact that it is composed of cellulose, hemicelluloses and lignin (Bridgwater, 2003; Luo et al., 2004), although it also contains triglycerides and fatty acids (Srivastava and Prasad, 2000; Demirbas, 2008a).

The use of triglycerides and waste fatty acids to produce biodiesel using the esterification/transesterification reactions is the subject of many recent research studies (Srivastava and Prasad, 2000; Demirbas, 2003; Marchetti et al., 2005; Wang et al., 2006; Dorado et al., 2006; Meher et al., 2006; Zheng et al., 2006; Canakci, 2007), but several factors inhibit the use of this technology, mainly when the raw materials are biomass wastes based on triglycerides. The major factors are the variation of the acidity index, the solids content, heavy equipment for large-scale productions, the need to use alcohol in excess and its recovery, and, in some cases, the purification of biodiesel (Meher et al., 2006; Demirbas, 2008b).

The pyrolysis of triglycerides based on biomass was used for fuel supply during the first and second world wars, especially in areas with a lack of petroleum. China, for example, used a pyrolysis batch system of tung oil. The bio-oil produced was used as a raw material for gasoline and diesel-like fuel production (Demirbas, 2003; Lima et al., 2004). The fast pyrolysis process offers an alternative way to convert triglycerides into fuels. The method is characterized by a reactor operation temperature of around 500 °C, low residence time and high heating rates (Onay and Kockar, 2004; Bridgwater, 2003). In some pyrolysis processes, like petroleum catalytic cracking, water is added to increase the heat transfer, due to the water radiation properties, and to reduce the coke formation (Hu et al., 2000).

Alencar et al. (1983) conducted pyrolysis experiments using a glass apparatus with babassu, piqui and palm oils and the products were alkanes and 1-alkenes. The conversion of used sunflower oil
through thermal and catalytic pyrolysis was performed by Dandik and Aksoy (1999) and the products consisted of hydrocarbons in the gasoline range. The pyrolysis of vegetable oils from macauba fruit with production of carboxylic acids, aldehydes, alcohols, alkenes and alkadienes were investigated by Fortes and Baugh (2004). Lima et al. (2004) used a batch system to perform pyrolysis experiments using soybean, palm tree and castor oil, showing formation of olefins, paraffins, carboxylic acids and aldehydes. The distillation of the pyrolysis products enables the production of fuel with physical–chemical properties comparable to fuels based on petroleum. The pyrolysis of lard, for example, using a fixed-bed reactor, was investigated by Adebanjo et al. (2005) confirming the possibility to obtain fuels from animal fats. The obtained from olefins from thermal cracking of canola oil was reported by Sadrameli and Green (2007) and catalytic cracking studies of palm oil for the production of biofuels were carried out by Tamunaidu and Bhatia (2007). Junming et al. (2009) compared the pyrolytic products from soybean oil pyrolysis over different kinds of catalysts. Wiggers et al. (2009) performed the pyrolysis of waste fish oil in a continuous pyrolysis plant and the products, purified to obtain light and heavy bio-oil fractions, were compared to the Brazilian-fuel specifications. Wisniewski et al. (2009) detailed the chemical composition of biofuels obtained from waste fish oil pyrolysis.

The reaction scheme presented by Maher and Bressler (2007) shows 16 types of reactions leading to the decomposition of triglycerides to carboxylic acids, acrolein and ketenes, which are cracked to form esters, carboxylic acids and hydrocarbons. According to Maher and Bressler (2007) and Demirbas (2008b) the fast pyrolysis of triglycerides is not as technologically well established as the pyrolysis of lignocellulosic based biomass, and the use of vegetable oils is focused on the transesterification reaction. For these authors, the fast pyrolysis of triglyceride materials is an alternative and renewable way to produce products for use in fuel and chemical applications, and research on this technology offers an opportunity for further studies in the areas of reaction optimization, product analysis and process scale-up.

Most studies reported in the literature regarding triglyceride pyrolysis are carried out in batch systems and laboratory scale reactors, using small amounts of biomass. Thus, in this study, a pilot plant for the pyrolysis process was designed and built up to operate in a continuous mode with a robust control system, which allows the experiments to be performed under isothermal conditions, the acquisition of data to evaluate the process parameters that lead to a high yield of liquid products, and physical–chemical analysis of products and an energy consumption analysis to be carried out.

2. Experimental

2.1. Materials and experimental design

In this study soybean oil was used as feedstock for biofuel production since it is an abundant source of triglyceride available all over the world.

After a series of preliminary runs, the experimental design, detailed in Table 1, was based on a factorial method with two levels ($2^n$), where n is the number of variables considered. The operation temperature and water content were considered as the most significant variables, resulting in four different experimental conditions. Based on the fast pyrolysis process conditions, the high and low temperatures for the process were established as 600 and 450°C, respectively. The water content values were 0% (low) and 10% (high). Two experiments were added to the experimental design to verify the intermediate operational conditions of temperature (525°C) and water content (5% as the intermediate value and 0% as the low value). The experiments were performed under isothermal and steady-state conditions.

2.2. Description of the experimental apparatus

The pyrolysis of soybean oil was carried out in a pilot scale tubular reactor. Fig. 1 shows the conceptual design of the process comprising: a feed system; a pre-heater section where the soybean oil is vaporized; the reactor where the pyrolysis occurs; a condensation section composed of two heat exchangers; a separation, collection and emission section; and the instrumentation and control section. The biomass feeder system consists of a reservoir and a NEMO® pump allowing continuous and constant feeding of the soybean oil. The biomass flows toward a serpentined inside a fixed-temperature pre-heater to be vaporized before entering the reactor where the pyrolysis reaction occurs. The reactor is made of stainless steel with a height of 2310 mm and internal diameter of 67 mm, comprising 12 electrical resistances with 1 kW in each unit, divided into four proportional-integral derivative controllers (PIDs) networks, which are responsible for maintaining the isothermal operation. The gas mixture from the reactor flows through two condensers. The first one, made of stainless steel, is cooled with tap water and the condensate is separated and stored in the first reservoir, and the remaining vapors are sent to the second condenser, made of glass, and cooled with water, the condensate being collected in the second reservoir. The instrumentation of the reactor is composed of type-k thermocouples, a device in the pump for measuring the mass flow through the frequency variation, pressure sensors and a system power consumption register in the pre-heater and along the reactor on the electrical resistances. The software SCADA (software control and data acquisition) is responsible for the user-machine interface. All data, such as temperature, pressure and the energy used in the process, are stored in a databank.

2.3. Experimental Procedure

The experimental procedure to carry out the pyrolysis experiments consisted of a 3-h time period for the start-up of the electrical resistances, reaching the programmed temperature conditions. After this period, water was fed for 2 h to promote operational temperature stability. The water was then replaced by feedstock until reaching the steady-state conditions of the pyrolysis reaction (approximately a further 3 h). After verifying the stability of the operational pilot plant conditions with the feedstock, the experiments were carried out according to Table 1. Thereafter, 2 h of steam were passed through the reactor as a cleaning procedure. The total time of operation for each experiment was approximately 13 h, resulting in one experiment per day.

2.4. Gas chromatography analysis

The gas chromatography analysis of the liquid products was performed on a Varian CP-3800 equipped with a CP Sil 8CB Low Bleed (30 m × 0.25 mm, film thickness 0.25 μm) column, FID and MS detector. The analysis conditions for the GC-FID were: injector temperature of 250°C operated in the split mode, detector temperature of 280°C and operated programmed to 60°C (5 min), ramping at 5°C min$^{-1}$ to 250°C (12 min). For the qualitative identification, the chromatogram was compared with homologous $n$-alkane standards, and the quantification was performed by total area integration. The GC–MS analysis conditions were: ionization mode electron impact (70 eV); MS operated in the total ion current mode, scanning from 40 to 550 m/z; interface temperature maintained at 240°C; GC oven temperature program comprising initial tempera-
ture 50 °C (2.5 min) followed by ramping at 6 °C min⁻¹ to 250 °C (19 min). Chromatographic data were recorded using a Saturn GC/MS Workstation, which was controlled by Windows NT (Microsoft) and equipped with the NIST 05 mass spectral library. Helium (>99.999% pure) was used as the carrier gas with a flow rate of 1.0 mL min⁻¹ for MS and 1.2 mL min⁻¹ for FID.

The analysis of the gas produced by the soybean oil pyrolysis process was performed on a Schimadzu GC-17A equipped with a Carboxem 1000 (60/80) (4.57 m × 3.17 mm) column, Methanizer, FID and TCD detectors. The GC operation conditions were: injector temperature of 100 °C, detector temperature of 280 °C and oven programmed temperature of 40 °C (6 min), ramping at 20 °C min⁻¹ to 220 °C (20 min). The identification and absolute quantification were performed by external calibration with a commercial standard mixture of gases obtained from White Martins S.A.

### Table 1

<table>
<thead>
<tr>
<th>Experimental design</th>
<th>Experiments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
<tr>
<td>Temperature (°C)</td>
<td>600(+)</td>
</tr>
<tr>
<td>Water:Feedstock content (kg)</td>
<td>1:9(+)</td>
</tr>
<tr>
<td>Operating variables</td>
<td></td>
</tr>
<tr>
<td>Time of operation (h)</td>
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</tr>
<tr>
<td>Reactor average temperature (°C)</td>
<td>605</td>
</tr>
<tr>
<td>Pre-heater average temperature (°C)</td>
<td>475</td>
</tr>
<tr>
<td>Pre-heater average outlet temperature (°C)</td>
<td>440</td>
</tr>
<tr>
<td>Mass flow (kg h⁻¹)</td>
<td>3.06</td>
</tr>
<tr>
<td>Residence time (s)</td>
<td>10</td>
</tr>
</tbody>
</table>

### Fig. 1.

Conceptual design of a tubular pyrolysis reactor.

2.5. Physical–chemical characterization of the products

The yield of bio-oil ($\eta_L$) from each experiment was calculated in terms of its mass over the initial soybean oil mass. The yield of biogas ($\eta_G$)¹ is the difference to give 100%.

A reduced simple distillation process was carried out to obtain purified products in the range of gasoline and diesel. The liquid products collected in the first reservoir were submitted to a simple distillation and the condensate in the range of 150–400 °C was separated and named heavy bio-oil (HBO). The liquid products from the second reservoir were submitted to a simple distillation and

¹ Note that the solid product in terms of coke deposition on the reactor and pre-heater walls was not considered in this analysis.
the condensate up to 220 °C was separated and named light bio-oil (LBO). These biofuels and samples of fossil gasoline and fossil diesel oil were submitted to a true boiling point (TPB) distillation (ASTM D86) for comparison. TPB is a batch distillation method used to analyze the distillation characteristics by plotting the distillation volumetric fraction against the controlled increase in temperature (Behrenbruch and Dedigama, 2007).

The high heat values (HHV) of soybean oil, bio-oils, HBO and LBO were determined using a IKA CCT 2000 instrument (ASTM D240).

2.6. Thermal analysis through mass and energy balances

In the thermal analysis of the process, the pre-heater and the reactor were considered as perfect mixture systems with isothermal and non-adiabatic conditions. In this physical situation, for the mathematical modeling, the following assumptions were adopted: complete vaporization in the pre-heater and all chemical components of the vapor undergoes reaction. The thermal analysis modeling did not take into account the occurrence of hydrolysis reactions in the pre-heater.

Fig. 2. Yields and results of the pyrolysis experiments.
3. Results and discussion

Table 1 gives the operating conditions of the experiments. The residence time was calculated through product density as a function of the composition of the products that leave the reactor and the average temperature of the reactor. It can be seen that the mass flow was constant but the residence time changed due to the temperature influence on the gas density. The operating times of all experiments were similar, in the range of 3.3 h, and the average temperatures were close to the set-point.

3.1. Bio-oil analysis

The gas chromatography analysis of bio-oil was used to predict the amount of the following three classes of compounds: the first (undesirable) having more than 22 carbons in the chain, named oily sludge (OS); the HBO having between 11 and 22 carbons, the range typical of fossil diesel; and the LBO having between 4 and 10 carbons, the characteristic range of fossil gasoline (Miskolczi et al., 2009). The relative compositions of OS, HBO and LBO were determined by gas chromatography as discussed previously. Therefore, it was possible to calculate the yields for the liquid products such as oily sludge (\( \eta_{OS} \)), heavy bio-oil (\( \eta_{HBO} \)) and light bio-oil (\( \eta_{LBO} \)) over the mass of liquid product.

The liquid yields, the results of the GC-FID analysis, and the HHV of the liquid products are shown in Fig. 2. In this figure, it is possible to note that the OS values for Experiments 3 and 4 are higher than those for Experiments 1, 2, 5 and 6. Considering the high yield of liquids, Experiments 5 and 6 are preferable to 1 and 2. The presence of water in Experiment 5 did not have a significant influence on the liquid yield, when compared to Experiment 6, or on its composition determined by GC-FID analysis.

3.2. Bio-oil fractioning and analysis

The products of Experiments 5 and 6 were submitted to a reduced simple distillation process to obtain the purified products. For this, 680 g of Product 2 from Experiment 6 (Bio-oil 6.2) was distilled and the condensate, up to 220 °C as the final temperature of distillation, was quantified in 200 g of LBO. The same procedure was applied using Product 2 of Experiment 5 (Bio-oil 5.2) and collecting 135.6 g of LBO. The simple distillation of 740 g of Product 1 from Experiment 6 (Bio-oil 6.1) was carried out, and the products, between 150 and 375 °C of distillation temperature, and 540 g of HBO were recovered. In the same way, 660 g of Product 1 from Experiment 5 (Bio-oil 5.1) gave 520 g of HBO. Samples of these biofuels and samples of gasoline and diesel oil were analyzed by TPB and Fig. 3 shows the plot of the percent recovered (by volume) against the distillation temperature. In this figure, it is possible to note that the LBOs have similar distillation characteristics to those of gasoline A from petroleum. The samples of HBO have a different behavior in the beginning of the curve, a problem associated with bio-oil fractioning.

Fig. 4 shows the percentage of the compounds in terms of the carbons in the chain for gasoline A and the LBO of both Bio-oil 5.2 and Bio-oil 6.2. Fig. 5 shows the same analysis for the diesel oil and the LBO of both Bio-oil 5.1 and Bio-oil 6.1. It is possible to note that the plots show a good similarity between the composition of the fossil fuels and the biofuels. The HHV values for the LBOs and HBOs, given in Fig. 2, are higher than that of the original bio-oil source.

3.3. GC–MS analysis of LBO and HBO

Samples of LBO and HBO obtained from the bio-oil produced in Experiment 5 were analyzed by GC–MS. Fig. 6 shows the Total Ion Chromatogram (TIC) and Selective Ion Chromatograms (SIC) of LBO. The analysis shows a high content of different compounds that are identified by fragments 77, 91 and 105 m/z characteristic of aromatics and 55, 69 and 83 m/z characteristic of alkenes. The main aromatic compounds found in the LBO were BTEX compounds: 1 = benzene, 2 = toluene; 3 = ethylbenzene; 4 = m,p-xylene; 5 = o-xylene. The alkenes identified were: 6 = hexene; 7 = heptene; 8 = octene; 9 = nonene; 10 = decene; 11 = undecene; 12 = dodecene. Olefins provide higher octane ratings than n-paraffins, but are more unstable in the presence of oxygen and can contribute to the production of gum deposits during long-term storage, requiring the use of antioxidants. The aromatic compounds have good octane numbers, but tend to be more toxic and there are specific regulations for some compounds, for example, benzene.

Fig. 7 shows the TIC and SICs of HBO. In this biofuel it was possible to note the residual presence of free fatty acids (0), derived from the partial cracking of triglyceride. For this biofuel, the presence of aromatics with higher molecular weights than those present in LBO was confirmed: 1 = toluene; 2 = ethylbenzene;
3 = m,p-xylene; 4 = o-xylene; 5 = C₉H₁₂ aromatics; 6 = C₁₀H₁₄ aromatics; 7 = C₁₁H₁₆ aromatics; 8 = C₁₂H₁₆ aromatics. Similarly, a homologous n-alkenes series was identified: 9 = octene; 10 = nonene; 11 = decene; 12 = undecene; 13 = tridecene; 15 = tetradecene; 16 = pentadecene; 17 = hexadecene. These results show that the thermal cracking process of soybean oil produces biofuels with a high number of alkenes (olefins) and aromatics.

3.4. Thermal analysis

This section presents the thermal analysis carried out and the mathematical modeling applied. The mass and energy balances for the pre-heater section can be described as follows:

- Mass balance in the pre-heater section:
  \[
  \frac{d}{dt}[m_{\text{PH}}] = m_{\text{(I)}} - m_{\text{(V)}}
  \]  

- Energy balance in the pre-heater section:
  \[
  \frac{d}{dt}[m_{\text{PH}}C_p{T_{\text{PH}}}] = [m_{\text{(I)}}C_p{T_{\text{(I)}}}] - [m_{\text{(V)}}C_p{T_{\text{(V)}}}] - \Delta{H_{\text{(V)}}}m_{\text{(V)}} + (\hat{q}_{\text{LO}} + \hat{q}_{\text{SO}})
  \]  

The mass and energy balances for the reactor section are presented as follows:

- Mass balance in the reactor section:
  \[
  \frac{d}{dt}[m_{\text{R}}] = m_{\text{(V)}} - m_{\text{(P)}}
  \]  

- Energy balance in the reactor section:
  \[
  \frac{d}{dt}[m_{\text{R}}C_p{T_{\text{R}}}] = [m_{\text{(V)}}C_p{T_{\text{(V)}}}] - [m_{\text{(P)}}C_p{T_{\text{(P)}}}] - \Delta{H_{\text{(P)}}}m_{\text{(P)}} + (\hat{q}_{\text{LO}} + \hat{q}_{\text{SO}})
  \]
Enthalpy energy supplied in the operation (\(q_{AV}\)) (kJ kg\(^{-1}\)) and the enthalpy available (\(q_{s}\)) (kJ kg\(^{-1}\)) as follows:

\[
\Delta H = \frac{[m_{L}]C_{p,L}T_{L} - [m_{V}]C_{p,V}T_{V} - (\dot{q}_{10}) + (\dot{q}_{11})}{m_{L}}
\]  

(6)

\[
\dot{q}_{s} = \frac{\dot{q}_{av} + \dot{q}_{s1}}{m_{L}}
\]  

(8)

By considering the steady-state operation of the pre-heater and of the reactor, as a further assumption, the mass balance for both sections can be rewritten as:

\[
m_{L}^{(i)} = m_{V}^{(i)} = m_{P}^{(i)}
\]  

(5)

The heat balances can also be written for steady-state conditions to predict the vaporization and the reaction enthalpy from experimental data, respectively, as:

\[
\Delta H = \frac{[m_{L}]C_{p,L}T_{L} - [m_{V}]C_{p,V}T_{V} - (\dot{q}_{10}) + (\dot{q}_{11})}{m_{L}}
\]  

Therefore, with Eqs. (5)–(7) and with the experimental data from the data acquisition system for the steady-state operation of the reactor, it is possible to predict the enthalpy values associated with the energy consumption of the process due to the phase change of the triglycerides (vaporization) and the endothermic global reaction that occurs during the pyrolysis. The heat losses by natural convection on the external wall of the insulated pre-heater section and in the reactor section were predicted using classical correlations from the literature (Kreith and Bohn, 2003) and by measurement of the external wall and room temperatures.

With the high heat value (HHV) of the products, it is possible to carry out a thermal analysis projection of the process by means of a comparison between the enthalpy supplied and the enthalpy available in the products when used as a fuel in the combustion process. In this regard, it is possible to define the enthalpy supplied (\(\dot{q}_{11}\)) (kJ kg\(^{-1}\)) and the enthalpy available (\(\dot{q}_{s}\)) (kJ kg\(^{-1}\)) as follows:

\[
\dot{q}_{s} = \frac{\dot{q}_{av} + \dot{q}_{s1}}{m_{L}}
\]  

(8)

Table 2
Results of mass and energy balances.

<table>
<thead>
<tr>
<th>Operating variables</th>
<th>Experiments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td>Energy consumption rate in the pre-heater ((q_{av})) (kJ s(^{-1}))</td>
<td>1.92</td>
</tr>
<tr>
<td>Energy consumption rate in the reactor ((q_{11})) (kJ s(^{-1}))</td>
<td>2.36</td>
</tr>
<tr>
<td>Energy loss rate in the pre-heater ((q_{10})) (kJ s(^{-1}))</td>
<td>0.93</td>
</tr>
<tr>
<td>Energy loss rate in the reactor ((q_{s})) (kJ s(^{-1}))</td>
<td>0.18</td>
</tr>
<tr>
<td>Enthalpy energy supplied in the operation ((q_{AV})) (kJ kg(^{-1}))</td>
<td>5028.93</td>
</tr>
<tr>
<td>Enthalpy of vaporization ((\Delta H_{V})) (kJ kg(^{-1}))</td>
<td>227.3</td>
</tr>
<tr>
<td>Enthalpy of reaction ((\Delta H_{R})) (kJ kg(^{-1}))</td>
<td>183.34</td>
</tr>
<tr>
<td>Enthalpy of the liquid products HHV(L) (kJ kg(^{-1}))</td>
<td>38,405.7</td>
</tr>
<tr>
<td>Enthalpy of the gas products HHV(G) (kJ kg(^{-1}))</td>
<td>30,867.0</td>
</tr>
<tr>
<td>Available enthalpy ((q_{av})) (kJ kg(^{-1}))</td>
<td>37,780.1</td>
</tr>
<tr>
<td>Percentage of excess energy ((q_{ex}))</td>
<td>86.7</td>
</tr>
</tbody>
</table>
\[ q_{AV} = HHV \frac{\eta_L}{100} + HHV \frac{\eta_c}{100} \]  

(9)

Thus, it is possible to calculate the percentage of excess energy \( (q_{exc}) \% \) according to Eq. (10):

\[ q_{exc} = \frac{q_s + 100}{q_{AV}} \]  

(10)

With the experimental yields, the high heat value of the products and the experimental data collected, it is possible to use the methodology proposed to carry out a thermal analysis of the process.

The results of the GC analysis of the bio-gas produced in Experiment 3, shown in Fig. 2, show that it is composed of hydrogen, methane, carbon monoxide, carbon dioxide and compounds with 2–6 carbons in the carbon chain and others. A correlation proposed by Ravich (1977) was used to calculate the approximate high heat value of this gas.

The results of the mass and energy balances in the pre-heater and reactor sections are given in Table 2. The values calculated for the vaporization enthalpy are similar to that for oleic acid, that is 238.62 (kJ kg\(^{-1}\)), calculated by Lide (2005). The enthalpy reaction values obtained show that experiments performed at higher temperatures have lower energy consumption than those performed at intermediate temperatures. This may be associated with exothermic reactions, such as hydrogenation of olefins.

The possibility to use the products as an energy source for the process does exist, and with a good percent of excess energy, which is extremely important in the scaled-up process.

4. Conclusions

The experiments carried out in a continuous pyrolysis process produced biofuels from soybean oil, with some similar characteristics to those of fossil fuels. The experiments conducted at 525 °C offered better conditions to maximize the liquid fraction. The GC-FID, GC–MS and TPB analysis showed that the biofuels obtained contained compounds similar to the gasoline and diesel oil fractions of petroleum. With the mass and energy balances, it was possible to demonstrate the possibility for the auto-thermal operation of the pyrolysis process.

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