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ANALYSIS OF AN INFRARED BURNER WORKING WITH HYBRID FUEL: LPG / BIO-OIL

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Abstract. *Biomass is considered the largest renewable energy source that can be used in an environmentally sustainable. From the pyrolysis of biomass is possible to obtain products with higher energy density and better use properties. The liquid resultant of this process is traditionally called bio-oil. The use of infrared burners in industrial applications has many advantages in terms of technical-operational, for example, uniformity in the heat supply in the form of radiation and convection, with a greater control of emissions due to the passage of exhaust gases through a macroporous ceramic bed. This paper presents a commercial infrared burner adapted with an ejector proposed able to burn a hybrid configuration of liquefied petroleum gas (LPG) and bio-oil diluted. The dilution of bio-oil with absolute ethanol aimed to decrease the viscosity of the fluid, and improving the stability and atomization. It was introduced a temperature controller with thermocouple modulating two stages (low heat / high heat), and solenoid valves for fuels supply. The infrared burner has been tested, being the diluted bio-oil atomized, and evaluated its performance by conducting energy balance. The method of thermodynamic analysis to estimate the load was used an aluminum plate located at the exit of combustion gases and the distribution of temperatures measured by thermocouples. The dilution reduced the viscosity of the bio-oil in 75.4% and increased by 11% the lower heating value (LHV) of the same, providing a stable combustion to the burner through the atomizing with compressed air and burns combined with LPG. Injecting the hybrid fuel there was increase in the heat transfer from the plate to the environment in 21.6% and gain useful benefit of 26.7%, due to the improved in the efficiency of the 1st Law of Thermodynamics of infrared burner.*

Keywords*: infrared burner, atomizer, liquefied petroleum gas, bio-oil, energy balance*

1. INTRODUCTION

In the last century, fuels derived from petroleum were the worldwide main sources of energy. Nowadays, with the increase in oil demand, there is need to develop an economic process for the sustainable production of fuels and chemicals, inserted within the political and environmental concerns about the use of fossil fuels (Huber et al., 2006). This need for alternative energy sources has increased interest in the use of biomass, because it is a renewable fuel capable to reduce emissions of CO_2 and sulfur. In this context, Brazil is the largest world producer and consumer of "bioenergy" (Peláez-Samaniego et al., 2008). The high rates of biomass use in Brazil are related to factors such as climatic diversity and abundance of agroforestry resources (Campos, 2008).

The use of biomass as a potential source of automotive fuels, chemical products and materials has given new impetus to the practice of pyrolysis in the last two decades, stands out as one of the most promising technologies for conversion into liquid fuels (Qiang et al., 2009). The control of some parameters of pyrolysis results in different products such as liquid and solid material, which can have varied applications (Faaij et al., 2005).

Pyrolysis is a thermal conversion process that involves the rupture of carbon-carbon bonds and the formation of carbon-oxygen bonds. The proportion of gaseous products, liquid and solid formed depends on the control of some process parameters (Tsai et al., 2006). The resultant liquid of this process is traditionally called bio-oil (Faaij et al., 2005).

Aiming a study concerning the use of bio-oil as fuel, through the efficiency valuation of the 1st Law of Thermodynamics, was used an infrared burner with macroporous ceramic bed coupled to a control and feeding semi-automatic system to accomplish the joint firing of bio-oil with liquefied petroleum gas (LPG).

The combined use of LPG allows the bio-oil to be burned more easily, because the gas and the infrared burner allows the involved temperatures in combustion reaches values close to 800 °C. This is explained by Howell (1996), who says that the insertion of a high emissivity ceramic structure causes the mixture of oxidizer and fuel to be preheated before the reaction zone, promoting an increase in the rate of chemical reaction, increasing the maximum temperature in the reaction zone, reaching values above the flame adiabatic temperature and lower emissions.

The dilution of bio-oil with absolute ethyl alcohol has the main objective the reduction of fluid viscosity, and improvement of stability and atomization. Diebold (2000) made a review of physical mechanisms and chemical stability

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of bio-oil and showed that the addition of solvents such as methanol and ethanol, improve its stability and decreases its viscosity.

2. MATERIALS AND METHODS

2.1. Production of raw material

The bio-oil used was obtained from fast pyrolysis of biomass made with sawdust. The process involves the injection of biomass in the pyrolysis plant, with a fluidized bed reactor operating at about 500 ºC, where the reaction occurs. The products obtained from the fast pyrolysis are charcoal and pyrolysis gases. By gravity, the charcoal falls into tanks and the gases follow, where they are subjected to a "washing" to remove small impurities, and after condensation, is transformed into bio-oil used in this study.

2.2. Bio-oil dilution

One of the problems with the bio-oil was the high viscosity, in addition to rapid aging and polymerization. To contour these problems, it was decided to begin dilution with 10% absolute ethanol, growing at around 5% until a maximum percentage of 25% (on volume basis) of the alcohol in the bio-fuel. It was observed that with percentages below 25% were unable to obtain a complete homogenization of the bio-oil. Thus, it was adopted standard dilution of 25% in all tests performed in this work. This fuel was initially named as BO25. Table 2.4 shows the basic data obtained from bio-oil from pyrolysis of biomass sawdust and petroleum fuel oils (Oasmaa e Czernik, 1999).

Table 1. Bio-oil and petroleum fuel oils basic data (adapted from Oasmaa e Czernik, 1999)

Physical Properties	**Bio-oil**	**Fuel oil**
Moisture content (%)	15 - 30	0,1
pH	2,5	-
Density (kg/m^3)	1200	940
Chemistry		
C (%)	54 - 58	85
H (%)	5,5 - 7	11
O (%)	35 - 40	1
N (%)	0 - 0,2	0,3
charcoal (%)	0 - 0,2	0,1
Higher heating value (MJ/kg)	16 - 19	40
Viscosity (a 50ºC) (cP)	40 - 100	180
Solids	0,2 - 1	1
Distillation residues	higher que 50	1

2.3. BO25 storage and filtration

The BO25 was filtered through a paper filter. Thus, it was removed some impurities and / or sludge still present in the fuel. After filtering, the fuel was stored in clear glass beaker at room temperature, under darkness and closed to avoid contact with atmospheric air.

2.4. Description of test bench

Figure 1 illustrates the schematic diagram of the infrared burner together with the equipment and instruments used during the tests and their respective locations.

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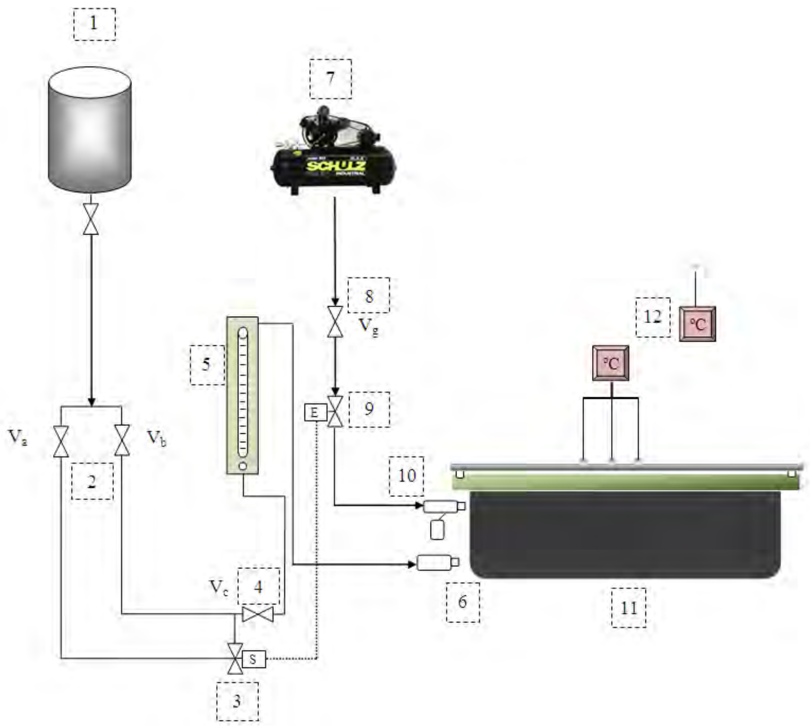

Figure 1. Diagram of the equipment used to carry out the burning of the hybrid fuel

Table 1 shows the description of the equipments shown in Fig. 1.

Table 1. Description of the equipments

Number	Description
1	Heat source – 13 kg commercial LPG gas cylinder
2	Control system of the burner flame – *Manifold*; V_a – Needle valve for high flame (high flow) V_b – Needle valve for low flame (low flow)
3	Solenoid valve that operates in the feed system of LPG
4	V_c – On/off valve (opening/closing)
5	Rotameter for measuring the flow of LPG
6	LPG injector nozzle – equipment responsible for inserting the LPG gas in the burner
7	Air compressor working with operation pressure of 300 kPa
8	V_g - Needle valve for regulating the compressed air
9	Electro-valve that operates in the compressed air supply system
10	Air/BO25 injector nozzle - equipment responsible for inserting the atomized mixture of air and BO25 in the burner
11	Infrared burner
12	Thermocouple for temperature measuring

2.5. Infrared burner

It was used a 6.1 kW Jackwal® infrared burner (Fig. 2). The burner was manufactured by forming of a carbon steel plate shaping a metallic housing. The housing is coated (enameled) with a layer of crushed glass and has the following dimensions: 170 mm wide and 405 mm in length.

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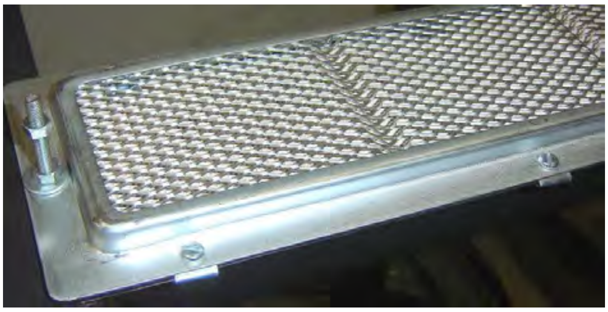

Figure 2. Infrared burner

2.6. Injector Nozzles

It was used a Jackwal® injector nozzle, with a 1.4 mm hole (Fig. 3), for the LPG. It was used a Leepro Tools® airbrush equipped with a reservoir and a regulator of liquid propellant to insert properly the air/BO25 in the burner through the injection nozzle, developed for this work. The compressed air line connected to airbrush works at a pressure of 300 kPa.

Figure 3. LPG injector nozzle

Figure 4. Compressed air/BO25 injector nozzle

2.7. Maximum temperature limiter system and fuel block

To allow the control of the maximum temperature to be reached in the surface of the aluminum plate, it was used a digital temperature controller/indicator manufactured by Tholz®, MDH – P299 model (Fig. 5) with range from 0 to 300 ºC in series with a relay manufactured by Telemecanique®, CA2KN model, responsible for triggering the solenoid valve and the electro-valve.

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Figure 5. Digital controller/indicator of temperature

One solenoid is responsible for blocking the injection of compressed air from BO25 feed system when it reaches the maximum temperature determined (270 ºC) and another solenoid valve (Parker® model DT-1908), connected to a manifold (set of LPG's flow regulating valves), who partially blocks the flow of LPG (regulating high heat / low heat) when the burner reaches the same temperature. Therefore, these valves are activated simultaneously (Fig. 6 and Fig. 7).

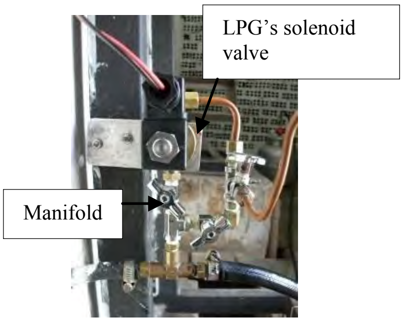

Figure 6. Solenoid valve

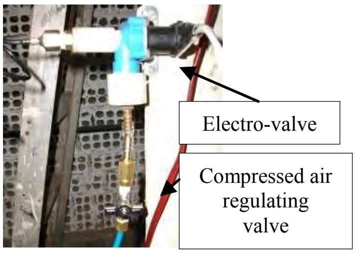

Figure 7. Blocking hybrid fuel electro-valve

2.8. Temperature measurement system

One of the most important parameters for determining the thermal energy in thermal systems is the temperature, which was a major focus of this study. The temperature was necessary to evaluate the performance of the burner. Were installed four K type thermocouples for the measurements of temperatures (°C). Three thermocouples were installed in the center of the aluminum plate and the latter in the laboratory for measurement of room temperature.

In these tests, the temperature measurements were performed by monitoring and recording the temperatures involved in the process. Time was controlled by a precision digital stopwatch.

2.9. Heating value

The heating values tests were performed in a bomb calorimeter. The samples were heated at 50 °C for a period of minute, to remove any water droplets.

2.10. Tests description

The test started from the ignition of the infrared burner through a pilot light in the LPG's gas injector nozzle. The heat from the exhaust gas was transferred to the aluminum plate (heat sink) by convection and radiation.

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The behavior of the heating profile was monitored by a temperature gauge attached to the aluminum plate, until it reaches the set point on the controller.

When the steady state of operation is reached, in other words, when there is no more significant variation in temperature, it is started the injection of BO25 in the infrared burner. From this moment, the simultaneous measurements of LPG consumption (mL/min) and BO25 (mL/min) is performed.

2.11. Measuring systems for LPG and BO25

There are several techniques to determine the flow of a fluid. In the specific case of this work, was chosen to use the measurement of volumetric flow of LPG with a rotameter with a precision digital stopwatch to control the flow time of high and low flame, when the infrared burner is operating at steady state.

The BO25's flow rate was measured simultaneously with LPG, using a 25 mL glass pipette calibrated to measure the volume. The flow time was monitored using a precision digital stopwatch.

With the BO25 injector in full operation, was recorded the volume variation in elapsed time of the measurement.

The volumetric flow of LPG and BO25was measured within a ten-minute time, in three bench tests. Subsequently, was calculated the mass flow rate through the specific mass of each fuel. Also, the arithmetic average and standard deviation was calculated of the three taken samples from each one.

3. RESULTS AND DISCUSSION

3.1. Viscosity test of bio-oil and BO25

The bio-oil's and BO25's viscosity tests were performed using a rheometer. Each test was made within a 300 seconds period and was taken 10 measurements during it. The first three points (30, 60, 90 seconds) were not considered because they were null values.

Table 2 shows the values for the bio-oil, where the average value for the viscosity was 40.92 cP.

Table 2. Viscosity values for the bio-oil

Point	Test time (s)	Shear rate (1/s)	Shear stress (mPa)	Viscosity (cP)	Temperature (K)	Torque (N.m)
1	120	0.002521	0.09959	39.50	300.32	0.00001476
2	150	0.002827	0.114	40.48	300.31	0.00001696
3	180	0.003285	0.133	40.51	300.3	0.00001972
4	210	0.003481	0.155	44.45	300.3	0.00002293
5	240	0.004261	0.177	41.50	300.3	0.00002621
6	270	0.005132	0.204	39.79	300.28	0.00003027
7	300	0.005853	0.235	40.21	300.33	0.00003488

Table 3 shows the values for BO25, where the average value for viscosity was 10.06 cP.

Table 3. Values for BO25 viscosity

Point	Test time (s)	Shear rate (1/s)	Shear stress (mPa)	Viscosity (cP)	Temperature (ºC)	Torque (N.m)
1	120	0,002233	0,02114	9,47	27,06	0,000003133
2	150	0,00252	0,0269	10,67	27,05	0,000003986
3	180	0,002919	0,03209	11,00	27,07	0,000004757
4	210	0,003633	0,03693	10,17	27,06	0,000005474
5	240	0,004283	0,04181	9,76	27,04	0,000006197
6	270	0,004764	0,04748	9,97	27,07	0,000007037
7	300	0,005624	0,05258	9,35	27,07	0,000007793

Thus, from the dilution of bio-oil with 25% of absolute ethyl alcohol was possible to reduce the viscosity at 75.4%, also reducing the polymerization reactions and improving the atomization of BO25 in the proposed injector nozzle.

3.2. Heating values of bio-oil and BO25

Through testing with the bomb calorimeter was possible to find the higher heating value of bio-oil and BO25. The results were: 16.759 kJ/kg for bio-oil, and 18.483 kJ/kg for BO25.

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From the dilution, the higher heating value was increased by about 10% compared to the bio-oil, with a very limited change in this feature.

From Eq. (1), was calculated the lower heating value of bio-oil and BO25. For the bio-oil, the value was 15.341 kJ/kg and the BO25 was 17.065 kJ/kg, ie, an increase of about 11%.

$$LHV = HHV - 218.13 \times H \tag{1}$$

In the equation: LHV is the lower heating value (kJ/kg), HHV is the higher heating value (kJ/kg) and H is the percentage of hydrogen in the fuel.

3.3. Measured temperatures

In order to obtain the heat transfer from the aluminum plate to the ambient were used three thermocouples fixed to the plate and one to measure the room temperature.

From the analysis of recorded temperatures was observed that temperatures were higher, when it was injected BO25 in the infrared burner, also with an increase in the rate of heating of the aluminum plate due to the use of hybrid fuel.

Temperatures measured on the plate produced very similar values, and the ambient temperature in all trials remained constant as well the fuels injected in the burner.

Considering the methodology used, it was found that the heating value decreased with the addition of BO25 in the fuel mass flow and the temperature transient increased with the inclusion of the hybrid fuel.

The first test, shown in Fig. 8, performed only with LPG, allowed the aluminum plate to be heated to 231 °C, showing a transient temperature (aluminum plate and room) equal to 203 ºC.

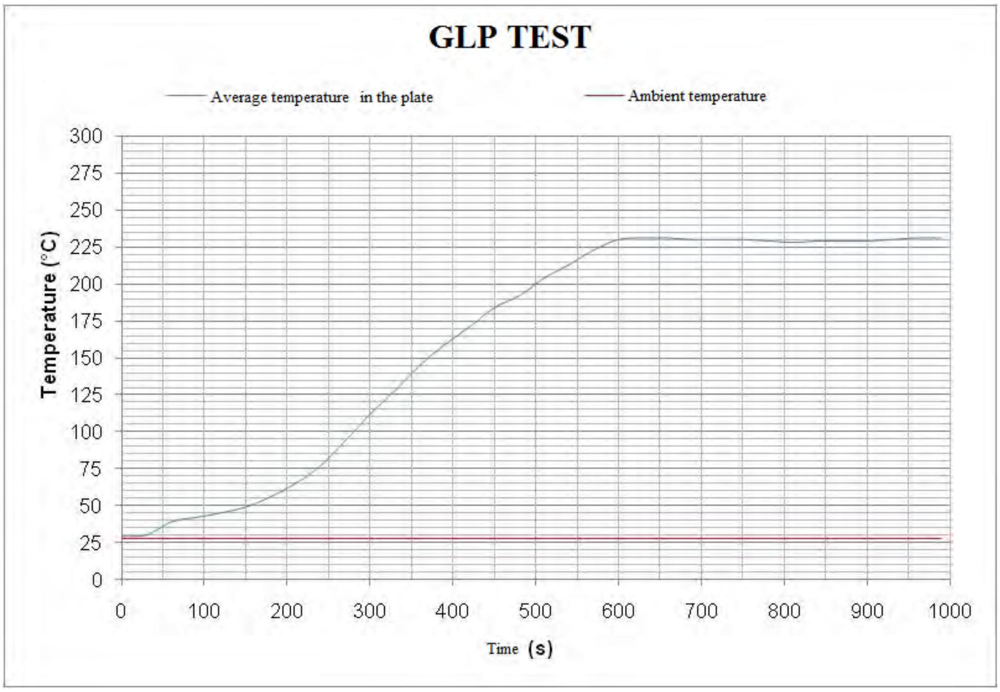

Figure 8. Temperatures in the first test - LPG

For the second test, illustrated in Fig. 9, performed with LPG + 10% BO25, the plate was heated to a temperature of 281 ° C and the temperature transient was 253 ° C. The average temperature of the aluminum plate was higher than those obtained in the first test. The second test had an increase of 21.6% over the previous.

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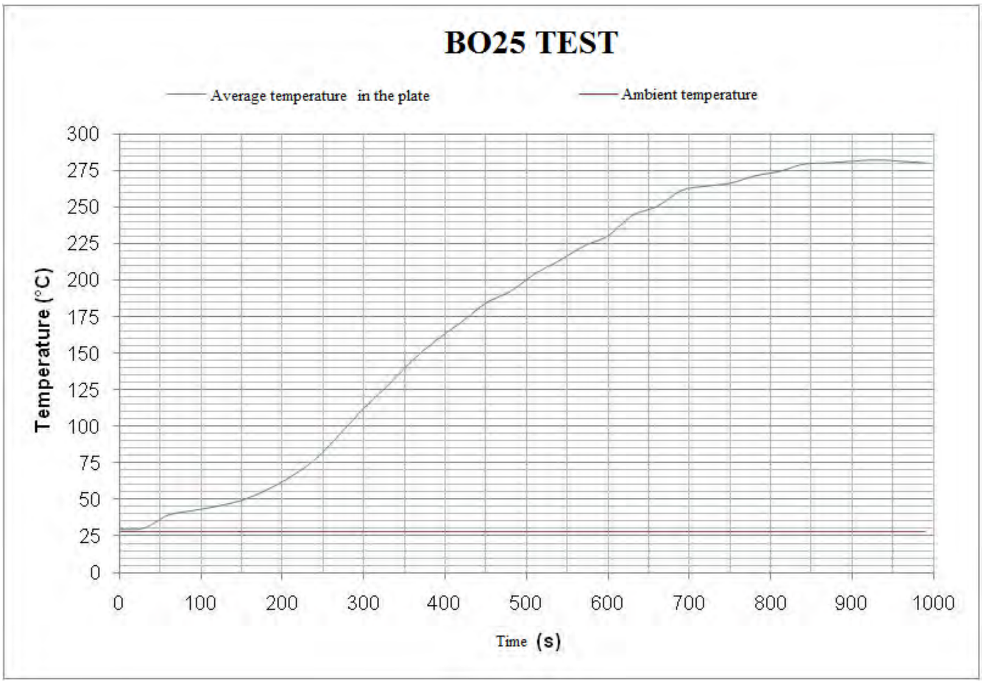

Figure 9. Temperatures in the second test – LPG + 10% BO25

3.4. LPG and BO25 flow

Table 4 shows the results of measurements of fuel consumption for each test. The flow of LPG has not varied in the two trials because there are separate nozzles for each fuel, and the adjustment of the manifold, responsible for the gas flame, remains the same.

Table 4. Hybrid fuel flow record

Parameter	Test 01 Only LPG	Test 02 LPG + 10% BO25	Condition
LPG gas flow (kg/s)	$8{,}51.10^{-5}$	$8{,}51.10^{-5}$	Steady state
BO25 flow (kg/s)	-	$8{,}62.10^{-6}$	
Total flow (kg/s)	$8{,}51.10^{-5}$	$9{,}38.10^{-5}$	

Regarding of the fire modulation time control up/down, it was observed that over two thirds of the time of the test, the bench remained under a low heat and one third over high heat.

3.5. Estimated efficiencies through the results - 1st law of thermodynamics

Table 5 shows the calculated data to estimate the performance of the infrared burner in accordance with conditions established in experimental trials. As mentioned in the methodology, was tried to study the heat transferred from the aluminum plate for the environment and thus achieve an analytical understanding of this performance from the calculation of the efficiencies of the 1st Law of Thermodynamics.

Table 5. Estimated efficiencies of infrared burner

Parameters	Test 01 LPG	Test 02 LPG + 10% BO25	Conditions
Lower heat value (kJ/kg)(1)	48.150	45.294	Steady state
Fuel thermal power (kW)	4,10	4,25	
Heat flow by convection and radiation (kW)	0,36	0,47	
Efficiency of first law of thermodynamics (%)	8,7	11,0	

(1) : whereas 1kg of fuel

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Although the heating value of the hybrid fuel has decreased by 5.9% compared to LPG, the thermal power was increased by 3.6% due to an increase in mass of fuel injected.

The quantity of heat transferred by convection and radiation to the environment, increased by 31.2% because of rising temperatures involved in each test. That ended up influencing the rise in values of efficiency of the infrared burner, resulting in useful energy gain of 26.7%.

In the tests, with the addition of BO25 below 10% the injector nozzle designed clogged. While over 10%, the problem was the clogging of the combustion chamber, due the precipitation of liquid fuel, causing flame return and flame below the ceramic substrate

4. CONCLUSIONS

The experimental methodology adopted in the tests met the proposed objectives, enabling the achievement of concrete results about the performance of the infrared burner running on hybrid fuel LPG/BO25.

The values of viscosity and heating value of bio-oil from pyrolysis of biomass sawdust were consistent with the data presented by Oasmaa and Czernik (1999)

The dilution increased by only 11% of the heating value of bio-oil, but allowed 75.4% decrease in fluid viscosity, improving atomization. Thus, the results provided consistent data for analysis of the parameters.

The injector nozzle designed to perform atomization of BO25 with compressed air met the objective. Visually there was no presence of coke in the ceramic matrix of the burner, thus proving that the atomization process was efficient.

When used BO25 that was stored for more than 15 days, it was observed that the nozzle clogged in some instances, indicating that the bio-oil, even diluted with absolute ethanol, showed polymerization reactions and problems of increase in its viscosity.

After the tests, it was possible the addition of 10% bio-oil diluted in the infrared burner used. This addition led the rise of temperature on the plate of 231 °C, obtained with the burn of LPG, to 281 °C when combined with the atomization of BO25. This is due to improved oxidation of burning hybrid due to excess air in the atomization of bio-oil.

Rising temperatures involved in the tests allowed an increase of 31.2% in quantities of heat transferred by convection and radiation, plus a useful energy gain of 26.7%, according to the elevation of the efficiency of the infrared burner.

5. ACKNOWLEDGEMENTS

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