Parameters Analysis of the Assisted Combustion of Residual Biodiesel Glycerol

Francisco S. Cavalcante Junior [a*], José Cleiton S. Alves [a], Francisco Sales A. Cavalcante [a], and Lutero C. de Lima [a]

[a] *Graduate Program on Applied Physics, State University of Ceará, BRAZIL*

A R T I C L E I N F O

A B S T R A C T

With the increased production of biodiesel, an excess of glycerol is being generated worldwide. One way to reduce the surplus of glycerol would be to use it as low calorific fuel in the own process of biodiesel production. However, being a high viscosity fuel with also high ignition point, its combustion requires severe control and monitoring due to the formation of the toxic pollutants. It is common practice mainly in developing countries to use biomass fuels in rural regions and it looks that with glycerol will not be different. The present article had as objective the construction of a simple chamber for the LPG assisted combustion of the biodiesel residual glycerol and the evaluation of all parameters related to the combustion itself. At a fixed mass flow of LPG different mass flows of glycerol were burnt and parameters such as O_2, CO, CO_2, NOx, exhaust gases temperature, combustion efficiency and excess air were measured.

1. Introduction

With the increase in world production of biodiesel, an excess of glycerol has being generated and many biodiesel producers can no longer give a suitable destination for the huge amount of produced glycerol. As consequence this brings not only reduction of price of glycerol but also the concern about impacts caused by the discharge of glycerol to the environment without adequate treatment (Fernando *et al.*, 2007). Volumetrically, for every 10

liters of biodiesel produced, a liter of glycerol is generated as residue. Glycerol is a co-product from the production of biodiesel and its chemical nomenclature is propane-1,2,3-triol, an organic compound belonging to the family of alcohol. It is odorless, hygroscopic and viscous. The glycerol with purity above 95% is also called glycerin and in its raw form has low commercial value because it may contain residues of methanol, sodium hydroxide, fatty acids, salts, sulfur and other contaminants (Barbosa, 2008). It is used primarily in the food, pharmaceutical and chemical industries. According to the National Petroleum Agency in 2008 Brazil has produced 1.17 billion liters of biodiesel. The production of glycerol was of about 117 million liters however in that year only 11 million liters was consumed by the Brazilian market. As highlighted before many biodiesel producers are concerned about not knowing what to do with the large amounts of glycerol produced. In the recent literature there are many articles related to different applications of glycerol. To name a few, Arechederra *et al.* (2007) performed experiments using glycerol as a source for a fuel cell. According to the researchers there are some peculiar characteristics that make glycerol a good alternative for this application because it is non-toxic, non-volatile, non-flammable at low temperatures, has high energy density, and is abundant due to the fact that it is a byproduct of biodiesel production. Adhikari *et al.* (2009) made a review of different generation methods, catalysts and operating conditions used to produce hydrogen using glycerol as a substrate. They stressed that most of the studies were focused on hydrogen production via steam reforming process and few work has been done on producing hydrogen from crude glycerol.

According to Bohon *et al.* (2011) one possible use for the excessive surplus of glycerol in the market is to use it as a boiler fuel to produce steam and co-generate electricity and if combined with biodiesel production, this has the added advantages of optimizing energy integration, eliminating transportation costs, and displacing the need for fossil fuels. Striugas *et al.* (2008) made analysis of combustion of emulsions of glycerol and heavy fuel oil. They made comparison on emissions of NOx, SO_2 and CO from the emulsions with the emissions of heavy fuel oil and they found better indexes of emission for the emulsions. Still, according to Striugas *et al.* (2008), it is difficult to atomize with conventional equipment because of its high density and viscosity, which means that it must be heated in advance. In fact, glycerol has quite a high auto-ignition temperature (370 °C) compared to other liquid fuels, so it flames up with difficulty. Another consideration highlighted by Striugas *et al.* is that when glycerol is heated around 280 °C, toxic acrolein is produced. They made research about the use of glycerol to

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produce fuel emulsions containing heavy fuel oil. They observed that the burning of such emulsions leads to the decrease in the emission of sulphur dioxide by up to six-fold less than the concentration produced by burning pure heavy fuel oil. They observed too that the concentration of NOx, CO, and SO_2 in the flue gases did not exceed the permissible levels of pollutants emitted from fuel combustion plants, as specified in EU Council Directives.

Patzer (2007) studied the combustion of mixture of glycerol and yellow grease in a chamber without specific adaptations and according to the author the results for the mixture presented better results than the combustion of raw glycerol. The same author stressed that it was not possible to realize a stable process of combustion due to the peculiar characteristics of raw glycerol as a fuel. Asavatesanupap and Santikunaporn (2010) presented a feasibility study on the production of solid fuel from glycerol and agricultural wastes. They mixed ground crop residues, dried durian shell and bagasse with glycerol from biodiesel in various weight ratios. They concluded that solid fuel derived from either dried durian shell or bagasse and glycerol can be used as an alternative fuel according to their energy contents even though amount of acrolein is fairly excessive. Bohon *et al.* (2011) developed a system where the glycerol is pressurized and injected into a combustion chamber. They reported a range of emissions measurements, including nitrogen oxides, total hydrocarbons, and particle mass for two grades of crude glycerol (methylated and demethylated) and compared these to No. 2 fuel oil and propane. They concluded that a properly designed refractory burner can provide the thermal environment to effectively combust glycerol, but that high particulate emissions due to residual catalyst are likely to be an issue for crude glycerol combustion.

Differently from all authors cited above, in the present article the combustion of raw glycerol was made in a simply designed chamber in combination with LPG. In fact LPG was the main fuel in the combustion and glycerol entered as an aggregate aiming to reduce the consumption of LPG. Almost every possible parameters of combustion were evaluated. Parameters such O_2, CO, CO_2, NOx, excess air, combustion efficiency and exhaust gases temperature were measured. These measurements have presented an interesting aspectwhich is the possibility to use raw glycerol as an energetic aggregate to the combustion of LPG representing potentially reduction in the consumption of such important fuel.

* Corresponding author (Francisco S. Cavalcante Junior). Tel/Fax: +55-85-31019902. E-mail address: juniornum@gmail.com

2. Material and Methods

Figure 1 shows a schematic diagram of chamber with accessories designed for the assisted combustion of raw glycerol. The chamber dimensions is 0.75 m height, 0.60 m width and 0.60 m depth and the experimental setup consists of (1) a raw glycerol recipient, (2) valves for the control of glycerol and LPG mass flows, (3) a stainless duct of 3.7 mm internal diameter, (4) inlet to the flue gases analyser, (5) a chimney of 2.4 m length and 6.5 cm internal diameter, (6) a commercial atmospheric LPG burner, (7) a LPG filter, and (8) a LPG tank.
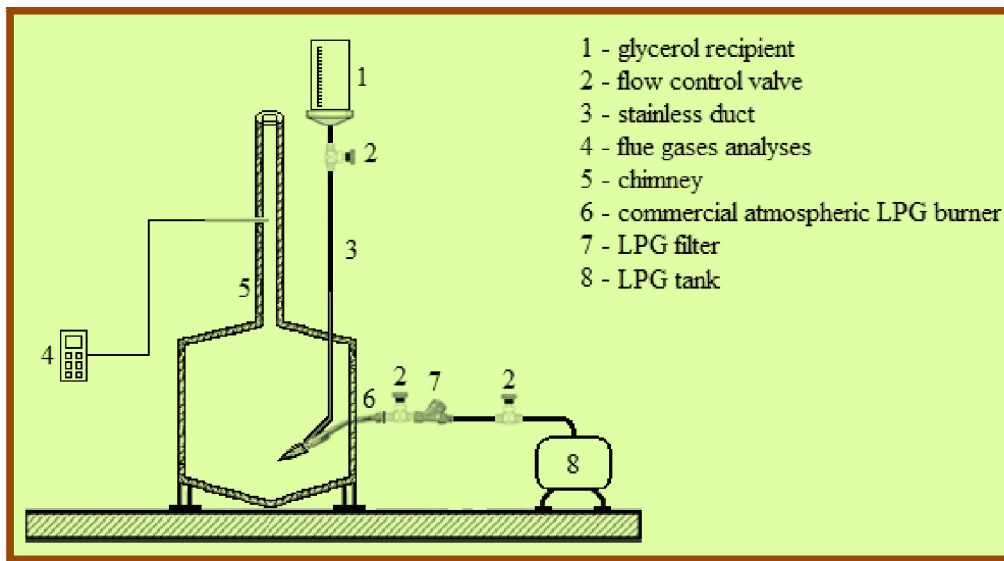

Figure 1: Schematic diagram of the experimental setup.

The LPG burner (Jackwal® - Brazil) with the nominal gas consumption of 0.19 kg/h   was permitted to work until steady-state regime was reached and the oxygen concentration in the flue gases was adjusted to 6.0%. The 6.0% of oxygen in the flue gases is an established criterion in the literature in order to quantify the emission of pollutants in combustion processes (Kuprianov et al., 2010).Raw glycerol at mass flows of 0.036, 0.072, .108 and 0.144 kg/h was fed to the preheated combustion chamber through a stainless duct as shown in Fig. 1. The glycerol feeding duct was maintained parallel and close to the head of the LPG burner in such a way that it burned inside the LPG flame.

The glycerol used was produced in the biodiesel plant in the State of Ceará – Brazil by the Petrobrás Biofuels Company. Basically the biodiesel produced in such Company 20% is derived from cotton and 80% is derived from soybeans. As provided by Petrobrás the glycerol sample contains 81.8% glycerol, 9.8% water, 5.8% ash, and 2.6% organic material.

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According to Metzger (2007) one kilogram of glycerol contains less chemical energy than kerosene and gasoline. Glycerol has an average of 16 MJ per kilogram of chemical energy and kerosene 42.8 MJ and gasoline 44.4 MJ.

All combustion parameters were measured by the flue gases analyser TESTO 330-2 LL. Such analyser has cells for the measurement of oxygen, carbon monoxide and nitrogen oxides. It has also thermocouples for the measurement of the ambient and flue gases temperatures. As provided by the manufacturer of such equipment the uncertainty for the measurement of O_2 is $\pm 0.2\%$. For the measurement of temperature the uncertainty is ± 0.5 °C and for the measurement of the other parameters (CO_2, CO, and NOx) the uncertainty was of $\pm 5\%$.

3. Results and Discussion

Figure 2 presents the oxygen concentration in the flue gases as a function of the glycerol mass flow. As stressed before, the zero mass flow of glycerol corresponds to the situation where only the LPG burner is working and the concentration of oxygen in the flue gases was fixed at 6.0%. For the glycerol mass flows of 36 to 108 g/h the oxygen concentration was in average 5.8% and for the mass flow of 144 g/h the oxygen concentration decreased to 5.3%.
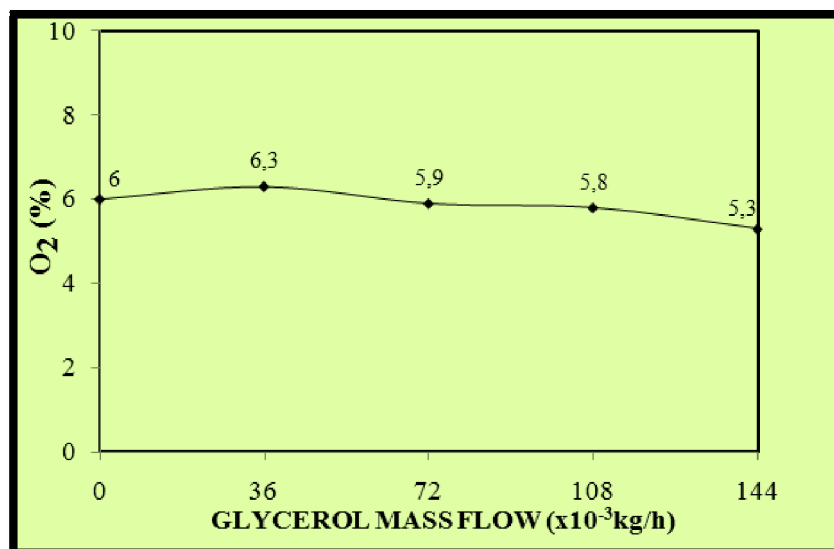

Figure 2: O_2 concentration in the flue gases for different glycerol mass flows

Figure 3 presents the concentration of carbon monoxide as a function of the glycerol mass flow. The percentage of CO increases with the increase in the glycerol mass flow. At zero flow of glycerol and at the fixed percentage of oxygen 6.0% considered for the only combustion of

LPG the CO concentration was of 15 ppm. It increased to 178 ppm at the glycerol mass flow of 144 g/h. Gonzalez *et al.* (2004) considered that this behavior is due to the fact that the furnace temperature rises as the mass flow increases and this contributes to the endothermic reaction $C + CO_2 \leftrightarrow 2CO$. At the other hand, Kuprianov *et al.*(2010) consider that the CO emission exhibits strong influences of both excess air and fuel quality comprehending carbon content and moisture. In general CO decreases with the increase in the excess air. So the reason for the increase of CO as a function of the increase in the glycerol mass flow is possibly due the carbon content of the raw glycerol used since the level of moisture in all samples tested was the same.
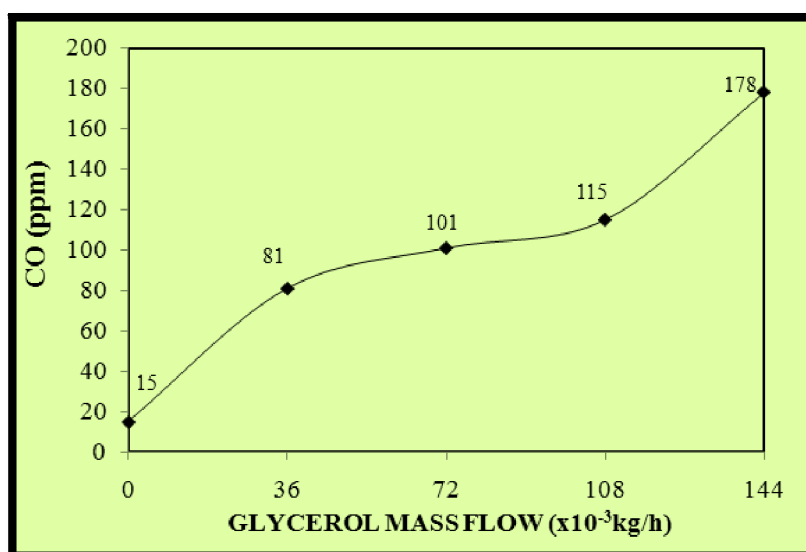

Figure 3: CO concentration in the flue gases for different glycerol mass flows.

Figure 4 presents the temperature and the percentage of carbon dioxide in the flue gases for all glycerol mass flows. It is observed that the percentage of CO_2 increases simultaneously with the increases of the flue gases temperature and glycerol mass flow. This can be explained by the fact that the combustion efficiency can be put as a function of the sensitive heat and not-burnt gaseous losses of the fumes. However the sensitive heat is dependent on the flue gases CO_2 besides fumes and ambient temperature (Gonzales *et al.*, 2004). As also it can be seen in Figure 5 the combustion efficiency kept practically constant (around 83%) at the glycerol flows tested.
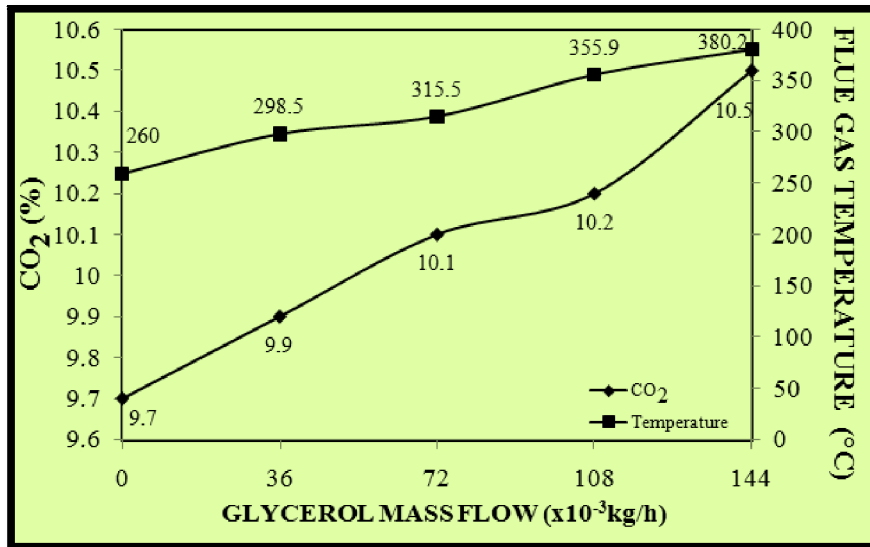
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Figure 4: CO_2 and flue gases temperature for different glycerol mass flows.

Gonzalez *et al.* (2004) observed that fuel mass flow scarcely influences combustion process efficiency, corroborating the finding of this study as depicted in Figure 5. Interestingly, Miranda *et al.* (2007) didn't reach the same conclusion when they studied combined combustion of various phase of olive wastes in a conventional combustor under varying fuel mixture and mass flows.
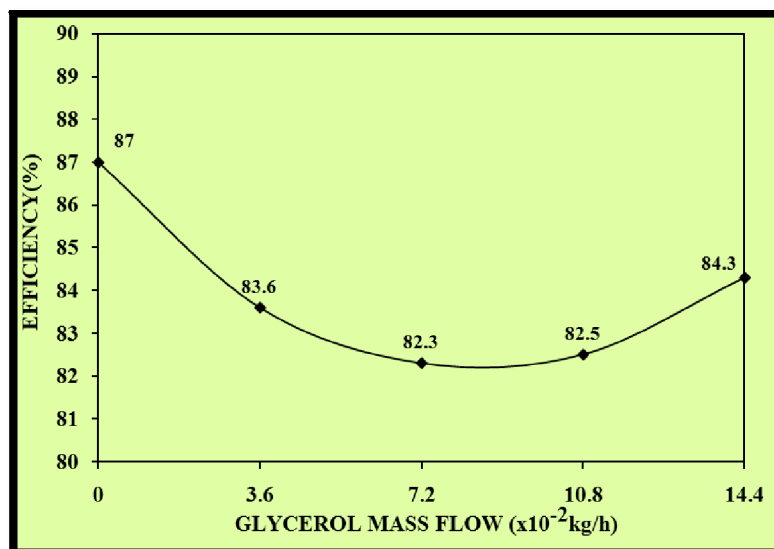

Figure 5: Combustion efficiency against glycerol mass flow.

Figure 6 presents the excess air as a function of the glycerol mass flow. For the reference condition where the only LPG combustion was maintained at 6.0% of oxygen in the flue gases the excess air was of 44.8%. With the introduction of glycerol the excess air decreased to 33.7%

at the mass flow of 144 g/h. This behavior is in some way expected since the more is the mass flow of glycerol the more the oxygen needed for completing the combustion.
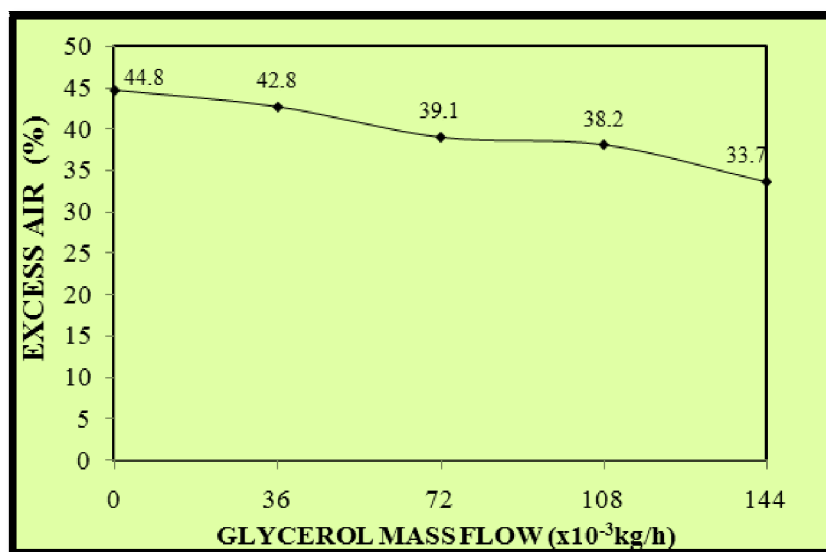

Figure 6: Excess air for different glycerol mass flow.

In order to effectively quantify the emission of pollutants resulted from the assisted combustion of raw glycerol the O_2 was fixed at 6.0% in dry basis and the values of CO and NOx were measured for different mass flows of glycerol. As already shown in Fig. 2, for no flow of glycerol and only burning LPG CO reached 15 ppm. This value reached 81 ppm for the flow of 36 g/h and increased to 178 ppm when the glycerol mass flow was 144 g/h. The same tendency of CO emission was observed by other researchers. Miranda *et al.* (2007) measured CO under the same basis (O_2 6.0%) and found value of about 2000 ppm for the combustion of olive kernel, 5000 ppm for the combustion of pulp and 2500 ppm for the combustion of residual olive pomace. Kuprianov *et al.*(2010) also for the same condition found values of CO at 350 ppm during the combustion of moisturized rice husk in a swirling fluidized-bed combustor. At other hand, Madhiyanon *et al.* (2010) found for the same condition values at the range of 50 to 550 ppm depending on the bed temperature of the combustion of rice-husk in a short combustion-chamber-chamber fluidized-bed combustor.

Figure 7 presents the emission of NOx as a function of glycerol mass flows at the condition of O_2 fixed at 6.0% for the flue gases under dry basis. For the condition of only burning LPG the emitted NOx was 36 ppm. For almost all glycerol mass flows the NOx emissions were about 27 ppm. However at mass flow of 144 g/h the emission reached 29 ppm. Bohon *et al.* (2011)

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found NOx emissions of 7 to 10 ppm for one of their prototype burner under the condition of 0% O_2 and of 160 to 240 ppm for other refractory-lined furnace. They considered differences in burner swirl and excess air, as well as differences in compositions between pure glycerol and actual crude glycerol wastes as the responsible. Miranda *et al.* (2007) found 50 to 120 ppm of NOx emission for their combined combustion of olive combustor. Their emission increased with the increase of the mass flow and flame temperature. Kuprianov *et al.* (2010) measured NOx at about 170 ppm and reduced it to 128 ppm when the best combustion and emission performance of the SFBC was achievable and when burning moisturized rice husk with moisture content of 2-25%, at excess air of 40-50%. Madhiyanon *et al.* (2010) reached almost the same range as Kuprianov *et al.* (2010) when they burned rice husk in SFB combustor.
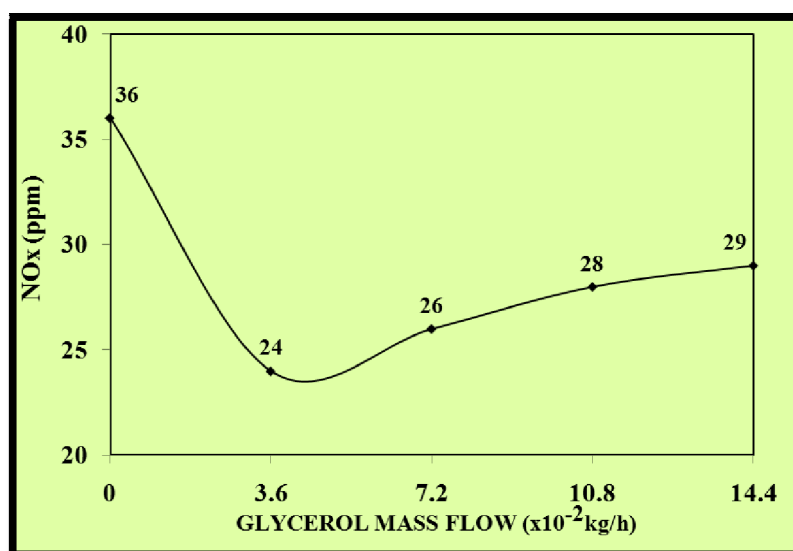

Figure 7: NOx emission at 6.0% O_2 for different glycerol mass flow

4. Conclusion

The LPG assisted combustion of different glycerol mass flows of raw glycerol in a simply designed chamber was realized in this study. Although glycerol is not considered a conventional fuel and presents many problems for its combustion, results in this study indicated that it is possible to burn glycerol. The emission level of CO under the condition of 6.0% O_2 in the flue gases (and in the literature established control condition for the measurements of CO and NOx emissions) for different glycerol mass flows and constant LPG mass flow was considered very high. However the emission of NOx under the same condition was quite low when compared with published experiments of biomass combustion. The pressurized spray of

* Corresponding author (Francisco S. Cavalcante Junior). Tel/Fax: +55-85-31019902. E-mail address: juniornum@gmail.com

glycerol, the formation of ash, particulate matters, and acrolein on the fumes are continued problems for the combustion of glycerol. In the present time the authors of this article are tackling such problems.

5. Acknowledgements

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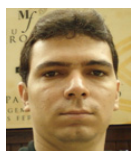
Francisco dos Santos Cavalcante Junior holds a degree in physics from the State University of Ceará. He is currently a student at the Master Program in Applied Physics of that university. In that program he conducts research related to renewable energy with emphasis on biomass combustion

José Cleiton S. Alves graduated in Mechatronic Technology (emphasis in Electrical Engineering) from the Federal Technological Institute of Ceará (2005), graduated in physics from State University of Ceará (2004) and Master of Science in applied physics from UECE, with an emphasis on Alternative Energies. Currently he is working on PetroleoBrasileiro S/A - PETROBRAS serving as the technical operations at the LUBNOR. He has experiences in the areas of Physics, Automation, Robotics, Combustion, Oil and Gas.

Dr.Francisco Sales A. Cavalcante earned his MSc (1996) and PhD(2000) in Physic from Universidade Federal do Ceará. His researches are in renewable energy, atmospheric pollution and respiratory mechanics.

Dr.Lutero Carmo de Lima graduated in Physics by the University of Santo Amaro, M.Sc. and Dr. Eng. in Mechanical Engineering by the Federal University of Santa Catarina and University of São Paulo, respectively. He is presently adjunct Professor at the State University of Ceará and basically works in fundamental problems of the thermal science, clean energy and instrumentation. He was awarded a Fulbright Fellow and inducted as Vice President of PHI BETA DELTA, Chapter Beta Theta, Honour Society for International Scholars, USA.

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