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EXPERIMENTAL EVALUATION OF GAS TURBINE EMISSIONS FUELED WITH BIODIESEL AND BIODIESEL-DIESEL BLEND

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ABSTRACT

Over the past years many researchers have been carrying out studies regarding the use of renewable fuels for internal combustion engines due the environmental and economic aspects. These studies have been conducted mainly applying biodiesel from vegetable oil or animal sources in compression engines. On the other hand, biodiesel can also be used as fuel for gas turbine despite scarce amount of work exists on the literature about this theme. This work reports results of a micro gas turbine running on biodiesel from vegetable source, blends of biodiesel-diesel (B50, B70 and B100) and compare such results with natural gas as fuel. The micro gas turbine was originally designed to operate with natural gas.

INTRODUCTION

Several researchers have been studied renewable fuels for internal combustion engines; however it is important to remember that alternative fuels can and should be tested in other thermal machines. Currently, several countries including Brazil follow a new trend in the energy sector, the development of distributed generation with emphasis on small-scale production. Among the various technologies that can be used in distributed generation and in small-scale, micro-gas turbines have become an excellent technology option. Micro-turbines are small thermal machines operating in the Brayton cycle to produce electricity in the range of 20 to 500 kW.

Diesel engines have several applications as on electrical production, industrial and agricultural activities, at transports of passengers. In all these areas petroleum fuels have been used in combustion engines. Although the undeniable diesel importance as fuel its application in the combustion process causes environmental problems.

Pollutants from diesel fuel combustion include carbon monoxide, CO, carbon dioxide, CO_2, oxides of nitrogen, NOx, sulphur dioxides, SOx and particulate matter. In this point of view a variable investigation on fundamental combustion characteristics and emissions of a heat engine using diesel oil have been conducted [1-4].

In this scenario is that the world is concerned to find alternative fuels that can be used in power machines, a great of attention has been paid to biomass fuels as renewable energy resources. Many types of biomass used for biodiesel production include rapeseed, cottonseed, sunflower, jatropha and palm oils. Palm oil is one of the most promising alternative fuels to liquid fossil fuels [7].

Another goal of the alternative fuels application is the aviation sector [9, 10]. The effect of the aviation fuel with petroleum-based on the environment is significant due to increased air traffic. At this sector the considered engines are the gas turbines to operate fuelled with biofuels. Besides the biodiesel application in automotive sector and heating processes, the use of them in aircraft and land-based gas turbines would benefit the economy and environment.

NOMENCLATURE

ANP	[-]	National Petroleum Agency
ASTM	[-]	American Society for Testing and Materials
BDXX	[-]	Biodiesel percentage indicator in the blend
Comb1	[-]	New fuel
GD	[-]	Distributed Generation
GNV	[-]	Compressed natural gas
HHV	[kJ/kg]	High heating value
$\dot{m}$	[kg/s]	Mass flow
SMD	[μm]	Sauter mean diameter
P	[Pa]	pressure
T	[°C]	temperature

A lot of biomass type has been used as fuel. A theory and experimental study of a biodiesel from vegetable oil have been carried out [1-10]. The analysis of heat transfer rate in various conditions along the furnace and the performance of biodiesel generally are compared with diesel oil. The results showed that diesel oil has a higher heat transfer rate in most parts exposed to flame. In these researches some authors detected that the combustion products have less dark coloration than the products generated by diesel oil, it was also verified that the burner was not presented problems with its operation after replacing diesel fuel by biodiesel.

Investigations on the use of biodiesel and its blends with direct injection diesel engine were realized in the last five years [1-2]. The production of biodiesel from inedible animal fat by the transesterification process and its use in diesel engines, were studied. The chemical properties investigation of fuel, density and viscosity were obtained according to ASTM D6751 and EN 14214. The biodiesel viscosity and density were found close to the value of diesel, the result of the analysis of the calorific value showed to be slightly lower compared to diesel. Addition of biodiesel to diesel promotes a decrease of the engine efficiency and an increase of the specific consumption due to the low calorific value of the biodiesel compared to diesel. Emissions of carbon monoxide (CO), nitrogen oxide (NOx), sulfur dioxide (SO_2) and soot were reduced by about 15%, 38.5%, 72.7% and 56.8 % respectively.

Research conducted in micro turbines started very recently. A study by Nascimento [6] about performance and emissions in a diesel micro turbine of 30 kW using biodiesel blends as fuel showed that the use of biodiesel promotes a slight increase of CO, low NOx emissions and no emission of SO_2. A development on optimization of a gas turbine emissions operating with biodiesel [5] including atomization, vaporization, combustion and emissions of biodiesel was realized and compare with the distillated diesel (DF2). In this the turbine used was a commercial gas turbine Capstone (C30) 30KW known as a micro turbine generator.

The analysis of the vaporization and atomization characteristics suggested that even improving the fuel injection system to reduce the levels of NOx emissions it does not reduce emissions below the level of DF2, therefore, another factor must be associated to this reduction which means that would be required further studies related to kinetic chemical mechanisms to provide better understanding of this case. An investigation about the atomization characteristics of diesel and palm methyl ester (PME), shown that there was no significant difference between the flow rate of the fuels [7]. Relation to the average size of drop (SMD), PME has fewer tendencies to formation of bright flame and soot than diesel and that for the same SMD and kinematic viscosity the NOx emissions from PME is lower than Diesel. The combustion processes are affected by the characteristics of the type of fuel, fuel atomization and injection [11].

The actual study presents an experimental investigation for determining the emissions generated by biodiesel and biodiesel-diesel mixtures. Initially the micro turbine that was designed to operate with natural gas, so the results was compared with this fuel. In the experimental tests the natural gas was change by biodiesel fuel blends in addition of natural gas. The obtained results of the tests include the exit emissions and exhausted temperature.

FUEL PROPERTIES

As the main focus of this study is to evaluate the emissions from a micro turbine operating with an alternative fuel, the determination of some fuel characteristics is important. The development of flexible systems or the adaptation of them to operate with different fuels requires a careful theoretical analysis, since there are many variables to consider such as stoichiometry, dilution, temperature and pressure characteristics of combustion in gas turbines. In the following topics some characteristics of the fuels that were used for this study is presented.

Natural gas

Natural gas is a fossil fuel formed by a mixture of hydrocarbons of low molecular weight, its main component is methane CH4, on the composition there are also propane C3H8, butane C4H10, pentane C5H12, hexane C6H14, isobutane iC4H10. There are minority fractions of carbon dioxide CO2, hydrogen sulfide H_2S, water, nitrogen and mercaptans. The calorific value can vary between 8,000 to 10,000 kcal/m^3 depending on the levels of heavy (ethane and propane) and inert gases (nitrogen and carbon dioxide).

In Brazil the composition of natural gas for the commercial purpose is determined of the act number 104, July 8, 2002 by the National Agency of Petroleum, Natural Gas and Biofuels (ANP). For the experiment it was consider the composition of natural gas defined by the same act 104/2002. The minimum limits of methane, ethane, propane and butane that is used at the southeast Brazilian region was adopted. The composition is shown in the Table 1.

Table 1 Natural gas composition

NATURAL GAS COMPOSITION	
CH_4	86% VOL
C_2H_6	10% VOL
C_3H_8	03% VOL

Diesel

A fossil fuel from distillated petroleum that has variable concentrations of sulfur, nitrogen and metal compounds. The main constituents of diesel are carbon chains from 6 to 30 atoms. Diesel fuel is composed of paraffinic, olefinic and aromatics formulated by mixing various distillations as diesel fuel, heavy naphtha, light and heavy diesel from various stages of processing the crude oil.

The components proportions in diesel fuel are those that allow the finished product fit within the specifications set by the ANP agency. The diesel fuel used in the tests is the same fuel sold to consumers and follows the specifications according to standard ANP 15 OF 03.19.2006.

Biodiesel

Biodiesel can be produced from various raw materials such as vegetable oils, animal fats, waste oils and residual fats from various processes. It can also be used pure or mixture with petroleum diesel in various proportions. In recent years technological developments shows trends for adoption the transesterification as the final process (ASTM - D6751). The biodiesel definition according to ANP agency is a fuel composed of alquilsteres and long-chain fatty acids derived from vegetable oils or animal fats.

Mixtures (compositions) of biodiesel and conventional diesel fuel are the most commonly products distributed for use in the retail diesel fuel. The system known as Factor B is frequently used to indicate the amount of biodiesel in any fuel mixture:

- Biodiesel 100% referred to as B100, while
- Biodiesel 20% labeled as B20
- Biodiesel 5% labeled as B5
- Biodiesel 2% labeled as B2

Following in Table 2 there are some specifications provided by Agropalma about Palmdiesel (PME). Agropalma industry provided the palm oil for development this work.

Table 2 Palm oil specification

	Palmdiesel	ASTM
Glycerol (%)	0,01	0,02 max.
Total glycerides (%)	0,08	0,24 max.
Residual carbon (%)	0,04	0,05 max.
Density (g/cm3)	0,843	0,82 - 0,87
Viscosity – 40°C (mm2/s)	3,98	1,9 - 6
Flash point (°C)	135	100
Copper strip corrosion	1	3
Water (%)	0,03	0,05 max.
Ash (%)	0,015	0,02
Acidity (%)	0,03	0,04

ATOMIZING CHARACTERISTICS

The atomizer was designed to use natural gas with liquid fuel (diesel or biodiesel) as shown in Figure 1. The atomization characteristics as SMD and cone angle of the spray were investigated. Figure 1 shows the experimental apparatus schematic. The fuel is pressurized by the supply of N2 gas in the fuel tank. The fuel is measured using a meter-type flowmeter from Omel manufacturer model number 4Q factory calibrated for a flow rate from 0 to 14 g/s, for a liquid with density 850 kg/m3 located in the fuel line before the injector.

The average size of droplets was measured by a laser system (Malvern MasterizerX) in which traverses the spray by a laser beam, initially parallel spreads through photodiode detectors located on a circular plate, collects the scattered light angular sectors individuals. To analyse the droplet size distribution, the formulation used by the system is the Fraunhofer theory, which states that a parallel beam and monochromatic light passes through a cloud droplets. The pattern obtained is a series of concentric light and dark discs whose spacing between them will depend on the distribution of the droplets. Each detector scans in the order of 2ms, each measure consists of 2,000 scans.

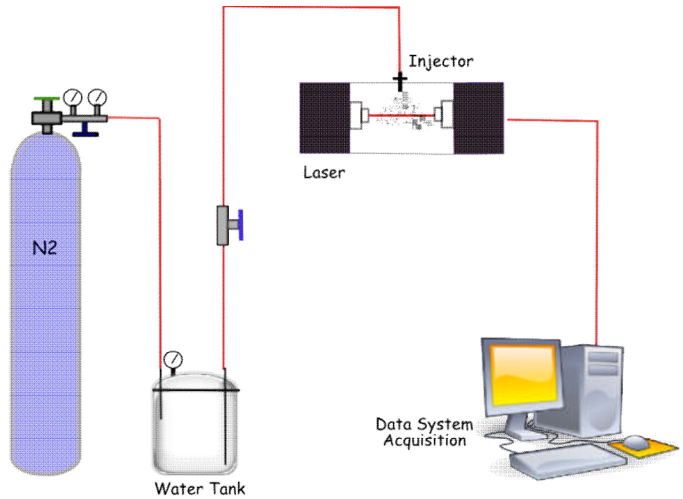


Figura 1 Experimental apparatus of the atomizer system.

EXPERIMENTAL APPARATUS FOR COMBUSTION EXPERIMENT

Figure 2 and Figure 3 show the experimental apparatus as well as the squematic used in testing the micro turbine. The data acquisition and control system of micro turbine is comprised of supervisory software developed at RSView32 platform from Rockwell manufacturer in which it is connected to a programmable logic control (PLC) model MicroLogix 1100. This system receives signals from the transducers, sensors, actuators and controls.

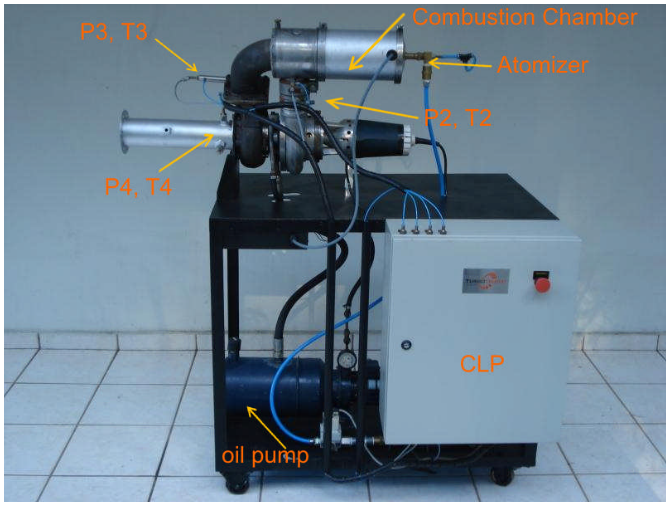


Figure 2 Micro turbine

Temperatures are measured using a thermocouple type K and one thermocouple T at each position. The operating range of the thermocouple type K is 0 to 350°C with an error of ± 1°C and the T-type thermocouple is 0 to 1250°C with an error of ± 2.2°C. The thermocouples are connected to an analog module Rockwell where the signals are sent to the PLC MicroLogix 1100.

The pressure measurements at each point shown in figure 2, was performed using a pressure sensor at each position. The sensor has a measuring range from 0 to 6 bar with an error of 1%. The rotation of the micro turbine is measured by an inductive-type Hall sensor. The counting of pulses is sent from the Hall sensor to a pulse counter Phoenix Contact MCR-f-UI-DC, visualization and control of rotation is made by the supervisory system.

The flow rate of natural gas is measured by an orifice plate, along with software that receives pressure data through a pressure transducer and solves the calculations based on specific data set obtained from the orifice plate, accounting the flow rate. To account the flow rate of liquid fuel (Diesel, Biodiesel and mixtures) a flowmeter manufactured by Omel, model number 4Q factory calibrated for a flow rate from 0 to 14 g/s for a liquid with density 850 kg/m3, was used. The flow meter was recalibrated for each fuel in advance before the tests. The emissions data of CO2, NOx, CO, and O2 were collected using a gas analyzer 8000 and the Greenline program DBGas2000.

The gas analyzer consists of a main unit (MCU, Main Control Unit) and a remote unit (RCU, Remote Control Unit). The gas is collected in the exhaust of the micro turbine through a tube and sent to the MCU. All the data analysis is done on the MCU. The control unit can be configured and controlled remotely through the RCU cable or Bluetooth communication.

A squematic draw in Figure 3 is the experimental apparatus used in this study. At this the air that is sucked from the atmosphere and compressed in the compressor, when it reaches the combustion chamber the combustion processes begins with the fuel which in turn reaches the atomizer through two fuel lines, one that provides natural gas and another that is sent to liquid fuel. With a spark the combustion is initiated, hence the reactions on combustion chamber produces hot gases that expand through the turbine providing shaft work or propulsion.

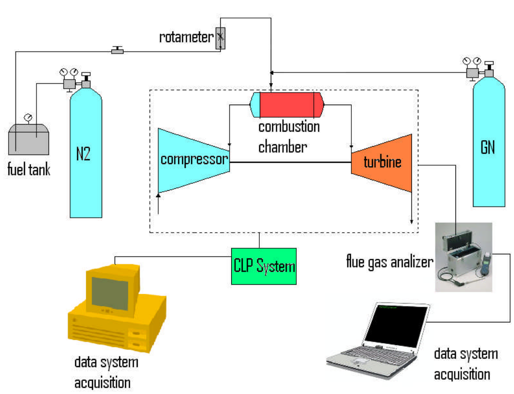


Figure 3 Experimental apparatus system

RESULTS AND DISCUSSION

Figure 4 shows the experimental results measured from SMD, each experimental value presented in figure is the mean value of 25 samples, with a satisfactory repeatability presented a maximum standard deviation of about 0.96% to 4 atm pressure. The increased pressure difference is expected and beneficial to the SMD. It causes the liquid discharge from the atomizer nozzle at high speed, providing a thinner spray, however according to the literature the droplet size presented by the atomizer is in the range of droplets greater than 100 micrometers. So, it has a greater vaporization time, increasing the mixing length and the combustion region.

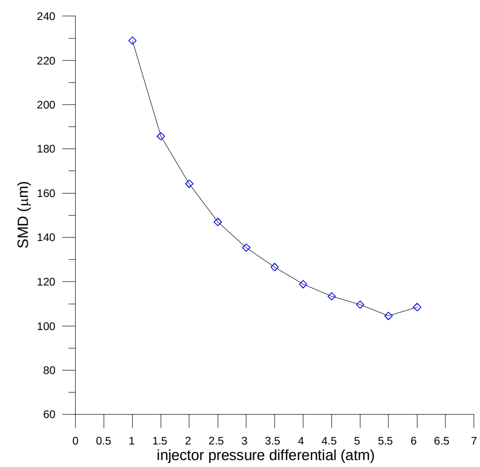


Figure 4 Average size of droplet.

The cone angle increases with pressure, this is easily expected since with increasing pressure and hence the tangential velocity, there is a tendency for the jet to be thrown over the sides increasing the angle. In Figure 5 the consequence of not developing the spray at low pressures is observed. The increase in cone angle of the spray when the pressure increases, cannot be noted for the atomizer, this is due to the geometrical characteristics of the injector.

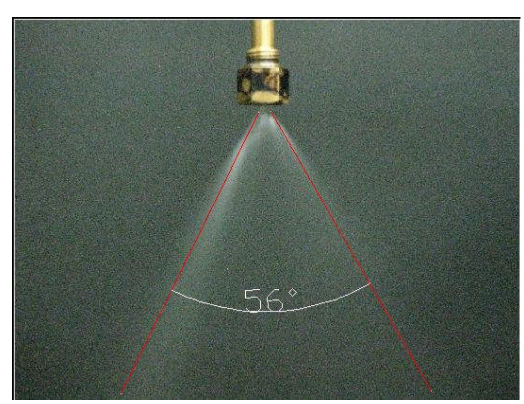


Figure 5 Atomizer system

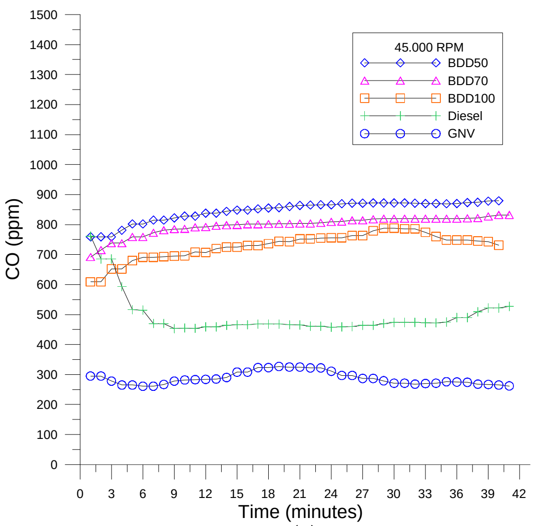
Analysis of emissions and gas temperature of exhausted for rotation of 45,000 rpm. CO_2 Emissions: Figure 7 compares CO_2

emissions of NG, Diesel, Biodiesel and blends, for all blends was an increase in emissions compared to NG from 17.76% for BDD50, 66.44% for BDD70, 69.97% for BDD100, and 76.97% for diesel oil.

CO emissions: figure 6 shows the comparison of CO for the fuels NG, Diesel, Biodiesel and blends; for all blends was an increase in emissions compared to NG from 2.53% for BDD50, 2.57% for BDD70, 2.69% for BDD100, and 1.79% for diesel oil.

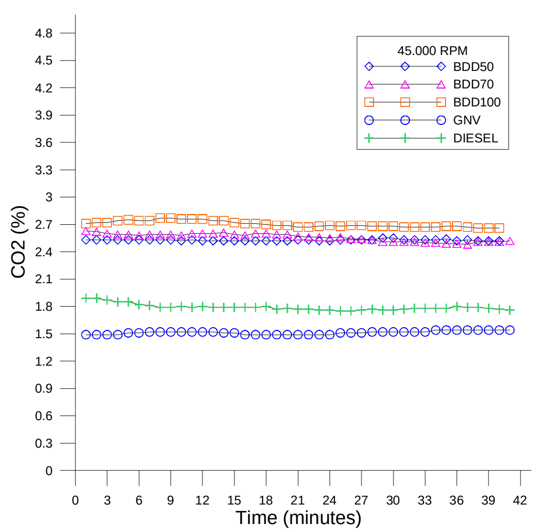
NOx emissions, Figure 8: can be observed that there was an increase of 12.5% in emissions compared to NG for Diesel BDD100. For BDD50 and BDD70 remained the same levels of emissions when compared to NG.

Gas temperature: it was observed, in Figure 9, that for all blends has an increase in temperature when compared to NG. This increase was of 39.40% for BDD50, 60.24% for the BDD70, 72.20% for BDD100, and 69.14% for diesel oil.



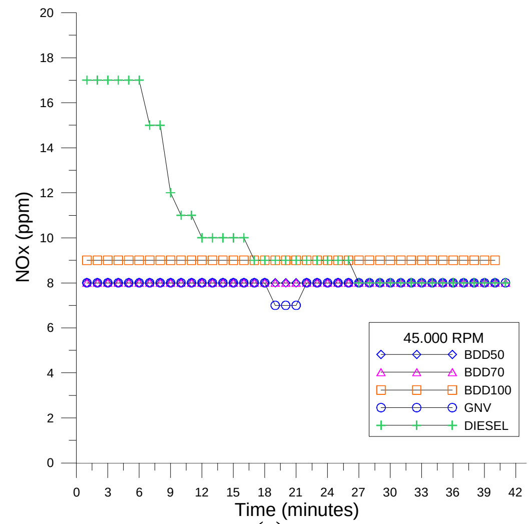
(a)

Figure 6 CO Emissions



(b)

Figure 7 CO_2 Emissions



(c)

Figure 8 NO_x Emissions

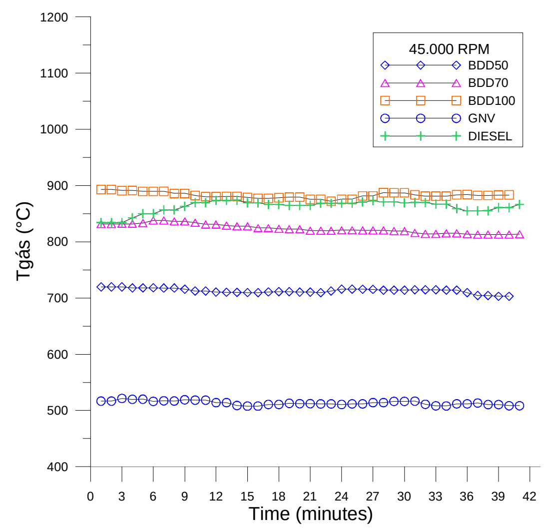


Figure 9 Exhaust temperatures.

CONCLUSION

Analyzing the results presented by the atomizer, comparing with the work of Hashimoto [7], for the SMD-type atomizing low pressure swirl SMD is presented in the range of 80 to 120 micrometers. So the atomizer used in this work presents a medium size drop much larger than that found in the literature, and cone angles were slightly lower for the same variation of pressure.

The emission results are primarily influenced by the equivalence ratio in the primary zone, the average size of droplet and the geometry of the combustion chamber. Since the combustion chamber is designed to operate with natural gas it has reduced geometries and thus impacting on the result of emissions for the combustion of liquid fuels like Diesel and Biodiesel.

Based on this statement we can conclude that for the rotation of 45,000 rpm the diesel oil had lower rates of CO and CO_2, while the BDD100 showed lower levels of NOx and temperature of gases. For rotation of 60,000 rpm, diesel had lower rates of CO and CO_2, while the BDD50 showed lower levels of NOx and temperature of gases.

However to obtain more conclusive results we should subsequently improve the atomizer, and modify the geometry of the combustion chamber in order to obtain similar combustion conditions for all fuels and operating conditions pre-established.

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