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PERFORMANCE ANALYSIS OF A DIESEL ENGINE OPERATING WITH TERNARY MIXTURES OF DIESEL, BIODIESEL AND ETHANOL.

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Abstract. *Alternative internal combustion engines are widely used by all countries in the world, mainly in the transport sector, implying a constant increase in the consumption of fossil fuels, such as diesel and gasoline, among others. There are many searches that look for ways to reduce this consumption without considerable loss of thermal efficiency of the engine. To this end, alternative fuels such as biodiesel, vegetable oil, ethanol and other fuels are currently used. Biofuels mixed with fossil fuels marketed in Brazil has been growing over the years as an alternative to reduce pollutant emissions from combustion, which are quite harmful to human health. The objective of this paper is to analyze the influence of the anhydrous ethanol (EA) in diesel oil addition's, in concentrations of 5% and 10%. For the tests, a direct injection single-cylinder diesel generator set was used. The diesel oil used in the tests was commercial diesel S10, 8% biodiesel blend with 72% diesel oil (B8) and anhydrous ethanol with 99% purity. The parameters analyzed were power, gas temperature, specific fuel consumption and thermal efficiency of the engine. In order to obtain these results, it was necessary to perform the engine instrumentation, located in the engine laboratory of the Federal University of Pará. Through this study, it is expected to identify the viability of this ternary mixture for diesel engines.*

Keywords: *Ternary Mixture, Diesel engine, Ethanol.*

1. INTRODUCTION

The world's largest energy consumption is of non-renewable origin: oil and its by-products. Therefore, the use of biofuels seeks to reduce dependence on petroleum, offering more options to users in the face of the scarcity of fuels derived from petroleum (ESTRADA et al., Jul, 2016). In Brazil the consumption of diesel oil can be divided into three major sectors: transportation, which represents more than 75% of the total consumed; agriculture, accounting for 16%; and the transformation, which uses the product to generate electric energy, corresponding to 5% of the total diesel consumed in the country (MORETTI, 2013). Diesel is the most consumed fuel in Brazil, as well as it contributes most to air pollution, making it necessary to improve its quality, as an important step towards the reduction of contaminants.

With this growing demand, a great deal of effort has been made in the last decades to reduce the emissions of polluting gases from internal combustion engines through the modernization of mechanical components, electronic fuel injection control systems, emission control systems and utilization of alternative fuels (OLIVEIRA, 2015).

In order to reduce the pollutant emissions from the burning of fossil fuels, the use of biofuels mixed with fuels marketed in Brazil has been growing over the years. Currently in Brazil, pure fossil fuels are not marketed; biodiesel is incorporated in diesel, and ethanol is incorporated in gasoline. In 2017 the percentage of biodiesel present in the diesel mix increased from 7% to 8%, with a new increase expected in 2019 to 10% (VIEIRA, 2016).

An alternative to reduce the use of pure diesel oil is its mixture with ethanol, seeking to maintain fuel quality and combustion efficiency, while reducing harmful agents to the environment (MORETTI, 2013). Brazil already has an advanced technology to obtain ethanol from sugarcane, being this fuel widely used in the national market, not only in engines driven exclusively by alcohol but also in gasoline engines, as an additive because of its proven anti-knock characteristics (SANTOS et al. al., 2004). To achieve this, it is necessary to analyze the combustion process that occurs in the diesel engine when it operates with the ternary mixtures of diesel, biodiesel and ethanol.

The feasibility of using ethanol in diesel engines can benefit companies that use diesel fuel as fuel in trucks, agricultural machines and electric power generating groups, by setting up factories to produce ethanol for their own consumption, avoiding transportation to the diesel oil to be used (OLIVEIRA, 2015). Thus, it will have not only the benefit of reducing CO2 emission levels but also an economic gain by avoiding transport costs.

The most attractive properties of ethanol as a fuel for internal combustion engines is that it can be produced from renewable energy sources such as sugar cane, cassava, many types of biomass waste material, corn and barley. In addition, ethanol has higher vaporization heat, oxygen content and flammability temperature and therefore has a positive influence on engine performance and emission characteristics of the CI engine (GNANAMOORTHI; DEVARADJANE, 2012).

When engines operated with diesel oil and ethanol, in all replacement ranges, the maximum powers are reduced. The increase in specific fuel consumption, noise intensity and ignition delay is obtained when compared to typical values in the standard engine mode using diesel. In these situations, the magnitude increases according to the percentage increase of the ethanol used in the fuel mixture (MORAIS, 2016).

The appropriate ratios for using a renewable fuel blend, respecting the physico-chemical properties established as standard for diesel oil are 84% diesel, 4.75% anhydrous ethanol, 0.25% hydrated ethanol and 11% biodiesel (MORETTI, 2013).

The objective of this paper is to evaluate the performance of a single cylinder diesel engine, burning commercial diesel fuel + Biodiesel - B8 and compare it with the performance of this same engine by burning the mixtures of B8 + 5% and 10% anhydrous ethanol, analyzing the power, fuel consumption, gas temperature and engine thermal efficiency.

2. EXPERIMENTAL PROCEDURE

For the performance tests, a BD-6500 BRANCO diesel generator, single-cylinder, direct-injection, air-cooled, compression-ignition engine was used without any alteration that decharacterizes the engine of the manufacturer's specifications, to show a comparison between diesel and ethanol blends.

2.1. Engine Instrumentation

The engine was instrumented and submitted to different load conditions according to table1, based on the apparatus assembled by (ROCHA, 2016), to measure and monitor temperatures, electric power, fuel consumption, mass air flow.

- In the temperature measurement, three K-type thermocouples were used, one for measuring the intake air, one for the exhaust gas and one for the fuel entering the injection pump.
- For the fuel consumption measurement, a precision digital scale DIGIMED DG-15WT of 1mg
- In the measurement of the mass flow rate of the intake air, the MAF HFM 5 meter,
- All of these instruments generated data that were automatically stored in the COMTEMP A202, acquirer and monitored by a DAQFactory-Pro v16.2 graphical interface.
- Electric power was measured using the Landis + Gyr SAGA4500, yielding performance curves for 60%, 80% and 100% engine load.

Table 1: Engine instrumentation

Instrument	Measurement	Precision	Unity
Type K Thermocouple	Temperature	1,0	°C
Digital Scale	Fuel Mass Flow	0,001	G
MAF HFM 5	Air Mass Flow	3%	Kg/h
SAGA4500	Electric Power	1%	W

2.2. Ternary Blends As Fuels

According to (ESTRADA et al., Jul, 2016) the addition of ethanol in the diesel oil causes, in the last physical and chemical changes, a notable reduction in the number of cetane, viscosity and flash point. These modifications alter the characteristics of the fuel injected in the cylinder, the quality of combustion and the emissions of pollutants from the engine. In this work, the ternary mixtures as fuels are to improve the conditions that the diesel oil offers as a pollutant and the modifications that ethanol causes in the internal combustion engine.

According to (VIEIRA, 2016), the use of emulsifiers and cetane number elevators allowed up to 5% of ethanol addition, with 8% values being theoretically possible. Although values above these are considered to be very high, ABU-QUDAIS, HADDAD and QUDAISAT have stated that the best compromise in terms of emission reduction would be close to 15% ethanol. The use of biodiesel then becomes an interesting idea, considering its use as an additive that allows higher concentrations of ethanol in the mixture because its molecule has polar and nonpolar parts.

A sample of each fuel was withdrawn and measured in appropriate graduated beakers for laboratory analysis for best results and comparisons after the tests performed.

For the beginning of the tests, the fuel samples were analyzed to determine the specific mass, the viscosity and the higher calorific value (HCV), according to Tab.2, below.

Table 2: Physical properties of fuels.

Fuel	Specific Gravity [kg/mm³]	Viscosity [CST]	HCV [kcal/kg]
Diesel	835,0	2,9 – 4,5	10950
Anhydrous Ethanol	791,5	1,2	6500
B8 + 5%EA	812,2	2,9	10728
B8 + 7%EA	804,5	2,9	10639
B8 + 10%EA	796,7	2,8	10505

2.3. Mechanical Tests

The first test was carried out using B8 diesel without addition of ethanol, with duration of 65 minutes, divided into four stages. The first 20 minutes of engine operation were done without load, so the engine entered the working temperature conditions and stabilized the operating regime. The next three stages lasted 15 minutes, with the addition of 60%, 80% and 100% engine loads. The data from the first test will be used as a benchmark for engine performance. These assays were repeated three times for greater consistency in the results.

Thus, new tests were carried out using the same time of the reference test and the tertiary mixtures B8 + 5% EA, B8 + 7% EA and B8 + 10% EA as motor fuel. These mixtures are referenced in the literature (VIEIRA, 2016) and (OLIVEIRA, 2015), following strictly the same process and methodology of the first reference test.

The comparative analysis was performed from the parameters of power, gas temperature and specific fuel consumption. The specific consumption was determined by eq. 1, de (BRUNETTI, 2002), using the values of power, mass fuel flow and motor thermal efficiency, determined by eq. 2, de (BRUNETTI, 2002), identifying the values of the lower calorific value - PCI. To obtain these results, it was necessary to perform the instrumentation of a compression ignition engine, located in the engine laboratory of the Federal University of Pará.

$$C_{esp} = \frac{\dot{m}_{comb}}{N_e} \quad (1)$$

$$\eta_{tglobal} = \frac{N_e}{\dot{m}_{comb} \times PCI} \quad (2)$$

3. RESULTS AND DISCUSSIONS

Among the tests carried out, the first round of tests was discarded due to inconsistencies in the measurements performed; the two series of tests used were performed according to the methodology described and the instrumentations mentioned above. A range of results were obtained, which were treated, analyzed and plotted graphically on the office Excel 2010 platform, for a better visualization of the performance of the ternary mixtures and their use for later tests.

Figure 1 shows the temperature values of the engine emission gases, observing the increase of the exhaust gas temperature as the percentage of Ethanol Anhydrous was added in the burned fuel mixture. Among the measured temperature values, the temperature gain with the addition of 7% EA was 13% of the value of the temperature at the burning with the B8 fuel.

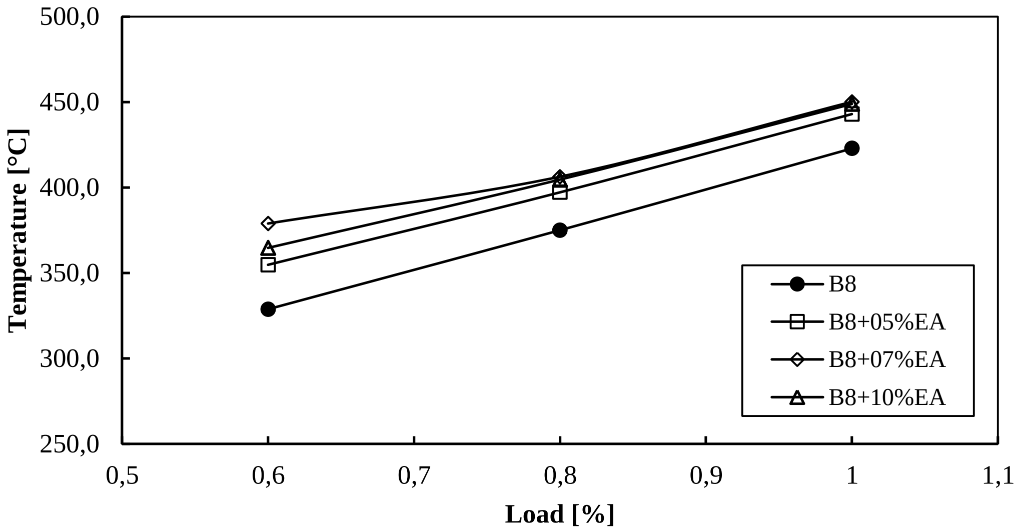

Figure 1: Exhaust gas temperature for different loads

Figure 2 shows the mass flow rate of fuel, which relates the increase in specific consumption with the increase in EA concentration, except in the mixture with 5% EA which showed lower fuel consumption. The fuel consumption values for the 5% EA blend were very close to the reference values using only B8.

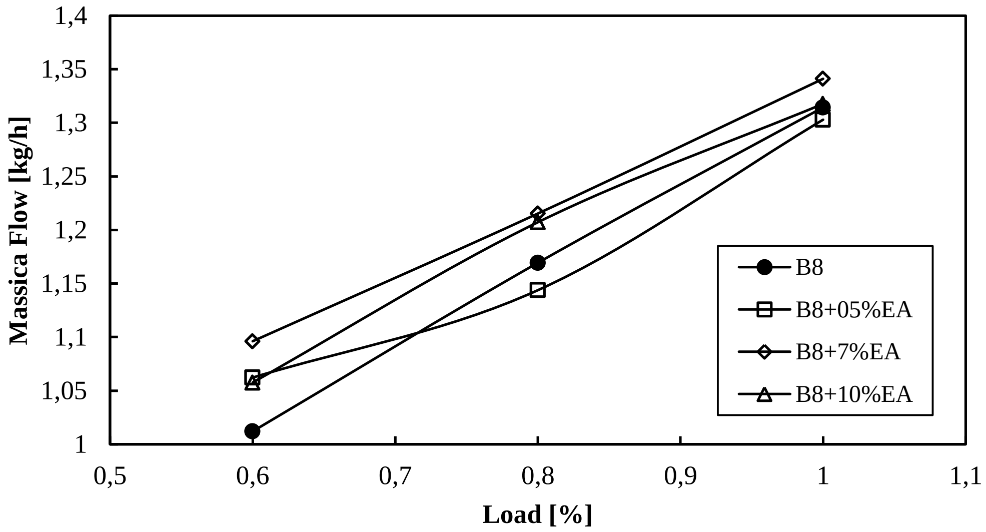

Figure 2: Mass fuel flow for different loads

The generated electric power curves were also obtained, shown in Fig. 3, which describes a large drop in the power of the generator when anhydrous ethanol was added to the mixture, expressing a drop of approximately 245W. It was also observed the increase of the specific engine consumption, as shown in Fig. 4, due to the use of ethanol in the fuel mixture.

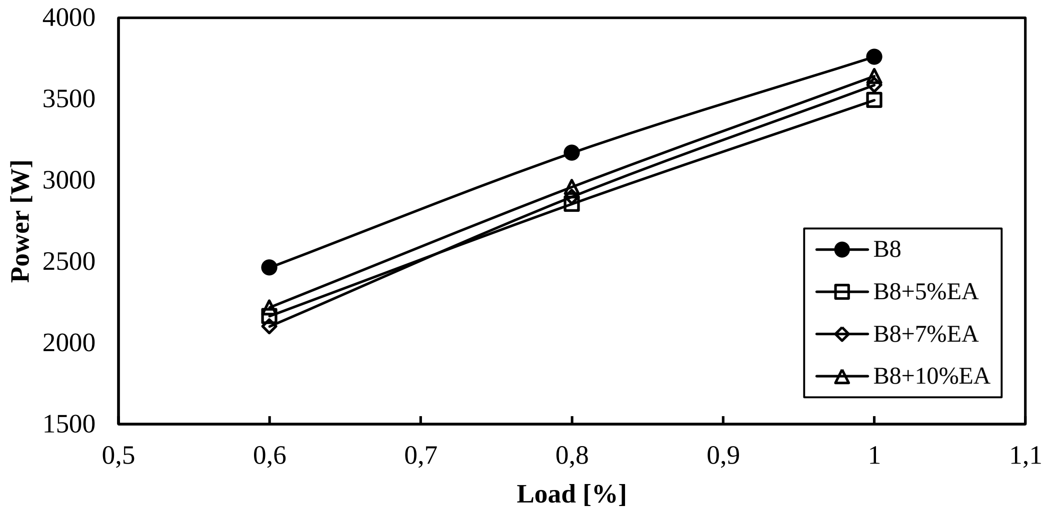

Figure 3: Power for different loads

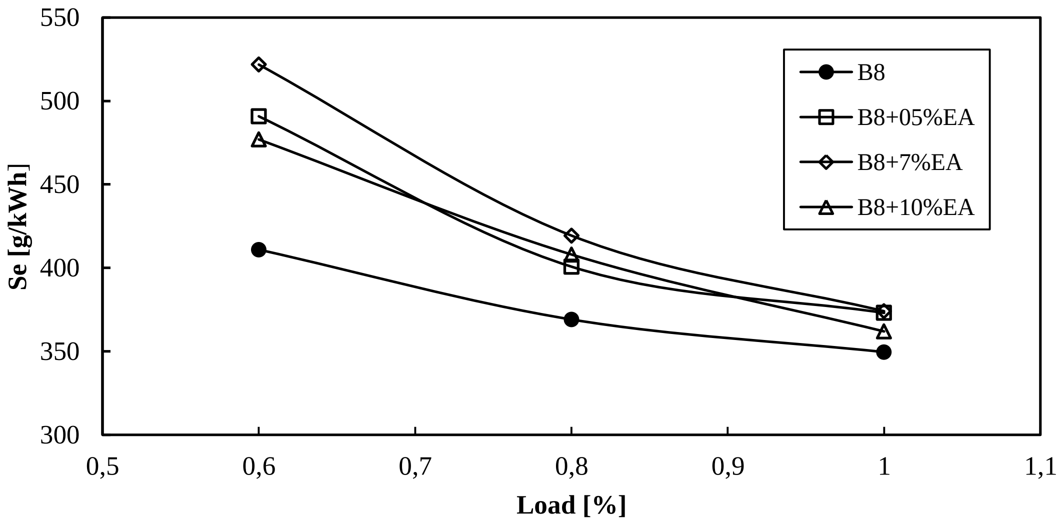

Figure 4: Specific consumption for different loads

It was discovered that the ternary mixture with 5% anhydrous ethanol was the best of the several blends tested with the percentage of up to 10% EA, showing the most similar to diesel; since, for a single cylinder engine, a great difficulty in the stability of the combustion was identified that allows a regime of continuous operation. Among the mixtures tested, the most likely mixture to decrease the use of diesel fuel (a non-renewable fossil fuel) in the fuel composition, which did not significantly affect engine performance, was the 5% addition of anhydrous Ethanol to B8 12.6% of biofuel used.

The idea is to produce diesel-equivalent or near-diesel performance fuels that are economical and cost-effective for large, power-generating companies that still operate on diesel, such as long-haul trucks that travel for long periods of time long distances.

4. CONCLUSION

This paper searches new ways of replacing diesel with less polluting and more economical fuels. Therefore, ternary mixtures of diesel + biodiesel + 5%, 7% and 10% anhydrous ethanol were tested. The comparative evaluation was performed based on the parameters of power, gas temperature, specific fuel consumption and thermal efficiency of the engine.

After all the tests, mixtures containing 5% and 7% EA were found to have reached a certain degree of stability under running conditions. However, the mixture containing 10% EA had a great difficulty to stabilize in operating mode, due to the variation of power caused by the injector pump regulating system, which equips the motor used in the tests, thus making it difficult to measure values more unstable and reliable as the load was varied.

In this way, the feasibility, in this first moment, focuses only on the interpretation of the test with the ternary mixture of 5%, which, in turn, stabilized the operating regime by presenting increased fuel consumption, exhaust gas temperature and decrease of effective power.

After all the completed experiments, it is possible to conclude the reduction of the overall efficiency for the use of the EA mixtures, from the increase of the specific consumption, because there is an inversely proportional relation between the two quantities. The experiment was performed in a single-cylinder engine, which made it difficult to perform better using ternary mixtures with more than 5% EA, due to the longer burning times. These problems, however, can be minimized if motors with more than one cylinder are used.

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6. RESPONSIBILITY NOTICE