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SCIENTIFIC PAPER

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COMBUSTION PERFORMANCE OF BIO-GASOLINE PRODUCED BY WASTE FISH OIL PYROLYSIS

Article Highlights

- Bio-gasoline obtained from waste fish oil pyrolysis was used as an additive
- Bio-gasoline was tested in a Honda CG 125 cc motorcycle engine
- Its performance was evaluated in terms of torque, consumption and gas emission
- At 4000 rpm the torque increased with the concentration of bio-gasoline
- The presence of bio-gasoline promoted lower concentrations for the evaluated gases

Abstract

Pyrolysis of triglycerides based on biomass was used at a large scale for fuel supply during the world wars. For this study, the bio-oil produced from waste fish oil pyrolysis was fractioned in a distillation column to produce a light fraction cut in the range of gasoline. This biofuel was tested in a motorcycle engine to measure its performance in terms of torque and to analyse its exhaust gas composition. The emissions were assessed by exploring the combustion of a fossil gasoline without additives and with blends of bio-gasoline, BG20 and BG30 fuels, meaning 20 and 30% of bio-gasoline in fossil gasoline, respectively. Results allowed for the identification of the torque and emission gases combinations for each fuel type and the determination that as the percentage of bio-gasoline in the gasoline was increased, the concentration of CO_2, CH_4, C_2H_6, C_3H_8 *decreased in direct relation to the engine rotation. The results show that bio-gasoline can be used as an additive of fossil gasoline with gains of performance in terms of torque and lower concentration of* CO_2 *in the emissions. The torque increased from 3.5 to 3.7 N m and from 4.0 to 5.0 N m in fifth gear and at 2000 and 4000 rpm, respectively.*

Keywords: biomass pyrolysis, waste fish oil, bio-gasoline, gas emission, motorcycle engine.

Energy supply resources are currently responsible for local and global environmental impacts [1]. Important technological developments in renewable energy are focused on the fields of solar, eolic and bioenergy, capable of minimizing the dependency on traditional fossil fuel and, therefore, substantially contributing to the minimization of the greenhouse effect. The use of fossil fuels can be considered as one of the responsible contributors. To minimize these impacts, research centers have invested in the development of studies that propose alternative and more accessible energy sources, technologically capable of fulfilling current and future generations' energy demands [2-6].

In recent years, several technological advances were developed, especially ones related to liquefied petroleum gas, natural gas compression, liquefied natural gas, methanol, ethanol, biodiesel and synthetic biofuels. Many of these technologies result in significant environmental benefits when compared to fossil fuels. On the other hand, some of these are costly technologies that, when used in the transportation sector, demand mechanical modifications to vehicles, and a new infrastructure for their separation and distribution [7,8].

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The renewable energy sources, particularly biomass, offer an alternative for the reduction and gradual substitution of declining fossil fuel resources [9]. Biomass is the only renewable source able to produce solid, gaseous and liquid fuels [10]. Biomass can be used in a range of energy conversion technologies such as direct combustion, thermochemical, biochemical and agrochemical processes [11], and pyrolysis and gasification are relevant techniques for the conversion of biomass into useful liquid and gaseous fuels [10] without requiring modifications in engines and in fuel logistics.

In this context, 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 [12,13]. The fast pyrolysis converts triglycerides into fuels promoting an increase in the bio-oil production of bio-oil (liquid fraction). The method is characterized by a reactor operation temperature of around 500 °C, short vapor residence time (0.5-20 s) and high heating rates [14,15]. In some pyrolysis processes, like petroleum catalytic cracking, water is added to increase the heat transfer, due to the radiation properties of water, and to reduce coke formation [16]. In fact, the fast pyrolysis of triglycerides has been investigated with the aim to be used in biofuel production [4,17,18]. According to the pyrolysis reaction scheme, presented by Maher and Bressler [19], many different chemical groups can be produced during the pyrolysis reaction. The bio-oil obtained from triglyceride pyrolysis has a very complex composition and requires the use chromatography for a precise determination of the composition [20]. This bio-oil can be used directly as a fuel or can be fractionated to obtain purified hydrocarbons in the range of gasoline and diesel. These biofuels have been compared to fossil fuels and the results show partial agreement with fossil fuel specifications [7,21,22].

Bio-oil has a large variety of compositions as a function of the feedstock. It can be produced from biomass based on triglycerides like soybean [18], castor [4,23,24] and canola [25], as well as animal fats [26], lard, poultry fat [27] and fish oil [17], and the major products are alkanes, alkenes, ketones, aldehydes, aromatics and carboxylic acids. In fact, bio-oils from triglycerides are quite different from those obtained based on lignocellulose materials [28].

The pyrolysis processing of biomass, whether made up of lignocellulosic compounds, or triglycerides, results in the creation of three fractions, as follows: liquid, solid and gaseous. A non-condensable by-product [21], the gaseous fraction, known as biogas, is made up of carbon dioxide, carbon monoxide, methane, hydrogen, and other light hydrocarbons in the range of C2-C4. The yields and the composition of the biogas depend on the feedstock being processed and the reaction conditions. On the other hand, the bio-oil is made up of mainly hydrocarbons and the solid fraction is known as char.

Indeed, the bio-oil cited has the potential and the characteristics to replace fossil oils and when fractionated and upgraded, yields hydrocarbons in the range of commercial fuels, which can be obtained [7,17,21,29]. Wiggers *et al.* [7,21] performed the pyrolysis of waste fish oil in a continuous pyrolysis plant and the products were distilled to obtain light and heavy cuts and were compared to the Brazilian fuel specifications. Wisniewski *et al.* [17] provide some results of the chemical composition of biofuels obtained from waste fish oil pyrolysis, such as aromatics and olefins, and according to the author these compounds indicate the possibility of applying the light fraction directly as biofuel or blending it with other fuels. Waste fish oil and its derivates (used frying oil of fish [30, 31], *Cyprinus carpio* fish oil [32], blend of castor seed oil and waste fish oil [33] are also described in literature for the production of biodiesel, with results within specified limits according to the ASTM standards.

The results presented in the literature show that the fast pyrolysis process represents an alternative technique for the large-scale production of biofuels from waste fish oil with characteristics similar to petroleum fuels [7,21]. Blends of diesel oil with vegetable oil or waste oil is an alternative being used. However, these blended fuels do not reach the fuel quality standards established by governments and by the engine constructors. Corrosion and polymerization are typical consequences of this use in the medium term. The benefit of a biofuel produced by pyrolysis is the compatibility with actual standards of engines. In this way, the main contribution of the present work was to test a biogasoline (light fraction of a distilled bio-oil) in an experimental apparatus designed to evaluate the combustion performance in a motorcycle engine, in terms of torque and quality of the emissions.

EXPERIMENTAL

Description of experimental apparatus

Figure 1 shows an experimental apparatus which was built to evaluate the engine operation and for data acquisition of combustion performance. The metallic structure is coupled with the engine and it makes possible to collect exhaust gas samples for both chemical analysis and measurement of engine power.

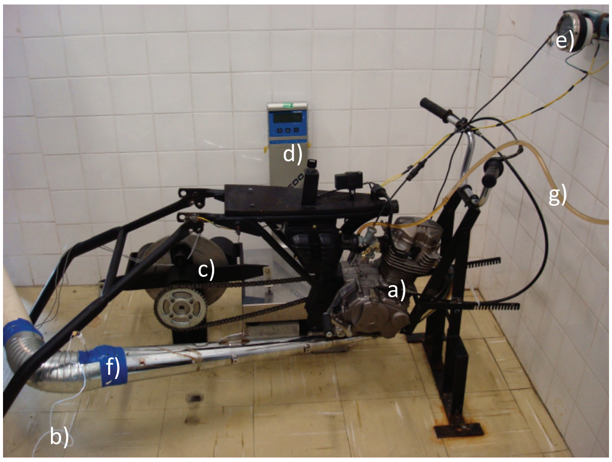

Figure 1. Experimental apparatus used for data acquisition: a) Honda CG 125 cc motorcycle engine; b) gas sampling; c) analogical tachometer; d) dynamometer; e) PT100 thermocouple; f) pipe to combustion gases exhaustion; g) fuel supply system.

Characteristic of fuel used in experiments

In the apparatus showed in Figure 1, the following fuels were used to perform the experiments: Podium® gasoline (G) and bio-gasoline (BG) from pyrolysis of fish oil [7,17,21]. The two fuels were mixed by using volumetric proportions with graduated pipettes and beakers, to produce blends as follows: a) 100% podium gasoline (G100); b) b) 80% of G and 20% of BG (BG20); c) 70% of G and 30% BG (BG30). The combustion tests enabled the assessment and evaluation of the torque and quality of gases emissions related to carbon dioxide, methane, ethane, and propane content, for the fuel blends cited above.

The Podium gasoline used in the work was a premium gasoline typically commercialized in Brazil, blended with anhydrous ethanol (added as an anti-knocking component), while the bio-gasoline was obtained by the thermal cracking of waste fish oil according to the experiments performed by Wiggers *et al.* [21]. Experiments were performed in a pilot-scale tubular pyrolysis reactor under continuous and steady-state operation, with a feed rate of 3 kg h^{-1}, and isothermally operated at 525 °C. The products from the thermal cracking process were purified by a simple atmospheric distillation, from initial boiling point up to 220 °C, resulting in a light fraction with a high heating value of 40.8 MJ/kg, similar to fossil gasoline as it pertains to its physical and chemical properties, according to chromatographic analysis performed by Wisniewski *et al.* [17].

Operation of apparatus

The mechanical apparatus for the tests was assembled from a Honda CG 125 motorcycle engine displacement, built in 1996. The engine was disassembled, cleaned and restored, maintaining its original function and mechanical properties. Some adaptations were done to facilitate handling, data collection, transportation, preventive and corrective maintenance. The motorcycle consists primarily of the carburetor housing, constant level bowl, and level control float, gauges, set screws, drain bolt, mix bolt, throttle control piston and throttle control piston holder. The throttle cable remained in its original place, with constant traction during all the tests. In addition, the polymeric slurry remained as factory original and the air-fuel mixing screw was adjusted as follows: closed completely and returned 1.5 turns using a screwdriver. The engine speed control has been set on the air inlet screw, known as slow control screw.

The experimental apparatus structure is composed of the mechanical apparatus, scale, dynamometer, fuel feeder, gas chromatograph, microcomputer and, on the table, the materials and tools used in the experiments. With the structuring of the apparatus completed, the experimental tests were initially inserting the fuel into the fuel feeder, starting the engine, accelerating, shifting gears, recording data from the operation and acquiring operating data such as quality of exhaust gases and power, these parameters as function of acceleration and gear.

Between single run experiment in steady state conditions with different tested fuels, the motor underwent maintenance, which included the removal of the cylinder head cover, the valve control, the cylinder head valves, the exhaust system and the carburetor. After each disassembly, the motor was cleaned externally, as well as internally, which included cleaning of the piston heads. Following maintenance, the motor was reassembled, the valves were adjusted and calibrated to a 0.8 mm gap, and the spark plugs were replaced.

Torque data acquisition

A dynamometer was used to measure the torque of the rotating mechanical system native to continuous current electrical motors, based on the Prony Brake principles. The dynamometer has a rotational axis attached to an aluminum crank, which brakes by electromagnetism, is powered by a voltage of 120 VDC and 0.8 A and features a 96 W electromagnet. This equipment was adapted in order to work with the Otto cycle of the internal combustion engine.

Sampling the exhausting gases

The motorcycle's gearbox is set to neutral, and the motor is set to rotate at 2000 rpm for 5 min before sampling. A probe, attached to the exhaust release pipe, collects the gases during a period of 10 min. Once that trial is concluded, the motor rotation is set to 4000 rpm, and after 5 min, new data is collected for these new operating conditions. The procedure is repeated for Podium gasoline, the BG20, and the BG30 mixtures. After the sequence of experiments, the chromatogram data for each type of fuel is analyzed by comparing them to a standard gas, to verify the characteristics of the gas emissions produced by the different fuel mixtures used in the experimental trials.

Chromatographic analysis of exhausting gases

Chromatographic analyses were performed to determine the composition of the combustion gases produced by the bio-gasoline, comparing those results to those obtained from the combustion of the Podium gasoline. The analyses were obtained using a CP 2002 P Chompack portable gas micro-chromatographer, with volumetric fraction sensitivity of 0.005 litters and above. A probe was attached to the gas micro-chromatographer, injecting 200 nL of gas into the HayeSep A column, made up of a solid support that absorbs divinyl benzene (DVB) and ethylene glycol di-methacrylate (EGDM). And with capability of separating oxygen, methane, ethane, propane, acetylene, ethylene and sulphurous gases, at an operating maximum temperature of 165 °C, and a level 7 polarity (scale of 1 to 10, where 1 = min and 10 = max).

The characterization was performed simultaneously, allowing for the plotting of the assessed physical parameters directly onto a computer. The equipment used enabled the identification of carbon dioxide, methane, ethane, and propane in the exhausting gases produced by the experiments.

RESULTS AND DISCUSSION

Operational quality of motorcycle engine

Once the experimental apparatus structure was ready, and the experiments began with, the operational quality in terms of mechanical stability, ignition, noise, combustion failure, visual quality of emissions, among others, was compatible with a regular operation. Considering the characteristics of the bio-gasoline being used, which, according to chromatographic analyses obtained by Wisniewski *et al.* [17], contains fractions of olefins, aromatics, paraffins, oxygenated compounds, as well as a substantial quantity of unknown material, when compared to regular and Podium gasoline, a preliminary assessment of the motor operation was a determinant factor in proceeding with the experimental trials.

According to Wisniewski *et al.* [17], bio-gasoline contains large fractions of olefins, which increase the gasoline's octane content, making it an excellent fuel for spark-induced internal combustion motors. The biggest restriction resulting from the presence of these compounds comes from their tendency to form residues and/or deposits during the combustion reaction. The physicochemical analyses performed for the bio-gasoline by Wisniewski *et al.* [17] show concentrations of aromatics similar to those found in gasoline A (pure gasoline without anhydrous alcohol), and higher than those found in gasoline C (with 25% of anhydrous alcohol).

During the initial trials, the motor exhibited a rotational instability requiring the necessity to adjust the carburetor idle. Experimental data was collected when the engine reached stability.

Sounds emanating from the motor, the valve control, and the exhaust were similar to the ones made by a regular motorcycle operated with fossil fuel and, at higher rotations. The motor showed similar operation, when compared to the motor that used Podium gasoline. There were no ignition failures throughout the bio-gasoline trials, even after repeatedly switching the motor on and off.

Evaluating the torque

Torque data was collected for four different fuels used. Figures 2 and 3 show the engine mechanical performance data as a function of torque, at 2000 and

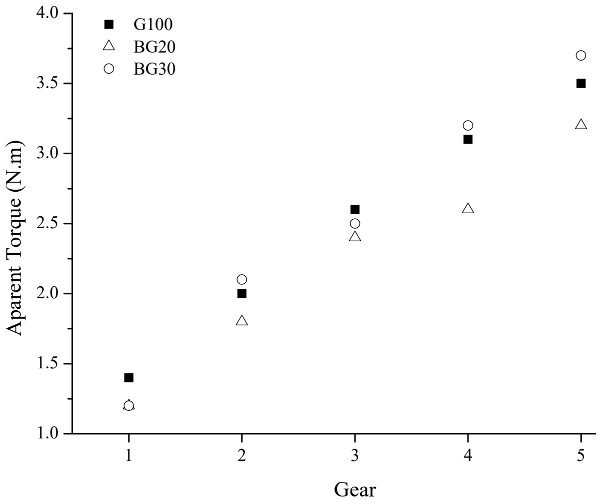

Figure 2. Relation between type of fuel and power (torque) at 2000 rpm.

4000 rpm, respectively, for each type of fuel indicated in this paper, and for five different gears, starting with the first gear and ending with the fifth gear.

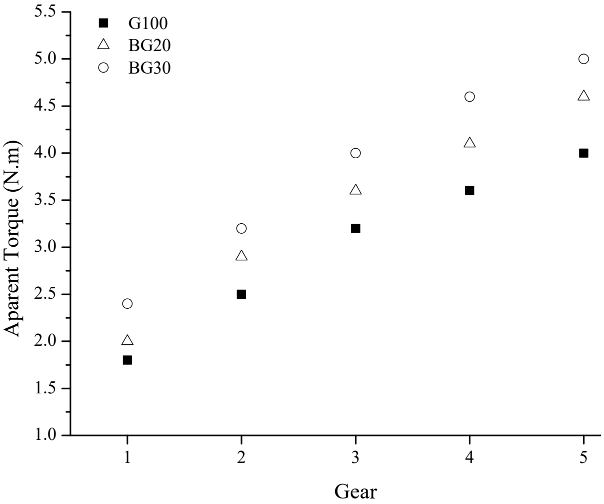

Figure 3. Relation between type of fuel and power (torque) at 4000 rpm.

For all tested gears, an analysis of Figure 2 shows that adding bio-gasoline to the Podium gasoline resulted in a different behavior. The torque increase is higher for G100 in first and third gears. BG30 is higher for second, fourth and fifth gears. The BG20 sample resulted in lower values.

As one can see in Figure 3, torque increases with RPM and gear and, for all cases evaluated, the torque with blended fuel is higher than that from G100. For this, one can observe that the use of gasoline and bio-gasoline mixed to the limit evaluated here shows that the biofuel can be used as good additive for the gasoline from petroleum.

Results also showed an increase in torque for the BG20 to BG30 combinations, as compared to the Podium gasoline. In general, an engine with higher efficiency develops higher force. The torque increasing for the higher gears, at a constant rotation, is due to their relation within the gearbox ensemble. A higher gear causes an increase in the pinion gear rotation, increasing not only the tangential, but also the angular velocities, which, in turn, results in a change in torque. The motor's power equation is directly linked to the rotation of the pinion.

Gas emissions

Table 1 shows CO_2 and hydrocarbon concentrations in the gas emissions from the motorcycle's exhaust pipe using the Podium gasoline (B100), BG20 and BG30 mixtures, at 2000 and 4000 rpm. The remaining gases might be nitrogen and oxygen. All compounds evaluated were decreasing concentration when compared to B100, especially for 2000 rpm. An error analysis of GC measurements was performed, which returned a relative error about 1.9%.

Table 1. Concentration of CO_2 and light hydrocarbons emissions from the motorcycle's exhaust pipe (% area)

Fuel	rpm	CO_2(%)	CH_4(%)	C_2H_6(%)	C_3H_8(%)
G100	2000	13.60	0.80	0.03	0.74
	4000	18.80	0.70	0.01	0.82
BG20	2000	11.80	0.50	0.01	0.46
	4000	18.50	0.40	0.01	0.53
BG30	2000	11.60	0.60	0.01	0.38
	4000	17.90	0.60	0.01	0.47

In the experiments with operation at 2000 rpm, the CO_2 emissions for BG20 and BG30 were similar and in smaller proportions than emissions from the Podium gasoline. This same behavior was also identified when operating the motorcycle at 4000 rpm. The results described are similar to results obtained by Usta *et al.* [34], Çetinkaya *et al.* [35], Canakci *et al.* [36], Pugazhvadivu and Jeyachandran [37], Utlu and Koçak [38].

The data also shows a significant reduction in ethane as the concentration of bio-gasoline is increased. This reduction is even more significant when considering the data collected at 2000 rpm. It was observed that ethane emissions for the Podium gasoline decrease when the motor is being operated at 4000 rpm, as opposed to 2000 rpm. The volumetric fraction of ethane emissions for the BG20 mixture, at 2000 rpm was under 0.005, with only a slight increase at 4000 rpm. When using the Podium gasoline, ethane emissions decrease with an increased rpm, but increase with an increase of bio-gasoline content (BG20 and BG30). The propane emissions are significantly higher for the Podium gasoline, emphasizing the decrease in emissions when the motor is operating with the BG20 and BG30 mixtures. All three tested fuels resulted in a higher propane emission with an increase in rpm.

For the rpm evaluated, a reduction of 13.6 and 15.8% in CO_2 gases emissions at 2000 rpm was obtained, for BG20 and BG30, respectively, when the results are compared with G100. When the data are evaluated in terms of 4000 rpm, there was no significant reduction in the CO_2 concentration, seeing approximately between 2 and 5.1% for two fuels evaluated in relation to this gas. With these results, the possibility of using bio-gasoline to produce neutral CO_2 is real. Considering that all the components evaluated suffered reduction in their concentration, it is possible to conclude that the combustion performance was better with blended fuels.

In addition to carbon dioxide, it was possible to detect the presence of hydrocarbons in the combustion gases, especially methane, ethane and propane. The analyses of the results for these gases were compared to what was produced by the Podium gasoline (Figure 4).

Methane concentration for the Podium gasoline, at 2000 rpm, was higher than for the mixtures BG20 and BG30, at 2000 and 4000 rpm. Results show that the presence of bio-gasoline in the tested fuel composition reduces methane gas emissions, which means that a better combustion was achieved. Comparing BG20 and BG30, the methane concentration is lower for BG20 and the lower rotation, as shown in Figure 5.

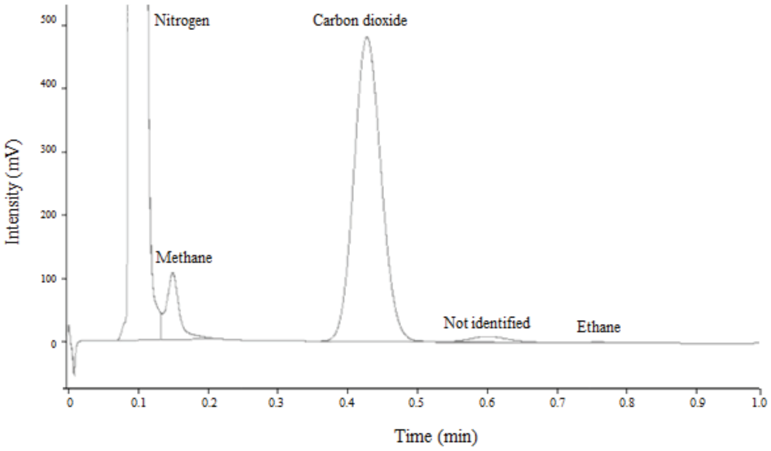

Figure 4. Chromatographic profile of G100 at 4000 rpm.

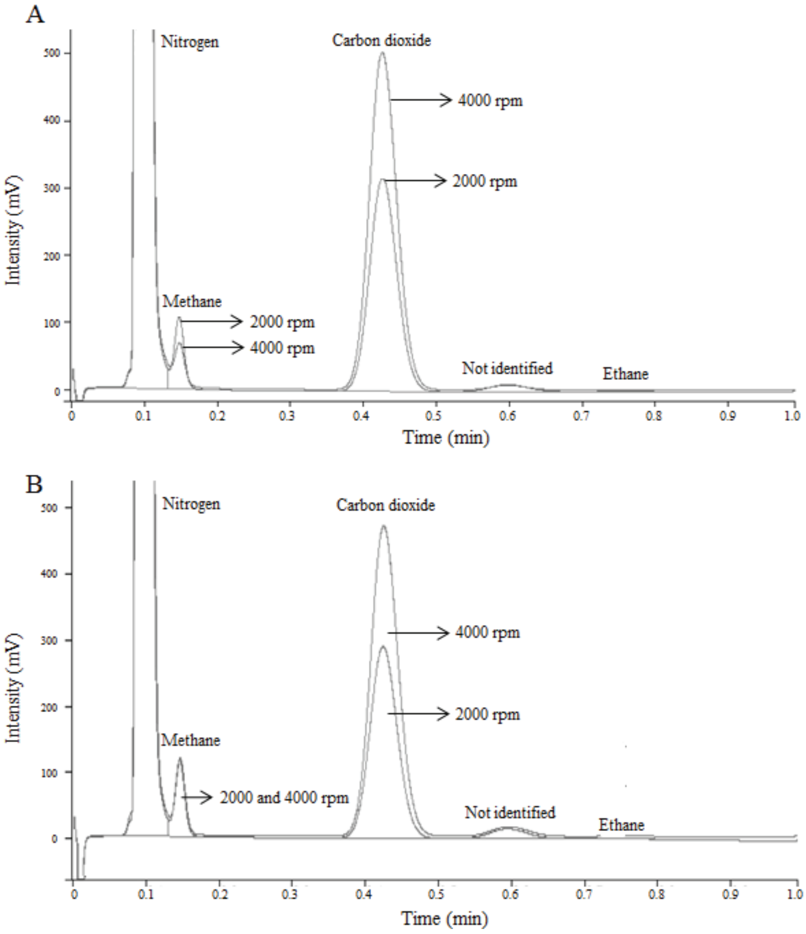

Figure 5. Chromatographic profile of A) BG20 and B) BG30 at 2000 rpm and 4000 rpm.

Saputra *et al.* [39] also observed a tendency in the reduction of CO_2 concentration using pure gasoline blended with biogasoline. Hydrocarbon content varied according to the operational condition. Hoang *et al.* [40] tested a biogasoline in a motorcycle engine. They also observed a reduction in hydrocarbon emissions, however, their results show an increase in CO_2 concentration.

CONCLUSIONS

The results herein show significant social and environmental potential gains as evidenced by the use of bio-gasoline as an additive to commercial gasoline, without any changes to the motor, and a torque performance similar to that of Podium gasoline at 2000 rpm, and substantially better at 4000 rpm. Biogasoline, as an additive, promoted gains of performance in terms of torque. The torque increased from 3.5 to 3.7 N m and from 4.0 to 5.0 N m in fifth gear and at 2000 and 4000 rpm, respectively.

The analyses of the combustion gases composition conceptualize that the presence of bio-gasoline in the Podium gasoline results in lower concentrations for the components evaluated for all fractions of biogasoline that were studied. However, deeper studies are required to evaluate this issue.

The perspective arising from this research enable new investigative opportunities in the area of biofuels that can contribute to building a more complete knowledge based on alternative fuels, in order to further expand the energy matrix.

NOMENCLATURE

G = Podium® gasoline
BG = bio-gasoline (BG) from pyrolysis of fish oil
G100 = 100% podium gasoline
BG20 = 80% of G and 20% of BG
BG30 = 70% of G and 30% BG

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NAUČNI RAD

PERFORMANSE SAGOREVANJA BIO-BENZINA PROIZVODNJENOG PIROLIZOM OTPADNOG RIBLJEG ULJA

Piroliza triglicerida iz biomase korišćena je u velikoj meri za snabdevanje gorivima tokom svetskih ratova. U ovom radu, bio-ulje proizvedeno pirolizom otpadnog ribljeg ulja frakcionisano je u koloni za destilaciju da bi se proizvela laka frakcija koja odgovara benzinu. Ovo biogorivo je testirano u motoru motocikla da bi se izmerile njegove performanse u smislu obrtnog momenta i analizirao sastav izduvnih gasova. Emisije su procenjene istraživanjem sagorevanja fosilnog benzina bez aditiva i sa mešavinama bio-benzina, BG20 i BG30, što znači 20 i 30% biobenzina u fosilnom benzinu, redom. Rezultati su omogućili identifikaciju kombinacije obrtnog momenta i emisionih gasova za svaku vrstu goriva i pokazali da sa povećanjem procenta bio-benzina mešavini, koncentracija CO_2, CH_4, C_2H_6 i C_3H_8 opada u direktnoj vezi sa rotacijom motora. Rezultati pokazuju, takođe, da se bio-benzin može koristiti kao aditiv fosilnom benzinu uz poboljšanje performansi u smislu obrtnog momenta i niže koncentracije CO_2 u emisiji. Obrtni moment je povećan sa 3,5 na 3,7 N m i sa 4,0 na 5,0 N m u petoj brzini pri 2000 i 4000 o/min, redom.

Ključne reči: Piroliza biomase, otpadno riblje ulje, biobenzin; emisija gasova; motor motocikla.