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GLYCERIN/ETHANOL BLEND BIOFUEL IN FLEX-FUEL VEHICLES

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Abstract. *Alternative solutions to fossil fuel consumption and the concern about environmental pollution and emissions of greenhouse gases indicate the relevance of biofuels nowadays, such as ethanol and biodiesel. Currently, in Brazil, ethanol already appears in the position of a real substitute to gasoline. On the other hand, there is still a long way that biodiesel must go to reach the position of a complete substitute to the mineral diesel. For each liter of biodiesel produced, it is obtained approximately 10% of glycerin, which is a by-product of biodiesel in a transesterification reaction. Furthermore, as in Brazil it is mandatory at least 13% of biodiesel blended with diesel, there is excessive production of glycerin. Based on it, the objective of this work is to ensure the production of biodiesel is as much economically viable as possible, introducing the new glycerin/ethanol blend fuel, which is produced by the mixture of ethanol and glycerin (a purified commercial product containing 95% or more of glycerol), to be tested and used in flex-fuel vehicles. Therefore, glycerin could reach the same position as ethanol and biodiesel. First, it was necessary to investigate the homogeneity of bidistilled glycerin (BG) /E100 (hydrous ethanol)/E27 (73% gasoline-27% ethanol) blends. Then, these biofuels were tested on a motorcycle. The road test showed the use of glycerin in E27-BG as not feasible, once the 2% of bidistilled glycerin present in the mixture was almost completely wasted, discarding its use of energy. In turn, the E100-BG presented itself viable, since the addition of 5% bidistilled glycerin resulted in an increase in consumption of 2.6%, which means that 2.4% of the glycerin were utilized to produce work. Glycerin is completely miscible in hydrous ethanol and the mixture of 5% of glycerin on hydrous ethanol worked adequately on the motorcycle tested, also showing no rise in emissions and noise.*

Keywords: *biofuel, glycerin, ethanol, biodiesel, flex-fuel vehicles*

1. INTRODUCTION

The search for alternative solutions to fossil fuel consumption has intensified since the 1970s, especially after the oil crisis in 1973 and the increased concern on environmental pollution and emissions of greenhouse gases into the atmosphere. Thus, some programs emerged intended to develop the use of renewable resources in several aspects. In this area, it is notorious the use of ethanol as an alternative fuel to gasoline, which presents a new promising future with the advent of 2nd generation ethanol technologies (Leal e Leite, 2007). Furthermore, the biodiesel introduced in the Brazilian energy matrix at the beginning of the 2000s is produced from renewable sources and more recently has been suffering an increase in its production, primarily due to the rising percentage of the biofuel in the diesel blend sold at gas stations.

Biodiesel is a renewable fuel made by the chemical reaction of lipids, oils and fats of animal or vegetable origin with primary alcohols. This chemical reaction is defined as transesterification. After the completion of the reaction, approximately 10% of the oil volume used is obtained as glycerin, which is a coproduct composed of 40% to 80% glycerol (propane-1,2,3-triol). Upon removing the glycerin and after being subjected to processes of purification, the biodiesel is ready to be added into the mixture with diesel commercialized in Brazil. Thus, large-scale biodiesel production provides excess glycerin, which could become an intense environmental problem. However, one of the alternative solutions to utilize crude glycerin could be in animal feeding. Industrially, after treatment to reach over 80% purity (technical glycerin) or over 99% purity (bidistilled glycerin, also known as glycerol), it shows many applications, for instance in medicines, plastics, food, and in personal hygiene products. Although having all these possible applications to consume the glycerin excess, there is not yet sufficient outcome for the amount of production expected for this chemical. In other words, the market is not able to absorb all the glycerin produced, and this fact has been motivating researchers to develop solutions concerning its use (Uchôa, 2015).

Targeting a solution to mitigate the inconveniences of discarding the excess of glycerin produced with biodiesel, the patent, number: BR 102015021610-6 (Dantas et al., 2015), grants to its holders the propriety of an invention referred to the formulation of a fuel based on mineral diesel and glycerin. On this invention, glycerin has its energetic potential used by burning it in an internal combustion engine. It was found that the obtained curve of power is similar to the one for mineral diesel alone and it even presented fewer emissions.

Thus, to make the production of biodiesel more economically viable and to avoid excess of glycerin, this paper aims to present the biofuel ethanol-glycerin (BEG) formulated through the mixture of ethanol and glycerin, as an alternative to be utilized on flex-fuel vehicles. Primarily, it is verified the homogeneity of the mixture of glycerin and ethanol-hydrated fuel (E100), and then with Gasoline type C (E27). After that, these fuels E100-glycerin and E27-glycerin are tested on a flex-fuel motorcycle to evaluate the consumption, noise, and emissions.

2. METHODOLOGY

This initial research consists of preliminary results and the work has been done in order to provide evidence that supports the use of glycerin/ethanol blend according to National Agency of Petroleum, Natural Gas and Biofuels (ANP) resolution N° 21, aiming to obtain prior authorization to test this new approach of experimental biofuel throughout the national territory.

According to the ANP resolution N°21, research involving fuels and biofuels in Brazil must be encouraged, and the interested agent in utilizing an experimental biofuel must submit to ANP an initial appointment containing as much information as possible about the referred biofuel tested. Hence, to obtain information about the BEG, four tests were performed. In the future, more rigorous tests will be performed, in accordance with Resolution No. 21 of the ANP.

2.1 Biofuel ethanol-glycerin (BEG)

The BEG is composed of two different fuels. The blends are formed with the referred percentages: E100-BG = 95%(v/v) of E100 and 5% (v/v) of bidistilled glycerin (BG); E27-BG = 98%(v/v) of E27 and 2%(v/v) of bidistilled glycerin. The chosen percentages of glycerin for each mixture were based in the solubility test of the mixtures E100, E27, and bidistilled glycerin.

The formulations proposed are in agreement with the methodology adopted to obtain fuels like Diesel BXX, which started to be developed in its beginning with a percentage of 2% (v/v) of biodiesel in the petroleum diesel (Diesel B2). Nowadays, the percentage has already reached 13% (Diesel B13) but was recently lowered to 10%.

The choice of bidistilled glycerin (BG) rather than crude glycerin is based on test results consulted in the literature, which provided adequate results to the usage as fuel, primarily in terms of its emissions. The bidistilled glycerin presents fewer residuals when compared to the other types of glycerin, besides a lesser percentage of toxic gases that are harmful to human beings and the environment (i.e. chlorine and sulfur oxides) (Maturana, 2011; Souza, 2012, Uchôa, 2015).

The glycerin is completely miscible in E100, but not in E27, because the composition of gasoline presents a mixture of molecules which contain large non-polar hydrocarbon chains, only permitting part of the molecules to mix with glycerin, as shown in Souza (2012) and Uchôa (2015). Considering this information, it is desirable and required that possible mixtures inside the flex vehicle tank always be homogenous. A manner to assure this is by evaluating the ternary phase diagrams. However, as the percentage of bidistilled glycerin to be added in the fuels is less than 10%(v/v), it is adopted a procedure to determinate a line segment that separates the regions of homogeneity/heterogeneity, divided into two stages: in the first stage it is determined the maximum percentage possible of bidistilled glycerin in E27; in the second stage, with the addition of different quantities of E100 in the blend, new possible percentages are to be determined.

To perform the miscibility test, 100 ml of E27 were added to an Erlenmeyer. Then, 0.5 ml of BG were gradually added and the mixture was manually stirred. After allowing the liquids to settle, the homogeneity of the mixture was visually assessed. The addition of BG was repeated until heterogeneity was observed and the total amount of BG added was registered. This was repeated adding more 100 ml of E27 to the mixture. After adding enough 0.5 ml aliquots of BG to produce a heterogeneous mixture, the total BG was registered. Afterward, 50 ml of E100 were added to the mixture, making it once again homogeneous. Again, 0.5 ml aliquots of BG were repeatedly added until heterogeneity was observed and the percentage of the mixture was registered. After that, for two times, 50 ml of E100 were, again, added to the mixture and successive 0.5 ml aliquots of BG were introduced, until heterogeneity was observed, in order to obtain more miscibility points.

2.2 Road tests with a flex-fuel vehicle

To evaluate the influence of E100-BG and E27-BG on the performance of a flex-fuel motorcycle, it was firstly observed the stability when working with the alternative fuel: cold start; acceleration quality; and the presence of smoke in the exhaust. The motorcycle used for this test was a Yamaha Fazer 250 (Figure 1).

The road test was done on the BR-040 highway, in the city of Juiz de Fora, State of Minas Gerais, between kilometers 778 e 799. The following data were collected: traveled distance, average speed, fuel consumption per kilometer. During the course, the driver observed the general behavior of the vehicle, including in climbs, aiming to observe some possible changes in engine power.



Figure 1. Yamaha Fazer 250 Motorcycle.

2.3 Noise level tests

For determining if the use of biofuel ethanol-glycerin changed the combustion of an internal combustion engine and considering that the main source of noise occurs in the process of combustion, comparative tests were performed to measure noise levels emitted by E100-BG, E100, E27, and E27-BG on the motorcycle presented in Figure 1.

The tests met the requirements of the Resolution N°493 of June 24, 2019, by National Council for the Environment (CONAMA), which establishes the stage PROMOT M5. Then, tests were performed following the norm ABNT NBR 9714:2000 – Noise emitted by vehicles in a stationary condition.

Summarizing: the test must be performed on a surface with high acoustic reflectivity such as concrete, asphalt, or an equivalent surface; there must be no obstacles within 3m of the meter, wind speed during the test must not exceed 5m/s; background noise must be at least 10dB less than the levels measured during the test; the engine must be at normal temperature conditions of work and gearshift lever positioned in neutral; the meter (Figure 2) must be positioned towards the gas outlet hole at a distance of 0.5m from it; the engine angular speed at the time of the tests must be stabilized at the value obtained by equation $3N/4$, where N is the maximum engine power angular speed established by the manufacturer; and the noise meter must be positioned at the height of the exhaust pipe outlet (or at least 20 cm from the ground), 50 cm away from its end and $45\pm 10^\circ$ from the exhaust pipe axis.



Figure 2. Noise level meter.

2.4 Emissions tests

The use of biofuel ethanol-glycerin (BEG) in engines cannot result in an increase in emissions of toxic gases to human beings and the environment, then, it is of paramount importance the analysis of emitted substances in the combustion of BEG.

Aiming to evaluate emissions of an engine fueled by BEG, the emissions tests of the motorcycle shown in Figure 1 were carried out in an Accredited Vehicle Inspection Body (AVIB), meeting INMETRO.

The AVIB was TECMETRO INSPEÇÕES JF, from Juiz de Fora city, which uses a gas and smoke analyzer – Sun CGS-5500PC (Figure 3).



Figure 3. Gas and smoke analyzer – Sun CGS-5500PC.

The motorcycled used in the tests, Yamaha Fazer 250 (Figure 1), was produced in 2019 and is 15592 kilometers driven.

To do a comparative evaluation, tests with the four fuels were done: E100; E100-BG; E27; and E27-BG. The volume used for each of these fuels was 250ml.

With the fuel tank empty, the following procedure was adopted to test each fuel:

1. Fill the fuel tank with 250 ml;
2. Start the engine of the motorcycle and introduce the exhaust gas capture probe;
3. Raise the rotation to 3500 rpm (about 200 rpm) and stay for 60 seconds;
4. Measure emissions at 3500 rpm;
5. Reduce rotation to idle and hold for 60 seconds;
6. Measure emissions at idle;
7. Turn off the motorcycle and completely drain the fuel tank;
8. Repeat the procedure.

Note: Write down the room temperature.

3. RESULTS AND DISCUSSIONS

Meeting the previously specified methodology, the obtained results are described below.

3.1 BEG formulation

The obtained results for two miscibility tests containing mixtures of E27, E100, and BG are presented in Table 1. In the first two columns, it is shown the established volumes according to the procedure, in the third column the volume of BG determined, and in the remaining columns the calculated values.

Table 1. Solubility test results of the mixtures E27/E100/BG.

E27 (ml)	E100 (ml)	BG (ml)	Blend (ml)	E27	E100	BG	BG/E100
100	0	2,00	102,00	98,0%	0,0%	2,0%	-
200	0	4,50	204,50	97,8%	0,0%	2,2%	-
200	50	10,25	260,25	76,8%	19,2%	3,9%	20,5%
200	100	16,00	316,00	63,3%	31,6%	5,1%	16,0%
200	150	24,75	374,75	53,4%	40,0%	6,6%	16,5%

The maximum percentage of BG permitted in the mixture E27/BG to ensure that the BG will not separate is 2.2%.

Considering that only E100 will be mixed with glycerin, that is, E27 without any glycerin, the maximum percentage of BG in the mixture with E100 is 16% to avoid any heterogeneity in the mixture.

On the other hand, considering E27 is already with 2% glycerin in its mixture, the maximum percentage of BG in the mixture with E100 that avoids heterogeneity is 12%. In case E27 is mixed with 1% glycerin, the maximum percentage of BG in the mixture with E100 is 14%.

3.2 Road tests of a flex fuel vehicle

There was not any observable change in the operating stability of the motorcycle (Figure 1) when operating with E100-BG and E27-BG: normal cold start; acceleration quality did not change; and no smoke in the exhaust.

The road test done in highway BR040 in Juiz de Fora, State of Minas Gerais, between the kilometers 778 and 799, resulted in the values presented in Table 2.

During the course, the driver observed a higher power when fueled by E100 than with E27, as expected, but the power of E100-BG did not change compared to the power with E100, the same with E27-BG and E27.

Table 2. Road test results.

Fuel	Travelled distance (km)	Speed (km/h)	Consumption (l/km)
E100-BG	235	78,3	0,0579
E100	233	80,9	0,0566
E27	233	79,6	0,0377
E27-BG	236	78,1	0,0383

From the road test results, it is possible to note that the consumption operating with E100-BG is 2.3% higher than operating with E100, despite the average speed being slower in the E100-BG case, which induces lower consumption. The same occurs with E27-BG, which consumption is 1.7% higher than the consumption with E27, despite the speed being a little lower for the case of E27-BG.

To analyze the test results, the following approximate lower heating values (LHV) were considered: E100 21 MJ/liter, E27 28MJ/liter, and BG 20MJ/liter. As the LHV of BG is close to the one for E100, if the 5% of BG in E100-BG did not change the combustion, the consumption would not change; and if it improved the combustion, the consumption would reduce. As the consumption increased 2.3% and not 5%, it means that BG does not substitute equally E100, but also it was not completely wasted. In the E27-BG case, as LHV of BG is less than LHV of E27, the 2% of BG in E27-BG almost did not bring any benefit in its use, once the consumption increased 1.7%, considerably superior to the 0.6% that was expected, considering the BG lower LHV.

Thus, tests have shown the use of E100-BG can be viable, differently from the use of E27-BG, with considerably lesser feasibility.

3.3 Noise level tests result

Following the procedure recommended by ABNT NBR 9714:2000, the motorcycle rotation established in the tests was 4.000 RPM and three different measurements were performed, with results reported in Table 3.

Table 3. Noise level tests results.

Measures	E100-BG	E100	E27	E27-BG
Background (dB)	51,0	44,7	44,9	44,6
01 (dB)	82,9	82,5	82,5	82,8
02 (dB)	82,9	82,4	82,4	82,9
03 (dB)	82,8	82,5	82,4	82,5

With the results shown in Table 3, it is observed that there are practically no differences in noise levels when the motorcycle is fueled by E100 and E27, as well as when fueled by E100-BG and E27-BG. Therefore, from the measurements referred to the noise level emitted by the motorcycle engine, it can be concluded that there is no change in combustion when the motorcycle is operated with different fuels.

3.4 Emissions tests

The measurements are shown in Table 4.

Table 4. Emissions tests results.

Emission	E100BG	E100	E27	E27BG	Limits ⁽¹⁾
Idle					
CO (% Volume)	0,01	0,03	0,01	0,00	0,5
HC (ppm)	23	34	28	32	50
3500 rpm					
CO (% Volume)	0,00	0,00	0,00	0,01	0,3
HC (ppm)	6	10	1	18	50

(1) Limits defined by Resolution N°493 of June 24, 2019 – Stage PROMOT M5.

Note: 21°C room temperature.

Analyzing the data presented in Table 4, it can be concluded:

Carbon monoxide (CO) and total hydrocarbons (THC) emissions decrease when shifting from idle to high rotations, indicating better combustion quality at high speeds, as expected.

The E100 emits more CO and THC than the E27, both at idle and at 3500 rpm, indicating that, on the motorcycle, the combustion of the E27 is better in terms of quality than the combustion of the E100;

The E100 emits more CO and THC than E100-BG, both idle and at high speed, a remarkable behavior, suggesting the presence of glycerin improves ethanol combustion;

The opposite behavior occurs with E27, the E27-BG emits more CO and THC than the E27, both at idle and at high rotations, indicating the presence of glycerin worsens gasoline combustion;

For comparison, the emissions limits defined by Resolution N° 493 of June 24, 2019 - PROMOT Stage M5 are shown. It is observed that the emissions with E100 and E27 fuels were lower than the limits, as expected. In addition, variations in emissions due to glycerin in its mixture are very small compared to the limits specified by regulation.

Therefore, the presence of glycerin with its specified proportions for great miscibility in the mixtures does not change the motorcycle engine emissions when operating with E100-BG and E27-BG fuels.

The smoke analyzed is not a relevant emission for Otto Cycle engines as the case presented. However, as it was possible to use the Gas and Smoke Analyzer – Sun CGS-5500PC (Figure 4), it was decided to evaluate the opacity index of the motorcycle exhaust gases to eventually note if the presence of bidistilled glycerin in the mixtures could generate smoke. As expected, the result was index $K = 0$ (m^{-1}), which means no presence of smoke. Note that the Resolution CONAMA N° 251 of January 7, 199, establishes the maximum value of index $K = 1.7$ (m^{-1}) for naturally aspirated diesel engines at altitudes below 350 meters.

4. CONCLUSIONS

The road test showed the use of glycerin in E27-BG as not feasible, once the 2% of bidistilled glycerin present in the mixture was almost completely wasted, discarding its use of energy.

In turn, The E100-BG is already presented itself as viable, as the addition of 5% bidistilled glycerin resulted in an increase in consumption of 2.6%, which means that 2.4% of the glycerin was utilized to produce work.

In the composition of the E100-BG, percentages above 5% can be evaluated, being possible to reach a percentage of 16%, as seen in the solubility test.

The use of E100-BG does not negatively affect the functioning of the engine tested in terms of emissions and noise.

Furthermore, with the larger acceptance of biofuel in Brazil, exemplified by the increase of ethanol and biodiesel in gasoline and diesel respectively, it is of paramount importance for future research to analyze the life cycle assessment of glycerin/ethanol blend biofuel, aiming to verify a possible reduction in the emissions of greenhouse gases (GHG).

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