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EMISSIONS ANALYSIS FROM S.I. ENGINE FUELED WITH ETHANOL , GASOLINE E25 AND NATURAL GAS

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***Abstract**. Brazil has a significant fleet of flex-fuel vehicles and more than 90% of the vehicles sold in 2014 have engines with flex-fuel technology. Thus, the assessment of greenhouse gas (GHG) becomes very important. This paper describes a comparative study of emissions from a 2.0 flex engine fueled with hydrated ethanol, gasoline E25 and natural gas. Conditions were set low and high revs in order to evaluate emissions in heavy traffic situations and free, respectively. The results showed that under conditions of high speeds all fuels presented to zero CO emissions. In turn the E25 gasoline showed a value close to zero at low speed. The CO2 emissions were similar to E25 gasoline and ethanol, however, the natural gas had the lowest emission. By analyzing hydrocarbon emissions (HC), it was found that the combustion of natural gas is set to high values at low speeds but at high speeds remained in ethanol and E25 gasoline standards. Verifying emissions of NOx, natural gas showed the highest content, followed by gasoline and E25 ethanol. From these results, it was possible to identify that natural gas is the fuel with the highest power of impact on GHG emissions, because it had the highest average of HC and NOx emissions in both conditions.*

***Keywords:** S.I. engine, greenhouse gas, hydrous ethanol, gasoline E25, natural gas.*

1. INTRODUCTION

Currently, worldwide, there is somewhat more than a billion vehicles with internal combustion engine (ICE) which operate with conventional petroleum fuels (Kell et al. 2012). Thus arises a growing concern due to air pollution caused by the emission of greenhouse gases (GHG) coming from S.I. engine exhaust gases. This has caused much interest in renewable fuels and environmentally friendly (Eyidogan et al., 2010; Canakci et al., 2013; Balki et al.,2014) and the development of high efficiency S.I engine (Sayin, Cenk; Balki, Mustafa Kemal, 2014). One of the alternatives to reduce and control GHG emissions derived from the S.I. engine is the addition of a percentage of anhydrous ethanol to gasoline and few countries with climate and land available for ethanol production cultivars Martins et al. (2014). In Brazil, ethanol is produced from sugarcane and the United States from corn. However , other countries such as Pakistan, India and Iran due to the fluctuation of international oil prices, found in compressed natural gas (NGC) an unconventional alternative to replace gasoline in automobiles, highlighting world leaders in this segment (Martins et al. 2014). The production of vehicles with flex technology engines fueled with hydrated ethanol, gasoline E25 or natural gas had featured in Brazil from 2006. For the control of pollution derived from motor vehicles, in Brazil, the CONAMA, National Environmental Council, slant of Resolution 418 of November 25, 2009, reduce CO emissions of such vehicles, 0.50% vol/vol to 0.30 % vol/vol, representing a reduction of 40 % and HC 200 ppm to 100 ppm, representing a decrease of 50 % compared to vehicles manufactured in 2005, from January 1, 2006 . The increased flex vehicle fleet in Brazil is expected mainly to the variety of fuels available in most of the country's filling stations and the relative volatility of fuel prices (Laranja, 2013). According to the National Energy Balance (BEN, 2015), of the total energy consumed in Brazil, the transportation sector in 2014 had a share of 45,7 %, increasing 5,7 % compared to the year 2013. According to a survey by the National Association of Vehicle Manufacturers (ANFAVEA, 2015), in 2014 they were produced 2,637.824 vehicles as flex engine. In Brazil there is 48,440 million light vehicles, licensees, which can be fueled with hydrated ethanol, gasoline E25 and natural gas. Of this total, the State of São Paulo has 16.4 million vehicles (DENATRAN, 2015). So it is relevant to evaluating emissions from vehicle exhaust gases with motor flex - fuel tetra. Nevertheless, the literature shows few studies on exhaust gas emissions from motor vehicles with flex - tetrahydro fuel. The objective of this study was to evaluate the emissions of exhaust gases especially carbon dioxide (CO2), carbon monoxide (CO), oxygen (O2), hydrocarbons (HC) and nitrous oxides (NOx) derived from a vehicle with motor flex tetra –fuel. The emissions analysis will be performed for the engine cases working with hydrous ethanol (96.4°), gasoline E25 and natural gas (CNG), respectively.

2. MATERIALS AND METHODS

The experiments were performed in a sedan vehicle equipped with a flex fuel engine 2.0 of 2009. Table 1 allows us to see the characteristics of the engine flex 2.0 used in this study. The vehicle was fitted with a natural gas rig relaying electronic injection , comprising a high-pressure cylinder (200 bar) with cylinder valve having a security system , high pressure tubing, supply valve central command key selector fuel , natural gas injectors operating at 2 atm low pressure pipe .

Table 1. S.I. engine characteristics.

Numbers of cylinders	4 in line
Firing order	1-3-4-2
Cylinder bore	86 mm
Course plunger	86 mm
Idle speed	800 at 1000 rpm
Cilindradas	1998 cm³
Number of valves per cylinder	2
Maximum power (ABNT/NBR 5484/ISO 1585)	121 CV (89 KW at 5200 rpm (gasoline) 128 CV (94 Kw at 5200 rpm (ethanol)
Maximum torque (ABNT/NBR 5484/ISO 1585)	179.5 N.m (18.3 kgf.m at 2600 rpm - gasoline) 192.3 N.m (19.6 kgf.m at 2600 rpm - ethanol)
Compression ratio (CR)	11.3:1
Recommended fuel	Gasoline E25 or ethanol (E100)
Maximum rotation engine	6400 rpm
System Injection	Bosch (S.F.I) Sequential Multi Injection

Source: General Motors do Brazil Ltda / Owner's Manual

In this work were used fuels available in the market such as hydrous ethanol (96.4°), gasoline E25 petrol (gasoline with 25 % ethanol) and compressed natural gas. Table 1 allows us to see the composition of the natural gas used in this study (COMGAS, 2015).

Table 2. Natural gas composition.

Element	Valor % (mol)
Oxygen	0.000
Carbon dioxide	1.616
Nitrogen	0.594
Methane	88.683
Ethane	5.844
Propane	2.339
Butane	0.328
Normal Butane	0.052
Hexane	0.025

The measurements of exhaust gases were carried out with the vehicle stationary. In the study were defined two engine operating conditions, according to CONAMA 418 Resolution of November 25, 2009, at low speed (600-1200 rpm) and high speed (above 2500 rpm), these conditions simulate situations heavy and fast traffic , respectively. These two conditions were carried out measurements of the emissions of CO2, CO, HC, NOx and O2, when fueled with hydrated ethanol, gasoline E25 and CNG, respectively (CONAMA, 2009).

Figure 1 shows the infrared gas analyzer (131 TM) brand Tecnomotor Electronics Ltd of Brazil, used for monitoring the exhaust gases. This equipment has been measured by the Institute of Weights and Measures São Paulo (IPEM/SP).

Figure 1. Infrared gas analyzer (TM 131).

During the temperatures were controlled experiments engine oil and coolant, which should be in the range of 92-101 °C and 89-105°C respectively, that in order to ensure the smooth operation of the engine. In addition, various other engine parameters were monitored using on-board diagnostic system with the aid RAVEN Scanner II, illustrated in Figure 2, as well as water temperature, air temperature, battery charge, spark advance, time fuel injection, oxygen sensor.

Figure 2. Scanner Raven II

Tables 3 and 4 allow observe the maximum CO and HC emissions established by Resolution CONAMA NR 418, of November 25, 2009, for vehicles with Otto cycle engine fueled with hydrated ethanol, gasoline E25 or natural gas. For the development of the tests, the engine was previously adjusted based on the parameters established by the CONAMA resolution 418 of November 25, 2009 for a motor vehicle with flex fuel 2006 onwards (CONAMA, 2009).

Table 3. Maximum levels of CO at low and high rotation.

Year of manufacture	Gasoline	Ethanol	Flex	CNG
All until 1979	6	6	-	6
1980 – 1988	5	5	-	5
1989	4	4	-	4
1990 – 1991	3.5	3.5	-	3.5
1992 – 1996	3	3	-	3
1997 – 2002	1	1	-	1
2003 – 2005	0.5	0.5	0.5	1
2006 onwards	0.3	0.5	0.3	1

Table 4. Maximum levels of HC at low and high emissions

Year of manufacture	Gasoline	Ethanol	Flex	CNG
All until 1979	700	1100	-	700
1980 – 1988	700	1100	-	700
1989	700	1100	-	700
1990 – 1991	700	1100	-	700
1992 – 1996	700	700	-	700
1997 – 2002	700	700	-	700
2003 – 2005	200	250	200	500
2006 onwards	100	250	100	500

3. RESULTS AND DISCUSSIONS

Figure 3 allows you to view test results in emissions of CO2, CO, O2, HC and NOx for ethanol, gasoline E25 and CNG. 10 trials were performed for each fuel, and 5 in low and high speed respectively. The results presented in Tab. 5 are an average of all measurements.

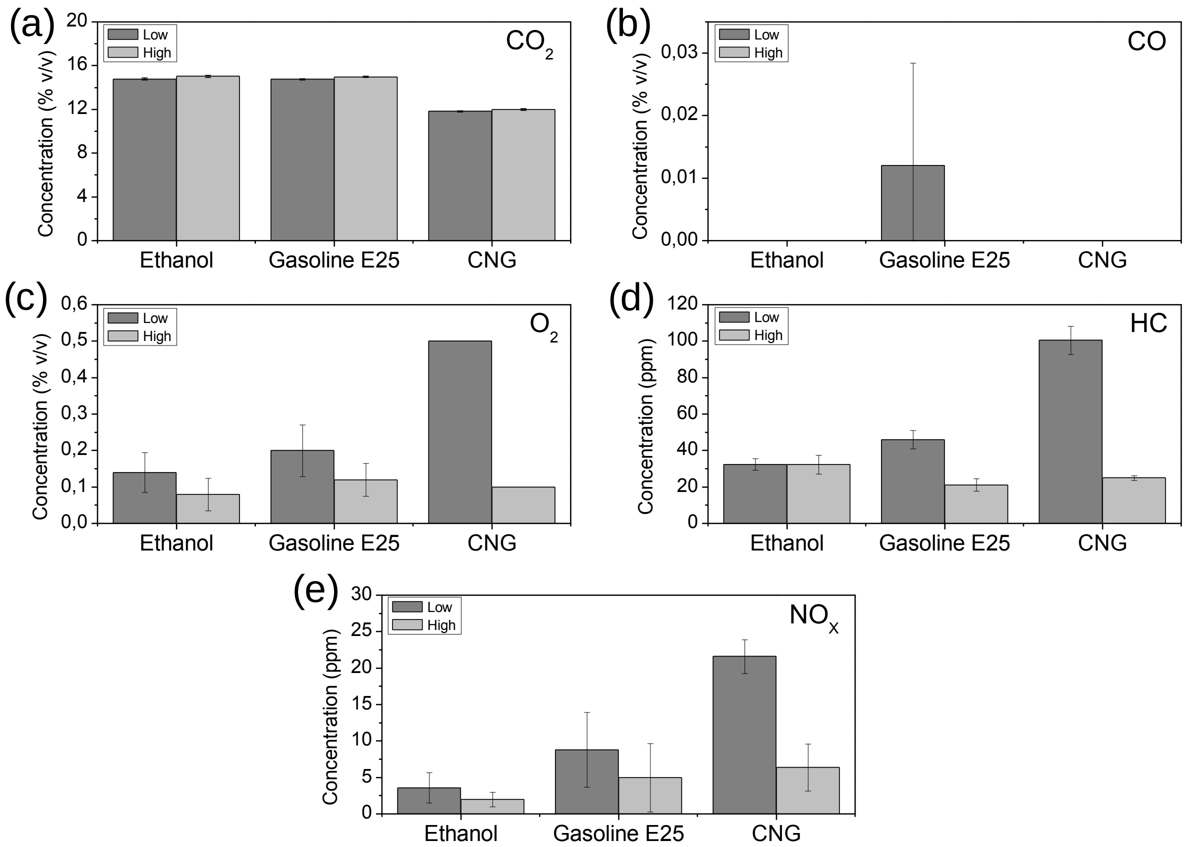

Figure 3. CO2 emissions, CO, O2, HC and NOx of each fuel at low and high rotation.

Table 5 shows the emission of CO2, CO, O2, HC and NOx for ethanol, E25 gasoline and natural gas in the low- and high speed respectively.

Table 5. Emission of CO2, CO, O2, HC and NOx for fuel at low and high rotation.

Exhaust gas	CO_2 (% v/v)		CO(% v/v)		O_2 (% v/v)		HC (ppm/vol)		NOx (ppm/vol)	
Rotation	low	high	Low	high	low	high	low	high	Low	high
Ethanol	14.78	15	0.00	0.000	0.14	0.08	32.4	32.4	3,6	2
Gasoline E25	14.86	15	0,012	0.000	0.24	0.10	28.2	13.6	8,8	5
CNG	11.82	12	0.00	0.000	0.50	0.10	100.6	25.0	21,6	6,4

From the results shown in Figure 3 and Table 5, it is observed that flex when operating the engine in a high speed condition exhibits an increase in CO2 emissions and a reduction of CO, O2, HC and NOx, respectively, considering all fuels. Increase in emission of CO2 at high speeds due to the increased intake air mass and fuel, as well as less variation in temperature of the combustion chamber.

Figure 3 (a) allows us to view CO2 emissions of the three fuels studied, which had similar issues in both low and high rpm respectively. The CNG displays to lower CO2 emissions, including both other fuels had the highest emissions of this gas.

Figure 3(b) allows us to visualize the CO, it is observed that only the combustion of gasoline at low speed presented CO at less than the limit set by CONAMA to flex engines (CONAMA, 2009).

Figure 3 (c) allows us to see the emission of O2. Note that the smaller emissions occur in the high speed condition in all fuels. This could indicate that SI engine shows good when operated in this condition. Thus, it can be argued that the combustion of natural gas is compromised when operating in a low speed condition. This result is similar to that shown in Milk (2012), which said that the combustion of ethanol is more efficient than gasoline and natural gas, however, the ethanol consumption is greater. By analyzing the emission of O2, it can be observed that the combustion of ethanol is more efficient than gasoline and natural gas.

Figure 3 (d) for verifying the emissions of HC for fuel. It is observed that ethanol exhibits the same issue in both low and high speed. However, the emission of HC at low speed for gasoline and CNG is twice and five times respectively that emissions of HC at high speed. It is noteworthy that the issue of CNG is the fullest extent permitted by CONAMA. Thus, ethanol demonstrating problems in burning this fuel at low speed.

Figure 3 (e) allows us to see the emission of NOx can be observed that in low speed condition to higher emissions of this gas corresponds to natural gas, followed gasoline E25 and hydrated ethanol respectively. This emission may be due to the temperature reached by the combustion of CNG. However, in high speed conditions the NOx emission gas is reduced remarkably. Since this condition the NOx emission of CNG is very close to gasoline. The lower emissions of this gas was for ethanol in both low and high speed respectively.

The findings of this study are consistent to those reported by Costa et al. (2009) and M. Tongroon, 2013, observed that where the substitution of E22 gasoline with hydrous ethanol reduces emissions of CO and HC but increases the CO2 and NOx.

M. Tongroon; H. Zhao, (2013) in general, alcohol fuel results advanced self-ignition and combustion faster than gasoline. In addition, their use can lead to lower HC, NOx and CO; Melo et al. and Masun et al. 2013a, CO emissions are reduced with the addition of ethanol due to the ethanol content of oxygen which contributes to oxidation to CO2; Balki, (2014); Bielaczyc et al. (2013), alcohol fuel such as methanol and ethanol emerged as good alternatives to vehicles with internal combustion engines are fluid because it has several physical and combustion properties similar to gasoline; Arroyo et al (2014); Bielaczyc et al. (2013), the main component of natural gas is methane, with a high octane number and high auto-ignition temperature, which makes it a great substitute fuel of gasoline in SI engines.

4. CONCLUSIONS

The tests led us to conclude that regardless of the type of fuel, the engine flex tetra- fuel produces higher emissions of greenhouse gases at low revs. Depending on the experimental results, ethanol has proven to be an environmentally friendly fuel for use in internal combustion engines because it has the lowest levels of CO and NOx compared to gasoline and natural gas.

This type of engine operating with hydrated ethanol or gasoline E25 with little to the emissions of HC, CO and NOx, both at low and at high rpm. However to work with CNG has an increase of emissions of HC idling. The formation of CO2 in combustion of gasoline E25 and ethanol is identical for both fuels, while the gas is less than 20 % both, for both high and low speeds.

Thus natural gas has proven favorable to use the SI engine reduced CO2 emissions by substituting in part gasoline nevertheless presents significant increase in HC emissions at low revs, good requiring periodic adjustment.

5. ACKNOWLEDGEMENTS

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