EMISSIONS IN TWO-STROKE ENGINE OPERATING WITH NON-COMMERCIAL FUEL BLENDS (GASOLINE/ETHANOL)

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Abstract. *The analysis of combustion products is important in the study of internal combustion engines, especially in assessing the efficiency of the combustion process and the determination of compliance with emission laws in force. Otto-cycle engines, as in the case of air blower and other two-stroke engines, emissions of CO, NOx and aldehydes are the of mainly interest. This paper presents results of experimental tests in a small air blower, two-stroke internal combustion engine, operating on non-commercial fuel for different proportions in gasoline and ethanol blends (A10 up to A30). Appropriate instrumentation was used to carry out the measurement of the main parameters. For this work was used the portable flue gas analyzers GreenLine 8000 and the methodology was based on regulations from ABNT – Brazilian Society for Standard Normatives (testing of internal combustion engines and ethanol determination in fuel blends). The parameters obtained are angular velocity (rpm) and exhaust gas emissions for O2 (%), CO2 (%), CO (ppm), NOx(ppm) and the UHC (ppm), besides, these parameters are correlated to specific fuel mass consumption (g.W/min). The results obtained are analyzed and discussed when varying angular velocity (~3000-7000 rpm), for each combination fuel blend (A10, A20 and A30), versus exhaust gas emissions O2, CO, UHC, NOx and CO2. Main findings are: a) Increases in angular velocity implies in higher quantities of UHC; b) A30 and A20 present, respectivelly, the higher and lowest UHC emission levels among all fuel samples.*

Keywords*: Combustion; Biofuels (ethanol); Energy conversion efficiency; Thermal machinery.*

1. NOMENCLATURE

A – Aqueous phase volume.
AER – Anhydrous ethanol as reference fuel.
AxHy – Percentage AER (x) and HER (y) in fuel sample.
B – Gas concentration in exhaust gas sample.
C – Volume of the fuel sample.
E – Ethanol quantity to be added in the fuel sample
F – Detection cell length.
Gasohol – vehicular fuel composed of gasoline and a certain percentage of AER.
G – Gasoline (pure) quantity to be added in the fuel sample.
HER – Hydrous ethanol reference fuel or AEAC
I – Wavelength Λ of radiation that has been transmitted to the detector.
I_0 – Wavelength Λ of radiation that is incident upon gas.
IR – Infra-red.
L – Molar absorption coefficient of the gas.
$\dot{m}_f$ – Mass fuel rate.
$\dot{m}_a$ – Mass air rate.
NDIR – Non-dispersive infrared sensors.
PCI – Lower heating values.
RGD – Reading.
t – AEAC content in the commercial fuel sample.
t' – AEAC content to be added in the fuel sample.
UV – Ultraviolet rays.
x – Mass fractions of unburned hydrocarbons.
τ – AEAC percentage (%).
Λ - Wavelength.
λ – Relative air/fuel ratio.
η_C - Combustion efficiency (%).

2. INTRODUCTION

Internal combustion engines are thermal machines, that is, devices that allow the conversion of chemical energy in the form of heat into mechanical work. The heat is obtained in fuel burning through the chemical exothermic process of oxidation, combustion, such reaction needs three basic components: fuel, oxidizer and contact. In internal combustion engines the contact is called ignition and classifies those machines in Otto Cycle (spark ignition) or Diesel Cycle (compression ignition). Other classifications of engines refers to the amount of cycles of operations, there can be two-stroke or four-stroke engines. Because of its simplicity, the lower power to weight ratio and the fact of them being more compact than four-stroke engines, two-stroke engines are interesting for small equipment appliance, and is used in hedge trimmers, chainsaws and air blowers, among others. Nevertheless two-stroke engines are highly polluting (Lin et al., 2006).

Emission refers to residuals harmful to the environment and to the human beings in giving concentrations, and atmospheric emissions are those from local processes (Wark & Warner, 1981). Pollution is an integral part of the industrial society, that is, one of the consequences of the generation of useful energy by the combustion process (Carvalho & Lacava, 2003). Its effects on the environment are related to problems of political, social and economic nature. Spark-ignition and diesel engines are a major source of urban air pollution resulting in normatives and laws towards the control of its emissions (Heywood, 1988).

An alternative in order to reduce emissions is the usage of biofuels instead of fossil fuel. Today´s most used biofuel is Ethanol, frequently blended with gasoline in commercial fuel for automotive applications. Ethanol addition to gasoline can improve emissions of regulated pollutants, such as CO and HC from a motorcycle engine (Jia et al., 2004). This promotes a higher evaporation heat, octane number, flammability temperature, and reduction of carbon monoxide emissions, but with the cost of an increase in fuel consumption (Koç et al., 2009). As a fuel for spark-ignition engines, alcohol (methanol, ethanol) has some advantages over gasoline, such as better anti-knock characteristics and the reduction of CO and UHC emissions (Hsieh et al., 2002).

The objective of this work is to identify the best operational conditions and fuel samples providing lower emissions levels, and in the case of lowest UHC corresponding to higher energy efficiency conversion. Thus, experimental tests are performed in a small two-stroke internal combustion engine (air blower BG 86 model), operating on non-commercial fuel for different proportions in gasoline and ethanol blends (A10 up to A30). The equipment is designed for sweeping work and assisting in cleaning tasks of various environments, and operates with commercial fuel mixed with lubricant oil in the proportions recommended by the manufacturer (STIHL).

3. METHODOLOGY

3.1 Intrumentation

In this work was studied a commercial air blower, with a single cylinder and manufactured by STIHL. Table (1) displays technical data about the engine of study.

Table 1. Technical data: Air blower BG 86 – STIHL[1]

Displacement (cm³)	27.2
Diameter of cylinder (mm)	34.0
Piston Stroke (mm)	30.0
Fuel tank capacity (cm³)	440
Empty weight (kg)	4.4
Power (kW)	0.8
Power-weight ratio (kg/kW)	5.5

The exhaust gases were identified and quantified by portable flue gas analyzer model Greenline 8000 (Eurotron) and the DBGas2004 data manager software. The gas analysis unit, called main control unit (M.C.U.), sored in an aluminum case, contains the remote control unit and all the connection cables, a mother board and a complete gas sampling system. A general system scheme is shown in the Fig. 1.

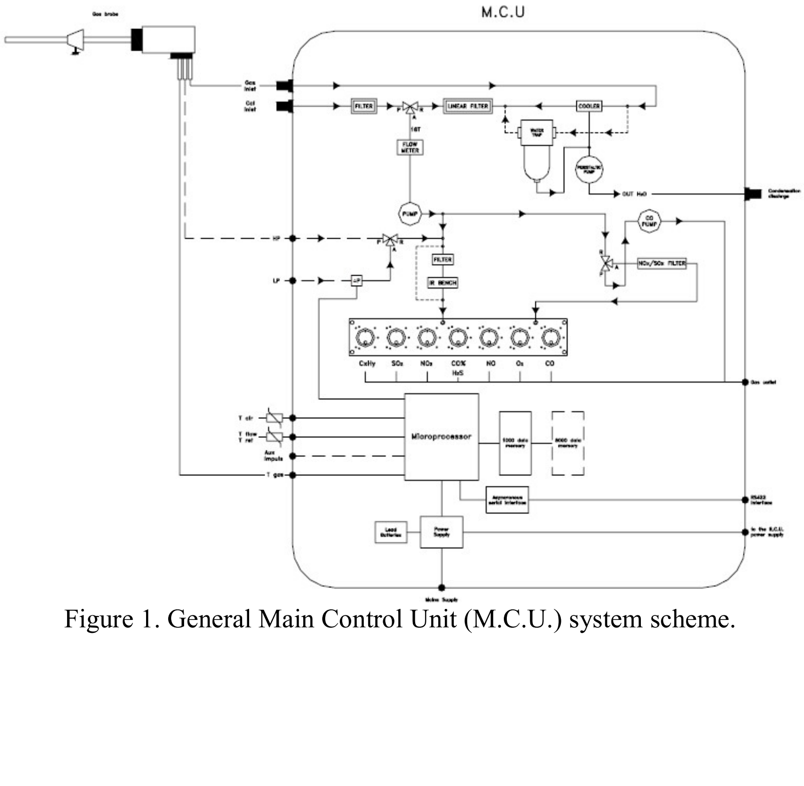

Figure 1. General Main Control Unit (M.C.U.) system scheme.

The flue gas is sucked into the analyzer through the probe by a primary pump. The power of the pump is regulated by electronics in order to keep constant the flow rate. The sample is cleaned up and dried by a dust filter and the condensation trap. The gas flows through a combined water trap and line filter to avoid the presence of condensation or suspended solid particles in the analysis circuit of the instrument. The water trap works using the expansion principle: the gas flow decreases its speed inside the cylinder, consequently, it is not able any more to carry dust or heavy particles. The humidity condenses and the solid particles fall down. At fixed intervals, that water is drained out by a peristaltic pump. The condensed water is periodically purged by a peristaltic pump.

The analyzer uses long life electrochemical cells for O2, CO (H2 compensated), NO, NO2, SO2 and CO%. The gas sensors are electrochemical cells composed by two electrodes (anode and cathode) and an electrolyte solution, depending on which gas has to be detected. The sampled gas goes through a selective diffusion membrane. The oxidation process produces an electrical signal output proportional to the gas concentration. This current signal is evaluated by the electronics, converted to digital, compensated in temperature, processed by the microprocessor, sent to the remote unit. For CO2 and UHC concentrations, the analyzer uses the non-dispersive infrared sensors (NDIR). A NDIR system consists of: an IR light source, a chamber containing the gas sample to analyze and a photodetector with optical filter. The light passes through the chamber and the gas sample is absorbed at a specific wavelength (e.g. 4.26μm for CO2) or at the specific band range (Eurotron, 2009). This sensor work in order to get a longer term and more stable response sensitivity than electrochemical cell sensors. Working at 2 different wavelengths, with this system, it is possible to detect CO2 and UHC with high precision, stability in time and high response time. The collected signal is then processed by electronic component and sent to the remote unit. Before the IR bench, along the pneumatic circuit, there is an optical filter optical non dispersive anti dust, that allows the photodetector identifying for sure the gas on the basis of the absorption spectrum. As stated by Brunetti (Brunetti & Garcia, 2012), this method uses Beer and Lambert law for the energy absorption of gases, according the Equation 1.

$$\frac{I(\Lambda)}{I_0(\Lambda)} = \exp(-L.B.F) \tag{1}$$

Table 2 shows accuracies and ranges for the gases studied in this work. Besides the gas analyzer and software was used an optical tachometer (Instrutherm), for angular velocity measure in rotations per minute, with range, resolution and accuracy, respectively 0.5 up to 19,999 (rpm), 0.1 up to1,000 (rpm) and ± 0,1%.

Table 2. Thermophysical properties of nanoparticles.

Parameter	Sensor type	Range	Resolution	Max response time	Accuracy
O_2	Electrochemical	0 – 25.0%	0.10%	20 sec	±0.1% vol.
CO	Electrochemical	0 – 20000 ppm	1 ppm	40 sec	±4% rdg up to 2000 ppm ±10% rdg >2000 ppm
CO_2	NDIR	0 – 40.0%	0.01%		±0.3% rgd <10%
UHC	NDIR	0 – 50000 ppm	1 ppm		±100ppm rgd <2500 ±4% rdg >2500

3.2 Fuel samples

For this work were established three fuel samples, each one containing different volume percentages of ethanol and gasoline (pure), these are Gasohol A10, A20 and A30, according to ABNT nomenclature. The blends were prepared according to the standard of ABNT: NBR 6.396 (ABNT, 1976); NBR 13.992 (ABNT, 2008); NBR 7.024 (ABNT, 2010); NBR 8.689 (ABNT, 2012) and NBR 13.993 (ABNT, 2013). Also from National Agency of Petroleum, Natural gas and Biofuel resolutions: n° 21 (ANP, 2009); n° 23 (ANP, 2010).

According to the procedure described in the NBR 13.992 (ABNT, 2008), the obtaining of the percentage of AEAC is given by a blend of commercial fuel with an aqueous solution. This aqueous solution is composed of pure water and 10% NaCl b/v. This solution, when added to the commercial fuel forms a two-phase mixture, which the upper phase, there is pure gasoline and in the lower phase, there is ethanol and the aqueous solution of sodium chloride (Fig. 2). A beaker of 100 ml is used for the preparation of the blends, therefore, as shown in Eq. (2), the percentage of AEAC (τ) depends on the final volume of the corrected aqueous phase (A).

$$\tau = \left[2(A-50)\right] \pm 1 \tag{2}$$

To prepare blends with different AEAC concentrations we use Eq. (3), where refers the new blends with content above the reference sample, and Eq. (4) to new blends with content below the reference sample.

$$E = \left[\frac{C(t-t')}{(t'-1)}\right] \tag{3}$$

$$G = \left[\frac{C(t-t')}{t'} \right] \tag{4}$$

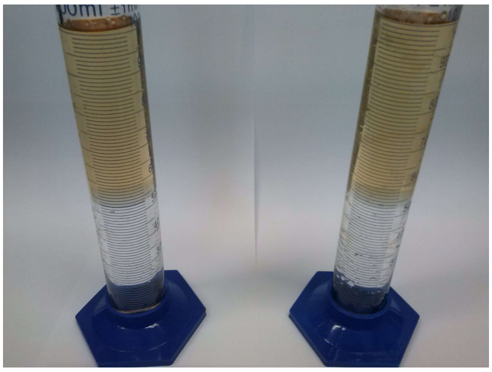

Figure 2. Blend biphasic pure gasoline/aqueous solution.

3.2.1 Combustion Stoichiometry

Engines obtain energy from the combustion of a hydrocarbon fuel with air. To hydrocarbon fuel be completely oxidized it is required stoichiometries oxygen, is it, the oxygen just enough to convert all fuel to CO2 and H2O. For example the chemical equation for the complete combustion of methane CH4 is given by:

$$CH_4 + 2O_2 \rightarrow CO_2 + H_2O$$

This reaction represents the theoretical combustion, the real combustion is more complex. Rarely fuel is burned with pure oxygen. The cost of using pure oxygen would be prohibitive (Pulkrabek, 2014), so uses air. The atmospheric air composition is, aproximatelly, 78% nitrogen, 21% oxygen and 1% other gases such as argon, helium and neon. Considering the complete combustion of a general hydrocarbon fuel of average molecular composition C_aH_b, with air, the overall complete combustion equation is given by Heywood (1988):

$$C_aH_b + \left(a + \frac{b}{4}\right)(O_2 + 3.773N_2) \rightarrow aCO_2 + \frac{b}{2}H_2O + 3.773\left(a + \frac{b}{4}\right)N_2$$

We can expand a general hydrocarbon to gasohol fuel. Alcohol, such as methanol (CH3OH) or ethanol (C2H5OH), is a pure substance. However, gasoline is composed of C4–C12 hydrocarbons, and has wider transitional properties (Hsieh, 2002). These considerations lead us formulate the general composition of gasohol blend such as:

$$C_2H_5OH + C_8H_{18}$$

These gasoline and ethanol blends result in different stoichiometric reactions. Next, chemical balance for A10, A20 and A30, respectively.

$$C_{7.4}H_{16.8}O_{0.1} + 11.55(O_2 + 3.773N_2) \rightarrow 7.4CO_2 + 8.4H_2O + 43.57N_2$$
$$C_{6.8}H_{15.6}O_{0.2} + 10.6(O_2 + 3.773N_2) \rightarrow 6.8CO_2 + 7.8H_2O + 39.9N_2$$
$$C_{6.2}H_{14.4}O_{0.3} + 9.65(O_2 + 3.773N_2) \rightarrow 6.2CO_2 + 7.2H_2O + 36.4N_2$$

Monitor UHC provides a good idea on the combustion efficiency. Bahr (1972) demonstrated that the efficiency can be expressed by Equations (4) and (5).

$$1 - \eta_C = (UHC + 0.232CO).10^{-3} \tag{4}$$

$$1 - \eta_C = \frac{\sum x.PCI}{\left[\dot{m}_f \big/ (\dot{m}_a + \dot{m}_f)\right].PCI} \tag{5}$$

With no direct effect on human health, the CO2 is one of the primary products of the hydrocarbon combustion, even so there are a monitoring and control due to environmental issues, as global warming, which is caused mostly by the accumulation of CO2 in the atmosphere. The CO reacts with hemoglobin causing damage to human health, is resultant from incomplete combustion (Carvalho e Lacava, 2003), and thus, in less than 1 hour of exposure to concentrations of 4000 ppm of CO can cause death.

3.3 Experimental Procedure

The experimental procedures used in this study took into account the NBR 6.396 (ABNT, 1976), concerning the performance tests for two-stroke engines. The angular velocity n (rpm) was obtained with the use of an optical tachometer positioned 0.5 meters from the axis of rotation and connected to a computer using the commercial software datalogger (Instrutherm). The gas analyzer probe was positioned a few centimeters of the exhaust pipe engine.

After each sample was prepared, it was placed in the fuel tank, and the engine was switched on. The time of stabilization is determined by the authors and is equal to 5 minutes, the same time for autocalibration to a gas analyzer. Thus the tests are started. Each test lasted 120 seconds and was made for three up to five different rotations, two of them previously established: slow (~3000 rpm) and maximum velocity (~7000 rpm). Completed tests, we use the data manager software mentioned above to organize sample data.

All samples analyzed follow the lubrication standard as indicated in the manual of the air blower. This is L1:50, where 1:50 symbolizes that in each milliliter of lubricant, 50 ml of fuel have to be added. Besides, another data used in this work to complete the two-stroke engine characteristic curves, was obtained using the experimental procedure described by Silva, Vieira e Brito Jr (2015).

4. RESULTS AND DISCUSSIONS

For the time test established were obtained 80 sample data, of which averages they were made and plotted the results that follow. Figure 3 shows the results for O_2 and CO_2 emissions *versus* angular velocity. The majority exhaust gas composed of carbon dioxide, being 1% formed of O2 and other inert gases (Brunetti e Garcia, 2012). Despite not being a pollutant, oxygen gas is a part of the combustion process, as well as a result of those reactions when there is no stoichiometric combustion. Noted in Figure 3 the high concentration of O2, very close to the fresh air concentration, mainly to the Gasohol A10 and A30. Constructive aspects of 2T engines show us that during the first stroke, burnt gases at high pressure are expelled from the combustion chamber, however at this moment, there is a partial mixture with the non-burnt gases from admission. Thus, high averages of concentration observed in Figure 3 are related to the exhaustion of burnt and non-burnt gases.

It's noted that the concentration of CO2 tends to grow in a more accentuated manner in A10 and A20 and more slightly to A30, showing once more that combustion tends to stoichiometry, the more you increase its angular velocity. The maximum production of CO2 is found when the relation of air/gas is stoichiometric because of the need of excessive air usage to attain complete combustion (Bizzo, 2003). CO2 emissions depends on the air–fuel equivalence ratio, CO emission concentration, and the maximum CO2 concentration appear at λ~1 (Chan-Wei Wu, 2003). Ethanol addition result in decreases on CO and UHC emissions and increase of CO2 emissions, as can be verified for Gasohol A30 in the angular velocity range 5500~6000 rpm. That behavior is related to air/fuel ratio (Hsieh et al., 2002; Al-Hasan, 2002; Agarwal, 2006; Topgül et al., 2006).

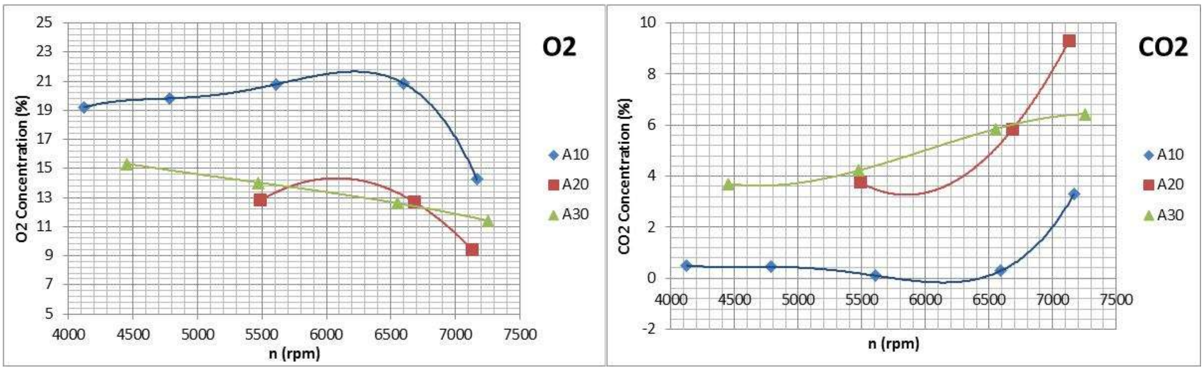

Figure 3. O2 and CO2 emissions behavior for Gasohol A10, A20 and A30.

Figure 4 shows the results for two fuel samples(A10 and A20) for different exhaustion products, CO and NOx. CO emission depends on the air–fuel equivalence ratio and with increases in ethanol content, CO emission is reduced due to oxygen enrichment coming from ethanol (Chan-Wei Wu, et al., 2003). The CO concentration, in Fig. 4, shows a trend of growth in emissions to the angular velocity between 6000-6500 rpm, with a tendency to decrease after that range, indicating incomplete combustion. The CO2 exhaust emissions have an opposite behavior when compared to the CO exhaust emissions (Gravalos, 2012), and this is found when we compare Fig. 3 with Fig. 4.

Also in Figure 4, NOx emissions decreases from 5500 up to 6000 rpm and small increases just after that range. These NOx (NO + NO2) emissions are generated when nitrogen is burned or oxidized, and it normally increases when combustion temperatures are higher (Martins e Ferreira, 2010). When in the atmosphere, NOx reacts with UV rays causing the formation of ozone.

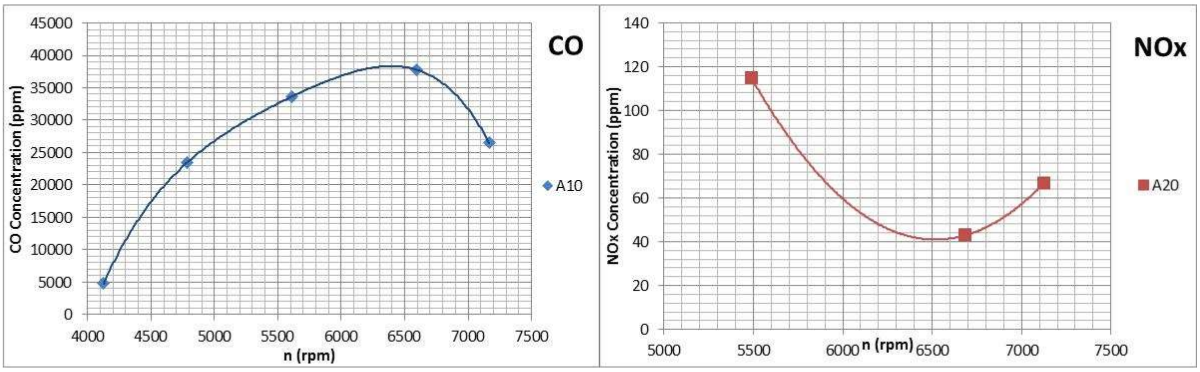

Figure 4. CO and NOx emissions behavior for Gasohol A10 (CO) and A20 (NOx).

The analysis between the results in Fig. 5 and also from Eq. (4) and Eq. (5) show that combustion efficiency tends to decrease after angular velocity ~6000 rpm, for A10 and A20 blends and for A30, the tendency is opposed, they increase. Another way to combustion efficiency estimatives is given by Heywood (1988), that considers mass emissions. From Eq. (4), η_C ~55% at ~7000 rpm for Gasohol A10, indicating that high angular velocities are not recommended either if required low emissions or high efficiency.

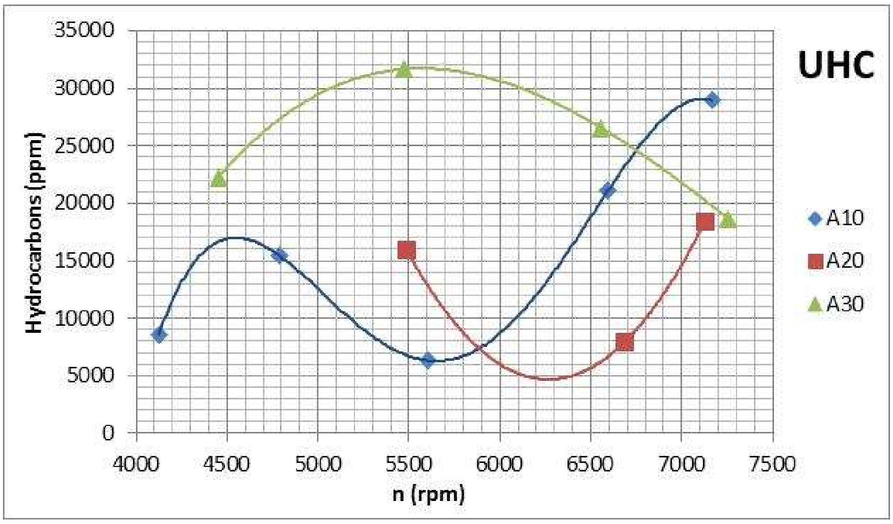

Figure 5. UHC emissions behavior for Gasohol A10, A20 and A30.

All results can indicate the blend with the best emissions performance. According Al-Hasan (Al-Hasan, 2002) The 20% ethanol fuel blend gave the best results of the engine performance and exhaust emissions. Ethanol-diesel blends up to 20% can very well be used in present day constant speed CI engines (Agarwal, 2006). On the other hand Yao (Yao, 2009) concludes that the high ethanol–gasoline blend ratio (20%) resulted in a less emission reduction than those of low ratio blends. To test the blend with the best emission performance and combustion efficiency is needed, to consider, especially the CO2, H2O and UHC concentration in the exhaust gas.

5. CONCLUSIONS

From results obtained, it was observed high pollution levels from two-stroke combustion engines. As mains findings it is possible to point out: a) Non-stoichiometric combustion occurs with a poor mixture ($\lambda > 1$); b) Increases in angular velocity implies in higher quantities of UHC, thus also reducing the energy conversion efficiency; c) A30 presents the higher emission levels among all fuel samples; d) A20 presents the lower emission levels for UHC and highest values for CO2 emission, and thus best energy conversion efficiency.

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7. REFERENCES

ABNT, 1976. "NBR 6396: Motores alternativos de combustão interna, não veiculares". 29p.

ABNT, 1976. "NBR 13992: Gasolina automotiva - Determinação do teor de álcool etílico anidro combustível (AEAC)".3p.

ABNT, 2010. "NBR 7024: Veículos rodoviários automotores leves - Medição do consumo de combustível - Método de ensaio". 13p.

ABNT, 2012. "NBR 8689: Veículos rodoviários automotores leves - Combustíveis para ensaio - Requisitos". 4p.

ABNT, 2013. "NBR 13993: Etanol combustível - Determinação do teor de hidrocarbonetos - Método volumétrico". 3p.

ANP – National Agency of Petroleum, Natural gas and Biofuel, 2009. "Especificações da gasolina de referência para ensaios de avaliação de consumo de combustivel e emissoões veiculares". 4p.

ANP – National Agency of Petroleum, Natural gas and Biofuel, 2010. "Especificações do álcool etílico combustível ou etanol combustível, de referência, para ensaios de avaliação de consumo de combustível e emissões veiculares". 2p.

Agarwal, A. K., 2007. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. Progress in energy and combustion science, 33(3), 233-271.

Al-Hasan, M., 2003. Efeito da gasolina sem chumbo etanol-mistura no desempenho do motor e emissões de escape. Conversão e Gestão de Energia , 44 (9), 1547-1561.

Bahr, D.W., 1972. Control and reduction of aircraft turbine engine exhaust emissions. In Emissions from Continuous Combustion Systems (pp. 345-373). Springer US.

Bizzo, W.A., 2003. Apostila de Combustão. Campinas, SP. Brazil.

Brunetti, F., & Garcia, O., 2012. Motores de combustão interna. São Paulo: Blucher, 10.

Carvalho, J. A., and Lacava, P.T., 2003. Emissões em processos de combustão. São Paulo: Editora UNESP, SP, Brazil.

Gravalos, I.; Moshou, D.; Gialamas, T.; Xyradakis, P.; Kateris, D.; & Tsiropoulos, Z. 2012. Emissions characteristics of spark ignition engine operating on lower–higher molecular mass alcohol blended gasoline fuels. Renewable Energy, 50, 27-32.

Hsieh, W.D., Chen, R.H., Wu, T.L., & Lin, T.H., 2002. Engine performance and pollutant emission of an SI engine using ethanol–gasoline blended fuels. Atmospheric Environment, 36(3), 403-410.

Heywood, J. B., 1988. Internal combustion engine fundamentals (Vol. 930). New York: Mcgraw-hill.

Jia, L.W., Shen, M.Q., Wang, J., & Lin, M.Q., 2005. Influence of ethanol–gasoline blended fuel on emission characteristics from a four-stroke motorcycle engine. Journal of Hazardous Materials, 123(1), 29-34.

Koç, M., Sekmen, Y., Topgül, T., & Yücesu, H. S., 2009. The effects of ethanol–unleaded gasoline blends on engine performance and exhaust emissions in a spark-ignition engine. Renewable energy, 34(10), 2101-2106.

Lin, C.W., Lu, S.J., & Lin, K.S., 2006. Test emission characteristics of motorcycles in Central Taiwan. Science of the total environment, 368(2), 435-443.

Martins, C.A. & Ferreira, M.A., 2010. Considerações sobre a formação de Nox na combustão. 6th Congresso Nacional de Engenharia Mecânica – CONEM 2010. Campina Grande-PB, Brasil. 11p.

Pulkrabek, W.W., 2014. Engineering fundamentals of the internal combustion engine. Upper Saddle River, NJ: Pearson Prentice Hall.

Silva, R.L.; Vieira, M.M. & Brito Jr., S.X. 2015. Two-stroke engine behavior (small chainsaw) operating with non-commercial fuel blends and diverse lubrication. Engenharia Térmica (Thermal Engineering), 14(2), 23-30.

Topgül, T., Yücesu, H.S., Cinar, C., & Koca, A., 2006. The effects of ethanol–unleaded gasoline blends and ignition timing on engine performance and exhaust emissions. Renewable energy, 31(15), 2534-2542.

Wark, K., & Warner, C.F. ,1981. Air pollution: its origin and control. United States: Harper and Row Publishers,New York, NY., USA.

Wu, C.W., Chen, R.H., Pu, J.Y., & Lin, T.H., 2004. The influence of air–fuel ratio on engine performance and pollutant emission of an SI engine using ethanol–gasoline-blended fuels. Atmospheric Environment, 38(40), 7093-7100.

Yao, Y. C., Tsai, J. H., & Chiang, H. L., 2009. Effects of ethanol-blended gasoline on air pollutant emissions from motorcycle. Science of the Total Environment, 407(19), 5257-5262.

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