TWO-STROKE ENGINE BEHAVIOR (SMALL CHAINSAW) OPERATING WITH NON-COMMERCIAL FUEL BLENDS AND DIVERSE LUBRICATION

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ABSTRACT

The paper presents results for experimental tests in a two-stroke internal combustions engine operating on commercial fuel (gasoline and ethanol blends), with different proportions in mineral oil for lubrication purposes. Appropriate instrumentation was used to carry out the measurement of the quantities of interest, namely fuel consumption (g/s), angular velocity (rpm) and emissions (CO2 and NOx). The methodology was based on regulations from INMETRO (motor vehicles energy conversion efficiency) and ABNT (testing of internal combustion engines). Results obtained are analyzed and discussed for the fuel consumption versus angular velocity (g/s x rpm) for each combination fuel blend and lubricating oil (quantities). Main findings are that fuel consumption increases non linearly as angular velocity increases and as lubrication lowers, while emissions decreases as angular velocity increases. Lowest fuel consumption and emissions occurred, respectively, for A25/L1:25 and A25/L1:50 (commercial fuel and standard lubrication)

Keywords: internal combustion engines, liquid biofuels (ethanol), emissions, lubricant oil

NOMENCLATURE

A	ethanol volume fraction, mL (see Fig. 2)
ANP	Petroleum, Natural Gas and Biofuels National Agency
API	American Petroleum Institute
C	fuel mass flow or fuel consumption, g/s
D	differences in two fuel consumption tests, %
E	fuel blend indication, %
EAR	anhydrous ethanol fuel
EHR	hydrous ethanol fuel
L	lubrication ratio, %
m	mass registered in tests by balance, g
n	angular velocity, rpm
ppm	particles per million
R	experimental data fitting quality
rev	revolutions (unitary full turn)
rpm	rotation per minute or revolutions/min
T	temperature, °C
t	time registered in tests by chronometer, s
TC	certification for two-stroke oils
u_a	uncertainty of quantity “a”
v	volume, m³
w	weight, kg

Greek symbols

ν	fluid kinematic viscosity, mm²/s
ρ	fluid specific mass (or density), kg/m^3
τ	EAR volume in fuel blend, %

Subscripts

1 or ’’	refers to test data, first set of results
2 or ’’	refers to test data, second set of results
final	refers to final fuel tank mass measured
initial	refers to initial fuel tank mass measured
n	refers to angular velocity
Δm	refers to fuel mass consumption
Δt	refers to time elapsed in tests
Lab	refers for laboratory environmental conditions

INTRODUCTION

Two-stroke internal combustion engines stand out by mechanical simplicity compared to four-stroke engines. Therefore, they are practical handling equipment since they have lower power-weight ratio and are more compact than four-stroke ones. Commercial two-stroke engines are available coupled with tools or equipment for maintenance purposes, as for example: chainsaws for cutting and pruning of branches and trees, lawn mowers, leaf blowers, water pumps, etc. Often, they are portable and thus maintain certain closeness to the user, which implies possible exhaust gases and/or particles from the exhaust system, during it whole operation. Given the large number of applications for small two-stroke engines, changes in the commercial fuel (intensification of biofuels as ethanol) and lubrication mixing can improve its performance in terms of energy conversion efficiency, minimize gas emissions, among other benefits as life span increases in the engine components and the machine as a whole.

In September 2014 (http://www.valor.com.br/empresas/3709986/dilma-sanciona-lei-que-permite-mais-etanol-na-mistura-com-gasolina, acessed on 15 September, 2014) Brazilian government has authorized an increase from 25.0% up to 27.5% for the ethanol in commercial gasoline, that is, a fuel blend of ethanol (27.5%) and gasoline (72.5%). Even if it is not mandatory for the ANP – National Agency for Petroleum, Natural Gas and Biofuels, a BR Distributor (Petrobras subsidiary), sold 535 thousand liters of that maximum ethanol fuel blend to vehicle manufactures (Volkswagen and Hyundai) to this companies make some researches, with this increase of ethanol. Commercial gasoline fuel, until then, presents 25% ethanol in its composition, and in November 2006 it was 23%.

The use of commercial fuel blends, as gasoline and ethanol, in Otto Cycle combustion engines is extensively explored in four-stroke configuration, considering that this feature is already being used in Brazil since the 70s. For success, countries like the United States have also adopted the measure in 2010 and increased from 10% up to 15%, the ethanol volume fraction in their commercial gasoline (http://www.unica.com.br/noticia/20255763920338419546/aprovacao-de-maior-mistura-de-etanol-na-gasolina-nos-eua-nao-significa-aumento-nas-exportacoes-brasileiras/, accessed on 10 February, 2014).

Authors consider that the research on how fuel samples considering ethanol addition or reduction in commercial gasoline in two-stroke engine performance analysis is something that should be looked for. Results can bring about advantages such as those observed in four-stroke engines by Gravalos *et al* (2013), that indicated lower CO and higher CO2 and NO emissions when gasoline/ethanol fuel blends increases from 2% up to 22%. Kumar *et al* (2012) offer advantageous data on the levels of emissions, when having 20% alcohol and 80% gasoline in fuel in a 2 stroke engine, with respect to pure gasoline. Thermal efficiency also improved in their study.

Albuquerque *et al* (2011) point out that synthetic lubricating oils, when compared to mineral lubricant oils, minimize hydrocarbons emissions (“non-burned” fuel) in exhaust gases at internal combustion engines. In two-stroke engines, lubricating oil is mixed directly in the fuel in a manufacturer´s predetermined proportion. When that lubrication proportionality is out of the specified, it can result in fuel wastage, reduced performance, combustion deficiency, or even compromising the engine moving and static parts life cycle. Wang and Lee (1997) developed an electrochemical sensor to verify the oils type that is used in engines.

METHODOLOGY

A typical four-row tube and plate A one-cylinder, two-stroke, 0.25 L (250 cm³), gasoline fuel, spark ignition (Otto Cycle) engine was used in the tests. Additional technical data are: displacement - 30,1 cm³; Cylinder diameter – 37 mm; Piston stroke – 28 mm; Power 1.3 kW at 8500 rev/min; 2.800 rev/min and 14.000 rev/min when in idle speed and maximum speed, respectively; Weigh - 3.9 kg; Power-weight ratio – 3.0 kg/kW. Ignition system is through magnetic ignition with electronic control. Fuel system works with membrane carburetor insensitive to the working position, with an integrated fuel pump. Torque information was not available in technical data from manufacturer´s manual (http://www.stihl.com.br/Produtos-STIHL/Motosserras/Motosserras-para-uso-dom%C3%A9stico/2212-1524/Motosserra-MS-170.aspx>, acessed on 15 Setember, 2014), and also it was not obtained in the present work.

Technical standards considered were for NBR 6396 (ABNT, 1976), which applies to reciprocating internal combustion engines in non-vehicular applications, when acquiring data in the present work (fuel consumption and angular speeds). Tests were carried out in UFGD/FAEN Energy Engineering facilities. The two-stroke engine was operated with commercial and non-commercial fuel blends (gasoline and ethanol), after uncoupling the saw and its fuel tank, which was positioned in a balance to fuel mass registration. The engine was originally coupled in a small chainsaw (manufacturer: STIHL, model: MS 170), as pointed out in Fig. (1).

a)

b)

Figure 1. Two-stroke engine used in tests at UFGD (a); Chainsaw at the equipment´s manual (b).

Fuel and lubrication samples

Fuel samples used in consumption measurement during tests were prepared according to standard requirements, as: NBR 13992 (ABNT, 2008), NBR 8689, NBR 13993 (ABNT, 2008, 2012 and 2013, respectively). According to definitions and terminologies, “EAR” is anhydrous ethanol reference fuel (or “AEAC”, anhydrous ethyl alcohol reference fuel) and “Gasool / Gasohol” is a fuel predominantly composed gasoline, also containing a percentage of “EAR” / “AEAC” and EHR is hydrous ethanol fuel. Then specification AxHy is for a vehicle fuel composed by “x” % of EAR and “y” % of EHR, as indicated in NBR 8689 (ABNT, 2012).

$$\tau = [\,2.(\,A - 50\,)] + 1 \qquad (1)$$

To determine the AEAC volume fraction in commercial Gasohol, samples were evaluated in accordance to NBR 13992 (ABNT, 2008). The original Gasohol is separated by using a 100 mL glass beaker. A fraction of gasoline (100% pure) remains in the top layer and, in the lower layer remains a mixture volume, A (mL), consisting of ethanol reference fuel (EAR) and aqueous solution of sodium chloride (NaCl) at 10% w/v (kg/m³). Then, EAR volume percentage, τ (%), is calculated by Equation (1), as pointed out in NBR 13992 (ABNT, 2008). This determination is shown in Figure 2, for τ = 25% and A = 62.5 mL. Then, commercial fuel samples in the tests were identified as gasohol A25 (25% EAR and 0% EHR), confirming that fuel purchased at a refueling point in Dourados-MS was under ANP standards at that time.

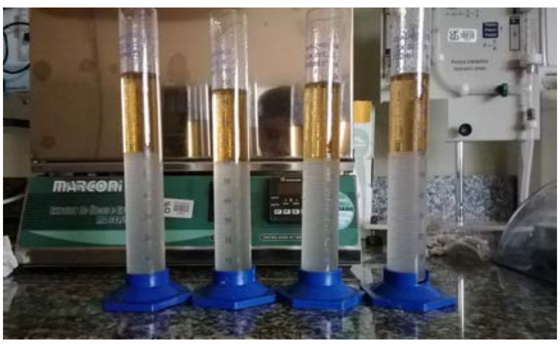


Figure 2. Commercial Gasohol samples for EAC volume fraction confirmation, UFGD facilities (2014).

Fuel samples with three diverse levels of lubrication oil were considered in this work: L1:25, L1:50 and L1:100. The second one corresponds to the standard recommendation, according to the chainsaw manual. First and third ones are, respectively, half and double the recommended fraction of lubrication oil. These fuel samples are identified in the results obtained as: A25/L1:25, A25/L1:50 and A25/L1:100.

The basic purpose of lubricant oil in a two stroke engine is to guarantee components lubrication and engine cleaning. Chainsaw manufacturer also indicates that, if using another oil brand, consider mixing ratio of L1:25 and de-carbonization after operating 300 h, instead of recommended lubricant oil (STIHL 8017 H) with mixing ratio of L1:50 and de-carbonization after operating 600 h. Lubricating oil tested has its technical specifications specified in Table 1.

Table 1. Lubricating oil specification for MS 170 chainsaw model.

STIHL 8017 H (air-cooled engine), developed by Castrol	E25 L1:50
Base	Mineral
Specification (ANP 0208)	API TC SAE 30
ρ (kg/m³), specific mass (at 15 °C)	882.1
ν = μ / ρ (mm²/s), fluid kinematic viscosity, at 40 °C	101.00
ν, at 100°C	11.72

Ambient conditions and instrumentation

Table 2 shows the average values for ambient conditions registered at the UFGD facilities when tests were performed. All tests were under requirements range, according to NBR 7024 (ABNT, 2010), except for a single one that was conducted at T = 30.7 °C, while recommended values are T_{Lab} = (25±5) °C. Measuring instruments and its technical specifications are available Table 3. Laboratory ambient conditions were registered manually.

Table 2. Laboratory conditions in tests.

Blend (E) and Lubrication ratio (L)	E25 L1:50	E25 L1:25	E25 L1:100
Temperature (°C)	28.2	30.7	29.9
Relative Humidity (%)	69	51	57
Barometric Pressure (hPa=10^2Pa)	958.5	956.5	957.5

Figure 3. Experimental apparatus at UFGD facilities and, at right, portable gas analyzer.

Table 3. Measurements instruments technical specification.

Instrument (Manufacturer, Model)	Measurement	Range	Resolution	Accuracy
Thermo-Hygrometer-Anemometer-Barometer (Instrutherm, THAB-500)	Barometric pressure	10.0 – 999.9 hPa	0.1 hPa (10 Pa)	1.5 hPa (150 Pa)
Tachometer (Instrutherm, TDR-100)	Angular velocity	0.5 – 19.999 RPM	0.1 < 1,000 RPM	± 0.1% or +1 digit
Balance (Balmak, ELP-10)	Mass	Max: 5 kg/ 10 kg	1 g	1 g / 2g
Thermo-hygrometer (Instrutherm, HT-200)	Temperature and Humidity	-20 ºC up to 70ºC/ 20% up to 99%	0.1ºC / 1% RU	± 1ºC / ± 5% RU
Chronometer (Instrutherm, CD-2800)	Time	23h59'59"	1/100"	1/200"
Data acquisition software&cable (Instrutherm, SW-U801 / SW20)	-	-	-	-
Gas analyzer (Madur, GA-12)	Emissions (CO_2 and NOx)	~4000 ppm	1 ppm	± 1ppm

Experimental procedure for data acquisition

General procedure

The minimum time to ensure the stabilization condition (steady state) was set at 10 min, for the two-stroke engine in this work. Since with this time can be observe a steady of operation, and there was the risk of prolonged use (risk of overheating and wear parts). Although the NBR 7024 (ABNT, 2010) also establishes the prior operation of 30 min to ensure the condition of stabilization in automotive vehicles.

Requirements and other information of interest described in NBR 6396 (ABNT, 1976), applicable to internal combustion alternative engines not vehicular, cycle 2 times were considered, such as the chainsaw, Fig (1). Authors identified additional standards for tests, but could not have it available, as ISO 7293:1997 – Forestry machinery - Portable chain saws – Engine performance and fuel consumption (http://www.iso.org/iso/catalogue_detail.htm?csnumber=25973, acessed on 15 Setember, 2014) that applies to engine performance and fuel consumption of forestry machinery. Future works will look for acquisition of that standard.

Measurements were performed in the engine speed range from idle up to maximum speed (wide open throttle valve), i.e., 2800 rev/min up to 14.000 rev/min, with steps of Δ1000-2000 rev/min. The engine angular velocity was varied trough the trigger positioning, with no load applied. Results for fuel consumption shown in this work are the average of two tests (duplicate) performed for each angular velocity, i.e., trigger positioning. Lubricating oil was

Then, for each fuel sample, 5 to 7 different angular velocities (rpm) and fuel mass flow (g/s) were obtained.

The experimental apparatus and measurement instruments are shown in Fig (3).

Measurements for fuel consumption and angular velocity

Fuel consumption measurements were performed considering the gravimetric method, NBR 7024 (ABNT, 2010), with small adaptations, i.e., fuel tank was positioned in the balance device and indicated values recorded manually.

The fuel tank is positioned in the balance, tachometer into a 0.5 m (minimum distance, tachometer's manual). A desktop computer with data acquisition software was used for angular velocity, n (rpm). The tests were performed in duplicate by the following procedure: record the fuel tank mass every 30 seconds during 2 minutes (120 s), and angular velocity each 1 s.

$$C = \left(\Delta m / \Delta t \right)$$

and its respective uncertainty given by

$$u_C = \sqrt{\left(u_{\Delta m}.1/\Delta t\right)^2 + \left(u_{\Delta t}.-\Delta m/\Delta t^2\right)^2} \qquad (2)$$

$$D = [(C_1 - C_2)/C_1] \times 100\% \qquad (3)$$

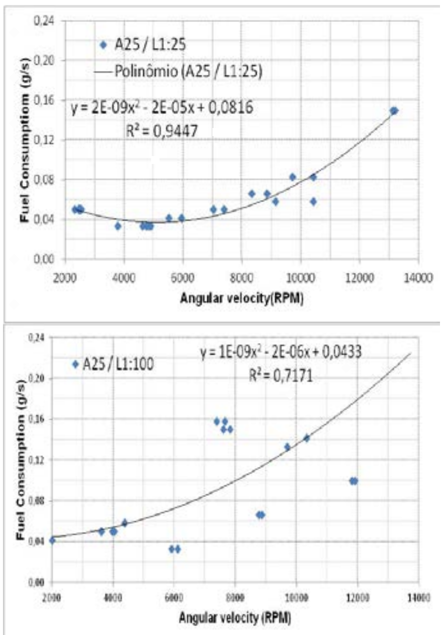
The fuel consumption (g/s) was determined by the Equation (2). Discrepancies were also determined, for D < 5% test results are acceptable according to NBR 7024 (ABNT, 2010), otherwise it is required to repeat the procedure until a valid pair of results is obtained. Equation (3) shows the model for calculating discrepancy (%) for two sets of fuel consumption, or fuel mass flow (g/s).

Where $\Delta m = m_{final}$ (g) and $m_{initial}$ (g), respectively, final and initial fuel tank mass measured. C1 (g/s) and C2 (g/s) are the fuel consumption in tests, first and second (duplicate) respectively, and D (%) is the discrepancy between them. Uncertainties, from Table 3, are: $u_{\Delta m} = \pm 1$ g, $u_{\Delta t} = \pm 0.005$ s and $u_n = \pm 1$ rpm.

EXPERIMENTAL RESULTS & DISCUSSIONS

Results for fuel consumption versus angular velocity, C (g/s) x n (RPM), are available in Fig. 4. There is a general behavior of increasing "C" when increasing "n", except when lubrication is higher than recommended by manufactures, i.e., A25/L1:25 and then it is occurs a minimum "C" around 5000 rpm and not in idle speed (~2000 rpm). Authors believe this is through the additional calorific value in the fuel sample overly lubricated, twice the recommended values, i.e., additional chemical energy is converted to thermal and then mechanical energy inside the engine combustion chamber. Lubricating oils for energy conversion is an interesting possibility, as indicated by Cerqueira (2004).

It is also worth notice that for fuel samples A25/L1:25 and A25/L1:50, experimental results (always in duplicate and D ≤ 5%) are well fit at the empirical equations (R^2 > 90%), better than A25/L1:100 and slightly better than A20/L1:50. Only a few experimental results for A20/L1:50 were usable, since other results were compromised due to scuffing damages (BRUNETTI, 2012) occurred in engine after tests on low lubrication (A25/L1:100) and authors could not obtain, at that moment, a complete set of experimental results.



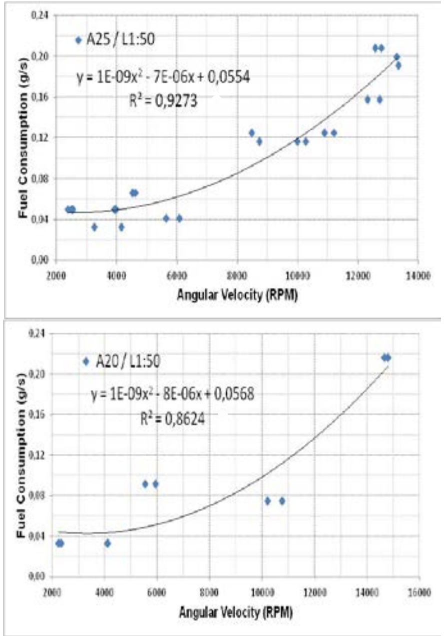


Figure 4. Fuel consumption at four fuel/lubrication samples – A25/L1:25, A25/L1:100, A25/L1:50 and A20/L1:50.

As for uncertainties, angular velocity values were obtained from direct measurements, then $u_n = \pm 1$ rpm (Table 3, tachometer). Uncertainties for fuel mass flow are mainly dependent from $u_{\Delta t} = 0.005$ s, while both minimum and maximum absolute standard uncertainties are ±0.008 g/s. However, for relative standard uncertainties, minimum and maximum values are, respectively, 3% and 25% (worst conditions for minimum fuel mass consumption).

Table 4. Experimental uncertainties, C(g/s) @n(rpm).

Extreme conditions identified	A25/L1:25	A25/L1:100	A25/L1:50	A20/L1:50
Maximum "C" & Minimum relative standard uncertainty	0.150± 6% ~13156 rpm	0.250±3% ~13577 rpm	0.208±4% ~12653 rpm	0.217±4% ~14722 rpm
Minimum "C" & Maximum relative standard uncertainty	0.033±25% ~4489 rpm	0.033± 25% ~6006 rpm	0.033±25% ~3699 rpm	0.033±25% ~2872 rpm

In Figure 5, throttle trigger position was held fixed and angular speed was registered during tests (2 minutes for each one) and refer to A20/L1:50 fuel sample which were still consistent to other fuel consumption. As authors pointed out previously, these results were obtained just after A25/L1:100 tests (lower oil lubrication). Angular velocity behavior presents several inverted peak points, what is consistent to the engine behavior at the scuffing condition originated mainly due to low oil lubricant quantities as shown by Brunetti (2012). These peaks do appear at angular velocity levels of 14000-15000 rpm, and authors believe that is due to the quick reciprocating movement between piston and cylinder.

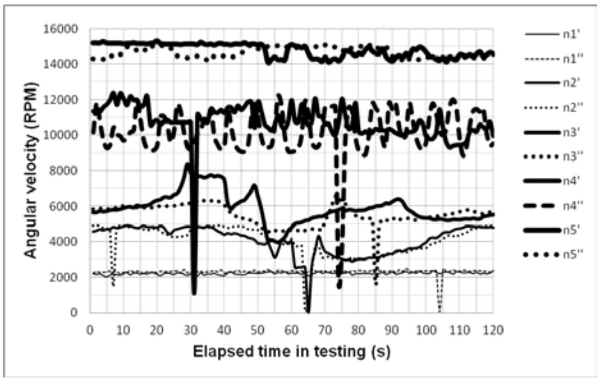


Figure 5. Angular velocity (rpm) behavior during tests for A20/L1:50.

Those inverted peak points occurred only during few second during two minutes tests and no sudden power shutdown occurred during these data acquisition. Then, authors are considering that mean values for angular velocities are presented in Table 5, and they are still reasonable values to be matched with fuel consumption in results previously presented in Figure 4.

Table 5. Angular velocity mean values, n (rpm).

Angular velocity (rpm)	n1	n2	n3	n4	n5
n', 1st set of results (mean value)	2225	4079	5917	10741	14791
n'', 2nd set of results (mean value)	2311	4096	5520	10197	14654
n (mean value from both duplicate results)	2268	4088	5719	10469	14723

Then, once the results obtained were previously analyzed and discussed, empirical equations representing the fuel consumption behavior as angular velocity varies are gathered in Figure 6. For all fuel samples, maximum "C" occurs for maximum angular velocity, around 13.000-14.000 rpm, and its values increases in the following order: ~0,15 g/s for A25/L1:25; ~0,19 g/s for A25/L1:50; ~0,19 g/s for A20/L1:50; ~0,20 g/s for A25/L1:100. That behavior indicates that, as the proportion of lubrication oil contained in the fuel sample decreases, it implies in higher fuel consumption that will result in lowering the engine efficiency, what is in accordance to results obtained by Wang and Lee (1997). Maximum fuel consumption stayed quite the same for different EAR proportion in the Gasohol, when comparing "C" for A25/L1:50 and A20/L1:50, ~0,19 g/s, in both conditions.

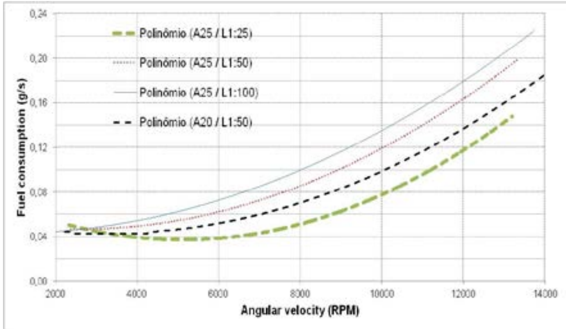
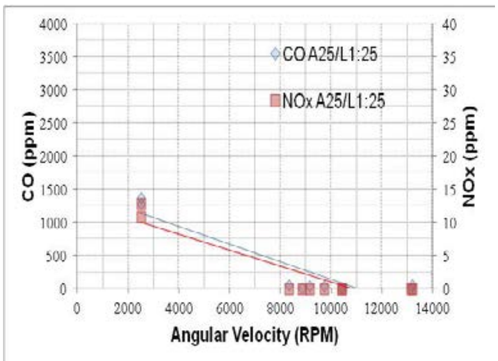


Figure 6. Empirical equations representing fuel consumption behavior at tests in this work.

Figure 7 shows results for the two-stroke engine emissions, CO2 and NOx. Authors would like to point out that GA-12 gas analyzer measuring range reached ~4000 ppm, and the two stroke engine (chainsaw) exceeded that limit. Then, in order to obtain at least a qualitative behavior, the gas analyzer was positioned ~0,15 m far from the exhaustion point were, after ambient air dilution, emission values were able to be registered. In that situation, quantitative values indicated in Figure 7 do not correspond to the real emission just after engine exhaustion. Thus, the behavior is as follows: CO2 and NOx emissions decrease as angular speed increases for all fuel samples. Higher values for CO emissions occur for A20/L1:50 (~3500 ppm at ~6000 rpm), the lowest ethanol quantity in the fuel sample, followed by A25/L1:100 (~3000 ppm at ~2000 rpm), the lowest lubricant oil in the fuel sample. In a similar behavior, NOx emissions are higher and for A25/L1:100 (~35 ppm at ~2000 rpm) and A20/L1:50 (~15 ppm at ~2000-6000 rpm). Lowest values for CO2 and NOx occurs for commercial fuel sample and standard oil lubrication mixture, A25/L1:50: CO2 emissions (~1500 ppm at ~4000 rpm) are at least two times lower than the worst test conditions (A25/L1:100 or A20/L1:50), while NOx emissions (~10 ppm at ~3000 rpm) are at least 1/3 up to 2/3 times lower than the worst test conditions (again, A25/L1:100 or A20/L1:50). Thus, commercial fuel and standard lubrication (A25/L1:50) showed to be the best option for emissions, probably due to air-fuel rates that were not altered during tests.



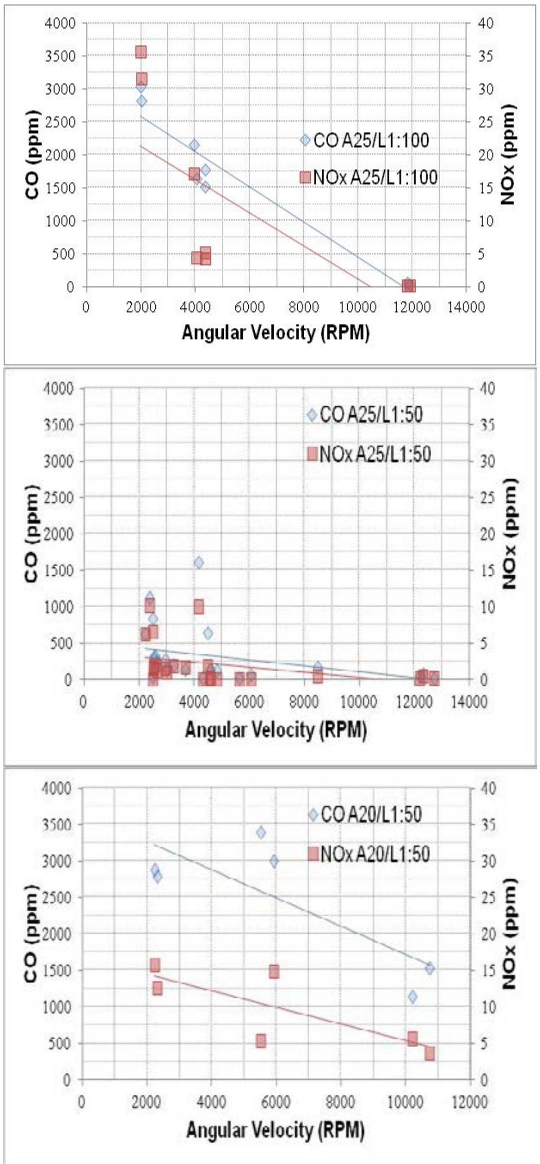


Figure 7. Qualitative results for CO and NOx emissions in the two-stroke engine tests.

CONCLUSIONS

The paper is the result of a laboratory tests on two-stroke internal combustion engine in which their performance was analyzed and compared using commercial and non-commercial fuel blends (gasoline + ethanol) and different lubrication oil mixtures. The realization of other studies with another two-stroke engine types and equipment for better measurements of new tests will be made in the future. Main findings in this work are pointed out next.

a) Fuel consumption (fuel mass flow, kg/s) increases non-linearly, as angular velocity increases. Exception occurs for higher lubrication than recommended (A25/l1:25), when fuel consumption decreases for low angular velocities before start increasing as the general behavior for all other fuel/oil samples;

b) Even though experimental results for A20/L1:50 were partially compromised by scuffing damage occurred at low lubrications tests, mean values for fuel consumption and angular velocity were good enough to join other fuel sample results analysis (R^2 > 86%);

c) As the proportion of lubrication oil contained in the fuel sample decreases, it implies in higher fuel consumption. It was not measured in this work, but according to the literature, that will result in lowering the engine efficiency;

d) Emissions (CO2 and NOx) qualitative behavior, for all fuel samples and lubricating oil mixing, indicated a decreasing as angular velocity increases;

e) Better performance, i.e, the lowest fuel consumption occurred for fuel sample A25/L1:25 (~5000 rpm) and the lowest emissions occurred for fuel sample A25/L1:50 (commercial fuel and standard lubrication).

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