ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

EMISSIVE AND THERMOMECHANICAL PERFORMANCE EVALUATION OF A SMALL ENGINE-GENERATOR GROUP OPERATING ON MONO FUEL AND DUAL FUEL MODES

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Abstract. *This work deals with the emission and performance results of an internal combustion engine (ICE), compression ignition (CI), single cylinder, coupled to an electric generator. The engine operation occurred in mono fuel mode: diesel oil (DO) or soybean vegetable oil (SVO); and in dual fuel mode: natural gas and DO (NG-DO) and natural gas and SVO (NG-SVO). In this latter mode the engine worked with a reduced fuel oil rate, i.e., with a pilot oil injection. The fuel need has, therefore, been supplemented by NG, being supplied to the engine by a system that regulates its dosage on admission. In the compression stroke, the NG-air mixture is compressed, increasing its pressure and temperature. At the end of this process the temperature is high enough to ignite the pilot DO or SVO injection, and thus, the NG-air mixture. The electricity generated was dissipated by electrical resistances to water contained in a reservoir. The fuel oil rate control was done via a mechanism which acts on the injection pump, allowing a stable condition in the dual fuel mode engine operation. The analysis of the combustion gases showed a moderate reduction of NOx in the dual fuel mode engine operation. However, it was observed a marked presence of hydrocarbons in the exhaust gases, indicating a probable excess of NG. Based on the fuel Higher Heating Value (HHV), the highest thermal efficiency values of the engine-generator group were observed for dual fuel mode: 34.7% for the engine operating with NG-SVO and 33.9% in NG-DO operation.*

Keywords: *internal combustion engine; compression ignition; diesel oil; mono fuel operation; dual fuel operation*

1. INTRODUCTION

Despite the ICE having low conversion efficiency, this type of engine is commonly used nowadays and especially in rural areas. In particular, the diesel engine requires the use of a fuel easy to ignite in the presence of air, and when subjected to high pressures. On contrary of DO, the NG has a great ability to withstand high pressures without burning in the presence of air. However, there is the impossibility of an ICE-CI to operate only with NG.

Camargo (2003) evaluated in a dynamometer the performance of a diesel engine single cylinder of 668 cm^3, powered on dual fuel mode (DO-NG). In this engine, the energy comes mostly from the combustion of NG, the main fuel, and DO has the function of producing the beginning of the gas combustion, having so a partial replacement of DO by NG, probably increasing the combustion efficiency. At the beginning, the author made tests only with DO. In the following, tests were carried out (with three replicates) varying the proportions of DO, NG and injection angles. The best performance was obtained with 22% of DO (0.270 $g \cdot s^{-1}$) compared to the maximum rate of the injection pump (0.526 $g \cdot s^{-1}$) and 13 $L \cdot min^{-1}$ of NG and injection angle of 21° (before top dead center - BTDC). In this case, the power increased by 14% and the specific consumption decreased 46% compared to the mono fuel operation: DO100.

Baldissera (2010) presents a theoretical evaluation and emissions of a single cylinder diesel engine, four strokes operating on NG-DO mode, in order to estimate differences in power and the difference in the level of emissions. In this study, the engine was tested at three different speeds in a dynamometer varying the fuel mixture, and the engine was monitored by the lambda probe and thermocouple in the exhaust, together with a load cell installed in the fuel tank. The results of power, combustion reaction stoichiometry, consumption and exhaust temperature were compared, and found that, with the exception of nitrogen oxides, all other emissions were reduced compared to the original engine. The power remained practically unchanged for the same speed with the substitution by NG of a portion of the total diesel admitted.

Ramos (2006) evaluates a diesel engine, single cylinder of 668 cm^3, powered on dual fuel mode DO-NG, being determined the parameters that should be monitored for the development of an appropriate controller. An electronic manager based on a fuzzy algorithm implemented by a microcontroller to optimize the volume of natural gas supplied

ISSN 2176-5480

to the engine was developed. The injection angle also accurately tracked by the system is synchronized with the camshaft, whose angular position reference is the BTDC of the cylinder. The findings contributed to the increase in engine efficiency as well as to reduce fuel consumption and emissions.

Kague (2010) made the conversion of a six-cylinder turbocharged diesel engine in diesel-gas by fumigation (pilot injection of DO with the function of starting the combustion of the fuel-air mixture), assessing the influence of some parameters on engine combustion: local injection of NG in the intake line engine (before or after the compressor); gas temperature injected; and air-fuel ratio. As a result of the study, it was identified that the behavior of the combustion, depending on the variations imposed, can be different for the various conditions of torque and speed and substitution rate of DO. However, according to the author, each operating condition of the engine can be individually explored with the potential of reducing the consumption of NG.

Egúsquiza (2011) conducted experimental tests with a diesel cycle engine, four-cylinder turbocharged, consuming hydrated ethanol or NG in partial replacement of DO. In this work the author investigates the influence of alternative fuels and evaluates the technical of diesel injection angle diesel and the partial restriction of the intake air, in the characteristic parameters of combustion, performance and emissions. Based on data from the pressure-crankshaft angle diagram, the author analyzed some combustion characteristic parameters: start of combustion; maximum pressure rise rate; and peak pressure. The performance engine parameters were analyzed using the thermal efficiency and emissions of CO and C_xH_y, particulate matter (PM) and NO_x. The results showed that the techniques evaluated in dual fuel mode with high DO replacement rates favored a better burning of the alternative fuels, reflecting favorably on lower emissions of CO and PM, as well as a small increase in thermal efficiency of the engine. However, there was also an increase in NO_x emissions, and in the specific case of the advancement of injection, it was noted a greater noise generated by the engine.

Yoon and Lee (2011) conducted an experimental investigation in a diesel engine, four-cylinder turbocharged, to study the influence on emissions and combustion efficiency, operating on DO100 mode (ultra-low sulfur diesel), on biodiesel mode (BD100) and dual fuel: biogas-diesel (BG-DO) and biogas-biodiesel (BG-BD). The BG was injected into the engine during the admission stroke by two electronically controlled injectors installed in the intake manifold. The results of this study showed that the combustion characteristics in the mono fuel operating mode (D100 and BD100) showed similar patterns at various loading conditions. In dual fuel mode at low loads, the peak pressure and heat released for BD-BG operation mode were slightly lower compared to the condition BG-DO. Already, at 60% load, the combustion engine of the BG-BD mixture showed slightly higher peak pressure, heat released and mean effective pressure compared to the DO100 operation mode. It was also noted by the authors that the ignition delay in the BG-BD mixture was lower than that for the BG-DO mixture because of the higher BD cetane number. In addition, the results indicated: lower NO_x emissions in dual fuel operation mode relative to mono fuel operation at all engine load conditions; and the BG-BD mixture combustion showed lower PM emissions due to the absence of aromatics, the presence of low sulfur content and the presence of O_2 in the BD.

The work herein presented reports the results obtained in studies that have been conducted with a small compression ignition engine. This engine powers an electric generator through pulleys and belts. The generated energy is dissipated from electrical resistances to water contained in a reservoir. The studies were performed through short duration tests with engine operating in the mono fuel mode (DO100 and soy vegetable oil - SVO) and in the dual fuel mode: NG-DO and NG-SVO.

2. MATERIALS AND METHODS

In this section some constructive features of the engine used in the development of the work, the main characteristic fuels used and also the methodology used for the experiments in order to compare the thermal and emissive performance parameters of the engine are presented.

The engine used in the tests is Agrale brand, model M90, single cylinder, and has the following constructive, operating and setting features: 668 cm^3 of displacement; direct injection (DI); fuel supply system by gravity; injection pump unit embedded in the block; fuel filter cartridge type (plastic) of 20μm mesh; forced air cooling by fan built into the flywheel; crankcase lubricating oil incorporated into the engine block, with capacity of 2.5 liters; speed control by acceleration lever and fuel oil rate adjustment by an eccentric mechanism acting on the injection pump; injection angle of 21° BTDC; injection opening pressure of 180 bar; and electric starter. It is noted that the fuel consumption of this engine was adjusted by the manufacturer to engine-generator (genset) version according to NBR ISO 3046/1/1995 standard.

The engine is coupled by belts and pulleys to an electric generator (alternator) three-phase Bambozzi brand, model 46530/05, 7.5 kVA of apparent power and voltage of 220 Volts with star connection. The generator operates at 1800 rpm and can receive resistive or inductive loads.

The main characteristics of the fuels used in this work are presented in the sequence. The DO used in the studies has low sulfur content and its main properties are presented in Tab. 1. Like all vegetable oils, the SVO is composed mainly of triglycerides (glycerol esters with fatty acids). Triglycerides have in the main bond three-carbon with a long HC chain attached to each carbon. These chains are joined through oxygen and carbon atoms, with the majority of the fatty

ISSN 2176-5480

acid chains of VO having eighteen carbons, composed by single bonds (saturated chains) and double bonds (unsaturated chains) with oxygen and hydrogen atoms (Chauhan et al. 2010). Table 2 shows the properties of the SVO.

Table 1. DO properties. (Adapted from Misra and Mutthy, 2010)

Property	Unit	Value
Density (20 °C)		0.855
Flashpoint	°C	76
Fluidity point	°C	-16
Kinematic viscosity (38 °C)	$mm^2 \cdot s^{-1}$	3.06
Higher Heating Value (HHV)	$MJ \cdot kg^{-1}$	43.8
Cetane Number (CN)	–	50

Table 2. SVO properties. (Adapted from Misra e Mutthy, 2010)

Property	Unit	Value
Density (20 °C)		0.9138
Flashpoint	°C	254
Fluidity point	°C	-12.2
Kinematic viscosity (38 °C)	$mm^2 \cdot s^{-1}$	32.6
HHV	$MJ \cdot kg^{-1}$	39.6
CN	–	37.9

The properties of the natural gas used in the experiments were obtained from Sulgás (2012) and are shown in Tab. 3, while the volumetric composition reported in Tab. 4.

Table 3. NG properties. (Sulgás, 2012)

Propriety	Unit	Average value
HHV	$MJ \cdot Nm^{-3}$	41.69
Lower Heating Value (LHV)	$MJ \cdot Nm^{-3}$	37.65
Relative density	–	0.602
Apparent molecular mass	$g \cdot mol^{-1}$	17.367
Air/NG stoichiometric ratio	–	9.96
Flame speed	$cm \cdot s^{-1}$	49.4
Upper flammability limit	% of gas in air	14.9
Lower flammability limit	% of gas in air	4.8

Table 4. NG average volumetric composition. (Sulgás, 2012)

Chemical species	Formula	%Vol.
Methane	CH_4	91.80
Ethane	C_2H_6	5.58
Propane	C_3H_8	0.97
Iso-Butane	C_4H_{10}	0.03
N-Butane	C_4H_{10}	0.02
Pentane	C_5H_{12}	0.10
Carbon dioxide	CO_2	0.80
Nitrogen	N_2	1.42

The tests were conducted on short duration mode (20 min.) in order to determine the thermal and emissivity performance of the genset. Thereby, it is necessary to know the consumption of fuels used, the power generated in the tests and analyze the combustion gases. The experiments were performed with DO100, SVO100 and on dual fuel mode: NG-DO and NG-SVO and the results obtained are the average of two tests for each mode of operation. In all tests, the fuel consumptions were adjusted so that the speed of the electric generator stays around 1800 rpm, and on dual fuel

ISSN 2176-5480

mode, both the DO and SVO rates were minimized to start the ignition of these fuels. Therefore, it was necessary to complement energy with NG.

The NG supply system comprises a storage cylinder of 30 liters at a pressure of 220 bar, i.e., able to store about 7.5 Nm^3, fitted with a connection supply. Further, the system is comprised by: a solenoid valve, which electrically releases the gas to the engine; a pressure reducing valve, which reduces the pressure from that of the cylinder to near the atmospheric pressure; a flow control valve; and a mixing apparatus, which sucks the NG by the passage of air to the engine, and so, the air-NG mixture is aspirated by the engine. All components of the NG supply system are connected by rubber hoses, and after the pressure reducing valve, a LAO brand, model G0,6 consumption meter is installed, which totalizes the amount consumed in a given measured time test. A water column manometer installed near the gas meter is used to measure the pressure of consumed gas.

The DO and SVO consumption was determined using a digital scale Marte brand, model AS 5500C, resolution of 0.01 g. Over the scale a DO or SVO container was placed, which was connected to the engine by a hose. Then, the variation of the total weight of the container over the time test was determined.

The electric power produced by the generator was measured by an energy analyzer Embrasul brand, being possible also to observe the voltage and electric current values. The speeds of the engine and of the electric generator were measured with an optical tachometer Extech brand, model 461920, resolution of 0.1 rpm. The output cables of the electric generator were connected to a switch that engages the resistive load (electrical resistance). Thus, it was possible to start the engine in the absence of load.

A flue gas analyzer Eurothron brand, model 8000 GreenLine was used, which has O_2, CO_2, CO, NO_x, SO_2 and C_xH_y sensors. In addition, this analyzer measures the ambient air temperature and the exhaust gases temperature, and determines the excess air coefficient (λ) and combustion efficiency. The exhaust gas sample is collected by a probe that conveys the gas by a hose into the unit, which processes the collected sample.

The data collection was initiated only 20 minutes after starting the engine, since it was cold. Between each test condition, a time of 5 minutes was allowed to stabilize the engine operation. Each experiment had 20 minutes duration in order to give enough time to measure the gas amount and the fuel consumption.

The average values of power and specific fuel consumption of the two experiments for each fuel mode operation of the engine were corrected for the standard reference conditions: pressure of 100 kPa, temperature of 298 K and relative humidity of 30%, according to NBR ISO 3046/1/1995. During the tests, dry bulb and wet bulb ambient air temperatures of the room test were measured with a fan-forced air psychrometer and the atmospheric pressure measured by a mercury column barometer.

The genset thermal efficiencies operating on mono and dual fuel modes were determined from the corrected specific fuel consumption and from the HHV of the fuels using Eq. (1) and (2), respectively.

$$\eta_{mf} = \frac{3{,}6 \cdot 10^6}{SC_{DO\ or\ SVO} \cdot HHV_{DO\ or\ SVO}} x100 \tag{1}$$

$$\eta_{df} = \frac{3{,}6 \cdot 10^6}{SC_{DO\ or\ SVO} \cdot HHV_{DO\ or\ SVO} + SC_{NG} \cdot HHV_{NG}} x100 \tag{2}$$

where, η_{mf} is the genset thermal efficiency on mono fuel operation, η_{df} is the genset thermal efficiency on dual mode operation, $SC_{DO\ or\ SVO}$ is the specific consumption of DO or SVO [$g \cdot kWh^{-1}$], $HHV_{DO\ or\ SVO}$ is the Higher Heating Value of DO or SVO [$kJ \cdot kg^{-1}$), SC_{NG} is specific fuel consumption of NG [$L \cdot kWh^{-1}$] and HHV_{NG} is the Higher Heating Value of NG [$kJ \cdot Nm^{-3}$].

3. RESULTS AND DISCUSSION

The tests were made at a speed of 1800 rpm for the electric generator, which means an engine speed of 2300 rpm, being observed, however, that during the tests the speed has varied ±10 rpm. As the load condition on the electric generator was constant during all tests, power was almost constant and the average value was 5389 W. This value was used along with the fuel consumption measured to calculate the specific fuel consumption for the genset, values that were subsequently corrected to the reference standard conditions.

3.1 DO100 tests engine without load

At first two tests were performed with the unloaded engine, but with the control consumption rate mechanism of the injection pump positioned in the original manufacturer condition. Thus, the genset speed adjustment in 1800 rpm was made by the acceleration lever and the DO consumption was required to maintain in motion the internal engine parts,

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overcoming the frictional resistant forces. The uncorrected average results of two tests are shown in Tab. 5 and serve as reference for other tests.

Table 5. Average results of the DO100 tests engine without load.

Parameter	Unit	Value
DO consumption	$g \cdot s^{-1}$	0.156
Exhaust gases temperature	ºC	128
O_2 concentration	% on dry basis (d.b.)	18.5
Air excess (λ)	—	7.95 (795% theoretical air)
Combustion efficiency	%	86.6
CO concentration	ppm on d.b.	259
NO_x concentration	ppm on d.b.	51
SO_2 concentration	ppm on d.b.	Not detected (n.d.)
CO_2 concentration	% on d.b.	1.13
C_xH_y concentration	ppm on d.b.	174

3.2 DO100 tests engine at full load condition

The mean values of two experiments in this mode of operation are reported in Tab. 6. In these experiments the control consumption rate mechanism of the injection pump was positioned in the original manufacturer condition.

Table 6. Average results of the DO100 tests engine at full load condition.

Parameter	Unit	Value
DO consumption	$g \cdot s^{-1}$	0.519
Corrected power	kW	5.97
Corrected SC	$g \cdot kWh^{-1}$	335.70
Exhaust gases temperature	ºC	466
O_2 concentration	% on d.b.	12.8
Air excess (λ)	—	2.45 (245% theoretical air)
Combustion efficiency	%	89.5
CO concentration	ppm on d.b.	1099
NO_x concentration	ppm on d.b.	447
SO_2 concentration	ppm on d.b.	n.d.
CO_2 concentration	% on d.b.	3.33
C_xH_y concentration	ppm on d.b.	135

The mean value of the DO consumption of 0.519 $g \cdot s^{-1}$ for the genset operating at 1800 rpm (engine speed of 2300 rpm) is similar to the value obtained (0.526 $g \cdot s^{-1}$) by Camargo (2003) from a similar engine operating at the same speed, although the corrected power obtained by this author was 7.62 kW (248.33 $g \cdot kW^{-}h^{-1}$). The results obtained by Baldissera (2004) for a similar engine (same manufacturer and model) operating at 2250 rpm with DO100 were the following: power of 9.23 kW; exhaust temperature of 349.12 °C; λ of 0.85; DO consumption of 1.70 $g \cdot s^{-1}$, and the specific consumption of 662.99 $g \cdot kWh^{-1}$.

Comparing the combustion characteristics presented in Table 6 with those of Table 5, it is observed that the application of the load decreases excess air (λ) from 7.95 to 2.45 because the amount of DO consumed is 3.3 times greater for the same amount of intake air. However, it is noted that at full load condition CO emissions are higher (4.2 times) and of NO_x (8.8 times larger), although has reduced 22.4% the C_xH_y concentration. The genset thermal efficiency based on DO HHV is calculated from Eq. (1) shown before.

$$\eta_{mf,DO} = \frac{3{,}6 \cdot 10^6}{SC_{DO} \cdot HHV_{DO}} = \frac{3.6 \cdot 10^6}{335.70 \cdot 43800} \cdot 100 = 24.5\%$$

3.3 SVO100 tests engine at full load condition

In these tests the engine started with DO and after 15 minutes of operation began operating with SVO100, staying in this operating regime for more 15 minutes when the test with SVO was initiated. The mean values in this operation mode are shown in Tab. 7. In these tests the control consumption rate mechanism of the injection pump was positioned in the original manufacturer condition.

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Table 7. Average results of the SVO100 tests engine at full load condition.

Parameter	Unit	Value
SVO consumption	$g \cdot s^{-1}$	0.582
Corrected power	kW	6.03
Corrected SC	$g \cdot kWh^{-1}$	378.04
Exhaust gases temperature	ºC	478
O_2 concentration	% on d.b.	12.6
Air excess (λ)	—	2.42 (242% theoretical air)
Combustion efficiency	%	88.9
CO concentration	ppm on d.b.	1384
NO_x concentration	ppm on d.b.	469
SO_2 concentration	ppm on d.b.	n.d.
CO_2 concentration	% on d.b.	3.65
C_xH_y concentration	ppm on d.b.	84

According to the specific SVO consumption result shown in Tab. 7, this value is 12.6% higher than that of DO (Tab. 6). This is expected because the HHV_{SVO} is smaller than the HHV_{DO} and to produce the same power, a higher SVO consumption is needed. The SVO combustion parameters obtained are similar to those for DO, with exception of an increase of 25.6% in CO emission and a reduction of 37.8% in C_xH_y emission. The genset thermal efficiency value is practically equal to that obtained in the DO100 operation, i.e.

$$\eta_{mf,SVO} = \frac{3{,}6 \cdot 10^6}{CE_{OVS} \cdot PCS_{OVS}} = \frac{3.6 \cdot 10^6}{378.04 \cdot 39600} \cdot 100 = 24.1\%$$

3.4 NG-DO tests engine at full load

These tests were carried out from the partial replacement of DO by NG, adjusting the position of the control consumption rate mechanism of the injection pump for a minimum fuel flow. Table 8 shows the average values to the NG-DO mode operation.

Table 8. Average results of the NG-DO tests engine at full load condition.

Parameter	Unit	Value
DO consumption	$g \cdot s^{-1}$	0.163 (31.4%*)
Corrected power	kW	6.11
Corrected SC_{DO}	$g \cdot kWh^{-1}$	105.60
NG consumption	$L \cdot min^{-1}$	13.3
Corrected SC_{NG}	$L \cdot kWh^{-1}$	143.52
NG consumption pressure	mmca	–26
Exhaust gases temperature	ºC	440
O_2 concentration	% on d.b.	12.6
Air excess (λ)	—	2.38 (238% theoretical air)
Combustion efficiency	%	90.2
CO concentration	ppm on d.b.	1162
NO_x concentration	ppm on d.b.	300
SO_2 concentration	ppm on d.b.	n.d.
CO_2 concentration	% on d.b.	3.01
C_xH_y concentration	ppm on d.b.	2126

* % of DO relative to condition at full load (Tab. 6)

Camargo (2003), for a similar engine and conditions closed to those identified in Table 8 (22% DO and 13 $L \cdot min^{-1}$) obtained the following results at 2300 rpm: power of 8.86 kW; exhaust temperature of 562 °C, SC_{DO} 48.9 $g \cdot kWh^{-1}$; SC_{NG} of 94.81 $L \cdot kWh^{-1}$. Baldissera (2010) also with a similar engine reported the following results at 2250 rpm and 20% DO: power of 9.23 kW, exhaust temperature of 367.52 ºC; λ of 1.30; DO consumption of 0.34 $g \cdot s^{-1}$, SC_{DO} of 130.94 $g \cdot kWh^{-1}$, and SC_{NG} of 530.39 $g \cdot kWh^{-1}$.

The combustion characteristics shown in Tab. 8 indicate values very similar to those shown in Tab. 6, with exception of NO_x emission, which was 32.8% lower for the NG-DO mode engine operation, and the concentration of

ISSN 2176-5480

C_xH_y, which was 15.7 times higher in this mode of operation. This high level of C_xH_y indicates an excess of NG supplied to the engine, greatly enriching the air-GN mixture.

The genset thermal efficiency is calculated by Eq. (2) and is shown in the sequence.

$$\eta_{dm,NG-DO} = \frac{3.6 \cdot 10^6}{105.60 \cdot 43800 + 143.52 \cdot 41690} \cdot 100 = 33.9\%$$

As can be observed the genset thermal efficiency increased from 24.5% on DO100 operation mode to 33.9% on NG-DO dual fuel operation, i.e, an increase of 9.4%.

3.5 NG-SVO tests engine at full load

These tests were performed from the partial replacement of SVO by NG, adjusting the position of the control consumption rate mechanism of the injection pump for a minimum fuel flow. The average results from two tests are shown in Tab. 9.

Table 9. Average results of the NG-SVO tests engine at full load condition.

Parameter	Unit	Value
SVO consumption	$g \cdot s^{-1}$	0.208 (35.7%*)
Corrected power	kW	5.96
Corrected SC_{SVO}	$g \cdot kWh^{-1}$	135.35
NG consumption	$L \cdot min^{-1}$	11.08
Corrected SC_{NG}	$L \cdot kWh^{-1}$	120.40
NG consumption pressure	mmca	–26
Exhaust gases temperature	ºC	482
O_2 concentration	% on d.b.	13.1
Air excess (λ)	—	2.52 (252% theoretical air)
Combustion efficiency	%	88.8
CO concentration	ppm on d.b.	1315
NO_x concentration	ppm on d.b.	363
SO_2 concentration	ppm on d.b.	n.d.
CO_2 concentration	% on d.b.	2.90
C_xH_y concentration	ppm on d.b.	1946

* % of SVO relative to condition at full load (Tab. 7)

In relation to the SVO100 operation mode is observed that the CO emission decreased 5.0%, the NO_x emission decreased 22.6% and a drastic increase of the C_xH_y emission, although it was lower than NG-DO operation mode seen before. As is shown in the following, a positive aspect of the NG-SVO operation mode was the biggest genset thermal efficiency, which is calculated from Eq. (2) and surpassed all previous cases.

$$\eta_{dm,NG-SVO} = \frac{3.6 \cdot 10^6}{135.35 \cdot 39600 + 120.40 \cdot 41690} \cdot 100 = 34.7\%$$

4. CONCLUSIONS

In this paper were presented the results of tests carried out with a small engine-generator group (genset) of 7.5 kVA operating on mono fuel mode with diesel oil (DO100) and with soybean vegetable oil (SVO100) and on dual fuel mode with natural gas/diesel oil (NG-DO) and with natural gas/soybean vegetable oil (NG-SVO). The tests were of short duration (20 min.) and occurred at 1800 rpm, which is the working speed of the electric generator (alternator), while the engine works at nearly 2300 rpm. The study was intended to compare the results of fuel consumption, emissions and thermal efficiency of the genset operating on the modes mentioned.

Although the results obtained are not conclusive since more tests should be run with a more reliable instrumentation, especially with regard to the fuel gas flow measurement, some important observations can be drawn from this work. It is understood that the gas analyses were sufficiently repeated and showed a moderate reduction of NO_x when the engine is operating on dual fuel mode, i.e., with a partial replacement of DO or SVO by NG. However, there was a marked presence of hydrocarbon in the exhaust gases of the engine, indicating likely excess of NG at intake engine with air. This suggests that different NG/DO proportions should be tried to minimize the presence of C_xH_y in the

ISSN 2176-5480

combustion products. Since DO and NG sulfur concentration is small, no SO_2 emission was detected by the gas analyzer used. In general, the combustion efficiency was very good, reaching a mean value of nearly 89%.

Regarding to the genset thermal performance the best values were observed for dual fuel operation mode. Particularly, the engine operating with NG-SVO reached the highest thermal efficiency of 34.7% against 33.9% in the NG-DO operation mode. Given the low values obtained for the thermal efficiency on mono fuel operation mode, i.e., with DO100 and with SVO100, the test shall be repeated, including the possibility of extracting more power from the alternator beyond the 5.389 kW obtained.

5. ACKNOWLEDGEMENTS

Special thanks to: FAPERGS and CNPq by the scientific initiation scholarships granted; Agrale S.A. by the M90 engine loaned, and Manegás by the kit of NG supply loaned.

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