Experimental comparative results of main pollutants monitoring for a spark ignition cogeneration engine fuelled with LPG and petrol

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This paper presents experimental results concerning the comparative monitoring of the LPG (Liquid Petroleum Gas) and Petrol fuel combustion which supplies an electrical generator driven by an internal combustion system. The main pollutants HC, CO, $CO_{2,}$ $NO_{X,}$ are monitored and the consequences on the cogeneration system are shown. The results indicate that even the LPG is a less polluting gas, for a nominal charge of the engine (2 kW), the amount of exhaust greenhouse gases is increased (CO_2); on the other hand the price for LPG (low cost in comparison to fossil gasoline/petrol) is an advantage.

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1. Introduction

The monitoring of combustion is an important issue in the design of energy systems, but, also it represents an essential tool for assessing their environmental impact. In contrast to environmentalist slogan "a clean man in a clean world ", it is more than obvious and actual that undesirable impact of internal combustion engines is reality, because they pollute the environment through harmful emissions, noise, but also generate other disadvantages. Such disadvantages are related to the necessity of the oil and fuel spills, waste management from manufacturing or recycling of vehicles, etc. [1].

The effect of the most important pollutant in internal combustion engines is due to the presence of harmful emissions in the combustion gases, emissions that occur mainly due to incomplete and imperfect combustion (attested by the presence of CO species, C_mH_n in the fuel gas from the internal combustion engine) and following the standard mechanisms of genesis of the NO_x) [2].

The installation conceived and presented in this article applies the principle of comparative substitution of two distinct forms of energy for a single primary energy system (LPG or Petrol) that is finally generating two simultaneous forms of secondary energy (Fig. 1).

Primary energy is considered that one that feeds the engine. The two forms of energy generated are *electricity* (at a voltage between 215-230 V at 50 Hz and an output of up to 4 kWh) and *heat*. The procedure is named cogeneration, and assures the best efficiency for given situations, in comparison with the case when the both secondary energy forms are obtained separately. The fuelling is assured by using in turn, LPG and Petrol.

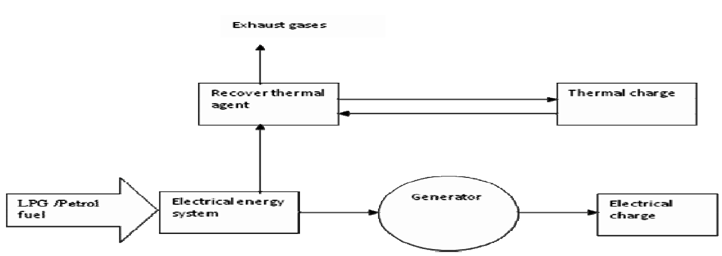

Fig. 1. Cogeneration with spark ignition engine by burning LPG/Petrol fuel.

The main components of the installation are:
- Spark ignition engine which, based on chemical energy of fuel combustion, generates mechanical energy, and is connected directly, without reducing speed, to the mechanical-electric power system;
- The generator itself that converts mechanical energy into electrical energy.
- Heat exchanger, which converts the energy of combustion of the spark ignition engine into useful heat;

- Rheostat group load generator that simulates (in the experiments) the electric charge;
- Data acquisition system that continuously monitors the thermodynamic parameters of the installation during the experiments [2].

Generator group is the main component of the cogeneration plant. The group is produced by Honda.

As Fig. 2 indicates the designed and used cogeneration group consists of an Otto engine (Honda), one Generator (BGS GE 6000 Plus) and a Tank. The Otto engine is produced in 2007, and has a single cylinder, using air cooling and ignition with Hall Effect. Turning on the engine is done exclusively manually.

Fig. 2. Generator group left view: 1-engine, 2-generator, and 3-tank.

Perfect combustion (not only in an ideal Otto cycle) leads to stable and nontoxic compounds only in the flue gases (O_2, N_2, H_2O), together with the presence of CO_2. However, in real conditions, the exhaust emissions contain pollutants: NO_x, SO_2, CO, CH_4, N_2O, etc. and greenhouse gas (CO_2), as Fig. 3 shows.

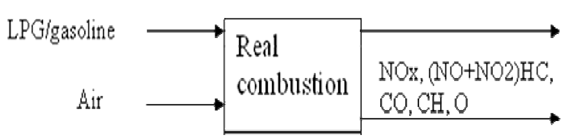

Fig. 3. The real combustion of LPG/Petrol fuel.

2.0 Pollutant description

The main pollutants are presented in the followings, as formed in an internal combustion engine:

2.1 Hydrocarbons – HC

These include gaseous products of incomplete and/or imperfect combustion. They refer to about 400 individual compounds, representing most classes of organic compounds, including saturated and unsaturated aliphatic hydrocarbons, aromatic hydrocarbons and polycyclic compounds, oxygenates such as aldehydes, ketones, alcohols, ethers, acids and esters, as well as nitrogen, sulfur and organ-metallic compounds. It was found that benzo-pripen, which is a cyclic hydrocarbons extracted from tar, exerts a powerful carcinogen action. Especially one mentions that secondary substances are very dangerous also because they are a main component of photochemical smog formation reactions [2].

Hydrocarbons, seen as a set of numerous chemical compounds, are considered primary substances resulting from the combustion process in an internal combustion engine. They are very harmful, including non-toxic compounds such as methane, but also highly toxic compounds like 4-hydroxyphenyl [3]. Some hydrocarbons are irritating and have reduced systemic effects, while others may have serious toxicological effects such as central nervous system failure and respiratory tract failure, or even carcinogenic effects [4].

2.2 Carbon monoxide – CO

Carbon monoxide is a colorless, odorless and tasteless gas, which is less dense than air. It is a relatively stable compound and participates in atmospheric chemical reactions. But CO is an intermediate product through which all compounds containing C are passing, when they are oxidized. In the presence of not sufficient O_2 during combustion (in order to avoid an intensive NO_x formation mechanism), CO is produced, and immediately afterwards it oxidized, turning into CO_2. This does not happen if the engine is running under load or deceleration conditions, meaning that these regimes are more supposed to be source of intensive CO emissions.

However it is known that in normal operation, diesel engines produce lower amounts of CO compared to petrol engines [9].

CO affinity to combine with hemoglobin is 220 times greater than for O_2, resulting carbo-oxyhemoglobin, which produces very serious disease of the nervous system, respiratory and cardiovascular systems, even if is present in small doses. Furthermore, CO poisoning generates also headache, fatigue, dizziness, blurred vision, irritability, palpitations, vomiting, fainting, coma and even death.

2.3 Nitrogen oxides - NO_x (NO, NO_2)

Nitrogen oxides are formed by reaction with atmospheric oxygen at high temperatures and pressure, specific to a burning chamber, in oxygen rich atmosphere and at higher changes of residence time. Nitrogen comes from either fuel or the air introduced for combustion. As temperature increases, increases also the share of the genesis mechanism of NO_x and gas concentration exhaust. NO_x is actually a symbol that includes multiple chemical species of nitrogen oxides [4].

Among the oxides in the exhaust gases is present and a certain amount of nitrogen dioxide (NO_2), which increases the amount of gas output in the atmosphere, by further oxidation of nitric oxide (NO) [5].

NO_2 is generally considered the most harmful nitrogen oxide to human health. Such statistics point to the risk of disease correlated with ambient concentrations. Allowable limits and standards are often expressed with direct reference to NO_2 and more general to NO_x.

Nitrogen dioxide is considered harmful, toxic effects resulting from inhalation and producing lung dysfunction, acute respiratory diseases, irritation of eyes and of mucous membranes in general. NO_2 produce harmful effects on the environment. It mentions acid rain, with adverse consequences for vegetation. NO_x are essential in the formation of ground ozone. When ultraviolet radiation is subject to solar NO_2, an oxygen atom is separated from the oxide molecule, combined with a molecule of oxygen and forming ozone (O_3) [7].

N_2O (nitrous oxide) is an oxide that is incriminate to be a very active greenhouse gas, but also with contributions to ozone depletion. It has extremely long lifetime. Because of ozone holes generated at high altitude and which unfortunately extend more and more, ultraviolet radiation is no longer filtered, leading to increased incidence of skin cancer in recent years [6].

NO_2 emissions are the second component as a percentage, which contributes to the greenhouse effect, after CO_2, and they also have an important contribution to photochemical smog [10].

2.4 Pollutant measurement with LPG combustion

Liquefied petroleum gas (or liquid propane gas, abbreviation LPG, GPL, LP Gas,) is a flammable mixture of hydrocarbon gases used as a fuel in heating systems and vehicles. When specifically used as a vehicle fuel it is often referred to as autogas. It is increasingly used more and more also as an aerosol propellant and a refrigerant, replacing chlorofluoro-carbons in an effort to reduce damage to the ozone layer. LPG is synthesised by refining petroleum or "wet" natural gas, and is usually derived from fossil fuel sources, being manufactured during the refining of crude oil, or extracted from oil or gas streams as they emerge from the ground.

The LPG is a cheap fuel being sold without excise, in most for the countries. The price for 1 liter of autogas is around 60 euro cents in Romania.

Depending on the chosen target for monitoring parameters of an installation, one planed to examine the phenomena which will be relevant for the conclusions. The aim is to have an action plan to monitor all parameters necessary to determine the effectiveness of co-generation and the pollution amount. Thus, the study focuses on depicting the influences of two major parameters: (i) Workload of the group, (ii) Type of fuel used.

Simultaneously, by altering these two thermodynamic parameters, the environmental impact of co-generative group was determined. In order to achieve the simulation as close possible to the real situation, a loading condition of 2 kW was chosen.

The specific method of continuous sampling was implemented by the following dependencies:

1. CO concentration variation depending on load and fuel type used;

2. NO and NO_x concentration dependences upon the load and fuel type used;

3. O_2 and CO_2 percentage changes ,depending on load and fuel type used.

In the next graphics are presented the variation of the CO, NO, NO_x, O_2 and CO_2 for a charge of the 2 kW with LPG.

The load of 2 kW is the result of consumers connected to the generator terminals. For this stage of loading, thermodynamic parameters of the plant (system) with continuous data acquisition program were determined. The fuel flow was recorded manually by reading the time unit of digital scales (for fuel) and meter (for heat - in our case water) in the flue gas emissions. The emissions were monitored continuously using the flue gas analyzer TESTO 350 M / XL.

By increasing the electrical load of the cogeneration plant, an intensified burning mechanism results. Enhancing the thermal regime translates into increased flue gas temperatures. So, the thermal component will increase the overall efficiency of the plant. At the same time, fuel consumption will increase and consequently the degree of pollution (environmental influence) will be increased [8].

The basic fossil fuel was replaced with alternative fuel (LPG). From the literature [8], it is known that internal combustion engine that uses liquefied petroleum gas presents an intensified thermal regime. Taking this into account, attempts were made and also some preliminary steps were done in order to determine the load.

In order to compare the thermodynamic parameters and pollution levels, for the two cases, tests were planned by simulation of comparative loads as in the situation when the engine was fueled with petrol.

The results of measurements are reproduced in graphical form.

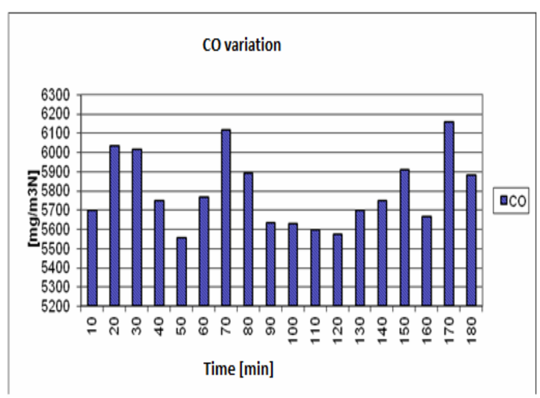

Fig. 4. Variation of CO for 2kW charge for LPG.

In Fig. 4 are showed the results of measurements of CO emission, expressed in mg/m^3_N and related to reference oxygen. The average value is 5700[mg/m^3N]. It observed an increase in the emission of carbon monoxide.

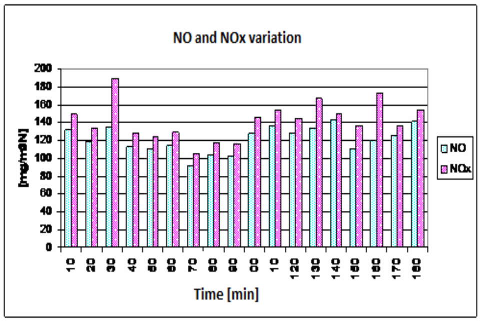

Fig. 5. Variation of NO, NOx, for 2kW charge for LPG.

Fig. 5 shows measured values for NO and NOx emissions expressed in mg/m^3_N and reported to the 3 % oxygen. Intensification mechanism inside burning internal combustion engine, is also reflected in increased emissions of NO and NOx. Average values obtained for these polluting species are for NO 121 mg/m^3_N and for NO_x 142 mg/m^3_N.

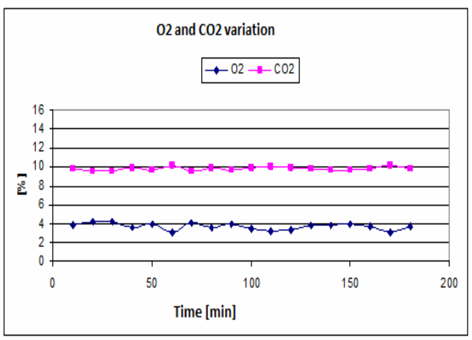

Fig. 6. Variation of O_2, CO_2, for 2kW charge for LPG.

Fig. 6 shows values for oxygen and carbon dioxide expressed as a percentage. The average values for these species were 3 % for oxygen and 9.8 % for carbon dioxide.

3. Results and discussions

A very important parameter in calculating combustion is air excess ratio [λ]. Gas analyzer does not directly measure this parameter, mainly it is calculated as the ratio of CO_{2max} and CO_2.

$$\lambda = \frac{L_{min}}{L} \qquad [-] \qquad (1)$$

where: L_{min} is the minimum air necessary for burning in m^3_N/kg,
L - the actual quantity of air in m^3_N/kg

Combustion calculation is done in several stages and is based on:

a) Mass percentage composition of gasoline: c = 85 %, h = 14.9 %, s = 0.05 % o = 0.04 %, h = 0.01 % by mass.

b) Petrol lower heating value H_i is guaranteed by the analysis and verified experimentally by calorimetric bomb test H = 43,698 MJ / kg.

For testing, the engine was loaded with 2 kW charge, using a single dimmer, connected directly to the generator through socket. At the end of the tests, were generated by a special developed data acquisition program, two separate files. One file shows the temperature values and the second indicates the values of pollutant emissions are generated. Fuel and water flow were recorded manually. The results are presented in graphical form, to be more intuitive analysis measurements.

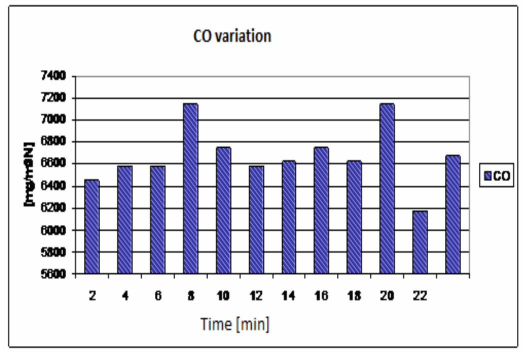

Fig. 7. Variation of CO for 2kW charge for petrol.

CO concentrations in Fig. 7 obtained from this system are high. Value recorded for this species is "normal" for a gasoline engine, air cooled, single cylinder, with the power system through carburetion and 4-stroke operation.

The values indicate that on the one hand burning is not perfect, the lack of oxygen resulting in significant CO concentrations. On the other hand, combustion is intensified, increasing the temperature inside the combustion chamber resulting in higher levels of NO concentrations. From the graph bellow can be seen that the values are constant.

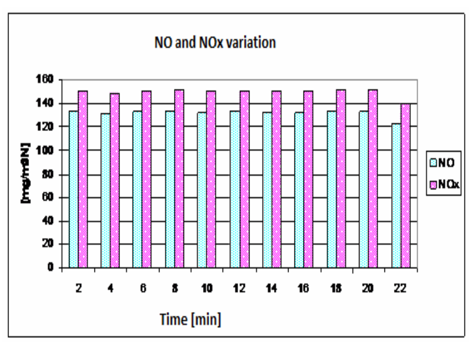

Fig. 8. Variation of NO, NOx, for 2kW charge for petrol.

The same increased values are found, also in the emitted NO_x and NO_2 concentrations.

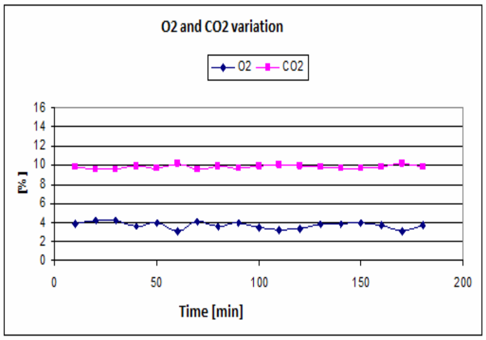

Fig. 9. Variation of O_2, CO_2, for 2kW charge for LPG.

For O_2 and CO_2 concentration one obtained the values shown in Fig. 9. A constant value around 8.73 % (volume parts) for the emission of CO_2, and for oxygen an average of 5.5 % volume parts were found.

In Fig. 10 are presented the average values of carbon monoxide emissions expressed in [mg/ m^3_N] reported to the oxygen reference. Values were recorded at a frequency of 10 minutes due to the installation system which has been constantly subjected. Reference Oxygen has two values in this case, because the plant was fed with two types of fuel.

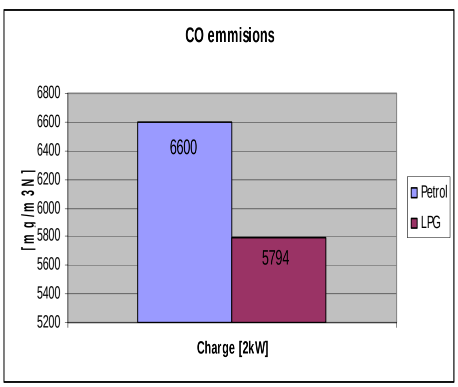

Fig. 10. Comparison of CO for petrol and LPG for 2 kW charge.

For liquid fuel the oxygen reference values is 5 % and for gas fuel is 3 %. One concludes that for a level of 2 kW load, powered by petrol, carbon monoxide expressed in mg/m^3_N is 6,600, which is higher than the value obtained for the electrical load of 2 kW (5,794 mg/m^3_N) in case of LPG. Based on the difference in terms of assessing the degree of pollution, one can say that the species of carbon monoxide, at the same mentioned value of loaded cogeneration plant of 2 kW is lower when using liquefied petroleum gas. Reducing pollution is explained according to the elementary composition of liquefied petroleum gas which consists only of propane and butane in various proportions by volume, depending on the season in which it is delivered to recipients.

From Fig. 11, in which the results when facility was charged at 2 kW are presented, one concludes for the two types of fuel, that the emission of NO, in the case of using gas fuel, were resulting in a lower value of 10 units.

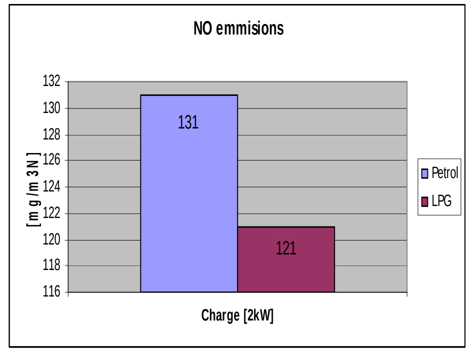

Fig. 11. Comparison of NO for petrol and LPG for 2 kW charge.

For both cases: (1) load of 2 kW petrol and (2) 2 kW LPG, the NO_x emission band is located on the same level. The differences between the two loads are small, about 7 units, as is it showed in the Fig. 12.

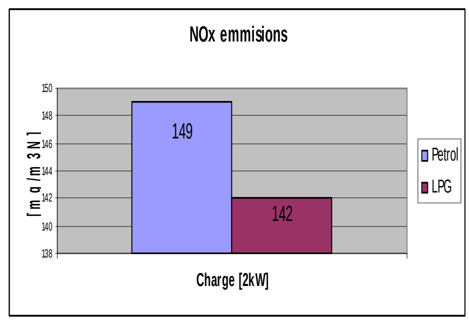

Fig. 12. Comparison of NO_x for petrol and LPG for 2 kW charge.

Table 1. Comparison of CO_2 amount exhausted for Petrol and LPG case study, for 1 unit and 1000 units.

Fuel	Charge [kW]	CO_2 [mg/ m^3_N]	Flow CO_2/unit [t/year]	Flow CO_2/1000 units [t/year]
Petrol	2	17,66	7,25	7245,54
LPG	2	20,04	8,22	8222,00

The emission of CO_2 requires strict control for any activity from either industry or energy sector. Carbon dioxide gas is not toxic, still contributes to the climate change with intense effectiveness. The only method of annihilation of the species is through photosynthesis. The process of obtaining heat and power cogeneration reduces

CO_2 emissions by lowering fuel consumption and would be needed to produce heat and power separately.

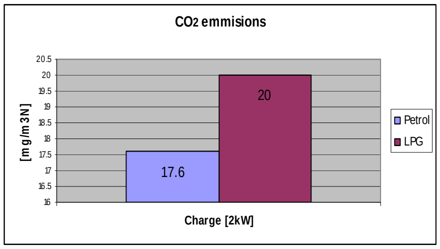

Fig. 13. Comparison of CO_2 for petrol and LPG for 2 kW charge.

Another aspect to note is that the amount of CO_2 will be reduced in direct proportion to the percentage of fuel volume used in combustion of organic nature. For example, if the primary fuel used to produce electricity and heat in cogeneration, should be at 100 % of organic nature, then the CO_2 emission of fossil origin would be zero. These are the so called CO_2 neutral fuels. Research achieved on the cogeneration plant in question have so far highlighted the advantages and disadvantages of using gasoline and LPG as primary fuel, both being of fossil nature. Future research will explore the existing possibility of cogeneration power of small groups with biogas. CO_2 reduction principle is fully applied in this way.

In Table 1 are the results of the CO_2 emissions as calculated, based on experimental results as well, for the two fuels considered producing heat and electricity through cogeneration. In order to determine the amount of carbon dioxide in tones per year, by generalizing from a single unit, generalised calculations have been recorded. From the table it is resulting that the thermal energy production in cogeneration power of 2 kW for charging was 7, 25 tons/year, when the primary fuel used to produce heat and power cogeneration was petrol, and more (8.22 t/year) in the case of LPG. Even the CO_2 emissions are increased, but it can be considered that the advantages of the better price (for LPG) are motivations determining the user to select with preperency.

Introducing GPL is a strategy that is based on the fact that NO_x might be also reduced by a selective solution, such as is proposed in [11]. If the origin af the gas is bio [12], it is obvious that the CO_2 amount, being of non-fossil origin, is thus neutral and contributes to the global trend to control the CO_2 concentrtaion in the ambient air.

The results are promising also in correlation with the air quality of urban air. Introducing GPL one can study, as for example in [13, 14] what might be the consequences uopon air quality.

4. Conclusions

Even if the LPG is a less pollution gas for a certain specific charge of the engine (tested at 2 kW) and the pollutant concentrations amount of CO_2 are increased, the overall price for fuel (LPG) is an advantage. The conclusions are drawn for comparative ranges of tests with normal fossil fuel and with LPG. The measurement of the emissions attested that the emissions were less for the LPG case (NO, CO, NO_x). Concluding, it was demonstrated that concerning the CO_2 the emissions were increased in the case of LPG use; and cogenerating the energy production is a method to improove the efficiency and reduce the pollution, in specific cases.

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