Effects of Re-designing of Two-Stroke Engine Fuelled with Gasoline - Ethanol Blend on GHG and Pollutant Emissions

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Abstract. The paper presents the research designed to develop a spark-ignition engine, two-stroke engine fuelled with ethanol and ethanol-gasoline blends. The test engine chosen was a small single cylinder, two strokes provided with a carburetor. The results of experimental research data obtained on this version were used as a baseline for the next phase of the research. In order to obtain the test engine configuration, the engine was modified, as follows: the compression ratio was increased from 8.0:1 to 9:1 to improve the engine efficiency; the carburetor was replaced by a direct fuel injection system in order to control precisely the fuel- mass per cycle, taking into account the measured air-mass intake. The cylinder's processes were simulated on a virtual model. The experimental research works were focused on determining the parameters which control the combustion process of two-stroke engine to obtain the best energetic and ecologic parameters. The fuel consumption data obtained during the tests are used to determine the emissions of GNG on basis of the emissions' factors.

The main conclusion of the results was the GHG emissions using "well-to-wheels" method. The pollutants were measured for all operating test points and were compared, taking into account the initial engine configuration.

Keywords: Air-fuel ratio · Combustion control · Ethanol · GHG
Two-stroke engine

1 Introduction

World urban areas face a number of major environmental challenges, their scale and intensity can vary, and thus, in this case, a common set of issues can be identified. They are related to the poor air quality, traffic volumes and congestion, high levels of ambient noise, lack of recreational areas, high level of greenhouse gas and pollutant emissions or other factors of this kind. The emission's increasing was observed for both categories: passenger transport and freight transport.

In order to fulfill the tasks at global level regarding diminishing fuel (energy) consumption, GHG and pollutants' emissions, a careful analysis "Well to Tank" of fuel (energy). is necessary to realize Therefore, the fuel or the power train shift can lead to minimum benefits or in a wrong direction.

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The greenhouse gases are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and synthetic gases (HFCs, SF6, CF4, C2F6). The main regulated pollutants resulting from fuel combustion are: carbon monoxide (CO), unburnt hydrocarbons (HC), nitrogen oxides (NO_x) and particulate matter (PM).

The use of bioethanol in the transport sector can contribute to decreasing the greenhouse gas emissions from vehicles. One of the most popular biofuels is ethanol. Ethanol is mainly produced from crops as sugarcane, beets and grains.

Other attractive properties include the increasing octane rating and enthalpy of vaporization compared to standard gasoline, which allow the use of increased compression ratios and the possibility of more favorable spark timings, increasing engine efficiency [1, 2].

The heat of ethanol's vaporization is 846 kJ/kg; this value is higher than that for gasoline, which is between 290 kJ/kg and 380 kJ/kg. This property of ethanol can contribute to the increasing of engine's power and efficiency due to the cooling effect of air-fuel mixture. Instead, at a lower engine's load, this effect can cause ignition difficulties due to the cylinder's lower temperatures. The ethanol's lower heating value is smaller than that of gasoline, but this difference is compensated by the difference between the stoichiometric values of the air. Under these conditions, the chemical energy of the air-fuel-mixture mass unity is practically the same (stoichiometric air-ethanol mixture presents 2975 kJ/kg, and 2925 kJ/kg for stoichiometric air-gasoline mixture) [2].

The two-stroke engine is used for ultra-light vehicles, motor scooters, motor-cycles, snowmobiles and boats, as well as, on lawn and garden equipment, such as: lawn mowers, weed trimmers, chainsaws, power blowers and sprayers.

2 The Ethanol Emissions' Analysis

In order to compare the energy, efficiency and emissions impact of different fuels and vehicle technologies on the environment, researchers use life-cycle models. The life-cycle model is known as "well-to-wheel" analysis.

This analysis can be splitted into two stages, the first "Well-to-Tank" which refers to the consumed energy, and emissions to obtain the fuel or energy in any forms, and the second stage, named "Tank-to-Wheel" refers to the efficiency of fuel consumption and the emissions of vehicle. One of the key analysis's concepts used in the Kyoto agreement is the notion of *CO_2 equivalence*. The greenhouse gases are characterized by their CO_2 equivalence: methane emissions are multiplied by 25 to obtain their CO_2 equivalence, nitrous oxide emissions are similarly multiplied by 298 and hydrofluorocarbons HFC-134a are multiplied by 1430, [3–7].

During the production of bioethanol from corn, GHGs and pollutants can be released at several stages and can be attributed to two different categories: direct emissions as the generation of energy, heat or steam; manufacturing processes which produce emissions; transportation of materials, products, waste and people; on-site waste management, such as emissions from landfill sites and indirect emissions as the consumption of electricity.

At first stage, corn cultivation, the following categories are included in the calculation of GHG emissions in relation to the cultivation of the biomass feedstock: agrochemicals (e.g. fertilisers and pesticides), seeding material (e.g. wheat seed), field N_2O emissions (e.g. emissions associated with the use of N-fertiliser and crop residues being left in the field), fossil fuel use (e.g. diesel usage for farm machinery).

The agricultural practices and the GHG emissions result essentially from the same crop are somewhat different. Some of the largest differences in GHG emissions result from the application of the fertilizer and are mostly dependent on the natural environment. Individual producers can influence the quantity of N_2O generated by varying the timing of fertilizer's application and by the use of slow release products; instead, natural conditions will dominate these emissions and the differences from region to region. Beside those mentioned above, emissions due to transportation, deposit, and distillation are added and reduced by carbon sequestration in secondary product as corn oil or animal food.

In Table 1. the emission factors for the fuels used during the experimental research are presented.

Table 1. Emission factors [6]

Fuel type	CO_2	CO_2	CH_4	CH_4	N_2O	N_2O	CO_2-e
Unit	(kgCO_2/Gallon)	(kgCO_2/kg fuel)	(g CH_4/Gallon)	(gCH_4/kgfuel)	(gN_2O/Gallon)	(g N_2O/kg fuel)	(kg CO_2-e/kg fuel)
Motor gasoline	8.78	3.076	0.38	0.133	0.08	0.028	3.088
Ethanol (100%)	5.75	1.911	0.09	0.030	0.01	0.003	1.913
E 85	–	2.086	–	0.045	–	0.007	2.089

In Table 2 the emission factors for consumed electricity from electrical grid are presented.

Table 2. National and European emission factors for consumed electricity [7]

Country	Standard emission factor (kg CO2/kWh-e)	LCA emission factor (kg CO2-e/kWh-e)
Romania	0.701	1.084
EU-27	0.460	0.578

LCA - Life-Cycle Assessment

3 Experimental Setup

A single cylinder two-stroke engine having a swept volume = 70.7 [cm^3] and bore/stroke = 50/36 [mm] was used to collect the experimental data in this research. The engine was connected to an Eddy Current Dynamometer type Schenk W40.

During experimental tests, the values regarding the cylinder's pressure were obtained using an AVL GH12D piezoelectric transducer correlated with the crankshaft position's values obtained by using a Heidenhain transducer type ROD 426A. The engine control parameters such as: intake manifold pressure and temperature, air flow rate, spark timing, fuel injection pressure, injection duration, equivalence ratio, exhaust manifold pressure and temperature etc., are collected. The fuel consumption during the experimental work was measured using an AVL fuel mass-flow meter. The main emissions were measured by means of analyzers for each test points, before the collection of experimental data the equipment was calibrated, using appropriate tools. The engine test incorporated a full electronic control of the spark, rate, and throttle. The experimental results of the engine having the compression ratio $\varepsilon = 8:1$ fuelled by carburetor and gasoline was considered as a baseline for the results obtained by engine re-designed. The Strata $^{\text{TM}}$ air-assisted fuel injector was used to realize a direct fuel injection into the cylinder.

The first version of the research engine was made by replacing the carburetor with an air-assisted direct fuel injection system, the crank train lubrication and durability remains a problem to be solved when E85 and E100 fuels are used and, the solution was to inject the lubricant into the fresh intake-air charge.

The second version is made by increasing the compression ratio of the engine from 8:1 to 9:1, in order to operate efficiently with carburetor and gasoline.

The third version combines the increasing of compression ratio with the direct injection-air-assisted system.

4 Research Results

The test two-stroke engine having a compression ratio of $\varepsilon = 8:1$ was selected for this research as a baseline.

It was provided with a carburetor, under these conditions, the process of air-fuel mixing takes place outside the engine realizing a homogenous air-fuel mixture. In order to improve the thermal efficiency and to exploit the high octane number of ethanol and ethanol-gasoline blend the value of compression ratio was increased at $\varepsilon = 9$. The increasing value of compression ratio greatly determines the influence on temperature of the cylinder. In case of replacing the existing carburetor system with an air-assisted fuel direct injection system, the mixing air-fuel process takes place in the cylinder. Under these conditions, by controlling the injection timing and the fuel spray characteristics, the mixture can be controlled in a homogenous state or in a stratified way in the combustion chamber.

Figure 1 shows the brake's specific fuel consumption at various engine speed conditions at full load. It presents that the fuel specific consumption values decrease at the engine version having ε = 9:1 for gasoline, E85 and E100 for both systems: carburetor and air-assisted direct fuel injection system.

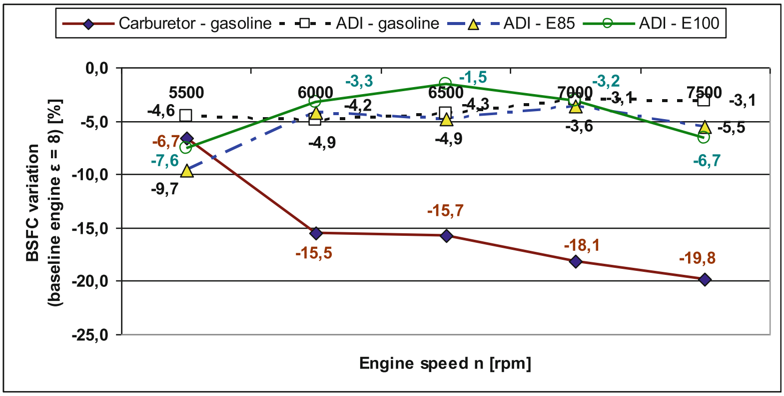

Fig. 1. The brake specific fuel consumption variation for new engine versions and fuels

Using the values for CO_2-e emission factors presented in the Table 1, the specific emissions of CO_2-e (unit kg CO_2-e/kWh) for the test engine and fuels versions were calculated. Comparing the obtained values taking as baseline the engine having ε = 8:1 and carburetor, results a decreasing of CO_2-e emissions for all engines and fuels' versions. The most important reduction was obtained for the versions with air-assisted direct injection and E85 and E100 (Fig. 2).

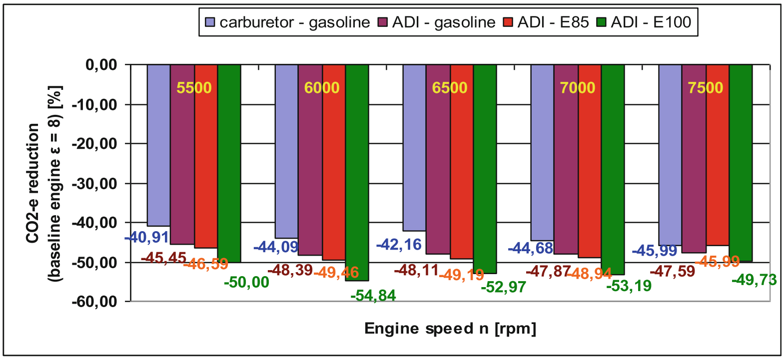

Fig. 2. Th CO_2-e variation for new engine versions and fuels

To compare the influence of fuelling system by using different fuels, as a baseline, the engine having ε = 9:1 provided with carburetor was chosen and it was found that the important reductions of specific emissions of CO_2-e present the engine equipped with an air-assisted direct injection system of E85 and E100.

Regarding the pollutant emissions, the increasing of the engine's compression ratio, the combustion process in the cylinder was improved and it resulted in a higher cycle-temperature which determined level of HC oxidation. The decreasing of HC emissions for these two compression versions fuelled with gasoline were: carburetor −3.1% at 5500 rpm and −8.2% at 7500 rpm, and for direct injection-3.8%(ε = 8:1) and −6.5% (ε = 9:1).

The influence of the system and the type of fuels are presented in Fig. 3. Replacing the carburetor by an air-assisted direct fuel injection system resulted in a great reduction (>70%) of HC emissions. These lower values of HC emission can be explained by taking into account: the reduction of air-fuel mixture loss by short-circuit, diminishing the influence of crevices, improved combustion process due to air-fuel mixture and state of cylinder's gases (Fig. 4).

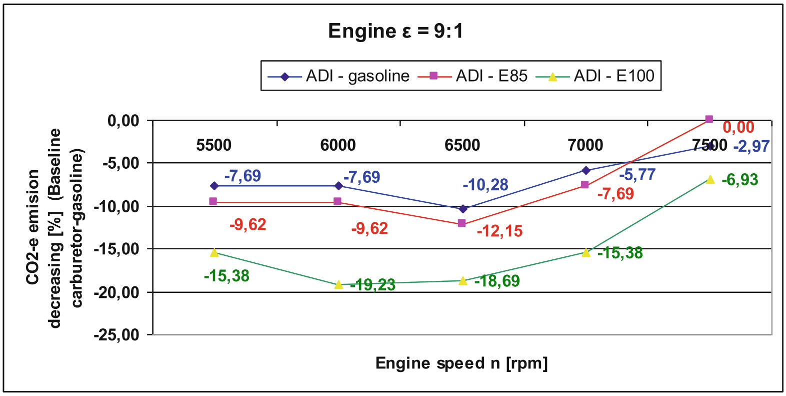

Fig. 3. The CO_2-e variation for ε = 9:1 the engine fuelled with air-assisted direct injection. and different fuels

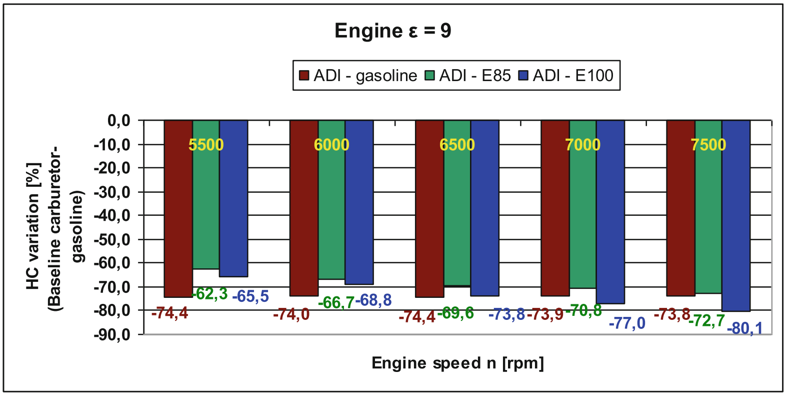

Fig. 4. The HC variation for new engine versions and different fuels

Interesting results of HC emissions can be observed for these two versions of engines when fuelled with E85 an E100. Because the E85 and E100 were tested by using only the injection system, the results could be compared with those obtained by using gasoline provided with the same system. Increasing the compression ratio to ε = 9:1, the HC emissions decreased in comparison with previous engine and for both fuels E85 and E100 decreased linearly with rising of engine's speed.

This evolution can be explained taking into account the level of the exhaust gases which contribute to the late oxidation of HC and CO.

Later, the engine's speed was increased; the heat loss diminished and the exhaust gas temperatures were higher and caused oxidation of hydrocarbons.

The engine provided with a carburetor presents higher CO emissions. When the carburetor was replaced by a direct injection system the combustion process was improved, as a consequence of the reduction of CO emissions. Comparing the peak of CO emissions for these two system the measured values decreased from −5.7 (%) to −71.7 (%).

The engine with direct injection system with E 85 and E100 and comparing the measured values for CO emissions with those obtained by using gasoline considered as a baseline, then, two situations can be encountered: the first one, for E85, the emissions of CO increase for a speed range 5500–7500 rpm, and these increases comprised between +70.1% and +12.5%, (Fig. 5).

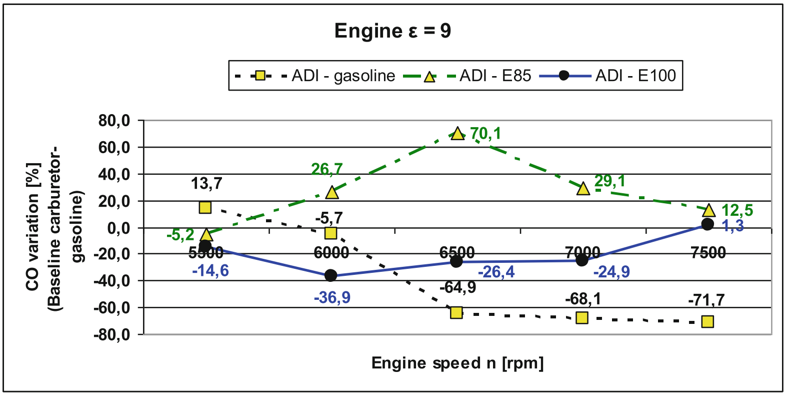

Fig. 5. The CO variation for new engine versions and different fuels

The second test is represented by CO emissions by using E100. In this case the emissions were lower than in the first case, the reduction being of −14.6% and −36.9%.

The increase of CO for E85 can be attributed to the reduction in fuel volatility and the expected increase in fuel impingement on the piston's crown caused by the very early first injection. The reduction for pure ethanol (E100) is thought to be caused by the removal of all high boiling point fractions existent in gasoline. Another reason for the increase in CO for the higher ethanol blends could be the reduced mixing leading to a reduced homogeneity associated with the longer injection duration.

The combustion of rich regions and flame quenching in overly lean regions is expected to increase the CO levels.

The level of NO_X emissions is highly dependant on the in-cylinder temperature, as the in-cylinder temperature increases, the rate of NOx formation also increases. The direct injection engine with E 85 and E100, for both cases, the emissions of NO_X are reduced for an engine's speed range 5500–7500 rpm, (Fig. 6).

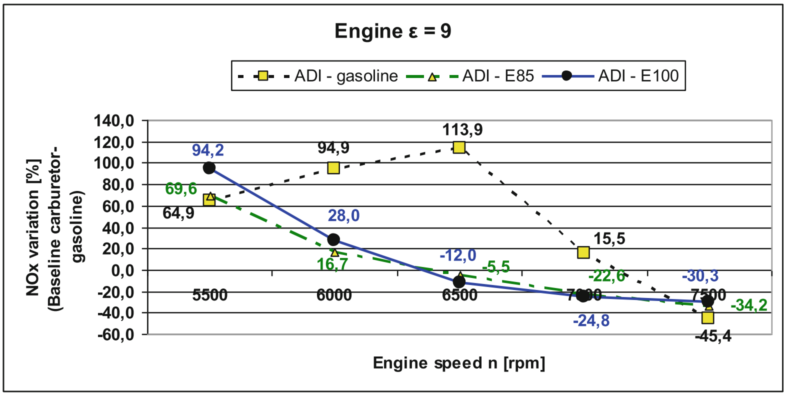

Fig. 6. The NOx variation for new engine versions and different fuels

5 Conclusions

Based on the experimental research on two-stroke engines with carburetor and air-assisted direct fuel injection systems using E0, E85 and E100, the following conclusions are drawn:

The effect of compression ratio when changed from 8:1 to 9:1 with gasoline for both engine versions carburetor and direct fuel injection systems, there were an increase of energetic parameters (power, torque) and a decrease of brake-fuel consumption, these determine a decrease of CO_2-e emissions. Regarding HC and CO emissions for all tests, the results show lower values, while the NOx level was found to be higher, with higher compression ratios due to a faster combustion and thus, higher in-cylinder pressure because of a combination of advanced combustion and higher flame speeds.

The use of E85 and E100 engine with direct injection presents higher energetic parameters, a better fuel consumption due to the improved combustion and stability. These effects resulted from advanced and faster combustion, from improved combustion efficiency are determined by a better evaporation (reduction of heavy fractions) and by a mixing process coupled with the presence of oxygen within the fuel molecule. The pollutant emissions of HC, CO and NOx present lower values compared with those of the engine with carburetor and gasoline.

The main conclusion of this research is that the E85 and E100 are suitable as alternative fuels for two-stoke S.I. engine.

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