IOP Conference Series: Materials Science and Engineering

Injection system used into SI engines for complete combustion and reduction of exhaust emissions in the case of alcohol and petrol alcohol mixtures feed

To cite this article: N Ispas *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **252** 012080

Injection system used into SI engines for complete combustion and reduction of exhaust emissions in the case of alcohol and petrol alcohol mixtures feed

N Ispas[1*], C Cofaru[2] and M Aleonte[3]

[1,2]Automotive and Transportation Department, Transilvania University of Brasov, Romania
[3] Karlsruhe Institute of Technology (KIT) – Institut für Kolbenmaschinen (IFKM), Karlsrue, Germany

[*]inicu@unitbv.ro

Abstract. Internal combustion engines still play a major role in today transportation but increasing the fuel efficiency and decreasing chemical emissions remain a great goal of the researchers. Direct injection and air assisted injection system can improve combustion and can reduce the concentration of the exhaust gas pollutes. Advanced air-to-fuel and combustion air-to-fuel injection system for mixtures, derivatives and alcohol gasoline blends represent a major asset in reducing pollutant emissions and controlling combustion processes in spark-ignition engines.

The use of these biofuel and biofuel blending systems for gasoline results in better control of spark ignition engine processes, making combustion as complete as possible, as well as lower levels of concentrations of pollutants in exhaust gases.

The main purpose of this paper was to provide most suitable tools for ensure the proven increase in the efficiency of spark ignition engines, making them more environmentally friendly.

The conclusions of the paper allow to highlight the paths leading to a better use of alcohols (biofuels) in internal combustion engines of modern transport units.

1. Introduction

The transport sector is almost completely dependent on oil and its derivatives both in the United States and in Europe, this sector accounts for about one third of total energy consumption and about 30% of CO_2 emissions [1]. The transport sector will contribute, following an EU-wide forecast, with an increase of about 90% in CO_2 emissions [1]. The increase in oil demand for transport in China, India and other Asian countries has led to rising prices and boosted the production of oil substitutes. Finding alternative solutions is a key issue and biofuels should be the easiest as alternative fuel because no significant changes are required in infrastructure or in existing vehicles and engines.

Currently, most transport fuels are derived from oil, with more subsequent negative attributes in terms of fuel and carbon emissions. Consequently, there has been renewed interest in the production and use of biofuels, such as biodiesel and bioethanol, which is produced from vegetable or animal oils, as well as bioethanol produced by fermentation. Biofuels are renewable and can be produced from agricultural products with the potential to reduce dependence on fossil fuels. Biofuels have low carbon emissions because they are produced in the short-term carbon cycle and their burning is as much atmosphere in the atmosphere as the one absorbed by these plants in the atmosphere. Therefore, unlike the burning of fossil fuels, combustion of biofuels has the potential to be carbon neutral. Ethanol can reach 96% as volume purity by distillation and is clear as water, this purity being sufficient to burn ethanol. Ethanol burns cleaner than many other fuels and produces low CO_2. When burning is complete, the exhaust products are just CO_2 and water. That's why ethanol is a favourite for ecological transport schemes and is used in many sustainable transport systems. However, ethanol readily reacts or dissolves some tires and plastics and cannot be used in engines that do not have new material changes. In addition, ethanol has a higher-octane rating than regular gasoline, requiring changes in compression ratio or spark advance to achieve maximum performance [2]. Alcohols such as ethanol or methanol have been and are still used in pure state or mixed in high proportion in gasoline for fuelled spark ignition four-stroke engines and spark ignition two-stroke engines. Ethanol and its oxygenated derivatives can be used in low proportions as additive fuel or gasoline additives. This mode of use is rational because the advantages and constraints are no longer the same as when used in high proportions in mixtures. Two-stroke engines produce more power and are more compact than the four-stroke engines, and they are lightweight and less costly. On the other hand, some fuel gets wasted in a two-stroke engine, decreasing its efficiency.

In the case of two-stroke engines, for every two strokes of the piston inside the cylinder, one power stroke is produced. In four-stroke engines, power is produced once during four strokes of the piston. For the same size engine, the power produced by the two-stroke engine is more that the four-stroke engine. Ideally the power produced by the two-stroke engine is double that of the four-stroke engine, but in actual practice it is only about 30% more than four-stroke engine. Also, since the power produced by the two-stroke engine is higher, these engines are small and compact in size [2]. One disadvantage that applies to both diesel and petrol two-stroke engines is the extensive cooling and lubricating requirements of the two-stroke engines. Since in two-stroke engines power stroke is produced after every stroke, a large amount of heat is generated within them. To reduce the temperature of the engine and keep the moving parts well-lubricated, good lubrication and cooling systems for the engine are required. For reasons relating to the simple construction of the two-stroke engine cylinder head due to the lack of valve distribution system, the easy positioning of the spark plug and the air-assisted ethanol injector was one of the advantages of choosing this type of engine for the experimental research described in this paper.

2. Experimental research

A single cylinder two stroke engine was used to acquire the experimental data in this research (Table 1). The engine having the specification presented in Table 1was connected to an Eddy Current Dynamometer type Schenk W40.

Table 1. Experimental engine characteristics

Engine type	*Parameter*
Two stroke,	
Spark ignition engine (SI)	
No of cylinders	1
Compression ratio	8:1, 9:1
Swept volume (cm^3)	70.7
Bore (mm)	50
Stroke (mm)	36
Connecting rod length (mm)	75
Fuel delivery	Carburetor, Direct injection air assisted
Fuels	E0; E85, E100
	Crankcase scavenging
	Schnürle full loop
Engine cooling	Air

First fuelling system was by the carburettor, used with optimal settings for ignition and air-fuel ratio. The second fuel delivery system was an air-assisted direct injection system. In the Figure 1. is shown the two-stroke engine equipped with the injection system. Details of air-assisted injector are showed in Figure 2.

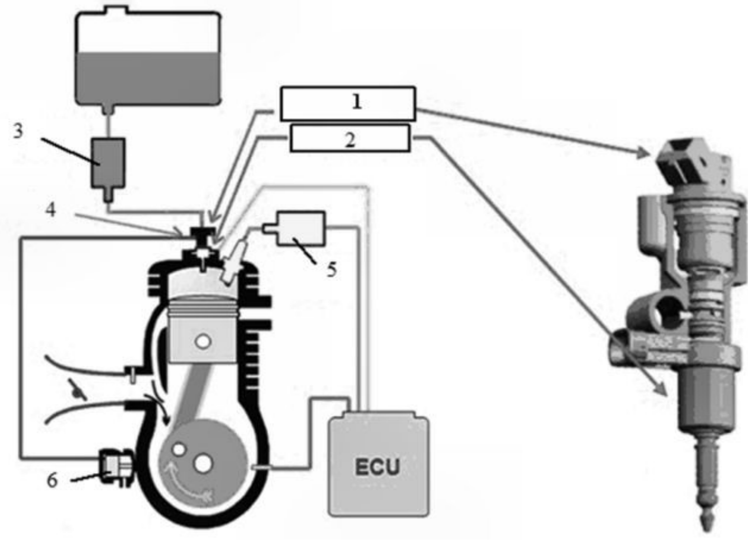

Figure 1. The two-stroke engine used in experimental and air-assisted direct injection system, where: 1- Fuel injector; 2 - Air-fuel mixture injector; 3 - Fuel pump; 4 - Pressure regulator; 5 – Ignition system; 6 – Air compressor; ECU – Electronic control unit.

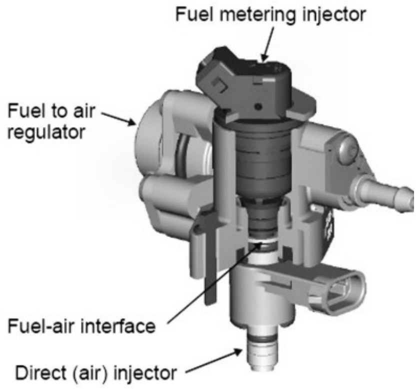

Figure 2. Details of air-fuel direct injection injector

The air-assisted injector operates in the following manner: the fuel pumped into the air-fuel mixture formation chamber contained in the air- assisted DI system had a pressure of 0.6 – 0.7 MPa. The air pressure was induced into the air-fuel mixture formation chamber in the air assisted direct injection system with a pressure of 0.45 – 0.55 MPa. In order to have a constant compressed air pressure, an air regulator was mounted on the air inlet system. The main advantage of air-assisted fuel injector is a good atomization of fuel; droplets' size having less than 60 SMD on the condition of air-assist pressure. In case of a direct fuel injection, the crank train lubrication and durability remain a problem to be solved; on this condition, the lubricant oil needs to be added to the intake air charge. The engine lubrication was made by fitting an oil pump as the oil is not mixed with the fuel, the pump delivering the oil into the intake air flow. The oil pump frequencies were controlled by taking in account the engine operating parameters.

3. Results and discussion

For two compression ratio values, using different fuel, the engine operating characteristics were determined according to the speed at full engine load. In Figure 3. engine torque (T), engine power (P), fuel consumption (FC) and brake specific fuel consumption (BSFC) for the two-stroke engine with spark ignition and air-assisted direct injection, at a compression ratio (CR) equal to 8 : 1 (petrol fuel) are shown.

In Figure 4. engine torque (T), engine power (P), fuel consumption (FC) and brake specific fuel consumption (BSFC) for the two-stroke engine with spark ignition and air-assisted direct injection, at a compression ratio (CR) equal to 9 : 1 (gasoline fuel) are shows.

As can see in Figure 5. the power and the motor torque in the version equipped with a compression ratio CR = 9 have a higher value than the variant equipped with CR = 8. At the speed of 5500 [rot / Min] for CR = 9, the power and the moment represent 106% for both cases of the value for CR = 8. At the speed of 6500 [rot / min] they become equal, because at the speed of 7500 [rpm] we have an increase of 2% and 3% respectively.

For fuel consumption at 5500 [rpm] for CR = 9 we have a 2% decrease and for a specific consumption of 5%. At 6500 [rpm] we have a decrease in hourly consumption and specifically by 2% and 4%, respectively. In this treatment, we considered the reference values obtained for the pneumatically assisted pneumatically-injected air-fuel mixture system and CR = 8.

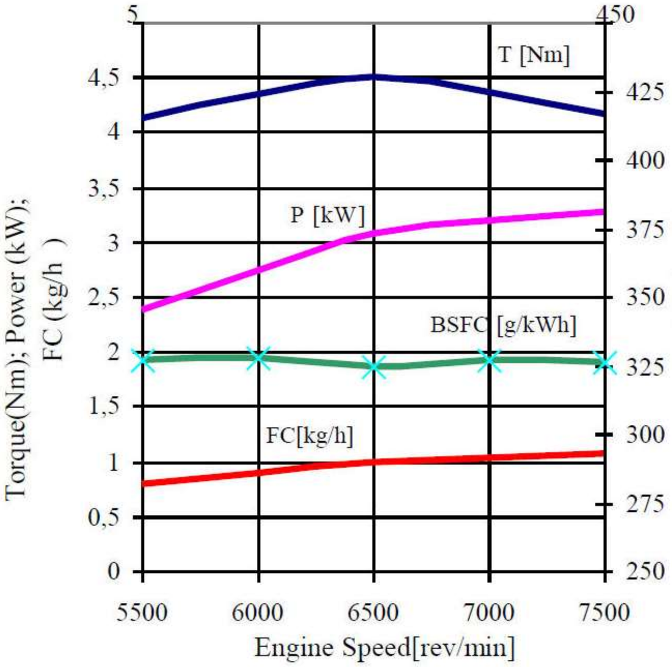

Figure 3. Engine speed operating characteristic at full load (CR = 8 : 1, petrol fuel).

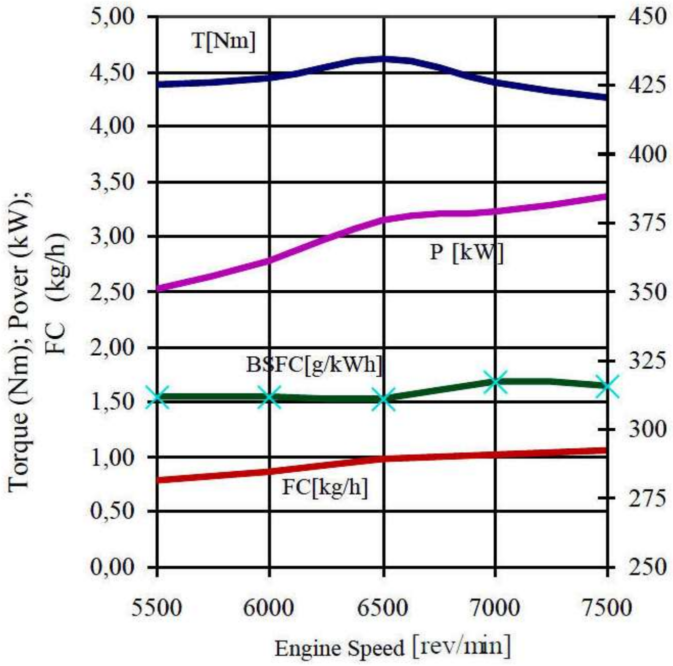

Figure 4. Engine speed operating characteristic at full load (CR = 9 : 1, petrol fuel).

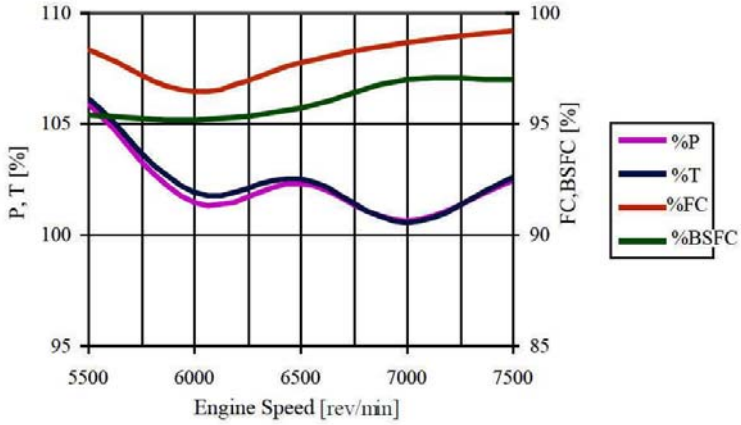

Figure 5. Comparison between engine parameters for CR = 8 : 1 and CR = 9 : 1 (gasoline fuel)

In Figure 6. engine torque (T), engine power (P), fuel consumption (FC) and brake specific fuel consumption (BSFC) for the two-stroke engine with spark ignition and air-assisted direct injection, at a compression ratio (CR) equal to 8 : 1 (E85 fuel – 85% Ethanol mixed with 15% gasoline, density = 781 [kg/m3) are shows.

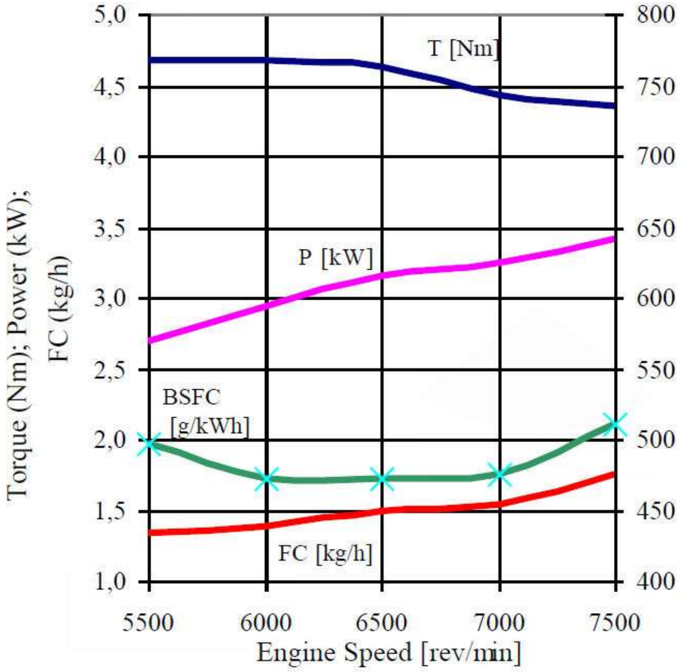

Figure 6. Engine speed operating characteristic at full load (CR = 8 : 1, E85 fuel).

In Figure 7. engine torque (T), engine power (P), fuel consumption (FC) and brake specific fuel consumption (BSFC) for the two-stroke engine with spark ignition and air-assisted direct injection, at a compression ratio (CR) equal to 9 : 1 (E85 fuel) are presented.

From Figure 7, for pneumatically assisted direct injection we can see that the engine power and torque, when operating with a compression ratio CR = 9, they have a higher value than the equipping option with CR = 8. Evolution of values can be see the in the Figure 8. Engine torque and power values reported at CR = 8 are equal for the given speeds. At the speed of 5500 [rpm] for CR = 9, the power and the engine torque These are maintained at 103% and at 7500 [rpm] their value being 102%. In the case of

FC at 5500 [rpm] for ε = 9 we have a decrease of 9% for the BSFC of 10%. At 6500 [rpm] we have one decrease in hourly and specific consumption by 2% and 5%, respectively.

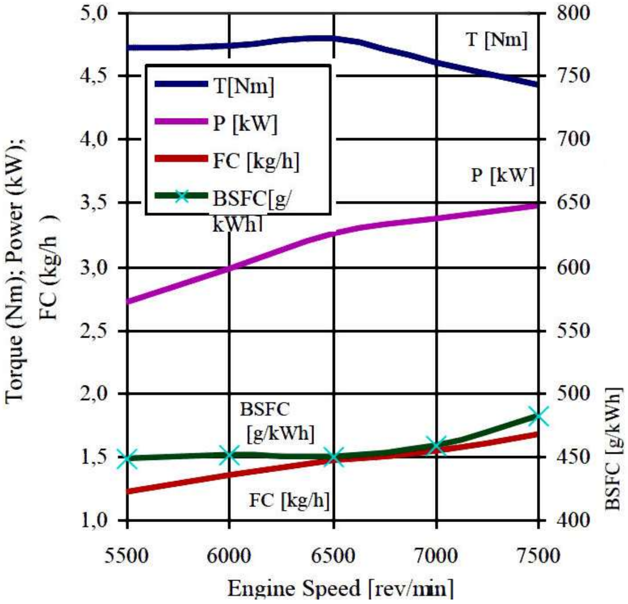

Figure 7. Engine speed operating characteristic at full load (CR = 9 : 1, E85 fuel).

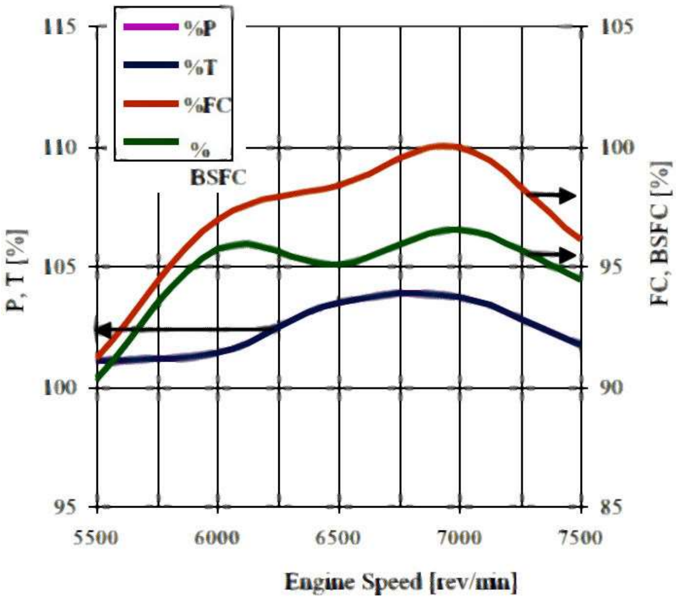

Figure 8 Comparison between engine parameters for CR = 8 : 1 and CR = 9 : 1 E85).

In figure 9. we can observe the evolutions of the engine torque (T), of the engine power (P), fuel consumption (FC) and brake specific fuel consumption (BSFC) for the engine with air assisted direct injection using E100 and operating with a compression ratio of 9:1.
From Figure 10, for air assisted direct injection, we can see that the engine power and torque, when operating with a compression ratio CR = 9, they have a higher value than the variant operating with CR = 8. The evolution of the values can see both in Figure 11 At the speed of 5500 [rpm] for CR = 9, power and torque represent 105%, for both cases, of the value for ε = 8. At speed of 6500 [rpm] these are maintained at 103% and at 7500 [rpm] their value being 102%. In case of fuel consumption at 5500 rpm, for ε = 9 we have a decrease of 3%, and for the specific fuel consumption of 8%.

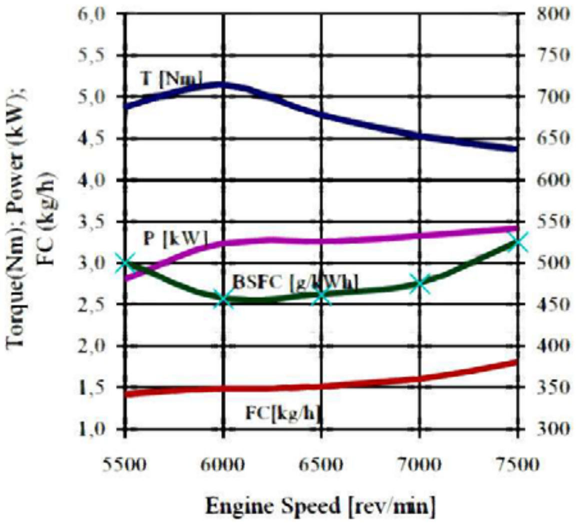

Figure 9. Engine speed operating characteristic at full load (CR = 8 : 1, E100 fuel).

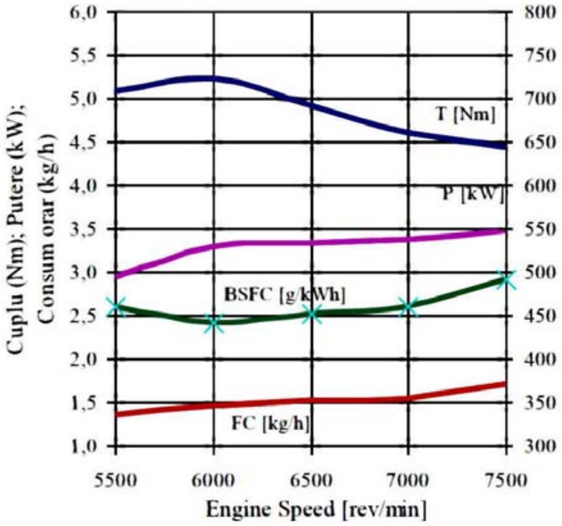

Figure 10. Engine speed operating characteristic at full load (CR = 9 : 1, E100 fuel).

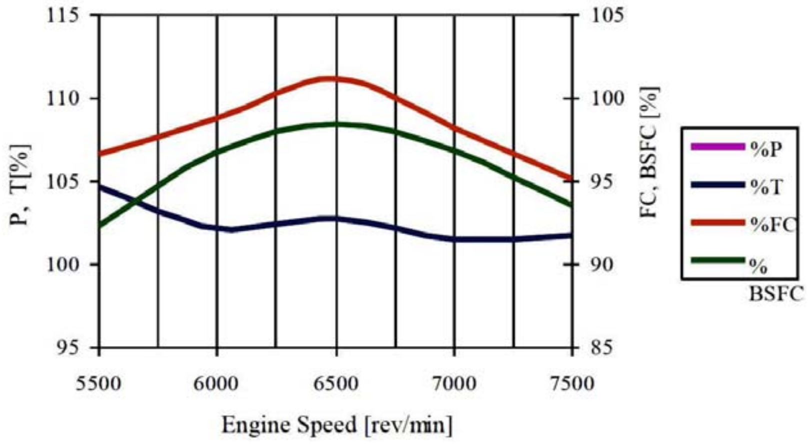

Figure 11. Comparison between engine parameters for CR = 8 : 1 and CR = 9 : 1, E100 fuel.

In Figure 12. shows the evolution of the heat release and heat release rate for engine fueled by E85 and air assisted injection system and a compression ratio CR = 8.
In Figure 13. shows the evolution of the heat release and heat release rate for engine fueled by E85 and air assisted injection system and a compression ratio CR = 9.

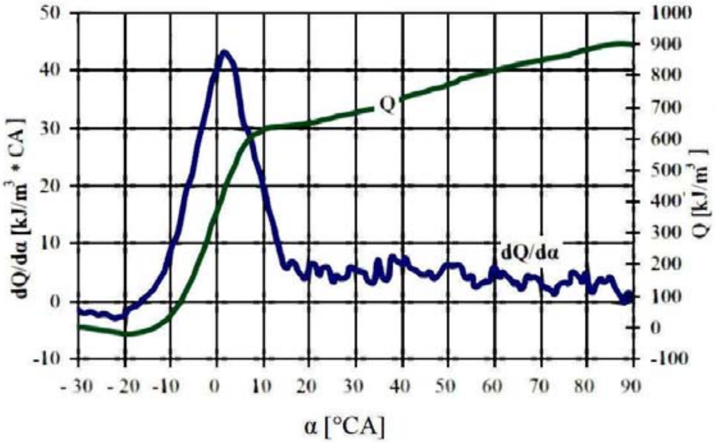

Figure 12. Heat release and heat release rate for engine running at maximum torque (CR = 8 : 1, E85 fuel).

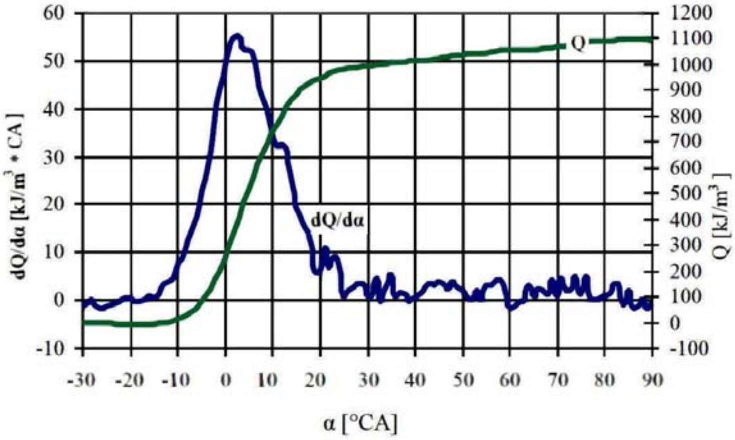

Figure 13. Heat release and heat release rate for engine running at maximum torque (CR = 8 : 1, E85 fuel).

The duration of the burning process for E100, E85, E20 and E0 is 15, 16, 18 and 25 ms. In the Figure 14. are showed the CO and CO_2 emission for all used fuelling system.

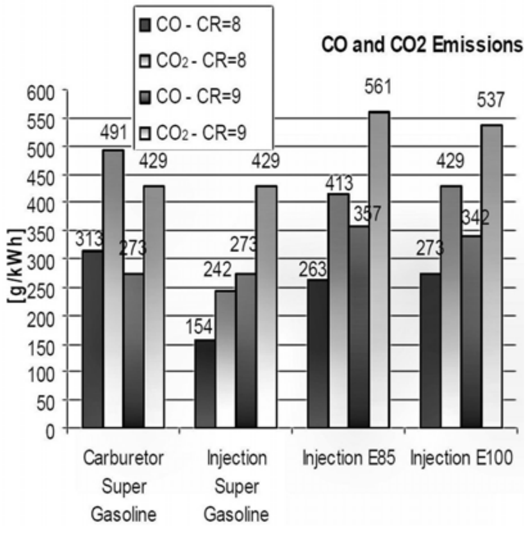

Figure 14. The CO and CO_2 emission for all used fuelling system.

The equipment needed for emissions measurements are presented in Table 2.

Table 2. Equipment for emissions measurement

Equipment type	Emissions
Hartmann & Braun Magnos 16 (%Vol)	O_2/N_2
Hartmann & Braun Uras 14 (%Vol)	CO_2
Hartmann & Braun Uras 14 (%Vol)	CO
ECO Physics CLD 700 EL (ppm)	NO/NO_x
Testa FID HC (ppm)	HC

4. Conclusions

In this paper, for fuelling systems, was study the direct injection-air-assisted system in order to exploit the vaporization properties of the fuels used. Air-assisted fuel injectors are used to permit the fuel to enter the combustion chamber in small droplets so, the fuel could atomize quickly and mix with the freshly scavenged air. It lessens the effects of charge and exhaust-gas mixing, significantly reduces short-circuiting, and offers precise air/fuel ratio control. Depending on the injection timing the homogenous mixture or stratified mixture may be organized in the combustion chamber. For early injection timing, when the intake ports are open, the air and the fuel have time to homogenize; simultaneously, a part of the mixture can escape through the exhaust ports. On the contrary, when the injection timing is set after the exhaust ports have been closed, there is no fuel lost to the exhaust. This second case may be able to promote mixture's stratified charge combustion at part loads, which greatly improves combustion stability especially at high levels of residual gas trapped.

One main change comprises the location of the Strata^{TM} air-assisted fuel injector in the cylinder to realize a direct fuel injection. Air-assisted direct injection is applied to a range of 2-stroke engines, from 50 to 500 cc/cylinder displacements. The air-assisted injector operates in the following manner: the fuel pumped into the air-fuel mixture formation chamber contained in the air- assisted DI system had a pressure of 0.6 – 0.7 MPa. The air pressure was induced into the air-fuel mixture formation chamber in the air assisted direct injection system with a pressure of 0.45 – 0.55 MPa. In order to have a constant compressed air pressure, an air regulator was mounted on the air inlet system. The main advantage of air-assisted fuel injector is a good atomization of fuel; droplets' size having less than 60 SMD on the condition of air-assist pressure. The use of these injection system in experimental research with two-stroke engines is motived by the following reasons [3,4]:

1. Two-stroke engines produce more power and are more compact than the four-stroke engines, and they are lightweight and less costly.
2. In the case of two-stroke engines, for every two strokes of the piston inside the cylinder, one power stroke is produced. In four-stroke engines, power is produced once during four strokes of the piston.
3. For the same size engine, the power produced by the two-stroke engine is more that the four-stroke engine.
4. Ideally the power produced by the two-stroke engine is double that of the four-stroke engine, but in actual practice it is only about 30% more than four-stroke engine.
5. Since the power produced by the two-stroke engine is higher, these engines are small and compact in size.
6. The times of injection of the air-fuel mixture, their control, determine the operating parameters of this system as well as the parameters of the combustion processes and the pollutant emissions caused by the combustion of fuels tested on the two-stroke spark ignition engine
7. The use of several types of fuels to carry out combustion processes, super gasoline, gasoline blended with alcohols and pure alcohol led to the control parameters of the direct injection feed system. By controlling this power system, optimum operating parameters were obtained at the different operating modes of the two-stroke spark ignition engine.

Compared to the carburettor feed system, the main advantages of air-assisted injection system are:

- Reducing the amount of fuel reaching the surface of the engine cylinder wall;
- Improving atomization of the fuel;
- Increased control flexibility in air-fuel mixture formation, which in turn facilitates: low-emission pollutants at cold and hot start, reduction of transient emissions;
- Provide better stability of the combustion process;
- Provide fast and reliable cold start.

Following experimental research on flame propagation in the constant volume combustion chamber using the E0, E20, E85 and E100 fuels, the following aspects were found [4]:

- The maximum pressure has been reached for the E100 fuel;
- Flame diameter for E100, E85, E20 and E0 is 4.80, 3.81, 3.65, and 2.88 cm respectively;

Among the main issues of using alcohol as a fuel in spark ignition engines can be listed:

- The tendency to reduce effective power at a constant injection rate of alcohols due to their lower calorific power compared to gasoline (when burning methanol, an amount of energy is released by about 50% less than in the case of the burning of a quantity Equivalent to gasoline, nd burning ethanol results in only 66% of the energy released from the combustion of petrol) [4], [5]
- The presence of oxygen in the molecular structure of alcohols ensures, on the other hand, the reduction of the oxygen requirement for combustion, so that overall the calorific value of the fuel-air mixture, relative to the volume of the mixture, is slightly modified (methanol requires 44% Less air for combustion than gasoline, and ethanol - only 6l% of the air required to burn petrol) [9]-[10]
-Therefore, it is possible to maintain unchanged power of the engine with a given cylinder, by increasing the fuel flow accordingly (to maintain the range of the vehicle, the capacity of the fuel tank must also be increased); [6] [7]
- The difficulty of cold start, caused by the low pressure of the vapors at low temperatures; In the case of the use of pure alcohols; Cold start can be solved by using auxiliary fuels (gasoline or liquefied petroleum gas) or by spraying (methanol requires 3.7 times more heat and ethanol - 2.6 times compared to gasoline); The tendency of worsening of evaporation in The intake system for carburettor engines, determined by high alcohol vaporising temperatures and requiring redesign of the intake system; [8], [9]
- The tendency to increase the incidence of incidents in the hot engine due to the formation of vapor plugs and the emission of alcohol (the boiling point of alcohols being low in gasoline); [9], [10]
- Unfavourable lubricating qualities, caused by the low viscosity of alcohols and directly affecting the friction torques, primarily at the pump level and in the high-pressure section of the feed system [10].

Even though one kg of gasoline contains about 850 grams of carbon and one kilogram of E85 contains only 570 grams of carbon dioxide (520 grams for E100), examining the Figure 13. shows an increase in CO_2 hourly emission, relative to the engine power, for the engine supply of E85 and E100 respectively, higher for CR = 9: 1 than 8 :1.

The main cause of this evolution is the drop in calorific power for E85 (29.29 MJ / kg fuel) and E100 (26.78 MJ / kg fuel) compared to the calorific power value of gasoline (43.5 MJ / kg of fuel).

Even when the United States came out of the Paris Accord, Europe and other countries (Japan, South Korea, Australia and others), continued efforts to reduce carbon dioxide emissions from human activities. Respecting the sustained natural cycle of ethanol production from the vegetal mass, using ethanol as a fuel in transport unit engines can help reduce substantial the carbon dioxide concentration in the atmosphere.

References

[1] Ispas N, Cofaru C, Aleonte M Carbon dioxide reduction by improving combustion of ethanol or petrol-ethanol mixtures into 2 stroke engines, 28th International Symposium on Transport Phenomena, University of Peradeniya, Sri Lanka, 22 – 24 September 2017.

[2] Cofaru C, Ispas N, Aleonte M Reduction emissions by optimizing the cylinder processes using ethanol and gasoline-ethanol blend into SI 2-stroke engine, 28th International Symposium on Transport Phenomena, University of Peradeniya, Sri Lanka, 22 – 24 September 2017.

[3] Ispas N and Nastasoiu M CO_2 Emission Determination in Accord with European Regulation for Old and Today Cars Powered by Diesel Engines, The Romanian Journal of Automotive Engineering, pp 13 – 18, RoJAE 22(1) 1 – 52, ISSN 1842 – 4074, 2016.

[4] Aleonte M Researches on using advanced air fuel mixture systems and the combustion by supplying with alcohols and their derivates and alcohols, derivates and gasoline's mixtures for a Spark Ignition Engine, PhD Thesis, Brasov, 2011.

[5] Ishibashi Y, Asai M, Improving the Exhaust Emission of Two-Stroke Engines by Applying the Activated Radical Combustion, SAE 960742, 1996.

[6] Jin, S. H., et al., An experimental study of the spray from an air-assisted direct fuel injector," Proceedings of the Institution of Mechanical Engineers Part D-Journal of Automobile Engineering, vol. 222, pp. 183-194, Oct 2008.

[7] Keskin, A The Influence of Ethanol-Gasoline Blends on Spark Ignition Engine Vibration Characteristics and Noise Emissions, Energy Sources Part a-Recovery Utilization and Environmental Effects, vol. 32, pp. 151-160, 2010.

[8] Lin, W. Y., et al., "Effect of Ethanol-Gasoline Blends on Small Engine Generator Energy Efficiency and Exhaust Emission," Journal of the Air & Waste Management Association, vol. 60, pp. 142-148, Feb 2010.

[9] Mittal, M. et al., Burn Rate Analysis of an Ethanol-Gasoline, Dual Fueled, Spark Ignition Engine. New York: Amer Soc Mechanical Engineers, 2009.

[10] Spicher U, Methoden zur Analyse der motorischen Verbrennung"," Institut für Kolbenmaschinen (IFKM) Universität Karlsruhe, 2006.