THE STUDY OF AUTO-IGNITION AND COMBUSTION QUALITIES OF RAPESEED OIL AND DIESEL FUEL MIXTURES

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Abstract. *The fuel for diesel engines must meet several goals: to ensure a safe and fast engine start at any environmental temperature, to allow a safe operation of the engine with a yield as high as possible, to burn completely without producing harmful substances for human health, not to act in a corrosive way on the metals, to allow the transport, storage and distribution to the customer without difficulties, while maintaining the properties. In this sense, the purpose of the experimental research has been to determine the combustion characteristics of the experimented fuels (cetane number, ignition delay, the start of the main combustion, the combustion period, the maximum positioning of the speed of released heat).*

Keywords: combustion period, cetane number (CN), ignition delay.

INTRODUCTION

The use of vegetable oils as fuel is not new but dates back in the late 19th century, when Rudolph Diesel, the inventor of the diesel engine [1,2] at the International Exhibition in Paris in 1900 presented and demonstrated the functionality of a diesel engine, being fed then by peanut oil [3].

Experience demonstrates that reduced combustion and fuel combustion quality, reflected in an increase in ignition delay and a slow or delayed combustion can have significant negative effects on the functioning of compression ignition engines. It is known that diesel engines' easy start depends directly on fuel self-ignition quality and indirectly on fuel's cetane index and viscosity [4]. The high viscosity of vegetable oils as a major cause of poor fuel atomization resulting in operational problems such as engine deposits was recognized early [5,6].

The changes made on the refining processes started in the '70s led to an increase of the fuel fractions from a thermal towards a catalytic cracking offered to the heavy oil market. Such fractions have hydrocarbon structures that are not favourable to an efficient use for diesel engines. When these fractions are introduced in the production of fuels, their ability to effectively self-ignite and burn is often irregular [7]. Thus, the direct information on the combustion properties are from this point of view extremely important for insuring a more efficient and fewer of the engine's problems. In addition, even more important is the fact that fuels with good combustion properties reduce the emission of harmful products to the environment. Until now it has been very difficult to determine the properties of combustion heavy fuels. Previously known methods used for determining the quality of these fuels, such as: Calculated Carbon, Aromaticity Index – CCAI and Calculated Ignition Index – CII, have proved to be innapropriate in detecting the fuels' problems. Moreover, such methods cannot detect the effects on the quality of combustion that additives or other contaminants that could be introduced into the fuel might have.

The cetane number (CN) of diesel, specified by ASTM D613, is a measure of its ignition delay time. A higher CN, a desirable property in diesel engine, indicates shorter time between the ignition and the initiation of fuel injection into the combustion chamber. The higher CN is correlated with the reduction of nitrogen oxides (NOx) and unburnt hydrocarbons (UHC) exhaust emissions, which is important for alleviating air pollution [8].

MATERIAL AND METHOD

The samples that have been used for experiments have been : diesel, the crude rapeseed oil, mixtures between crude rapeseed oil and diesel and rapeseed methyl ester:

- diesel fuel;
- rapeseed methyl ester (RME);
- 80% diesel fuel - 20% crude rapeseed oil (80D_20R);
- 50% diesel fuel - 50% crude rapeseed oil (50D_50R);
- 25% diesel fuel - 75% crude rapeseed oil (25D_75R);
- 100% crude rapeseed oil.

The apparatus used for this paper was FIA-100 (*fuel ignition analyser*).

FIA 100 allows the supplier or fuel user to determine the quality of combustion to the compression-ignition engines based on the measured delay in self-ignition. The positioning of FIA 100 and of the computer is presented in figure 1. The fuels's sample injected in the FIA 100's combustion chamber selg-ignites and burns as in a real engine. The self-ignition and combustion conditions in the FIA 100's combustion chamber have been automatically simulated with an external electric source (230 V CA/50 Hz) and compressed air (at 50 bars).

Fig. 1. The stand with FIA 100;(1) the apparatus FIA100; (2)- the unit for data recording (computer).

A sample of the investigated fuel has been injected in this combustion chamber by using a high pressure injection pump, mechanically activated, and an injector. During the injection, the fuel jet self-ignited and burned in the combustion chamber with a constant volume. The testing conditions and the combustion process have been carefully monitored, and the measured data have been registered in a separate electronic unit which includes a microprocessor. The data is immediately presented on the computer's monitor, analysed, stored and saved in the computer.

The instruments for testing the fuel are based on a combustion chamber with constant volume. The basic idea was to stimulate the conditions of the combustion process of a real combustion-ignition engine. The advantage of this technology is the ability to make repeated, highly precised measurements, in a controlled environment.

The combustion chamber is endowed with temperature and pressure sensores that gather the data of the process during the ignition and combustion phases.

Together with an advanced electronic system and a soft for controlling the process the automatic functioning of the instrument has been possible at a high accuracy and repetability of measurements.

The data obtained by using this instrument have been represented by a number of parameters that can be used for the quantitative as well as the qualitative analyses of the sample.

Sample based on fuel from rapeseed oil was tested on 100 FIA device according to the procedure established for this instrument for heavy fuels (Figure 2). Thus, the investigation took place at an air pressure of 4.5 MPa and its temperature of 500 º C.

Fig. 2. The apparatus FIA 100; (1) cylinder; (2) injector; (3) fuel tank; (4) high pressure pump; (5) control electronic unit with microprocessor.

Depending on the viscosity of the sample the fuel was preheated to get an injection viscosity of fuel at about 15 mm^2/s . The kinematic viscosity of crude rapeseed oils is about an order of magnitude greater than that of conventional, petroleum-derived diesel fuel.

During the fuel's combustion, the increase of the pressure is monitored and transmitted towards a computer for analyses and recording. The reported parameters have been calculated for an average of 14 individual combustion cycles.

On FIA 100, the delay in self-ignition is defined as the time interval, expressed in milliseconds, from the start of the injection when an increase in pressure with 0,02 MPa over the initial chamber pressure has been noticed.

Moreover, the starting phase of the main combustion is determined as being the time (in ms) in which an increase in pressure can be detected, with 0,3 MPa over the initial chamber pressure.

The delay period for self-ignition is strongly influenced by the physico-chemical properties of the fuel. The physical component mostly depends on viscosity, superficial tension and fractioned composition, and the chemical component on the molecular structure. Thus the delay includes a phase of physical changes, in which the fuel is sprayed, partially vapored and mixed with the aer, and another one of chemical changes, when the oxidation reactions take place and the reach of the self-ignition temperature. The two time periods are simultaneous [9,10]**.**

The start of the main combustion has been used for establishing the quality of the fuel's self-ignition tested as "CC FIA" (cetane number). The base for "FIA Cetane Number" is a reference curve for the instrument, which shows the ignition properties for mixtures that are between the reference fuels *U15* and *T22* (standard fuels) determined by *Phillips Petroleum International* [7]. Thus reference curve establishes the relation between the quality of the ignition registered in milliseconds and the cetane number of different mixtures of the basic fuels. In the case of heavy fuels, the self-ignition properties are between CC=18.7 up to CC=40.

Thare are usually at least 12 injections/ignitions at each test. Between each injection there is a pause of approximately 5 minutes until the installation reaches the characteristics for starting the injection (chamber pressure, chamber temperature, the fuel's temperature and the cooling water's temperature).

Based on this data, the average delay period for self-ignition has been established, as well as the starting point of the main combustion, the cetane number – CC FIA and the speed of the released heat.

The cetane number (or the cetane index) is the numerical value that represents the percentage in volume of cetane (n-hexadecan, $C_{16}H_{34}$) in its mixture to α-methylnaphthalene. In order to approximate the cetane number an arbitrary scale has been chosen according to which cetane ($C_{16}H_{34}$) has the value 100, and α-methylnaphthalene ($C_{10}H_7$-CH_3) has the value 0 (zero). The cetane number shows the tendency to self-ignite of the fuels (e.g.:diesel fuel, etc.) used for diesel engines. The higher a fuel's cetane number is, the easier the fuel ignites.

Cetane number increases with chain length, decreases with number of double bonds and the carbonyl group move toward the centre of the chain [11]. The authors have also cited that the cetane number of pure esters of stearic acid was approximately 75, but for esters of linolenic acid with three double bonds, cetane number had dropped to the ~25. Cetane number increased from 47.9(C12) to

75.6(C18) for saturated C10 through C18 esters. At and above C12, the cetane numbers were above 60. G. Knothe has presented that cetane numbers of fatty esters generally increases with : the number of methylene groups (CH2) in the chain of fatty compound, number of CH2 groups in the ester moiety and with increasing saturation of the fatty compound [12].

An easy start up of a diesel engine depends of the quality to self-ignite of the diesel, as well as on viscosity and the frozing temperature of diesel (especially for external temperatures) [13].

The determination of the cetane number is being done in a special engine at the speed of 900 rot/min, with an injection advance of 13^0, at the injection pressure 10.5 MPa, according to ASTM D 613-79.

The behaviour at self-ignition of the diesel fuels can be calculated with the help of some easy to determine characteristics. Out of these the cetane index can be mentioned.

The density of diesel fuel decreases with the decrease in the content of aromatic hydrocarbons and the increase of the n-paraffins. Using these comparison indexes, it has been established an appreciation criteria of the sensitivity of self-ignition for diesel, called the Diesel index (DI). The Diesel index is being established by knowing the value of the diesel's density, expressed in degrees API (*American Petroleum Institute*) and the anylin point according to the standard test ASTM (D 976-76).

The determination of the cetane number for Diesel with FIA 100 has been optimized with respect to the comparability to the results obtained on a conventional testing engine. As an evaluation bases the lanmarks for the determination of cetane number according to standard DIN 51773 have been used.

RESULTS AND DISCUSSION

After experimenting 6 fuels with FIA 100, their self-ignition characteristics have resulted. Each sample has been submitted to a number of 14 injections. Each of them has been done in conditions closed to the real ones that take place in a combustion-ignition engine. After the experiments it has resulted: ignition delay, the period of combustion, start of main combustion, the rate of heat released (*ROHR*) and cetane number.

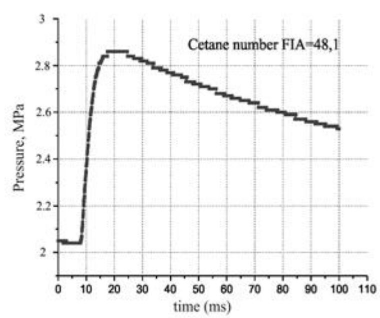

Fig. 3. The graphic representation of the pressure to time for crude rapeseed oil

Figures 3 - 8 present the variation curves of pressure to time and the value of the cetane number for the analysed fuels. In order to represent the pressure curves to time, it has been taken into consideration the injection with the closest value to the average delay in self-ignition.

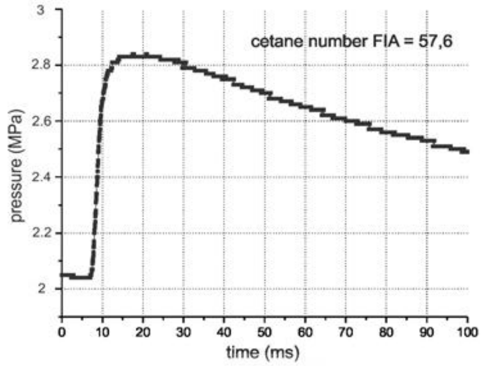

Fig. 4. The graphic representation of the pressure curve to time for diesel fuel

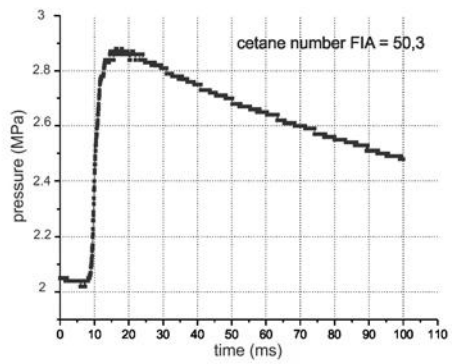

Fig. 5. The graphic representation of the pressure curve to time for RME

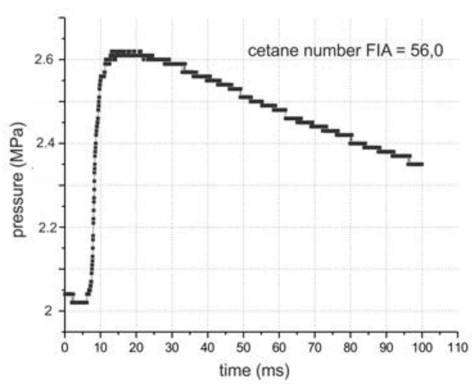

Fig. 6. The graphic representation of the pressure curve to time for 80D_20R

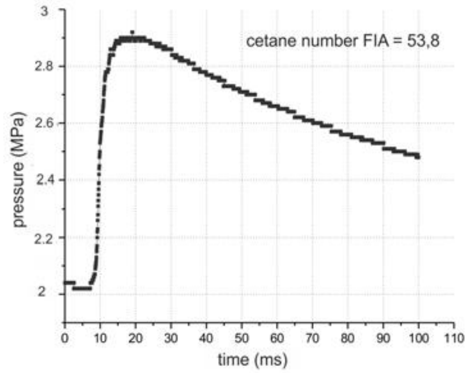

Fig. 7. The graphic representation of the pressure curve to time for 50D_50R

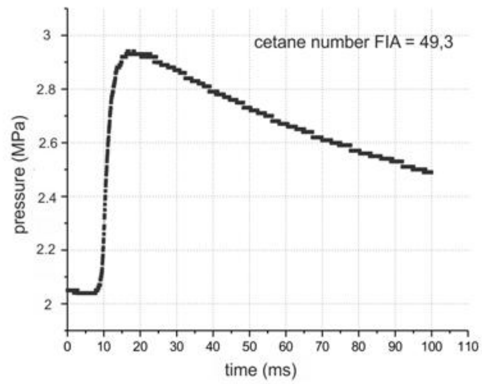

Fig. 8. The graphic representation of the pressure curve to time for 25D_75R

Table 1 presents the main characteristics of the self-ignition and burining processes of the experimented fuels, and figures 9-14 present the properties of the used fuels in comparison to the witness fuel, the diesel.

Table 1

The results of the main characteristics of the self-ignition processes of the used fuels

Sample	Ignition delay (ms)	Start of main combustion	Cetane number	Combustion period (ms)	Positioning of Rate of Heat Released	Maximum level of the Rate of Heat Released
Diesel Fuel	8,7	8,7	57,6	11,2	8,7	0,26
RME	9,99	10,1	50,3	10,3	10,3	0,23
80D_20R	8,66	9,1	56	10,2	8,9	0,19
50D_50R	9,51	9,51	53,8	10	9,8	0,26
25D_75R	10,3	10,35	49,3	12,1	10,6	0,2
Crude rapeseed oil	9,86	10,7	48,1	12,2	10,5	0,13

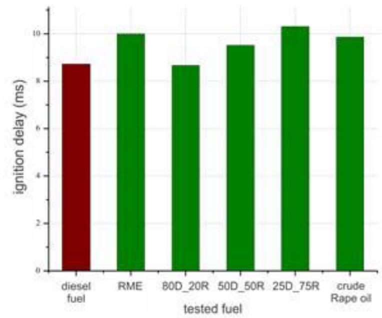

Fig. 9. Ignition delay of fuels function to the rapeseed oil's concentration

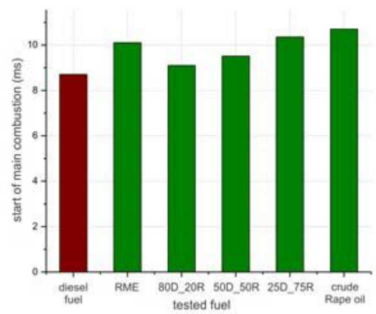

Fig. 10. Start of main combustion function to the rapeseed oil's concentration

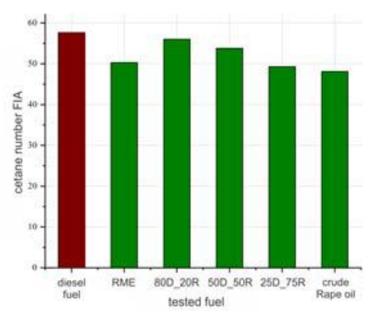

Fig. 11. Cetane number of fuels function to the rapeseed oil's concentration

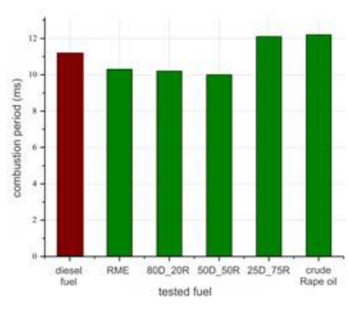

Fig. 12. Combustion period, function to the rapeseed oil's concentration

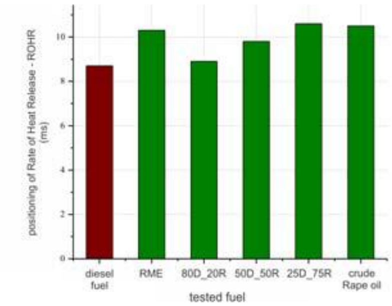

Fig. 13. Positioning of Rate of Heat Released function to the concentration of rapeseed oil

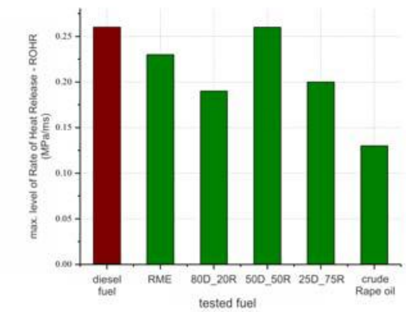

Fig. 14. Maximum level of the Rate of Heat Released heat function to the concentration of rapeseed oil

CONCLUSIONS

After the experimental results it has been noticed that the value of the cetane number of the fuels used within the experiment decreases according to the concentration of crude rapeseed oil within them. Thus, the lowest cetane number belongs to the rapeseed oil (CC=48,1) compared to the cetane number of diesel (CC=57,6). The closest value of the cetane number to the one of diesel belongs to the fuel mixed out of 80% diesel and 20% rapeseed oil (CC=56). The Rape-Methyl-Ester (RME) has a value of the cetane number of CC=50,3 (see Table 1).

The fuel with low cetane number, so with a greater resistance to self ignition, leading to more violent functioning of the engine by increasing the chemical component, which is illustrated by increasing the pressure on bearing crankshaft lower cetane number considerably increased startup time, enhanced formation of deposits in the combustion chamber and exhaust smoke.

For as good combustion of fuel in the combustion chamber, it must burn spontaneously and have a minimum self ignition delay.

According to experimental results, it was found that the lower self ignition delay in diesel is 8.7 ms, while crude rapeseed oil is 9.86 ms. Rapeseed methyl ester (RME) has a value of the self ignition delay of 9.99 ms..

The start of main combustion is closely connected with experienced fuel cetane. When the fuel is injected in the combustion chamber, it does not start to burn immediately. First of all it mixes with the air in the combustion chamber. It is heated until it reaches its self ignition point, then begins to burn. All these processes take time. After it starts combustion, the pressure, temperature, turbulences in the combustion chamber and the combustion process accelerates a lot.

The diesel fuel- etalon fuel – has the value of the combustion period of 11,2 ms, and rapeseed oil 12,2 ms, with 1 ms more. This can be explained by the fact that crude rapeseed oil has physical and chemical characteristics different from diesel oil (viscosity, density are higher), which adversely affects in the combustion process.

ACKNOWLEDGEMENTS. This paper was supported by the project "Develop and support multidisciplinary postdoctoral programs in primordial technical areas of national strategy of the research – development – innovation" 4D-POSTDOC, contract nr. POSDRU/89/1.5/S/52603, project co-funded from European Social Fund through Sectorial Operational Program Human Resources 2007-2013.

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