CORRELATION BETWEEN AUTOIGNITION DELAY AND CETANE NUMBER OF RAPE FUELS AT VARIED DIESEL ENGINE WORK CONDITIONS

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Abstract. The autoignition delay in the diesel engine, depending on the temperature and pressure in the combustion chamber, is directly related to the cetane number of fuel. Higher cetane numbers of fuels derived from crude oil result in shorter autoignition delay times. The following considerations and the results of tests conducted on a test engine show that, in the case of vegetable fuels, the knowledge of their cetane numbers do not yield any conclusions concerning their autoignition potential at varied diesel engine work conditions.

1. Introduction

Vegetable oils which may be considered as engine fuels are produced from oil seeds by cold extraction or extraction at increased temperatures. They have only slightly higher density than diesel fuel but their viscosity is even 10 to 20 times higher, which is a significant disadvantage when used as diesel fuel. This viscosity may be radically decreased by appropriate chemical treatment of vegetable oil in the transesterification process. This process give a fuel which may be applied directly without readjustment of the fuel system. Such fuel being usually a mixture of alcohol esters, mainly methyl fatty acids of rape oil, is defined (not quite correctly) in literature as rape methyl ester. However, the production cost of such fuel is at present considerably high so it cannot be competitive with conventional diesel fuel.

Many vegetable oils and its mixtures with diesel fuel were considered as potential engine fuels [2,3,4,5,6,7,8]. In Poland, best economic effects are brought by rape plantations and thus this vegetable may be considered as the potential source of fuel.

2.Theoretical analysis

The autoignition delay is of basic importance for the subsequent combustion process; thus phenomena accompanying this period are the subject of continuous tests and analyses. Considering the phenomena accompanying the autoignition, two basic parts of the autoignition delay may be separated: the physical part and the chemical part. The share of each part in the total autoignition delay depends on the ambient temperature, fuel properties and the fuel-air mixture preparation method. The physical part contains time needed to generate the fuel spray by the injector nozzle, to disintegrate the spray into droplets, to mix the fuel droplets with the air and to evaporate a part of the fuel dose. The length of this part of the autoignition delay depends on the fuel spraying quality (determined by the injection pressure, injector nozzle orifice diameters, fuel viscosity and air pressure in the cylinder), fuel evaporation rate and fuel-air mixing rate (determined by the droplet size, distribution and velocity, air temperature and pressure, combustion chamber design, heat of vaporization and fuel volatility) as well as fuel spray penetration (determined by the injection pressure, droplet size, air density and concentration of fuel droplets in the air). Chemical reactions determine the value of autoignition delay mainly at low temperatures as chemical reaction rate drops with decrease of temperature. At high temperatures, chemical reactions are faster and the autoignition delay is determined by physical processes, especially by fuel evaporation and its mixing with air.

On the chemical and the physical part of the autoignition delay influences chemical composition of fuel molecules, fuel viscosity and fuel distillation curve. Fuel viscosity influences the ignition delay by determining fuel droplets size, as well as shape and range of fuel spray. Larger fuel droplet diameters resulted in longer autoignition delays (longer for vegetable oil). In this respect, vegetable oils are much worse than diesel fuel. Some examples in the form of droplet diameter distribution curves are given in Fig. 1, for three different fuels: diesel fuel, rape oil and rape oil methyl esters [3]. Fuel was injected into the atmosphere by a single-orifice injector nozzle under a pressure of 25 MPa.

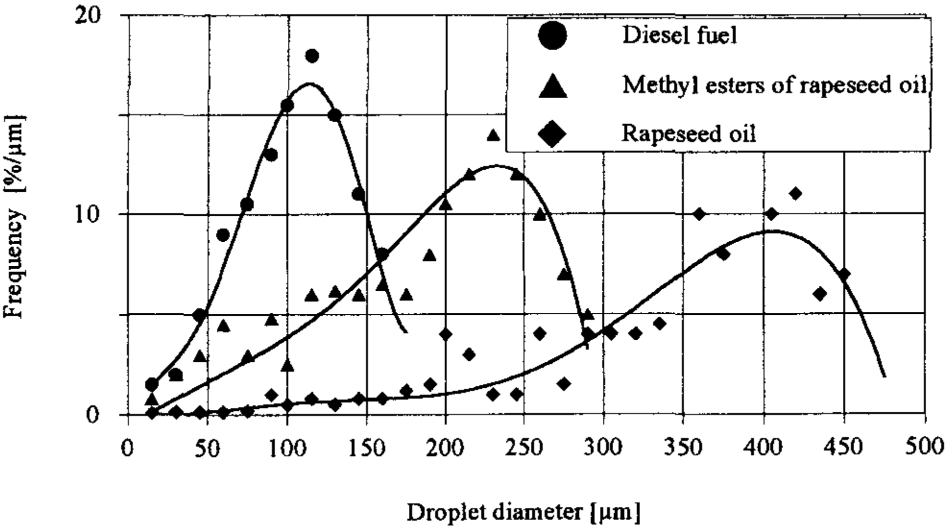

Fig. 1. Droplet diameter distribution curves for diesel fuel, natural rape oil and rape oil methyl esters [3]

In comparison with diesel fuel droplets, the diameter of rape oil droplets is four times larger; these droplets also demonstrate considerable diversity. A positive influence of rape oil transesterification is visible, as the average droplet diameter of rape oil methyl esters is only twice larger than that of diesel fuel.

Distillation curves of vegetable oils differ considerably from the corresponding diesel fuel curve. They occupy higher temperatures and the range of evaporation temperatures is much narrower. Additionally, in laboratory conditions, the boiling curves apply only to 20 to 80% (depending on the type of vegetable oil) of the volume subjected to distillation. Outside this range the phenomenon of cracking (thermal destruction of vegetable oil) occurs, which is probably the cause of deposits in the combustion chamber.

The autoignition ability of a fuel expressed by means of its autoignition delay describes cetane number. This number is determined on a standard, one-cylinder test engine, e.g. CFR Waukesha engine with a pre-combustion chamber and adjustable compression ratio. Thus cetane number is directly linked with the autoignition delay, depending in turn on the temperature and pressure in the combustion chamber. Fuels with higher cetane numbers feature shorter autoignition delays and stronger autoignition tendencies. It should be noted that cetane number is a universal, comparative indicator but not a physical parameter of fuel, although it depends on the chemical composition of fuel and some of its physical properties such as viscosity, density and surface tension being functions of temperature.

It was proved in [7] that cetane number is the real measure of fuel autoignition ability only for these fuels which feature the same relationship between the autoignition delay and chamber temperature as reference fuels used in the tests. Vegetable oils do not meet this condition. It can be seen in Fig. 2a to 2c, describing the relationship between the autoignition delay and temperature inside the constant – volume bomb for reference fuels (blends of n-cetane and heptamethylnonane), diesel fuel, degummed sunflower oil and sunflower oil methyl esters. The tests were conducted in a constant-volume bomb, simulating conditions inside the diesel engine (air pressure of 3 MPa, temperature ranging between 700 and 1200K). The autoignition delay was determined basing on the pressure increase. Cetane numbers of fuels were determined on a CFR engine.

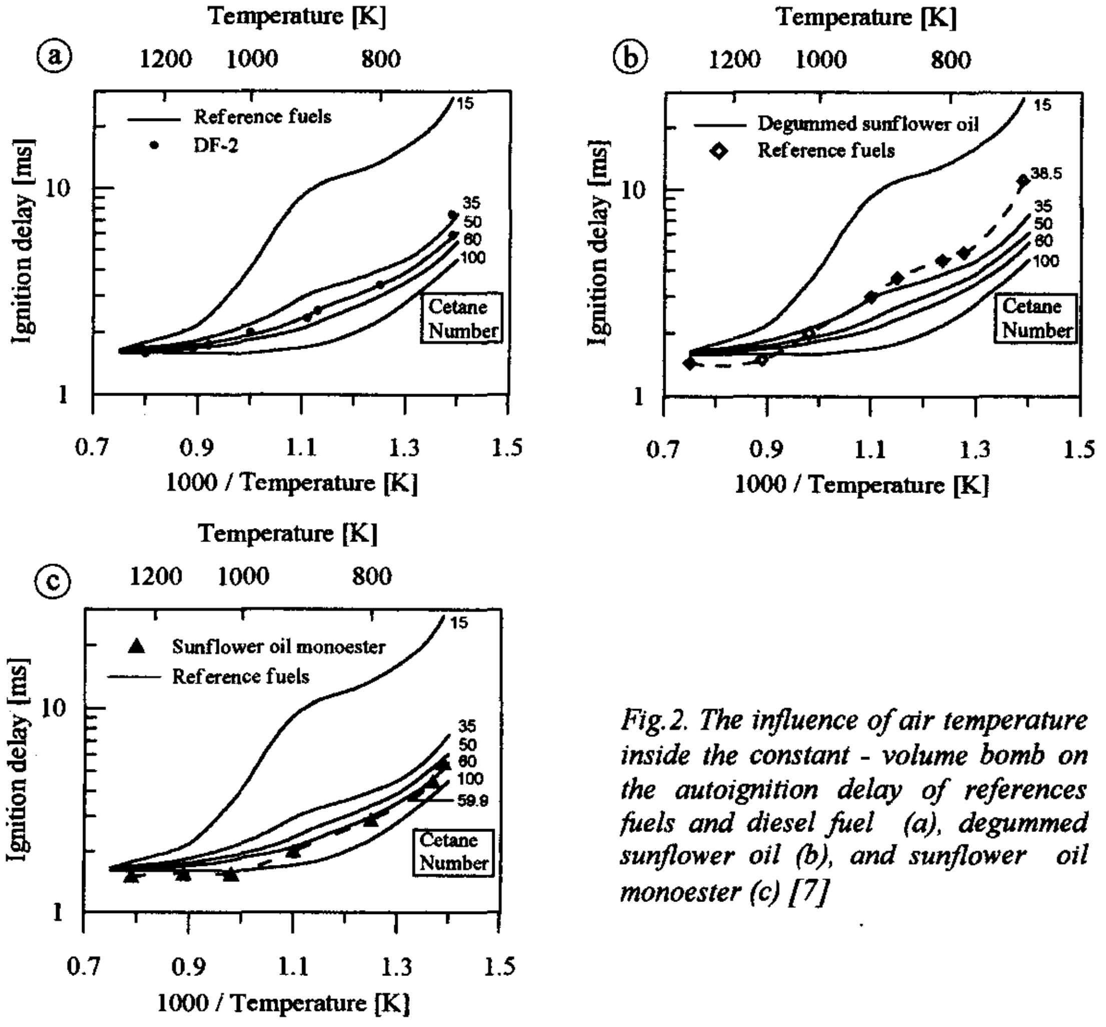

Fig.2. The influence of air temperature inside the constant - volume bomb on the autoignition delay of references fuels and diesel fuel (a), degummed sunflower oil (b), and sunflower oil monoester (c) [7]

Looking at the curves shown in Fig. 2a, one can find that diesel oil with a cetane number of 50,1 features practically the same autoignition delays as the reference fuel having a cetane number of 50 (curves for diesel fuel – DF 2 and reference fuel are the same) in the whole range of test temperatures (700 to 1200K). Thus one may expect that in the real engine conditions (from cold start to hot running) the autoignition ability of diesel fuel should be the same as that of the reference fuels having the same cetane number.

The curve for sunflower oil (cetane number = 35,8) is different (Fig. 2b) and crosses the reference fuel curve (cetane number = 35) at a temperature of 940K; only at that temperature the autoignition delays for both fuels are the same. At lower temperatures the autoignition delays for sunflower oil are longer, whereas at higher temperatures - shorter. At high temperatures, the autoignition delay for sunflower oil is even shorter than that of the reference fuel having a cetane number of 100. This leads to the conclusion that sunflower oil will demonstrate worse cold startability and stronger tendency to hot autoignition (shorter autoignition delay) than hydrocarbon fuels having the same cetane number.

In case of sunflower oil ethyl esters (cetane number = 59,9) it was found (Fig. 2c) that at temperatures lower than 940K the autoignition delays are generally similar to those of the reference fuel having a cetane number of 60, whereas at higher temperatures the autoignition delays are lower than those of the reference fuel having a cetane number of 100 and similar to those of natural sunflower oil. This indicates that sunflower oil ethyl esters should demonstrate the same autoignition tendency as the corresponding (in respect of its cetane number) reference fuel at the engine start and at low-torque operation.

Probably as a result of the problems with determining cetane number which are described above, these values given in literature for rape oil show significant differences, ranging between 36,9 and 44.Similarly, in case of rape oil methyl esters, various cetane numbers between 54 and 58 are given, but they are usually higher than the numbers given for diesel fuel.

The results of tests described above lead to the conclusion that at low temperatures, in the cylinder of engine working at idling speed and at low engine loads the autoignition tendency of vegetable oils will be generally weaker than that of diesel fuel. At high temperatures occurring at high engine loads the autoignition tendency of vegetable oils may be better than in case of diesel oil.

In order to confirm the conclusions given above, the appropriate tests were conducted. The engine was fuelled by a mixture of rape oil and diesel oil. The rape oil content of the fuel being changed between 0% and 100%.

3. Results and discussion

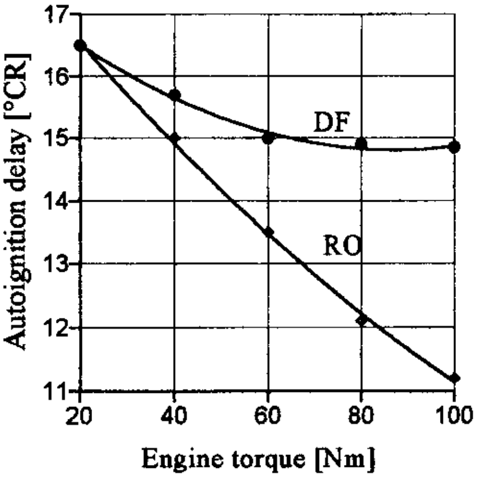

Fig.3. The influence of engine torque on autoignition delay for rape oil (RO) and diesel fuel (DF) (SB.3.1 engine, n = 1600 r.p.m)

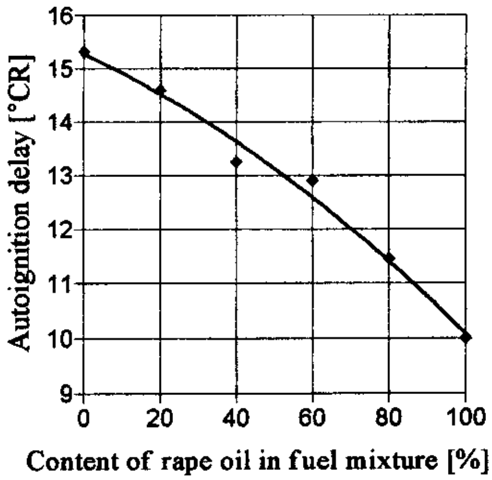

Fig.4. The influence content of rape oil in rape oil-diesel fuel mixture on autoignition delay (SB.3.1 engine, n = 2 200 r.p.m, engine torque = 95 Nm)

As it is shown in Fig. 3, the autoignition delay time of natural rape oil is shorter, and it decreases along with increasing engine load (and combustion chamber temperature) quicker than for diesel oil. Replacing some diesel oil with rape oil also leads to shorter autoignition delay times (at constant engine loads) - see Fig. 4.

When the temperature in the combustion chamber is low, which occurs, for example, during engine start-up, autoignition delay times are longer. This was confirmed by the tests of start-up capacity conducted on an engine fuelled with natural rape oil and its mixtures with diesel oil. The results are shown in Fig. 5. Higher values of the start-up temperature are caused by longer autoignition delay times in such fuels.

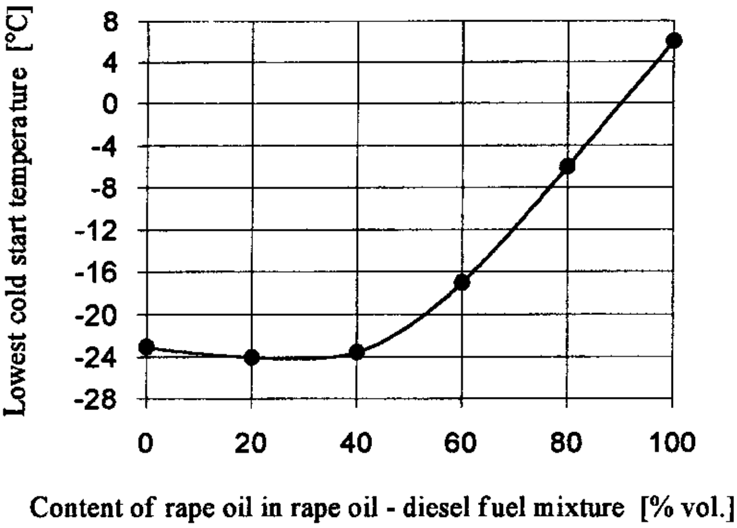

Fig. 5. The influence of the fuel composition (rape oil content of its mixture with diesel fuel) on the lowest cold start temperature, at a constant start-up fuel dose (90 mm^3/cycle) and start-up injection timing (30° CR BTDC).

The lowest cold start temperature curve has a distinct minimum. This minimum occurs for the mixtures containing up to 40% of rape oil and indicates that this amount of rape oil additive lowered the lowest cold start temperature of the engine tested. By replacing some amount of diesel fuel with rape oil, the viscosity of the mixture increases, which produces initially an advantageous influence of the increasing actual start-up dose on the lowest cold start temperature. If a certain value of viscosity is exceeded this positive effect may be dominated by a negative one, involving the reduction of the start-up dose volume as a result of lower efficiency of the cylinder injection pump filling. It was found that, at the lowest temperatures, the viscosity of mixtures containing up to 40% of rape oil increases when the rape oil content increase, but the viscosity of the mixtures containing 60% and 80% of rape oil as well as that of pure rape oil is, at the lowest cold start temperatures, almost the same. The same viscosity may indicate that the minimum fuel dose, necessary to initiate autoignition and to start the engine, is then injected.

The results of tests described above confirm that, owing to different effects of the temperature in the combustion chamber on the autoignition delay of vegetable fuels, their cetane numbers determined in engine tests (e.g. according to ASTM methodology) do not give unambiguous information about their autoignition ability at varied air temperatures in combustion chamber. In particular, higher cetane numbers of rape oil methyl esters (determined by the traditional method) do not provide sufficient basis for expecting better start-up characteristics of an engine fuelled by rape fuel.

4. Conclusion

Autoignition delay times of vegetable fuels depend heavily on the temperature in the engine combustion chamber. The knowledge of the cetane number in the case of vegetable fuels do not yield any conclusions concerning their autoignition potential under various conditions that can be found in the engine combustion chamber. This is caused by the fact that the cetane number is a good measure of autoignition potential only for these fuels for which the autoignition delay time depends on the air temperature in the same manner as for model fuels derived from crude oil.

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