COMPARISON OF INDICATOR AND HEAT RELEASE GRAPHS FOR VW 1.9 TDI ENGINE SUPPLIED DIESEL FUEL AND RAPESEED METHYL ESTERS (RME)

Jerzy Cisek

Cracow University of Technology, Faculty of Mechanical Engineering
Warszawska Street 24, 31-155 Krakow, Poland
tel.:+48 12 6283675, fax: +48 12 6481344
e-mail: jcisek@pk.edu.pl

Abstract

The results of investigation of 1,9 TDI engine (285 Nm, 85 kW, type AJM without any modification) equipped with injection units supplied conventional diesel fuel (ON) or B100 fuel (RME) have been presented in article. Investigations have been realized at the engine speed of 2000 rpm and variable load within the range of 0 to 275 Nm. The pressure, temperature and heat release velocity runs have been subjected to analysis. Particular attention has been paid to the release of the heat used for the effective work and internal energy increase of the working medium (enthalpy) during combustion inside the engine cylinder versus the crank angle for both investigated fuels.

It was found among the others that mentioned fuels differ in the heat release, heat velocity and the maximal combustion temperature, which for the B100 fuel is bigger than for the conventional diesel fuel.

Bigger combustion dynamics of tested biofuel (compared with standard diesel fuel) results higher concentrations of Nitrogen Oxides NOx in exhaust gases. The easiest way is of course the use of the later start of fuel injection biofuels and/or increase the exhaust gas recirculation EGR. These treatments, however, result in a worsening of the energy performance of the engine. It was concluded also that the combustion of RME works properly at higher engine loads. Then reduce the negative difference between the combustion of biofuel (RME) and standard Diesel fuel.

Keywords: *RME, FAME, indicator diagrams, heat realise, diesel engine*

1. Introduction

Recent years have seen a renewed interest in biofuels in the European Union, although some voices of searing criticism have been heard, indicating both certain toxic components of exhaust gases produced by biofuels and their adverse effects on operating parameters of combustion engines. Due to these reasons, if an engine is to be supplied this type of fuel (e.g. RME), particular attention must be paid not only to an answer to the question whether or not a biofuel has adverse effects on specific parameters (such as NOx emissions in exhaust gas), but also to the reasons of these effects. Indicator diagrams based on measured values and the resultant calculated curves of heat release rates as a function of crankshaft angle degrees (CAD) are very useful in a cause and effect analysis of the combustion process in a combustion engine. This paper discusses the effects of RME (as compared to conventional diesel fuel ON) on a variety of parameters determined basing on defined curves of indicator diagrams, combustion temperatures and heat release rates which enabled the author to draw a series of interesting theoretical and practical conclusions.

2. Test stand

A test bed has been constructed to achieve the objective of the research project: define the effects of RME (as compared to ON) on the characteristics of the combustion process in the cylinder of a compression-ignition engine; the layout of the test bed is shown in Fig. 1. The test bed consists of the following major measuring modules:

- a Schenck W150 electrical brake – control and measurements of engine torque,

- an AVL Fuel Balance mass fuel meter – measurements of fuel consumption,
- an AVL CEB II measuring system – measurements of gaseous components of exhaust gases (CO, CO_2, NO, NO_x, THC, O_2),
- an AVL Smoke Meter 401 – measurements of soot concentrations in exhaust gases using the Bosch method,
- a measuring system with a tunnel used to dilute exhaust gas – measurements of particulate matter (PM),
- an AVL Indimeter 617D measuring system – measurements of rapidly changing pressure values of the working medium and pressure values of the fuel in the injection system and the movements of the injector needle,
- an AVL VideoScope 513D measuring system – used to visualize the fuel injection and combustion processes in the engine cylinder, to determine the flame propagation probability and the distribution of isotherms in the flame.

A test bed equipped as above certainly facilitates a wider scope of tests [1, 3, 4], but it is not the aim of this to discuss visualizations of the fuel injection and combustion processes in an engine cylinder or thermal imaging. Particular attention is paid to the measured indicator diagrams and the resultant calculated curves of heat release rates and combustion temperatures (as a function of CAD) for the tested fuel types (ON and RME).

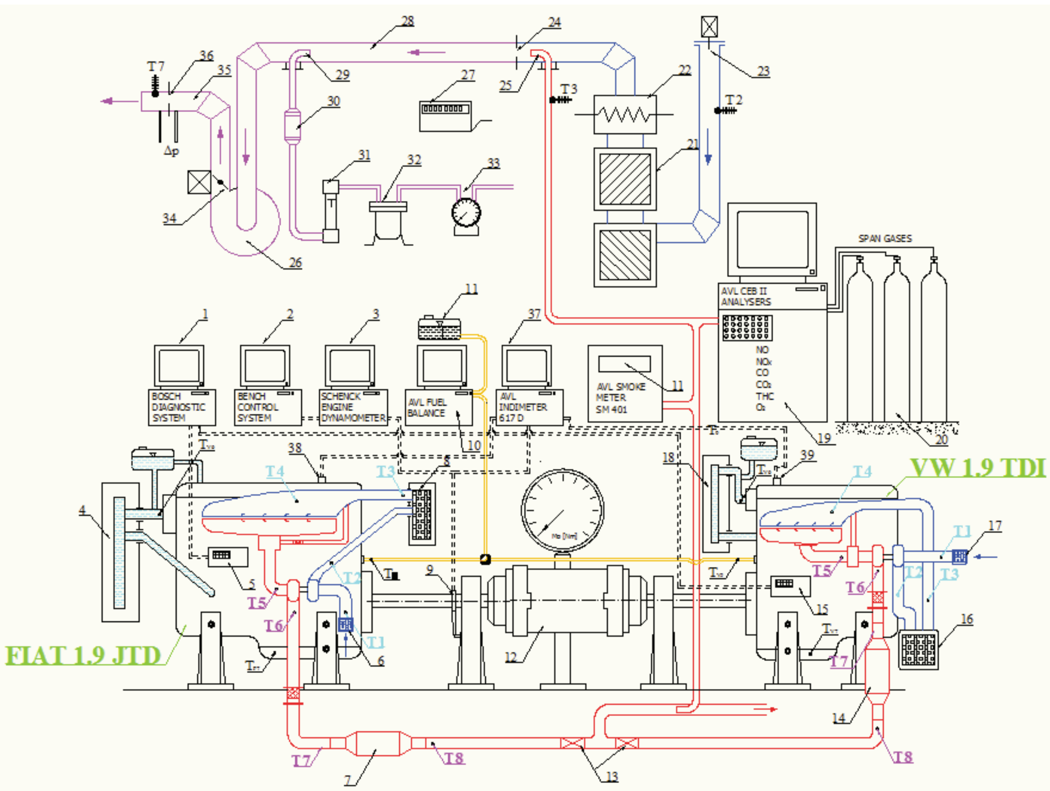

Fig. 1. Scheme of the measurement (described in the text)

3. Research results

The measured data indicates that an engine supplied standard ON is characterised by lower hourly fuel consumption (Fig. 2) than en engine supplied rapeseed oil methyl ester (RME). Naturally, the value of hourly fuel consumption in these circumstances cannot be regarded as a comparative parameter (even at a constant rotational speed and a constant engine load), because the fuels differ in their calorific values. Therefore, Fig. 3 shows the effect of the load acting upon an engine supplied both tested fuel types on the overall engine efficiency η_e.

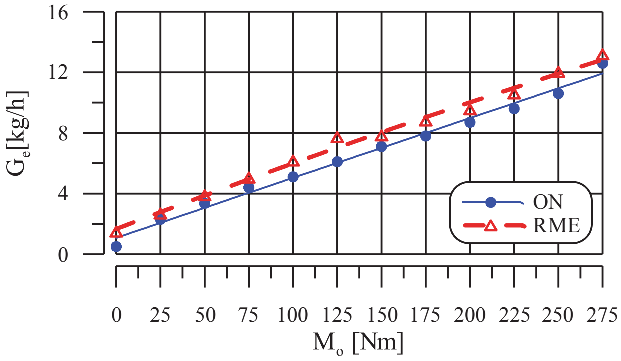

Fig. 2. Fuel consumption for the tested fuels

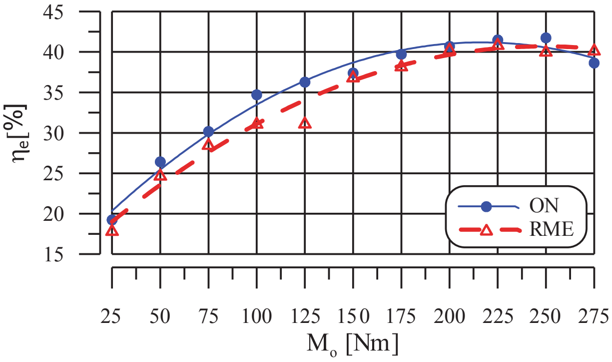

Fig. 3. Total efficiency for the tested fuel

The data indicates that the values of η_e are slightly higher for RME than for ON only at high loads acting upon the engine. This observation may confirm a desirable effect of high combustion temperatures (associated with high engine loads) on the injection, evaporation, spontaneous ignition and combustion processes in engines supplied biofuels. However, this may also result from the influence of those physical properties, which distinguish this biofuel from diesel fuel and affect the characteristics of injection of the tested fuels. A more detailed cause and effect analysis is provided by the pressure and temperature curves and the rates of heat use as a function of crankshaft rotation angle (crankshaft angle degrees – CAD) presented below for varying loads acting upon an engine supplied the tested fuels. The open indicator diagrams for standard, conventional diesel fuel (ON) are shown in Fig. 4.

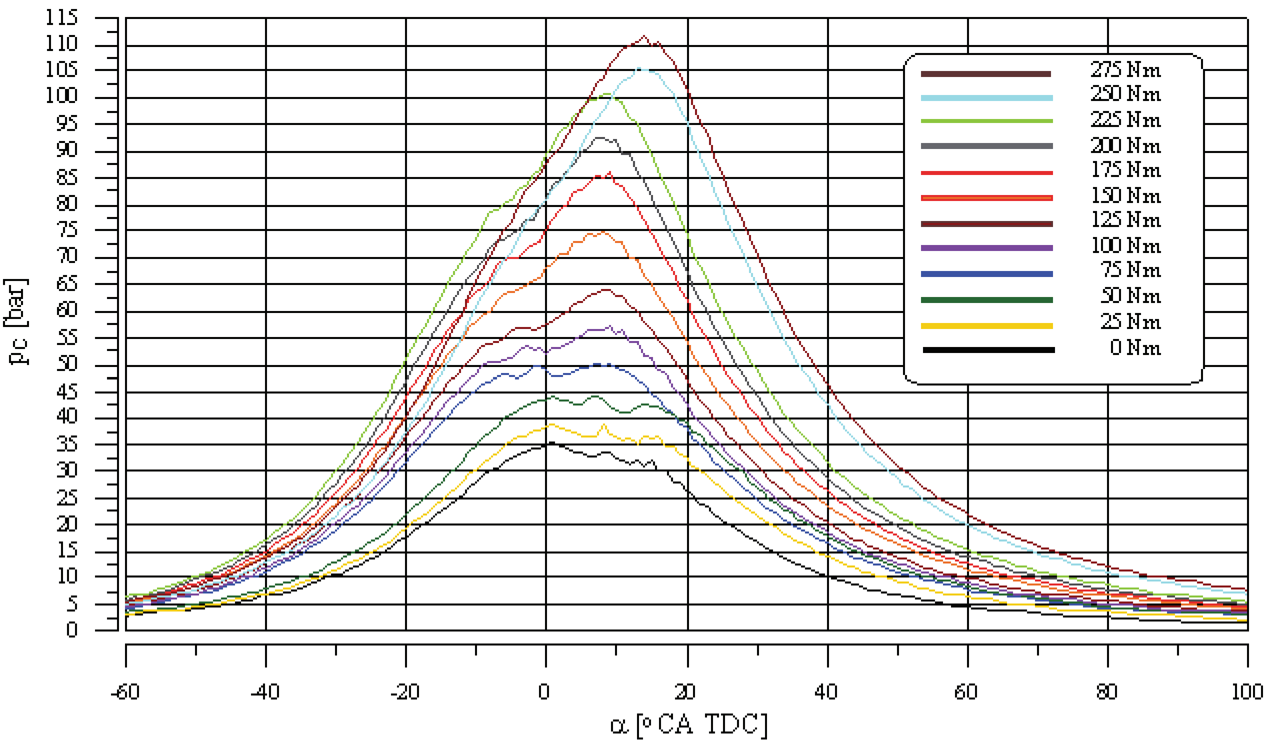

Fig. 4. Open indicator diagrams for the 1.9 TDI VW feed standard diesel fuel ON

Measurement of this type of indicator diagram for RME (FAME) allowed determining and/or calculating the number of parameters (shown in the illustration below) to facilitate the comparative analysis of combustion ON and RME. For example, maximum value and occurrence of max. combustion pressure, for tested fuels, was shown on the Fig. 5, 6.

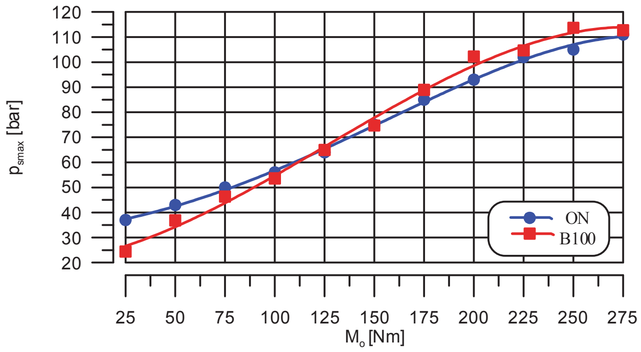

Fig. 5. Max pressure of combustion for tested fuels

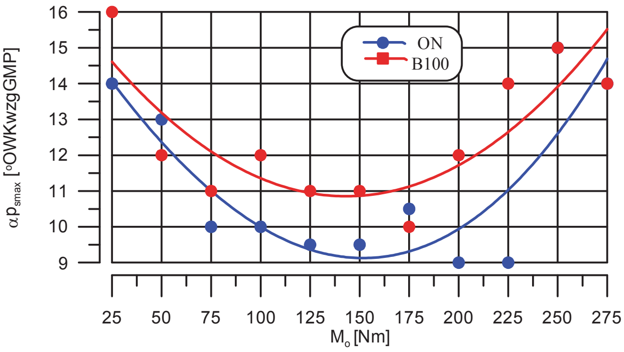

Fig. 6. Occurrence of max combustion pressure for tested fuels

A comparative qualitative analysis demonstrates that the process of spontaneous ignition and combustion of the pilot charge of fuel is more clearly visible in the case of diesel fuel (particularly at lower loads acting upon the engine). This fact itself confirms that the same small pilot charge of fuel is used more efficiently to produce heat in the case of diesel fuel than in the case of RME. Also the grade of injected fuel affects the initial moment of spontaneous ignition of both the pilot and the main fuel charge. This is shown in Fig. 7 and 8.

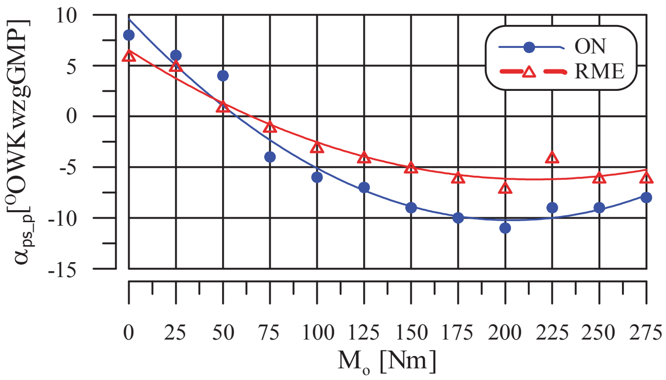

Fig. 7. Start of autoignition pilot dose for the tested fuels

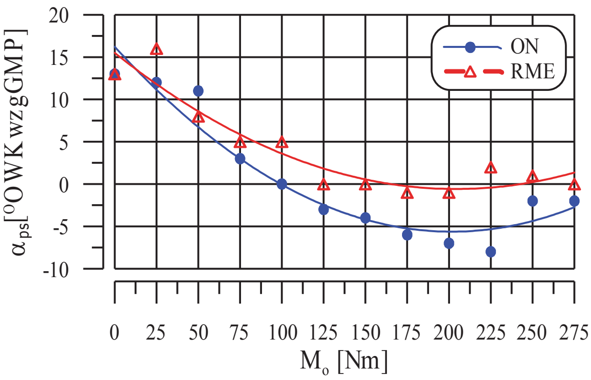

Fig. 8. Start of autoignition the main dose of fuel for the tested fuels

It is clear that when the engine is supplied the biofuel, spontaneous ignition is delayed practically in the entire range of applied loads (excluding idle run) as compared to the operation of the same engine when supplied diesel fuel. This difference increases with increasing load values for both the pilot and the main charge of fuel, and reaches ca. 5CAD at high load values. The shift between initial moments of spontaneous ignition of the fuel (when various fuels are used) may result from two reasons: a shift of the initial moment of fuel injection (due to the effect of physical properties, mainly the viscosity, of the fuel on hydraulic resistances) or from the effects of chemical properties which distinguish the two fuels and influence their susceptibility to ignition. As demonstrated by the data shown in Fig. 8, the initial moment of injection of the tested fuels is basically almost the same. At high values of engine loads, the initial moment of injection α_{pw} is slightly earlier for rapeseed oil methyl esters than that for diesel fuel (the difference is less than 1 CAD). This effect results from a higher viscosity of the biofuel injected as compared to diesel fuel. An earlier initial moment of injection usually extends the delay time of spontaneous ignition τ_s. However, so small differences in initial moments of injection of diesel fuel and RME cannot explain the significant delay of the initial moment of spontaneous ignition τ_s which results from the data contained in Fig. 9.

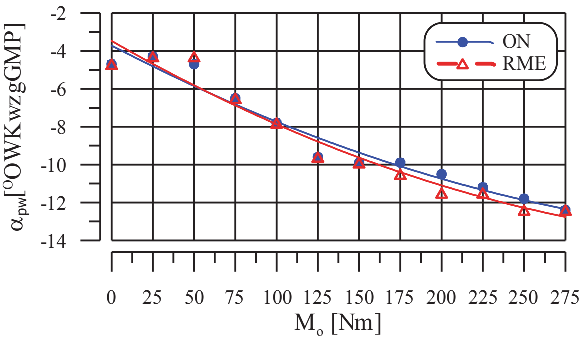

Fig. 9. Start of injection for the tested fuels

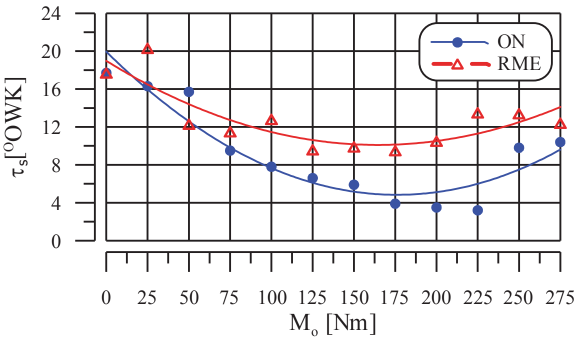

Fig. 10. Delay of autoignition for the tested fuels

This significant increase in delay time of spontaneous ignition in the case of RME (as compared to ON) must result from a lower susceptibility to spontaneous ignition of glyceride particles forming rapeseed oil methyl esters as compared to that of hydrocarbon particles.

An extended delay of spontaneous ignition means an extended time between the initial moment of injection and the initial moment of fuel ignition. Consequently a larger amount of fuel is accumulated in the combustion chamber until the moment of spontaneous ignition (even if the total fuel charge remains the same). The spontaneous ignition phase, at a longer delay time of its initial moment, is more explosive, and the combustion process more dynamic which is indicated among others by larger values of combustion pressure increase rates (Fig. 10), larger loads acting upon the piston and rod system and in an increased combustion noise. With an extended delay time of spontaneous ignition, also theA combustion temperatures become higher.

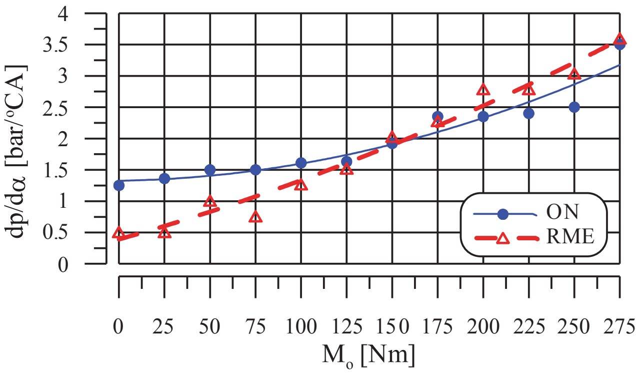

Fig. 11. Max combustion pressure rise $(dp/d\alpha)_{max}$ for the tested fuels

The maximum value of combustion temperature (Fig. 12) and its time related to the top dead centre of the piston TDC (Fig. 13) are indicated on the graphs.

It is clear that when a compression-ignition engine is supplied an RME-type biofuel, the maximum combustion temperature is higher than in an engine supplied diesel fuel. The lower the engine load, the higher the difference between the temperature values. This is another parameter, which confirms the advantageous effect of a high engine load on the adverse differences in the combustion curve of rapeseed oil methyl esters as compared to that of diesel fuel. In addition, a later moment of the maximum combustion temperature of RME (exceeding 4 CAD) reduces the value of this fuel as compared to diesel fuel. This is one of the factors that reduce the thermal efficiency of an engine supplied RME which translates into the overall efficiency values (Fig. 3).

At small engine loads, the difference between the maximum combustion temperatures for RME and ON is as high as 500°C. This not only affects the heat load of the engine but also significantly contributes to an increased concentration of NO_x in exhaust gas (Fig. 14).

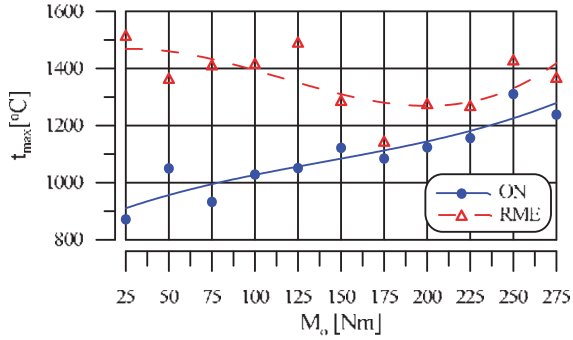

Fig. 12. Max temperature of combustion for tested fuels

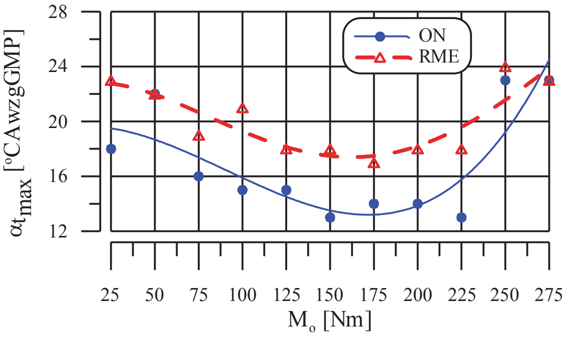

Fig. 13. Occurrence of max combustion temperature for tested fuels

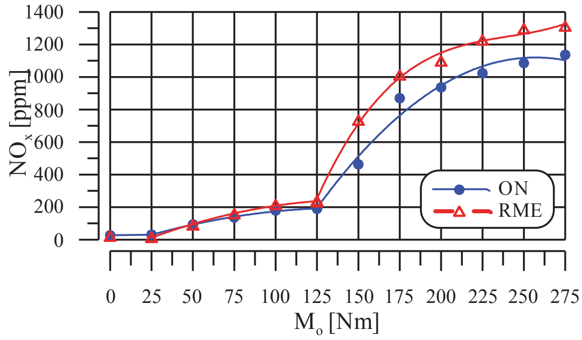

Fig. 14. Concentration of NOx in exhaust gases for tested fuels

The higher the engine load, the higher the difference between these concentrations. At the full engine load, the increase in NO_x concentration amounts to ca. 13% as compared to diesel fuel. The figure clearly demonstrates a change in the NO_x curves as a function of engine load for both fuel types at the load value of 125 Nm. At this load value, the engine controller dramatically reduces exhaust gas recirculation (from 46% to 4.8% EGR) which results in a further rapid growth of NO_x associated with increasing load values. Usually a phenomenon of this type, i.e. an increase in the maximum combustion temperature (and consequently increased NO_x emissions in exhaust gas) is correlated with an increased rate of heat release according to Fig. 15.

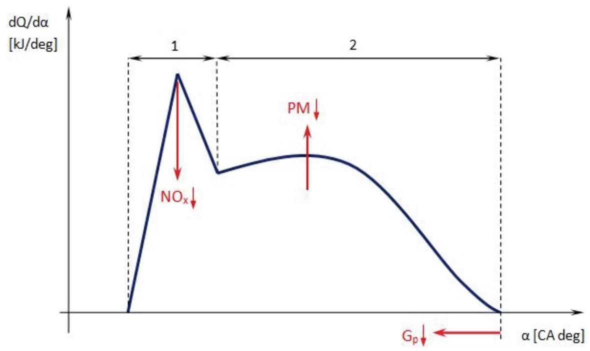

Fig. 15. Chart of flow the heat release rate in the cylinder

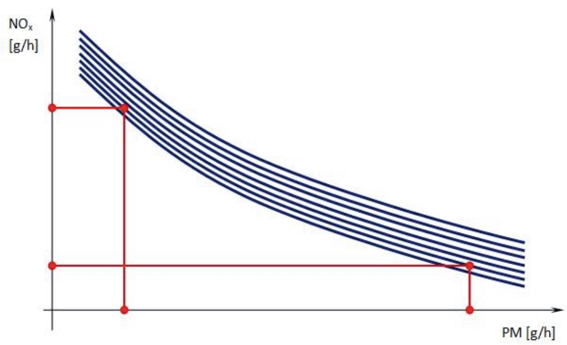

Fig. 16. Schematic of dependence of the emissions of a diesel engine particulates matter E_{PM} and nitrogen oxides E_{NOx}

To confirm the existence of this phenomenon also for the tested fuel types, the coefficients of heat released in the engine cylinder, used to perform work and increase the internal energy of the working medium, were calculated. The maximum rate of kinetic combustion $dQ_{ikmax}/d\alpha$ is responsible for nitrogen oxide (NO_x) emissions while the maximum rate of diffusion combustion $dQ_{idmax}/d\alpha$ is correlated with PM emissions. An increase in the $dQ_{ikmax}/d\alpha$ value results in a growth of combustion dynamics and consequently of the concentration of NO_x in exhaust gas while an increase in $dQ_{idmax}/d\alpha$ offers the opportunity to burn a larger portion of particulate matter already in the engine cylinder and thus to reduce PM emissions in exhaust gas. In a conventional compression-ignition (CI) engine whose control settings (e.g. the initial moment of fuel injection) are configured so as to obtain optimum energy parameters (engine power), the maximum rate of kinetic combustion is significantly higher than the maximum rate of diffusion combustion (cf. the diagram). In present-day CI engines, the maximum rate of kinetic combustion is reduced as far as practicable using control measures and design solutions as well as by controlling chemical composition and structure of fuels, due to the stringent limits of exhaust gas toxicity (NO_x). An example of this type of engines is the VW 1.9TDI engine used for testing purposes in which a pilot charge of fuel, EGR and a relatively late initial moment of fuel injection are applied to obtain such conditions in which the maximum rate of kinetic combustion $dQ_{ikmax}/d\alpha$ is even lower than the maximum rate of diffusion combustion $dQ_{idmax}/d\alpha$. This is shown in Fig. 17 and 18 where the value of $dQ_{ikmax}/d\alpha$ reaches 30 kJ/m^{3}deg while $dQ_{idmax}/d\alpha$ has a maximum value of 110 kJ/m^{3}deg.

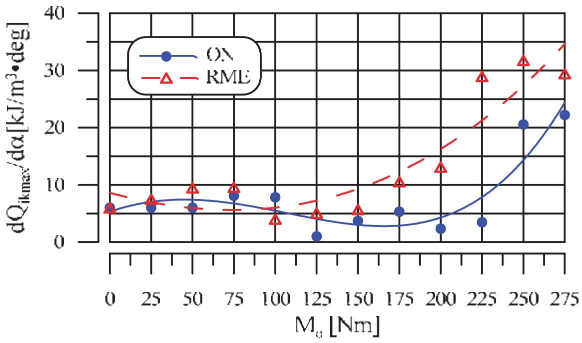

Fig. 17. Max rate of the kinetic combustion for tested fuels

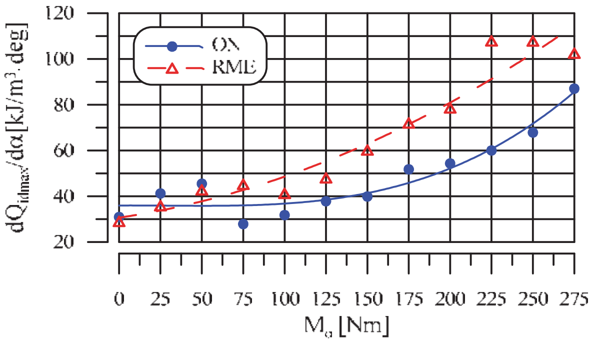

Fig. 18. Max rate of the diffusion combustion for tested fuels

These values of heat release rates effectively and significantly reduce both nitrogen oxide (NO_x) and particulate matter (PM) emissions. This is particularly important in view of the fact that most of the internal solutions applied in engines to reduce NO_x concentrations cause an increase in PM emissions and vice versa. This results in the so called counterbalance effect whose diagram is shown in Fig. 16. The occurrence of maximum rate of kinetic combustion $\alpha_{dQikmax/d\alpha}$ and the maximum rate of diffusion combustion $\alpha_{dQidmax/d\alpha}$ are shown in Fig. 19, 20.

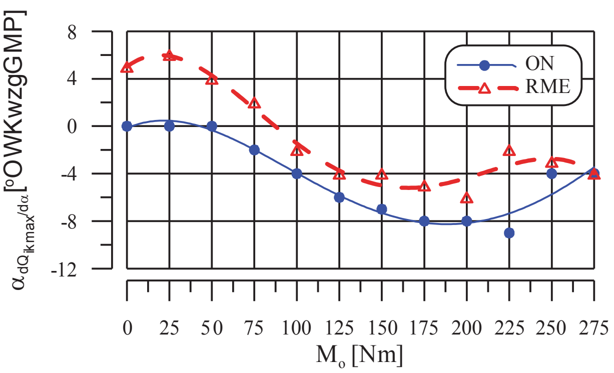

Fig. 19. Occurrence of max rate of kinetic combustion

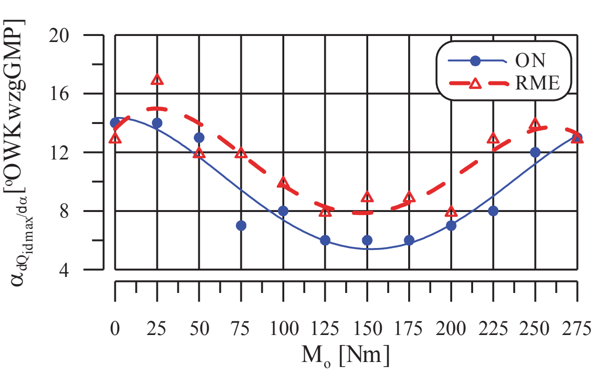

Fig. 20. Occurrence of max rate of diffusion combustion

The presented data confirms the observation described above: that the combustion process of rapeseed oil methyl esters is delayed by ca. 4 CAD as compared to diesel fuel combustion. This is an undesirable phenomenon in view of energy parameters of an engine (its power, fuel consumption per unit), because the discharge loss increases due to an increase in temperature.

4. Conclusions

The described tests substantiate the following theoretical and practical conclusions:

1. Supplied a compression-ignition engine RME (instead of ON) leads to an increased dynamics of combustion and higher maximum combustion temperatures. This results in an increase of the concentration of NOx in exhaust gas by ca. 10%.
2. RME has no effect on the initial moment of fuel injection as compared to ON. However, as a result of the extended delay period of spontaneous ignition of the tested biofuel, the initial moment of spontaneous ignition is later by several CA than for ON. This also entails a later ending moment of the combustion process which adversely affects the thermal efficiency and consequently the overall efficiency η_o of the engine.
3. An increased engine load reduces the adverse effect of RME on energy parameters of the engine (including η_e) due to the increased combustion temperature.

References

[1] Cisek, J., *Optical research on the fuel injection into a diesel engine for diesel fuel*, RME and rape oil, Journal of KONES Powertrain and Transport, Vol. 19, No. 3, pp. 65-74, Warsaw 2012.

[2] Cisek, J., Mruk, A., *Emission of toxic exhaust components of the engine a8C22 working in the locomotive SM-42 and supplied by the mixture RME with diesel fuel in the test F of the 2004/26/WE directive*, Technical Journal of Cracow University of Technology 4-M/2012 exercise book 9/109, Politechnika Krakowska, pp. 23-34, Kraków 2012.

[3] Cisek, J., *Effect of Biofuels (FAME) on the Coking Level in Diesel Engine Injector*, XLII. International Scientific Conference of Czech and Slovak University Departments and Institutions Dealing with the Research of Combustion Engines. Zylina, Słovakia 2011.

[4] Cisek, J., *Combustion of RME with Water Emulsions on Diesel Engine*, International Conference „Biofuels for Energetic 2009, Praga 2009.