EXPERIMENTAL TEST OF COMMON RAIL DIESEL ENGINE SUPPLIED WITH DIESEL FUEL – RAPE SEED OIL MIXTURES

Marek Klimkiewicz, Remigiusz Mruk

Warsaw University of Life Sciences, Faculty of Production Engineering
Nowoursynowska Street 164, 02-787 Warsaw
tel.: + 48 22 59 345 85, + 48 22 59 345 78
e-mail: marek_klimkiewicz@sggw.pl, remigiusz_mruk@sggw.pl

Paweł Oleszczak

Warsaw University of Technology, Institute of Heat Engineering
Nowowiejska Street 21/25, 00-665 Warsaw, Poland
tel: +48 22 234 52 83
e-mail: polesz@itc.pw.edu.pl

Abstract

In the next few decades, the resources of oil will be depleted. From the other hand, growing market and usage of oils cause increase of oil price. Additionally, only some countries have oil deposits large enough to be independent from foreign suppliers. All these reasons show need for searching and development of new fuels, which can replace traditional ones produced from oil. One of the solutions for Diesel engines are bio-fuels produced from various vegetable oils like rapeseed, coconut or palm oil.

Nowadays, the majority of new Diesel engines are equipped with Common Rail fuel injections system. It enables to achieve higher power of the engine, lower emissions and lower fuel consumption. This suggests that the Common rail system should be also utilized in Diesel engines supplied with bio-fuels, produced from various plants, as it was mentioned above. However, the bio-fuels have some properties much different from those of conventional Diesel fuel, for example they usually have significantly higher viscosity. In consequence, the fuel supply and fuel injection systems require some modifications.

The paper presents results of the experimental test of Common Rail Diesel engine supplied with four fuels: standard Diesel fuel, rapeseed oil and two mixtures of these fuels: 70% of Diesel with 30% of rape seed oil and 50% of Diesel fuel with 50% of rape seed oil. For the research, a new test bench was built in Faculty of Production Engineering, Warsaw University of Life Sciences. The main element of the test bench is one cylinder, direct injection engine Farymann Diesel 18W. Originally, the engine was equipped with mechanical Bosh direct injection system, which was replaced with Common Rail system. The test bench enables measurements of various parameters: torque, pressure inside the cylinder, temperature of cooling water and exhaust gases, emissions etc. The tests of the modified engine were conducted with use of several types of piston and injector.

Keywords: *Diesel engines, Common Rail, bio-fuels, rape seed oil*

1. Introduction

According to estimation of international organizations e.g. OPEC, SPE, WPC, the oil resources will probably be consumed within next several decades. Moreover, the oil resources are concentrated in only a few countries of the World what makes other countries dependant on the foreign supplies. Besides, energy production with use of the fossil fuels causes increase of carbon dioxide concentration in atmosphere what probably has an impact on the global temperature rise.

The problems concerned with use of fossil fuels motivate searching of new fuels, which potentially could replace traditional ones. One of the options is bio fuels, e.g. various vegetable oils: rapeseed oil, coconut, palm etc. The bio fuels can be potentially produced from various vegetables planted in given region of the World. The first test of application of the rape seed oil in Diesel engines of agricultural and other heavy vehicles were performed in thirties of the last century in Germany, Italy and Belgium. In United States research on utilization of palm and fish oil as diesel fuel was conducted. Nowadays, tests of use of various vegetable oils produced from different plants are conducted by many research centres in USA, Japan, Germany and in many other countries.

The rapeseed oil properties, especially heat of combustion and viscosity, are different from those of traditional Diesel fuel. Therefore, utilization of rapeseed oil in Diesel engines, particularly in new, modern Common Rail engines, requires addition of e.g. traditional diesel fuel. The additions change the properties of the fuel and enable proper work of the fuel injection system and the engine as well as make the production of the fuel more complex and expensive. Nevertheless, the use of the rapeseed oil and other bio fuels can reduce consumption of the fossil fuels, particularly in small scale, for example in the farm, where the rape can be planted and the produced rapeseed oil can be than used in the fuel production.

The paper presents results of the tests conducted on the research facility constructed in Faculty of Production Engineering of Warsaw University of Life Sciences. The research on the use of the rapeseed and other oils a fuel for Diesel engines has been conducted at the Warsaw University of life Science for about 10 years. The first tests were conducted on constant volume chamber and were aimed on ignition delay and combustion of various fuel mixtures. The presented results were obtained with use of the research facility basing on a one cylinder, small marine engine equipped with Common Rail fuel injection system. The main aim of the research presented in the paper was to study an influence of Diesel oil content in mixture with rapeseed oil on parameters of work of Diesel engine with Common Rail fuel supply system. The results of the tests conducted for various configuration of the facility are presented in the paper.

2. Research facility

The main element of a research facility is engine Farymann Diesel type 18 W Marine „Yellow River Star" (FD18WM). It is one cylinder, four-stroke commercial Diesel engine with direct fuel injection and uncharged, atmospheric respiration. The compression ratio of the engine equals 20, the swept volume is equal 290 cm³, bore and stroke of the piston are equal to 82 mm and 55 mm, respectively. The scheme of the engine is presented in Fig. 1. The fuel supply system of the engine has been modified. The original elements of the mechanical fuel supply system have been replaced with electronically controlled Common Rail fuel supply system. In the new fuel supply system Bosh fuel pomp CR/CP1H3 is used as well as CR rail type CR/V4/10-12S (Bosh). In the research several injectors were tested, the maximal fuel pressure in the system was not higher than 150 MPa. The view of the fuel supply is shown in Fig. 2.

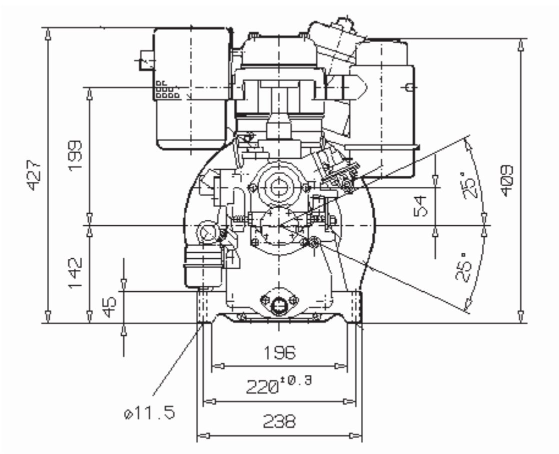


Fig. 1. Scheme of engine with its main dimensions

Fig. 2. View of the CR fuel supply system. 1 –rail (accumulator), 2 fuel injector

In the research, two combustion chambers and three injectors were tested. The results of the tests conducted with use of one of the injectors (injector 1) and one combustion chamber (piston1) are described. The piston was a standard piston of the Farymann 18W engine and the injector had 6 nozzles.

3. Results of the tests

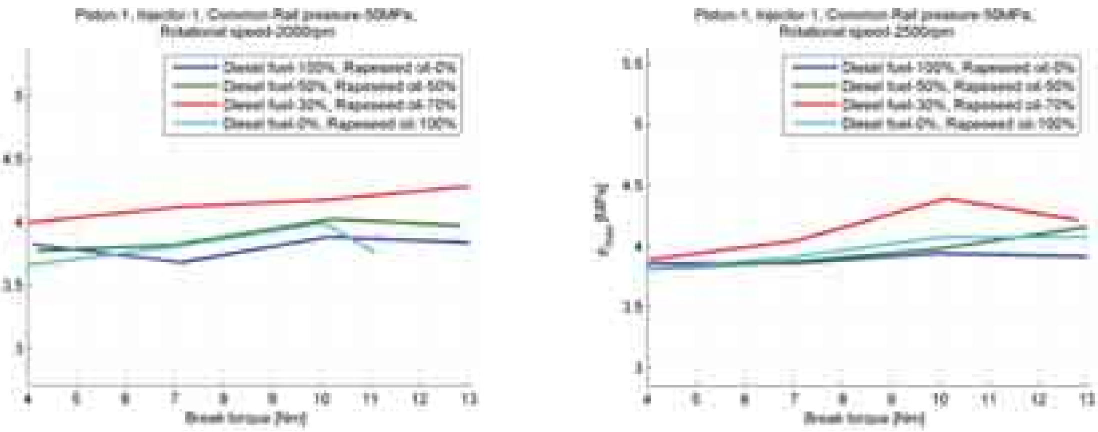
The experimental tests of the engine were conducted for various configurations of the engine and various parameters. The following elements and parameters were changed during the research, as it was described in previous chapter. The exemplary results of the conducted experiments are presented in the following sub chapters. Each of experimental points on the presented below graphs equals an average of values obtained during the tests.

3.1. Common Rail fuel pressure 50 MPa

The results of the tests conducted with use of one of the tested injectors (injector 1), one of the tested pistons (piston 1) and with pressure in the Common Rail system equal to 50 MPa are presented in Fig. 3-8.

Figure 3 presents maximal pressure inside the cylinder in function of torque measured for four fuels: pure Diesel fuel, mixture of 30% of Diesel fuel and 70% of rapeseed oil, mixture of 50% of Diesel fuel and 50% of rapeseed oil and pure rapeseed oil. The graphs presented in Fig. 3a shows results obtained for rotational speed of the engine equal to 2000 rpm and those in Fig. 3b for rotational speed equal to 2500 rpm.

As it can be seen on the presented graphs, the maximal value of the pressure is increasing with increase of the torque and the highest values were registered for the mixture containing 30% of Diesel fuel for both rotational speeds of the engine. It can be concluded, that in case of 2000 rpm values of the maximal pressure for pure Diesel fuel and pure rapeseed oil are similar in the range of tested torques and smaller than those for mixtures of the fuels. For 2500 rpm maximal values were also registered for the mixture containing 30% of Diesel fuel but in this case maximal pressures for mixture of 50% of diesel fuel and 50% of rapeseed oil are very similar to values for pure Diesel oil. Moreover, the maximal pressures for pure rapeseed oil are higher than those for pure Diesel fuel and mixture containing 50% of Diesel fuel. The differences of the maximal values of the pressure inside the combustion chamber for various fuels are relatively small and in order of 13.5% (2500 rpm, torque equal to 10 Nm) but it looks like the influence of the rapeseed oil content in the mixture is not monotonic and depends e.g. on the rotational speed of the engine. The non-monotonic influence is particularly seen in case of the mixture containing 50% of Diesel fuel, what will be shown in the following chapters of the paper. Comparison of the graphs in Fig. 3a and Fig. 3b also reveals that increase of the rotational speed has only limited influence on the maximal pressure in the cylinder.

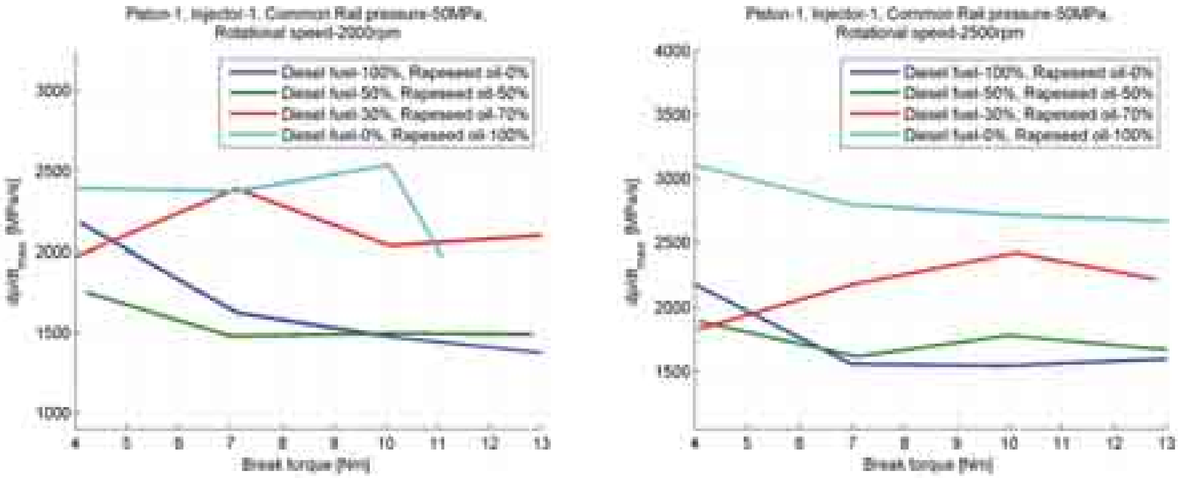


a) 2000 rpm *b) 2500 rpm*

Fig. 3. Maximal pressure inside the cylinder in function ofbreak torque for two rotational speeds of engine

The next graphs, presented in Fig.4, show maximal rate of pressure rise in the cylinder of the engine in function of the torque for four tested fuels and two rotational speeds of the engine: 2000 rpm and 2500 rpm.

As it can be seen in the graphs, the highest values of the rate of the pressure rise were obtained for pure rapeseed oil and the lowest for pure Diesel fuel. It can be also concluded that for both rotational speeds increase of the Diesel fuel content in the mixtures resulted in decrease of the maximal value of the pressure rise rate in the range of tested torques.



a) 2000 rpm *b) 2500 rpm*

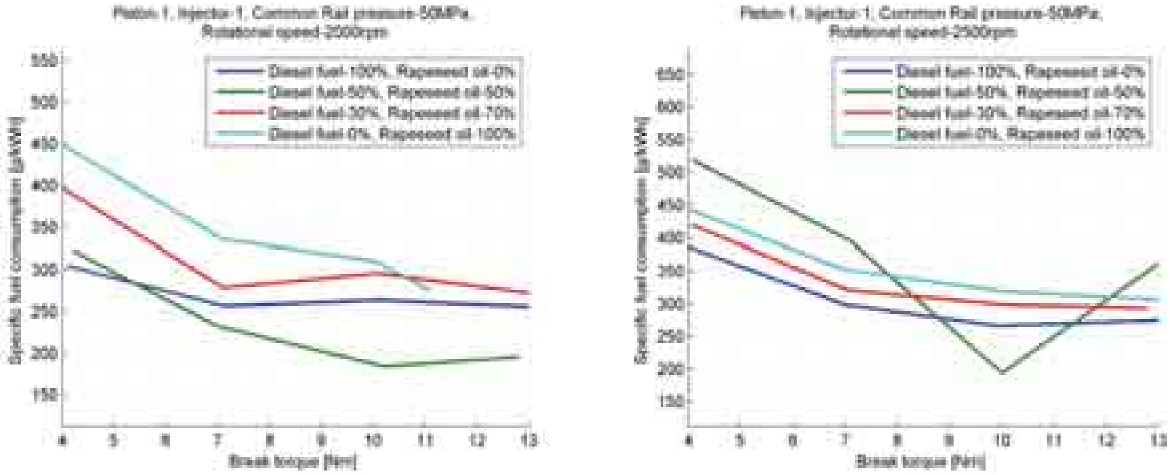
Fig. 4. Maximal rate of pressure rise in function of break torque for two rotational speeds of engine

In the case of maximum value of the pressure rise rate the differences of the values for different fuels are quite significant and reaches even 100%, for example for rotational speed equal to 2500 rpm and torque equal to 10 Nm.

Figure 5 presents specific fuel consumption in function of the torque for the same mixtures of fuels and rotational speeds of the engine like in the previously described figures. The general conclusion is that increase of the torque resulted in decrease of the specific fuel consumption. As it can be seen on the graphs, the correlation between the specific fuel consumption and the content of the Diesel fuel in the mixture is clear for pure rapeseed oil, pure Diesel fuel and mixture of 30% of the Diesel fuel and 70% of rapeseed oil: the increase of the Diesel fuel content results in decrease of the specific fuel consumption. However, the results obtained with use of mixture of 50% of Diesel fuel and 50% of rapeseed oil depend strongly on the rotational speed of the engine and on the torque. For rotational speed equal to 2000 rpm the specific fuel consumption was the lowest for almost all tested values of torque. The difference in comparison with pure Diesel oil was in order of 60% (2000 rpm, torque equal to 10 Nm). For higher value of the rotational speed the specific fuel consumption for mixture of 50% of Diesel fuel and 50% of rapeseed oil was the highest for torque equal to 4, 7 and 13 Nm and it was the lowest for 10 Nm.

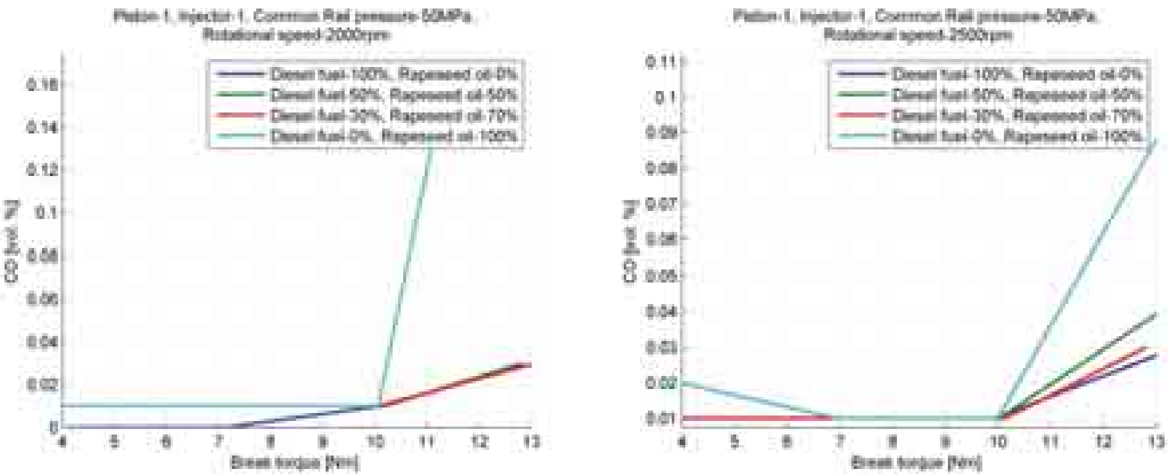
Graphs presented in Fig. 6, 7 and 8 shows content of CO, HC and NO_x in the exhaust gases measured during the conducted tests.

Figure 8. presents volume fraction of NO_x in exhaust gases, measured for various fuels, different torques and two values of rotational speed. As it can be seen in the presented graphs, the maximal emissions were registered for the mixture of 30% of Diesel fuel and 70% of rapeseed oil. The emissions obtained for other fuels, especially for pure Diesel fuel and pure rapeseed oil, were very similar. The emission of NO_x for mixture of 50% of Diesel fuel and 50% of rapeseed oil was a little higher than for pure fuels for rotational speed equal to 2000 rpm and higher values of torque.



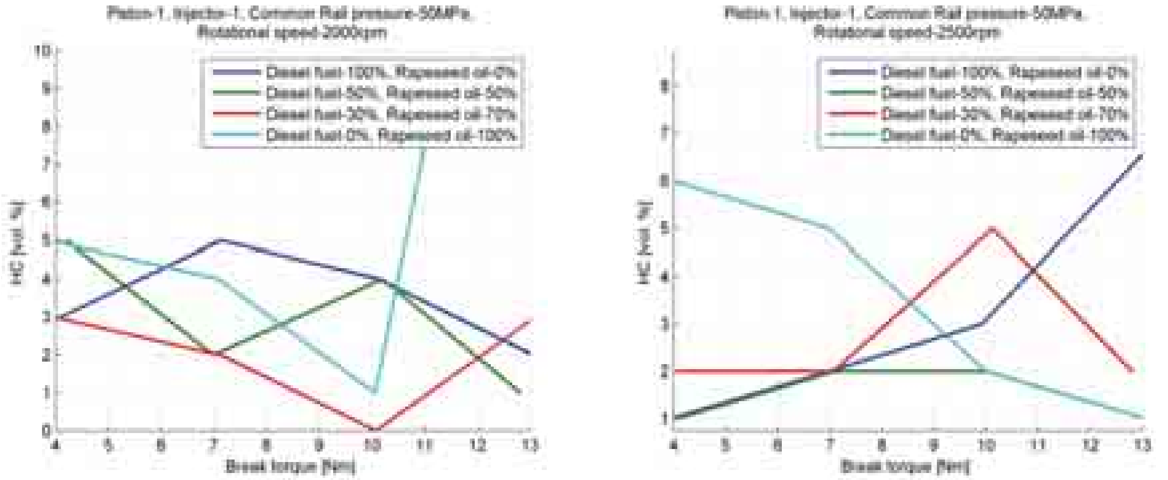
a) 2000 rpm b) 2500 rpm

Fig. 5. Specific fuel consumption in function of break torque for two rotational speeds of engine



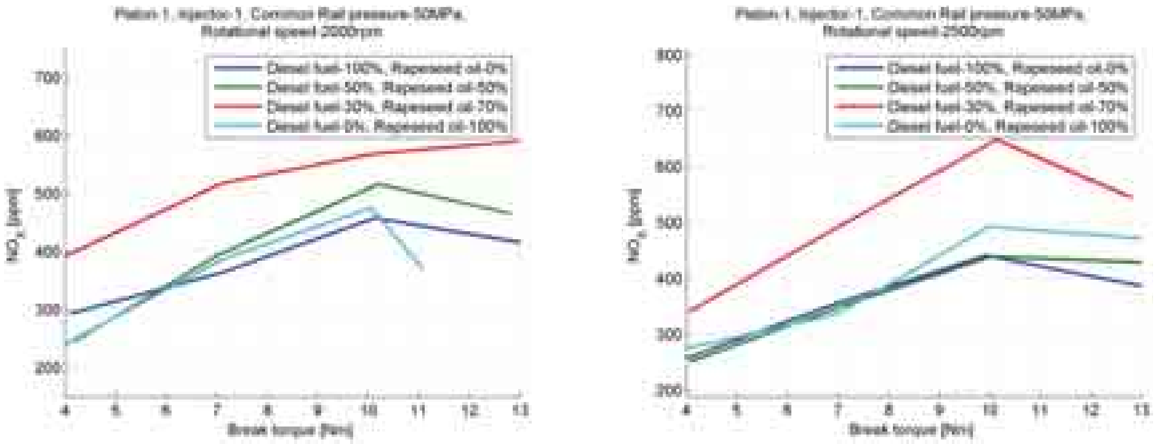
a) 2000 rpm b) 2500 rpm

Fig. 6. Content of CO [vol.%] in function of break torque for two rotational speeds of engine



a) 2000 rpm b) 2500 rpm

Fig. 7. Content of HC [vol.%] in function of break torque for two rotational speeds of engine



a) 2000 rpm *b) 2500 rpm*

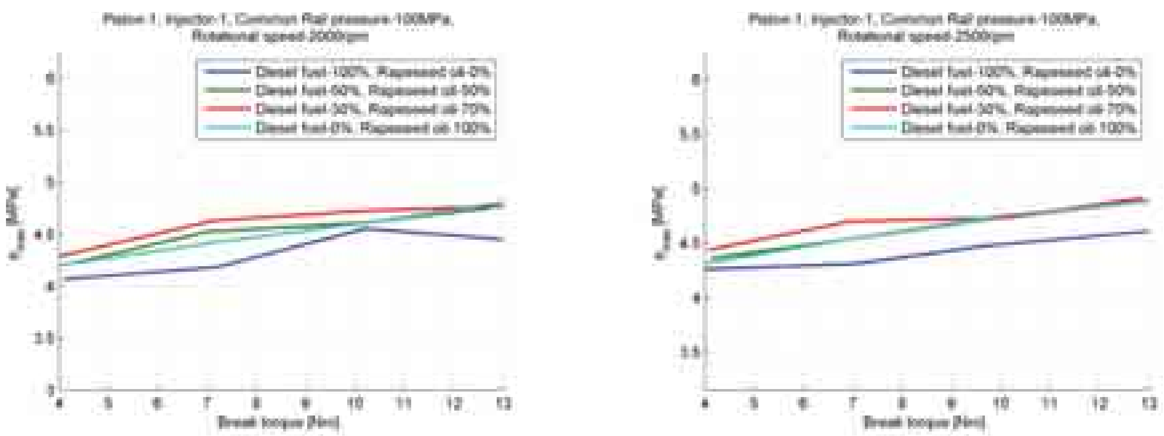
Fig. 8. Content of NO_x [ppm] in function of break torque for two rotational speeds of engine

3.2. Common Rail fuel pressure 100 MPa

The results obtained for higher pressure in Common Rail fuel injection system equal to 100 MPa are presented in Fig. 9-14.

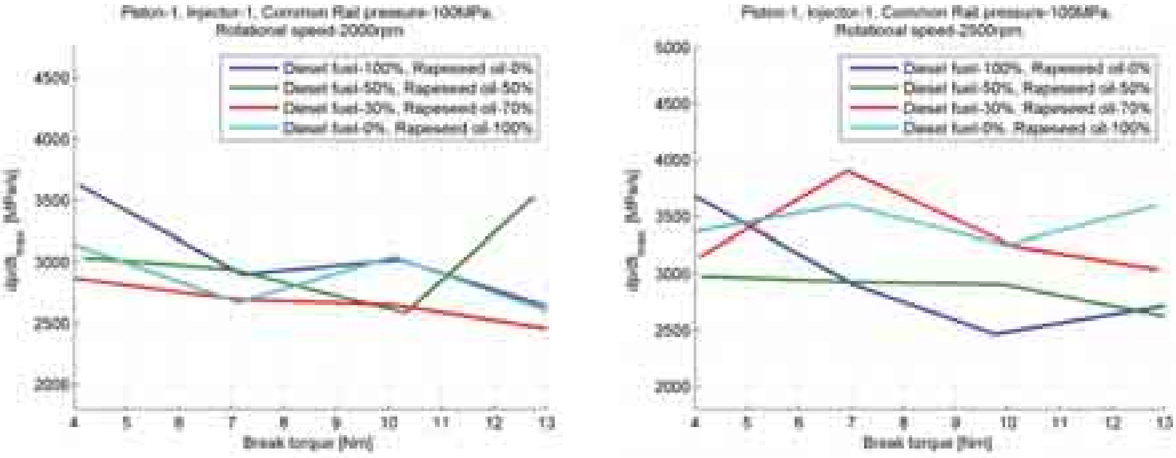
Fig.9 presents maximal pressure in the cylinder in function of torque for four tested fuels and for two tested rotational speeds of the engine. Comparison of the graphs in Fig. 9 with those shown in Fig.3 shows, that general conclusions are very similar. It can be seen, that for highest Common Rail system pressure the highest values of the maximal pressure were also obtained for mixture containing 30% of Diesel fuel and the lowest for pure Diesel fuel. The maximal values of pressure for mixture of 50% of Diesel fuel and 50% of rapeseed oil are very similar to those obtained with pure rapeseed oil. It can also seen that in the range of tested torques the increase of the Common Rail system pressure resulted in higher maximal pressure in the cylinder.

The maximal pressure rise rates in function of the torque for various fuels are presented in Fig.10. Increase of the fuel pressure in the Common rail system caused increase of the pressure rise rates as it can be seen by comparing Fig.10 with Fig.4. It can be found on graphs in Fig.10, that the influence of the mixture content on the maximal pressure rise rates depends on the speed of rotation. For lower value of the rotational speed the highest values were generally obtained for pure Diesel and only for torque equal to 13 Nm the highest value was obtained for mixture of 50% of Diesel fuel and 50% of rapeseed oil. For higher rotational speed the highest pressure rise rates were obtained for pure rapeseed oil, mixture of 30% of Diesel oil and 70% of rapeseed oil or for pure Diesel fuel, depending on the torque. Higher value of the Common Rail system pressure also resulted in smaller differences of the maximal values of the pressure rise rate for various fuels



a) 2000 rpm *b) 2500 rpm*

Fig. 9. Maximal pressure inside the cylinder in function ofbreak torque for two rotational speeds of engine

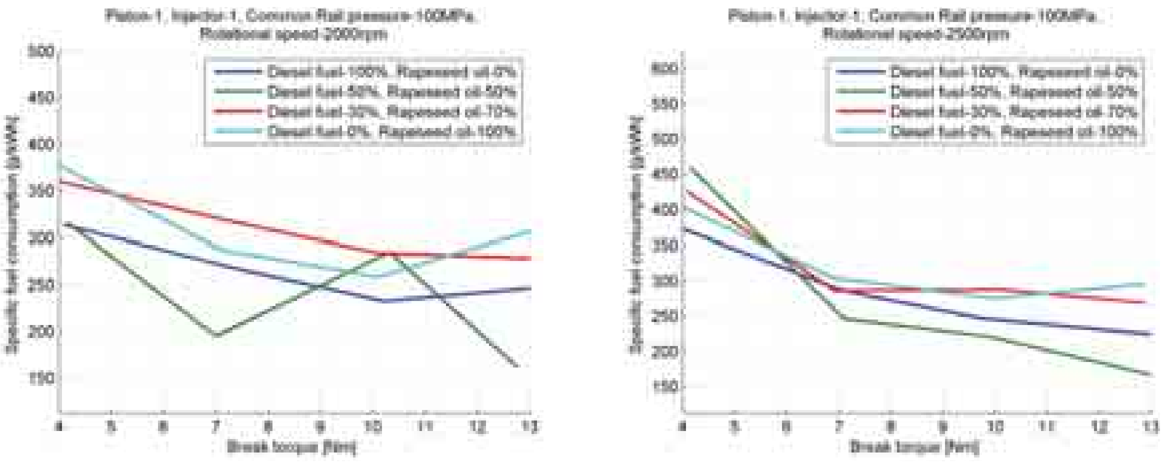


a) 2000 rpm *b) 2500 rpm*

Fig. 10. Maximal rate of pressure rise in function of break torque for two rotational speeds of engine

Figure 11. presents influence of the torque, the mixture of the fuel content and the rotational speed on the specific fuel consumption. In the case of elevated pressure of the Common Rail system, the specific fuel consumption is lower than for lower value of the pressure. It can be seen in Fig.11 that the highest specific fuel consumption was observed for mixture of 30% of Diesel fuel and 70% of rapeseed oil for most of tested torques and both rotational speeds. The minimal values were observed for mixture containing 50% of Diesel fuel in most of the conducted tests. The specific consumption for pure Diesel fuel was lower than for pure rapeseed oil.

Figure 14. presents volume fraction of NO_x in exhaust gases, measured for various fuels, different torques and two values of rotational speed. The general conclusions are very similar to those withdrawn for lower value of the Common Rail system: the maximal emissions were registered for the mixture of 30% of Diesel fuel and 70% of rapeseed oil. Comparison of the graphs in Fig.14. with those in Fig.8 shows, that the increase of the pressure of fuel in injection system resulted in slight increase of NO_x emission for all tested torques and for both rotational speeds.

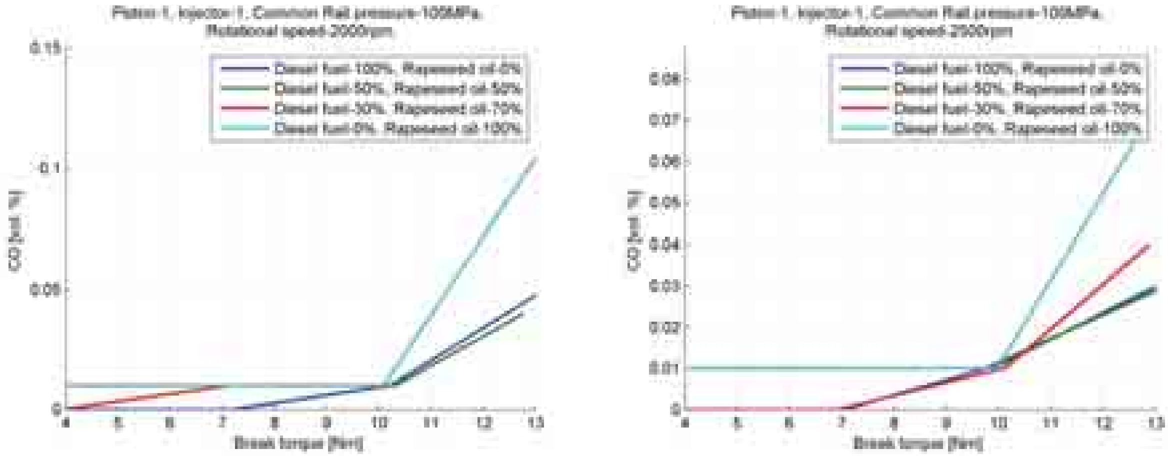


a) 2000 rpm *b) 2500 rpm*

Fig. 11. Specific fuel consumption in function of break torque for two rotational speeds of engine

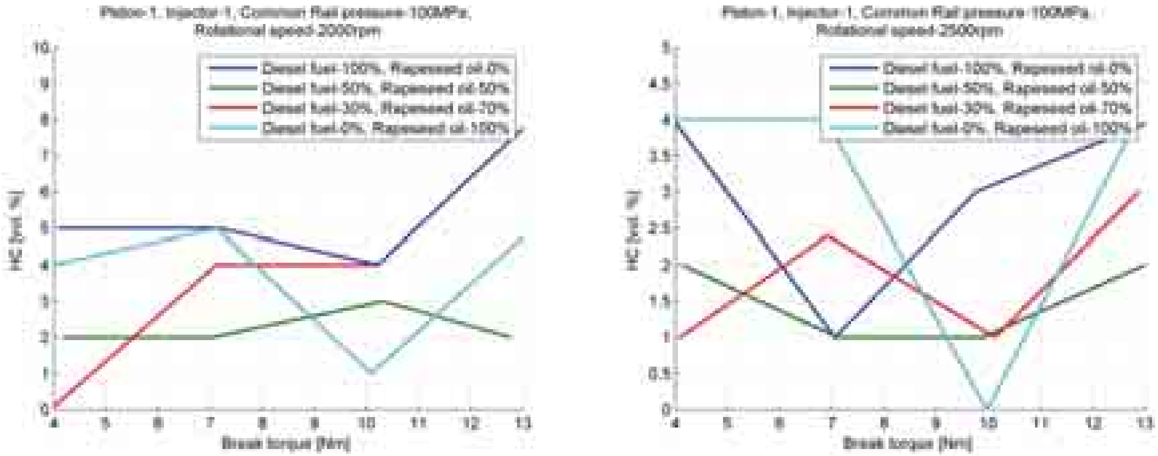
3.3. Common Rail fuel pressure 150 MPa

The results of the tests conducted with the Common Rail system pressure elevated to maximal value used in the research, equal to 150 MPa, are presented in Fig.15-20. The maximal cylinder pressure in function of the torque and mixture composition is presented in Fig. 15. As it can be seen in the figure, the highest values of the pressure were obtained for pure rapeseed oil for lower rotational speed and for mixture of 30% of Diesel fuel and 70% of rapeseed oil for higher rotational speed. This observation differs from those for lower pressures in the Common Rail system, where the highest values were usually obtained for mixture containing 30% of Diesel fuel. The lowest values were obtained for pure Diesel fuel, what agrees with previously presented results.



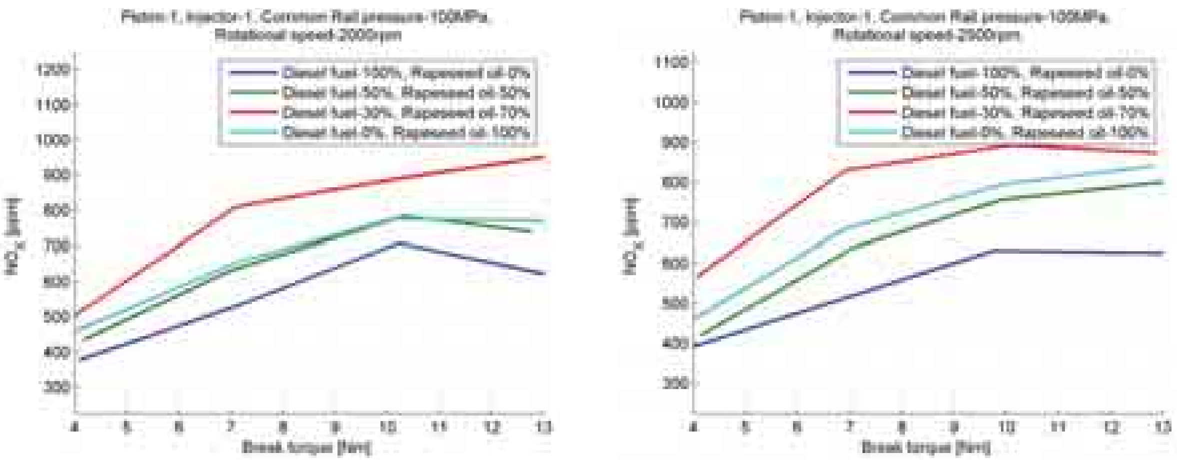
a) 2000 rpm b) 2500 rpm

Fig. 12. Content of CO [vol.%] in function of break torque for two rotational speeds of engine



a) 2000 rpm b) 2500 rpm

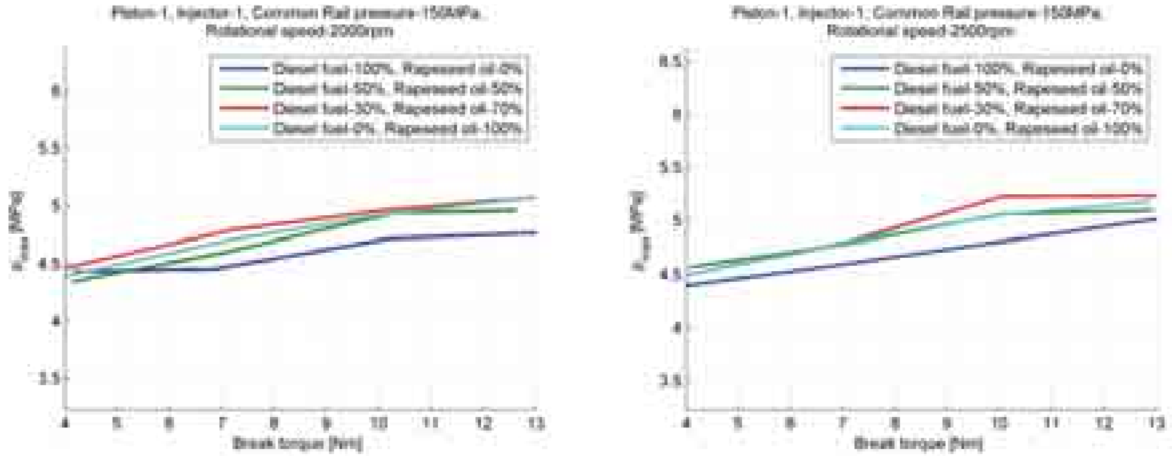
Fig. 13. Content of HC [vol.%] in function of break torque for two rotational speeds of engine



a) 2000 rpm b) 2500 rpm

Fig. 14. Content of NO_x [ppm] in function of break torque for two rotational speeds of engine

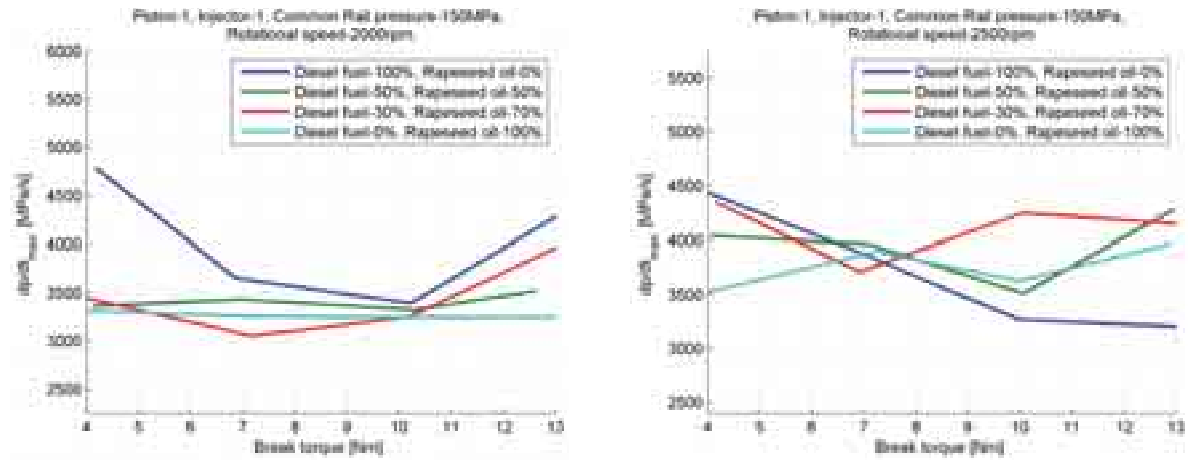
Comparison of the graphs in Fig. 3, Fig. 9 and Fig. 15 shows that increase of the Common Rail system pressure causes smaller impact of the fuel mixture composition on the maximal pressure in the cylinder. For 150 MPa the maximal difference of the pressure was in order of 11% (rotational speed 2000 rpm, torque 13 Nm) and for 50 MPa the difference was in order of 13.5%.



a) 2000 rpm *b) 2500 rpm*

Fig. 15. Maximal pressure inside the cylinder in function ofbreak torque for two rotational speeds of engine

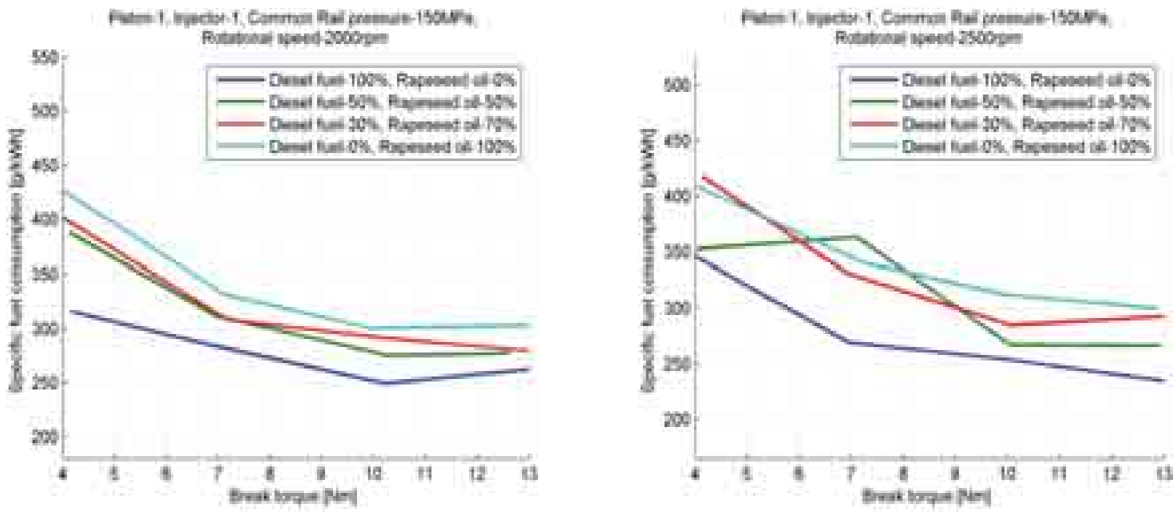
Figure 16 presents maximal pressure rise rate as a function of the torque and the mixture composition. It can be concluded that influence of the mixture composition depends on the torque and the rotational speed of the engine. Comparing the figure with Fig.4 and Fig.10 it can be found, that increase of the Common Rail system pressure results in smaller influence of the mixture composition on the maximal pressure rise rates. In case of the Common Rail system pressure equal to 150 MPa the maximal difference between various fuels is in order of 33% (rotational speed 2000 rpm, torque 13 Nm), while in case of 50 MPa it was even 100%, as it was mentioned above.



a) 2000 rpm *b) 2500 rpm*

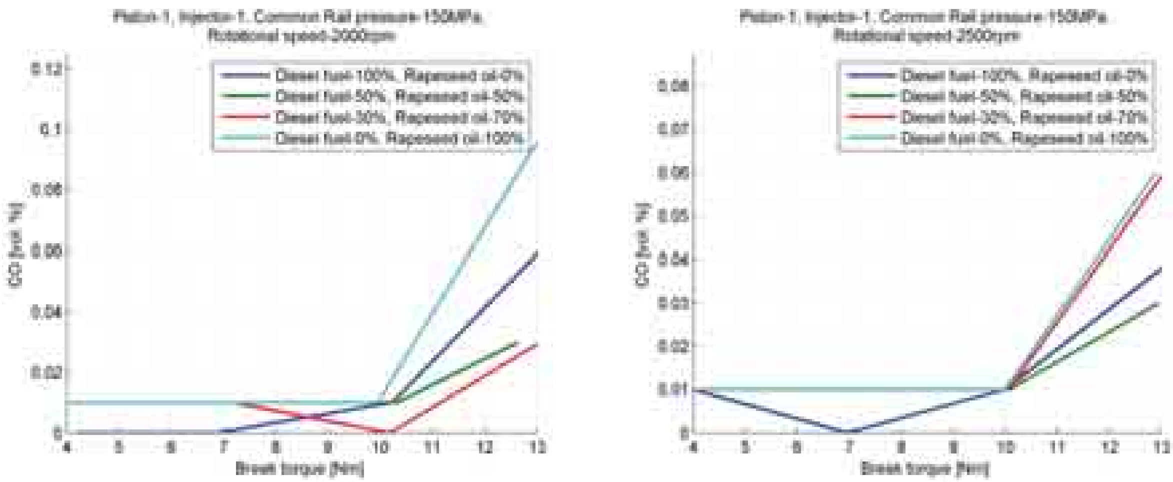
Fig. 16 Maximal rate of pressure rise in function of break torque for two rotational speeds of engine

The next graphs, presented in Fig. 17, shows influence of the torque and mixture composition on the specific fuel consumption. As it can be seen, the highest specific fuel consumption was registered for pure rapeseed oil. The result is very similar to that obtained for lower Common Rail system pressure, equal to 50 MPa (Fig. 5). It can be also seen that in this case the correlation between the specific fuel consumption and the fuel composition is clear and monotonic for most of the torques and both rotational speeds: the increase of Diesel fuel content in the mixture results in lower specific fuel consumption.



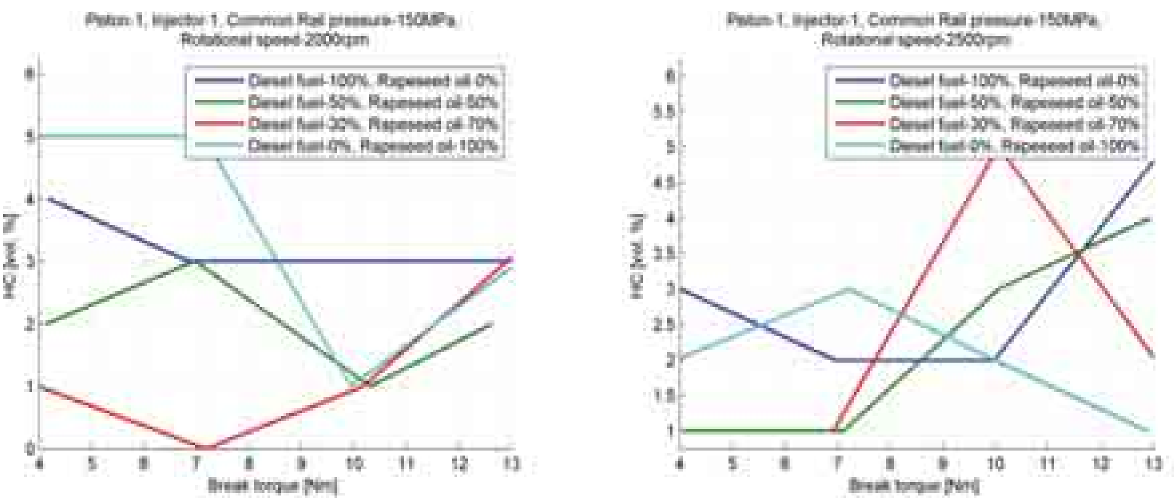
a) 2000 rpm *b) 2500 rpm*

Fig. 17. Specific fuel consumption in function of break torque for two rotational speeds of engine



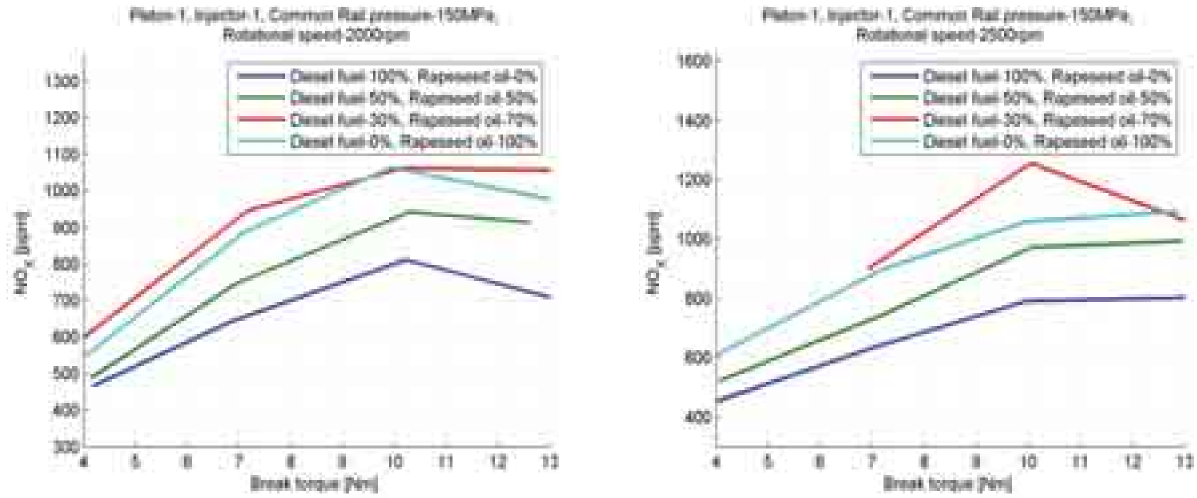
a) 2000 rpm *b) 2500 rpm*

Fig. 18. Content of CO [vol.%] in function of break torque for two rotational speeds of engine



a) 2000 rpm *b) 2500 rpm*

Fig. 19. Content of HC [vol.%] in function of break torque for two rotational speeds of engine



a) 2000 rpm *b) 2500 rpm*

Fig. 20. Content of NO_x [ppm] in function of break torque for two rotational speeds of engine

Figure 14. presents volume fraction of NO_x measured for various fuels, different torques and two values of rotational speed. Comparison of Fig. 20 with Fig. 14 and Fig. 8 reveals that general conclusions are very similar to those withdrawn for lower values of the Common Rail system: the maximal emissions were registered for the mixture of 30% of Diesel fuel and 70% of rapeseed oil. Comparison of the graphs on Fig. 8, 14 and 20 also shows that the increase of the pressure of fuel in injection system resulted in slight increase of NO_x emission for all tested torques and for both rotational speeds.

4. Conclusions

The results of the experimental investigation into influence of the fuel, being various mixture of Diesel fuel and rape seed oil, on parameters of work of CR Diesel engine are presented in the paper. From the results of the research presented above following conclusions can be withdrawn:

– the maximal pressure in the cylinder increases with increase of CR fuel pressure and
– the differences between maximal pressure inside the cylinder for various fuels are decreasing with increase of the CR fuel pressure. The highest values of the maximal pressure were obtained for mixture of 30% of Diesel fuel and 70% of rape seed oil for most of the test parameters configurations,
– the maximal rate of pressure rise is increasing with increase of the CR fuel pressure. The influence of the fuel on the maximal pressure rise rate depends on the CR fuel pressure and requires further research,
– specific fuel consumption depends on the fuel. The minimal values were obtained for mixture of 50% of Diesel fuel and 50% of rape seed oil for most of the cases. For the highest value of CR fuel pressure, equal to 150 MPa, the lowest specific fuel consumption was obtained for pure Diesel fuel but within the mixtures it was obtained again for mixture of 50% of Diesel fuel and 50% of rape seed oil,
– the highest NO_x emission was registered for mixture of 30% of Diesel fuel and 70% of rape seed oil,
– influence of the fuel on the contents of CO and HC depends strongly on the parameters of the test and requires further research,
– the influence of rapeseed oil content in the mixture with Diesel fuel on the parameters of work of the engine is not monotonic and requires further research, both experimental and theoretical.

References

[1] Kossowicz, L., Skręt, L., *Podstawowe problemy jakości olejów napędowych*, materiały seminarium Polski Przemysł Rafineryjnych 2000, Płock 1997.
[2] Kozaczewski, W., *Wpływ paliw na emisję składników spalin*, Journal of KONES, 1995.
[3] Kasendorf, J., *Zasilanie wtryskowe olejem napędowym*, WKiŁ, Warszawa 1990,
[4] Szczawińska, M., *Paliwa silnikowe,* Paliwa, Oleje i Smary w Eksploatacji 5, 6 i 7, 1993.
[5] Bocheński, C., *Biodiesel – paliwo rolnicze*, Wydawnictwo SGGW, Warszawa 2003.
[6] Głąb, J., Kaźmierczak, U., Kulczycki, A., *Rozwój paliw silnikowych w krajach Unii Europejskiej i w Polsce*, Eksploatacja i Niezawodność 5, 2000.
[7] Górski, W., *Stan aktualny, potrzeby i perspektywy w zakresie normalizacji biopaliw*, Paliwa, Oleje i Smary w Eksploatacji 10, 2002.
[8] Sitnik, L., *Ekopaliwa silnikowe*, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2004.
[9] Podkówka, W., *Rzepak jako surowiec do produkcji biodiesla i pasz*, Nowoczesne technologie w rolnictwie, materiały konferencyjne, Łódź 2002.
[10] Bocheńska, A., Bocheński, C., Oleszczak, P., *The Appraisal of the Combustion Process in the Research Chamber for the Rapeseed Oil and Gasoline Mixtures*, KONES Powertrain and Transport, Warsaw 2008.
[11] Bochenski, C. I., Oleszczak, P., Siwiec, S., *Research on Gas Oil and Rape Oil Methyl Esters Sprayed in Constant Volume Chamber*, Journal of KONES Internal Combustion Engines, Vol. 11, No. 1-2, 2004.