Comparison of parameters and composition of exhaust fumes of engine fuelled by rapeseed oil and its mixtures with diesel and gasoline

K Tucki1,*, A Bączyk1, M Klimkiewicz1, J Mączyńska1, M Sikora1

1 Warsaw University of Life Sciences, 166 Nowoursynowska St., 02-787 Warsaw, Poland

E-mail: karol_tucki@sggw.pl

Abstract. The paper presents results of testing of fuelling a Farymann 18W engine by diesel oil (ON), rapeseed oil (ORZ) and their mixtures (30%ON + 70%ORZ, 50%ON + 50%ORZ, 85%ORZ + 15%BEN). The tests were carried out in conditions determined for specific speeds of the crankshaft (2000 and 2500 min⁻¹). To allow an ecological review of the engine a presentation was made of test results pertaining to emission of toxic exhaust gas components (THC, CO, NOx), greenhouse gases (CO2), and a comparison was performed of values of unit fuel consumption and exhaust gas smoking. The studies indicate that the use of rapeseed oil causes the increase of exhaust gas smoking and increased fuel consumption. The addition of rapeseed oil or kerosene to diesel oil leads to increasing the emission of THC, CO, CO₂ and a decrease of the NOₓ emission.

1. Introduction

Presently to reduce the amounts of toxic compounds and greenhouse gases formed during the fuel combustion process, increasingly frequently substitutes of diesel oil or biocomponents are sought, which may help improve ecological fuel indices. This is also one of the elements of the adopted climate and energy policy of the European Union, which is oriented at reducing the dependence on conventional fuels (import) and reductions of greenhouse gas emissions [1]. In the paper the authors focus on the use of rapeseed oil, including its mixtures. Studies on the use of rapeseed oil as fuel and its impact on operation of compression-ignition engines have already been commenced in Poland in the 1990s [2-5]. However, further analyses concerning changes of engine operation indices, the wear of its parts and the determination of optimum parameters of their operation are still being performed [6-10]. Over the past few years we have been observing a clear trend of reducing usage of non-renewable fuels for fuelling vehicles, which arises from numerous economic and social factors, as well as changes of the market trend of promoting solutions that are ineffective with respect to energy and energy-consuming [11]. All the same it should be borne in mind that adding biocomponent admixtures to conventional fuels appears to be only a solution of a transitional nature [12], which could be advantageous merely within a short-term perspective.

The objective of the paper was to identify parameters and toxicity of exhaust gases related to operation of a compression ignition engine fuelled by different types of fuels.
2. Methodology of analysis execution

The studies comprised an appraisal of fuelling a Farymann type 18W diesel engine with direct fuel injection operating at the engine rotational speed of n=2000 min⁻¹ and n=2500 min⁻¹. The engine was propelled by diesel oil (ON), rapeseed oil (ORZ) and mixtures: 30%ON + 70%ORZ, 50%ON + 50%ORZ and mixture with petrol (BEN): 85%ORZ + 15%BEN.

The tests were executed on a measurement stand with the use of an electrical break (type AFA-130/4-8 EU), digital meter of rotational speed, torque measure shafts (type T10F manufactured by HBM) and an opacimeter (AVL type 439). Measurements of toxic components of exhaust gases were performed using measuring appliances consistent with EU/ECE Regulation 49. Components of exhaust gases (CO, CO₂, THC, NOₓ), were measured using AVL type CEB II measuring appliances: heated THC analyser and analyser of nitrogen oxides, carbon oxide and carbon dioxide analyser.

Prior to the execution of the experiment it was assumed that in the fuel system an increase of resistance of fuel flows would be taking place due to the greater viscosity of rapeseed oil (0.913 g/cm³) than diesel oil (0.833 g/cm³). To avoid this a heat exchanger was furnished in the fuel system (heated with water from the engine cooling system), which heated fuel at the inlet to the engine. Heat exchanges was applied to fuel mixtures containing rapeseed oil.

The course of fuel consumption during the tests was determined on the basis of the standard PN-EN ISO 8178-1, while values of concentrations of exhaust gas component flow were determined with the use of theoretic concentrations of air flow sucked in by the engine.

Load characteristics executed during the analyses were completed at the time when smoking of exhaust gases achieved the value of ca. 4 m⁻¹. For this reason also the last item of the characteristics does not end in each case at the time of full opening of the lever that controls the injection pump (ALPHA=100%).

3. Results

The engine fuelled by rapeseed oil consumed more fuel than in the case of diesel oil. This was caused by the biggest density of rapeseed oil, and consequently its lower calorific value.

The addition of rapeseed oil to diesel oil leads to an increase in the emission of tested factors. According to the analysis the CO₂ concentration grew on average by ca. 7%, and the concentrations of CO and THC by ca. 100%. Only emissions of NOₓ were by 10-25% lower (figure 1 and figure 2).
Figure 1. Load characteristics of engine $n = 2000^{\text{1}}$. All abbreviations of fuels are adequately explained in the text.
If the mass share of carbon in the rapeseed oil particle is known, a reduction of CO₂ emission in the tested exhaust gases could have been expected. However, the value of carbon dioxide value in standard conditions is significantly affected by two elements: (1) bigger fuel consumption caused by lower calorific value of rapeseed oil, (2) lower engine performance caused by slowing down of the heat generation process. To obtain the same power of rapeseed oil as in the case of diesel oil, it is necessary to inject more fuel into the cylinder, as an effect of which the CO₂ concentration in exhaust gases grows.
The usage of rapeseed oil caused an increase in exhaust gas temperature of the tested engine by an average of ca. 30°C. As regards an engine with rotations at the level of 2000 min\(^{-1}\) (figure 3), the highest combustion temperature was recorded for the mixture of rapeseed oil and kerosene (ca. 60°C as compared to 30°C of diesel oil and ca. 40°C for rapeseed oil).

**Figure 3.** Load characteristics of engine (2) n = 2000\(^{-1}\).
All abbreviations of fuels are adequately explained in the text.
In the second case (figure 4) the temperature of rapeseed oil (ca. 80°C) was over twice higher than the one of diesel oil (ca. 30°C). This means that the combustion process of this fuel has been extended in relation to operation with the use of diesel oil. This phenomenon may be explained by a lower value of the cetane number, and consequently also the longer delay time of self-ignition that characterises rapeseed oil and kerosene.

Figure 4. Load characteristics of engine (2) n = 2500 rpm.
All abbreviations of fuels are adequately explained in the text.
The course of emission characteristics (figure 1 and figure 3) and the increase of exhaust gas temperature if rapeseed oil is used indicate that in the studied engine a delayed process of heat generation takes place. To improve the functioning of this engine it would be recommended to increase the angle of injection advance of ignition for rapeseed oil or addition to fuel of additional agents to increase the cetane number, which hasten the process of fuel components oxidising. Transitional means for hastening combustion in the cylinder (such as increasing the angle of injection advance, or increasing the opening pressure of the injector), were impossible to apply in the analysed engine for technical reasons. A change of the injector situation (increasing the angle of injection advance) would surely improve the effectiveness of engine operation, which in turn would lead to reduced fuel consumption and CO₂ emission. Yet this would most likely case an increase of NOₓ emission (as a derivative of increasing the maximum circuit temperature) and increasing of CO and THC emission as a result of lowering the exhaust gas temperature.

The value of NOₓ emission in engines with direct fuel injection depends on the phase of kinetic combustion (first phase of combustion process). Its sequence determines to a large extent the maximum circuit temperature of engine operation. The course of the latter one is affected first of all by the quality of fuel spray and the quality of its mixture with air [12].

While making an analysis of results related to fuel consumption it should be borne in mind that at the rotational speed of 2000 min⁻¹ a bigger difference occurs of fuel consumption between rapeseed oil and diesel oil than at the speed of 2500 min⁻¹. Concurrently at the speed of 2000 min⁻¹ there is a noticeably bigger disparity between NOₓ concentrations and emissions than at the speed of 2500 min⁻¹. Consequently it may be presumed that at the speed of 2500 min⁻¹ the rate of heat generation in the case of diesel oil and rapeseed oil is similar, while at the speed of 2000 min⁻¹ characteristics of heat generation for both fuels differ. Most likely this situation arises from inferior fuel vaporisation and insufficient load turbulence inside the cylinder at lower rotational speeds (2000 min⁻¹) as compared to requirements of rapeseed oil.

To hasten the combustion process, 15% of kerosene were added to rapeseed oil. Taking into account its properties, kerosene should evaporate quicker in conditions prevailing inside the cylinder during fuel injection, and as an effect cause acceleration of heat generation, especially in the first phase of combustion. The conducted analyses confirm this phenomenon (figure 1 and figure 2). Recorded was a significant decrease in the emission of CO and CO₂ and of fuel consumption as a result of adding kerosene to rapeseed oil. Unfortunately the emission value of THC, CO and CO₂ are less advantageous as compared to values obtained for diesel oil.

4. Conclusions
The executed studies allow drawing the following conclusions:

- Parameters of selected fuels depend on physical and chemical properties and on structural and operational factors of engines [12].
- The use of rapeseed oil in a diesel engine causes an increase in fuel consumption by the engine from 6 to 13% [13, 14].
- Diesel oil with the addition of rapeseed oil or kerosene causes an increase of CO, CO₂, THC emission and a decreased emission of NOₓ [6,15,16].
- Characteristics of an engine fuelled by a mixture of fuels (30%ON + 70%ORZ, 50%ON + 50%ORZ, 85%ORZ + 15%BEN) remain between values obtained for diesel oil and pure rapeseed oil.
- There is a need for further execution and implementation of tests related to optimising the angle of injection advance for rapeseed fuels to achieve more advantageous operating parameters of engines.

Currently increasingly frequently the trend may be ascertained of withdrawing from diverse types of biodiesels, among others due to adverse effects of this fuel, not only on injection appliances, but also on engine performance [17]. The second factor that causes changes in selection of low-emission fuels are amendments to European regulations which point to new development directions of biofuels. The EU legislation gradually limits (until 2020) the production of first generation fuels and concurrently promotes an increase in the importance of advanced fuels.
References

[1] Kruczyński S, Orliński S and Gis M 2016 Trans. Samoch. 2 95-110
[2] Cisek J 1998 Wpływ oleju rzepakowego i jego mieszanin z olejem napędowym na własności silnika wysokoprężnego (doctoral thesis, Kraków: Cracow University of Technology)
[3] Lotko W 1997 Zasilanie silników wysokoprężnych paliwami węglowodorowymi i roślinnymi (Warszawa: WNT)
[4] Lotko W and Adamczyk A 1990 Auto-Tech. Moto. 11
[5] Lotko W and Luft S 1995 Auto-Tech. Moto. 2
[6] Pasyniuk P and Golimowski W 2011 J. Res. Appl. Agric. Engng. 56 118-21
[7] Klimkiewicz M, Błaszczuk K, Mruk R and Tucki K 2013 Inż. Rol. 143 113-21
[8] Pasyniuk P 2013 Wpływ zasilania silników plejem roślinnym na parametry eksploatacyjne ciągników rolniczych (Falenty: Wyd. ITP)
[9] Kruczyński S, Orliński S, Fudalej-Kostrzewa E and Gis M 2016 Trans. Samoch. 2 81-93
[10] Szczypiński-Sala W 2012 Czas. Tech. Mech. 8 209-18
[11] Directive (EU) 2015/1513 of the European Parliament and of the Council of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources (L 239, 15.9.2015)
[12] Stobnicki P 2013 Badawcza analiza wtrysku paliwa w aspektie właściwości ekologicznych silnika o zapłonie samoczynnym (doctoral thesis, Poznań: Poznań University of Technology)
[13] Czaban J, Szpica D, Weresa E and Banaszuk P 2015 Comb. Engin. 162 335-40
[14] Szpica D, Czaban J, Weresa E and Banaszuk P 2015 Comb. Engin. 162 548-55
[15] Ashraful A M, Masjuki H H, Kalam M A, Rizwanul Fattah I M., Intenan S, Shahir S A and Mobarak H M 2014 Energ. Convers. Manage. 80 202-28
[16] Buyukkaya E, Soyhan H S and Gokalp B 2014 Int. J. Energ. 14 101-24
[17] Suchecki A and Nowakowski J 2016 Autobusy 6 1148-54