Int. Agrophysics, 2008, 22, 179-183

INTERNATIONAL
Agrophysics
www.international-agrophysics.org

Influence of FAME addition to diesel fuel on exhaust fumes opacity of diesel engine

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Received November 28, 2007; accepted March 7, 2008

A b s t r a c t. The work presents the results of research on the influence of the addition of rapeseed oil fatty acid methyl esters (FAME) to diesel oil, in the quantity of 1-5% by volume, on exhaust fumes opacity of a diesel engine powered by such fuel. The research employed rapeseed oil FAME the additive. The results obtained proved that the use of FAME and methyl esters as an additive to diesel fuel (DF) in the quantity of 5% causes a reduction of exhaust fumes opacity of diesel engine.

K e y w o r d s: biofuel, biodiesel, exhaust fumes opacity, emission

INTRODUCTION

The threat posed to natural environment by toxicity of exhaust gasses emitted by internal combustion engines is an important issue, especially when emission of harmful substances from engines used in agriculture, and therefore a threat to agricultural environment, is taken into consideration.

A majority of tractors and self-propelled machines employ self-ignition diesel engines, thus, agriculture is greatly dependent on diesel fuel produced from processed petroleum. This follows from the fact that diesel engines are energetically the most efficient engines among all in use.

Growing petroleum consumption causes an increase in the emission of energetic gases that play a major role in the creation of the greenhouse effect, and it also poses other serious threats to the natural environment. The toxic compounds emitted by self-ignition engines are mostly nitrogen oxides, NO_X, unburned hydrocarbons, HC, carbon oxide, CO, but foremost particulate matters, PM (Baczewski and Kałdoński, 2004; Merkisz *et al*., 2005).

The term particulate matter usually denotes soot particles with all the other particles they contain. They are by far more carcinogenic than other harmful components of exhaust gases *eg* polycyclic aromatic hydrocarbons at a comparable emission level. Due to their microscopic sizes, the above compounds easily migrate into the atmosphere or the human organism (in the process of breathing). They are extremely dangerous on account of their small dimensions, as when they become deeply rooted in the lung tissue they are virtually irremovable.

New propelling units allow lowering of the content of harmful components in exhaust emissions, which has been possible thanks to improvement in fuel quality, engine design modifications, and the use of catalysts and filters in exhaust systems (Baczewski and Kałdoński, 2004).

In Poland, however, old and much-used tractors still prevail. They pose a far greater threat to the environment. Using fatty acid methyl esters (FAME) of plant oil as fuel is a viable way of reducing the amount of harmful components of exhaust emission (Wawrzosek and Piekarski, 2006; Vellguth, 1983). FAME of rapeseed oil are used most commonly in Poland; such fuel may be used as autonomous fuel or in a blend with diesel fuel (DF). However, when judging the usefulness of FAME as fuel or as DF component, a vital question rises with respect to their practical characteristics which can influence both engine operation and FAME reaction to the conditions of storage and distribution. Despite the fact that 10-year-long experience has shown that it is possible to use the esters without much trouble both in the case of new and second-hand machines, many tractor producers still enforce warranty limitations on the users (Szlachta, 2002; Tys *et al.*, 2003; Williamson and Badr, 1998). The majority of producers permit only a 5% share of FAME in fuel. Such proportion of the esters grants adherence to the fuel regulations and has no influence on the technical condition of the engine. There is yet another

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argument in favour of such proportion, namely, limited production will not allow FAME to play a major role as a substitute for DF (Duda *et al*., 2002; Graboski and McCormick, 1998; Jakóbiec, 2006; Piekarski and Zając, 2003).

Due to the above, this work tries to evaluate the influence of the addition of FAME into DF in the amount of 5% on selected ecological parameters of an engine powered by such fuel.

MATERIAL AND METHODS

The objects of the research were blends of mineral diesel fuel with rapeseed oil fatty acid methyl esters, of ester content of 1, 2, 3, 4, and 5% by volume. The blends were prepared from commercial diesel fuel (DF) – Ekodiesel Ultra F – and rapeseed oil fatty acid methyl ester (FAME) from an industrial installation.

Ekodiesel Ultra F is a low-sulphur fuel with characteristically high combustion index and high Cetane number. This fuel adheres to the requirements of the standard PN-EN 590 "Automotive fuels – Diesel – Requirements and test methods".

Methyl esters used in the research were tested for their consistency with the standard PN-EN 14214 "Automotive fuels. FAME for diesel engines – Requirements and test methods".

The esters were blended with diesel fuel establishing the right voluminal proportions for the blends, thanks to which the fuels of the following composition and marking were obtained:

B1 – 1% FAME, 99% DF blend;
B2 – 2% FAME, 98% DF blend;
B3 – 3% FAME, 97% DF blend;
B4 – 4% FAME, 96% DF blend;
B5 – 5% FAME, 95% DF blend.

In order to determine their ecological parameters, the above blends were tested physicochemically in an accredited laboratory and used for powering a 2CA90 engine on a dynamometric bench.

Resulting from the fact that sufficiently simple, cheap and quick methods for the determination of the level of particulate matter emission have not yet been devised, the determination of exhaust fumes opacity is performed in its place or as its supplement. Despite the fact that fumes opacity determinations do not reflect the emission of particulate matter, and that they only determine the soot content in exhaust emission, they have found their use thanks to the ease of performance of such tests and less complicated design of the measuring apparatus alone (Merkisz *et al.*, 2005).

The determination of exhaust fumes opacity was performed on the test bench of the research laboratory of the Department of Power Engineering and Vehicles of the University of Agriculture in Lublin . The test bench included the following components:

– diesel engine, 2CA90;
– electro whirl brake, AMX 210;
– control and measurement system, AMX 201, AMX 211;
– exhaust fumes opacity measurement system fumes adsorption meter, MDO 2;
– environment measurement system: ambient temperature t_{ot}, atmospheric pressure and air humidity φ.

A diagram of the test bench with the particular component elements is shown in Fig. 1.

The determinations of exhaust fumes opacity were performed following proper adjustments for each of the tested fuels. Parameters that were necessary for processing the data indispensable for plotting the engine load characteristics were registered in the research. The characteristics were plotted for the following two engine speeds: $n_{Momax} = 2250$ r min^{-1} that corresponded to the maximum torque speed, and n_{Nemax} = 3000 r min^{-1} that corresponded to the maximum engine

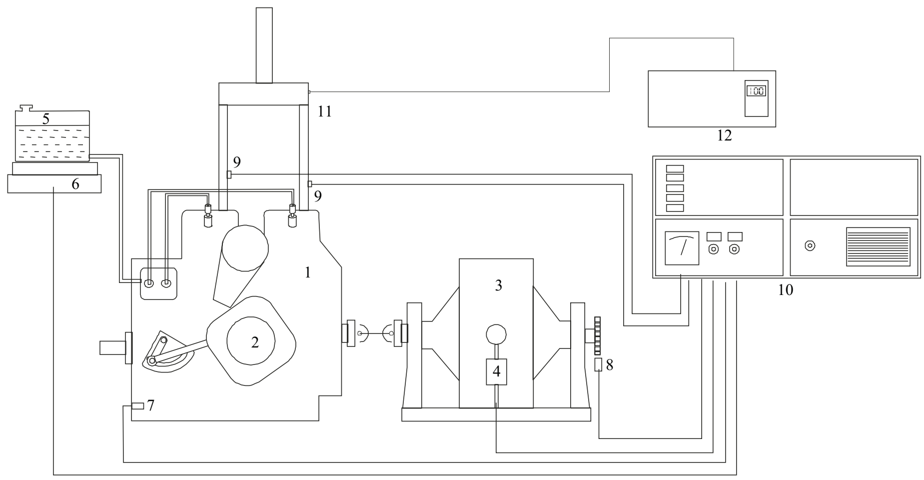

Fig. 1. Test bench diagram: 1 – 2CA90 engine, 2 – engine control, 3 – AMX 210 electro whirl brake, 4 – tensometer, 5 – fuel tank, 6 – scales for measuring fuel consumption, 7 – diesel fuel temperature sensor, 8 – engine speed sensor, 9 – exhaust emission temperature sensor, 10 – control measurement panel, 11 – exhaust emission intake probe, 12 – MAHA MDO-2 fumes meter.

power. The determinations were performed after the temperature conditions of the engine had been established, and after the measurement of both atmospheric pressure and air temperature. The engine load was increased by 5 Nm for the constant rotational speed that had been adopted, which resulted in obtaining 10 measurement points for the speed n_{Momax} and 9 measurement points for the speed n_{Nemax}. Exhaust fumes opacity was registered after stabilising the working conditions for each of the points. Exhaust emission samples for the exhaust fumes opacity measurement were collected at the outlet of the exhaust manifold for each point of measurement of engine load characteristics. MDO 2 absorption fumes meter was employed in order to determine the opacity of exhaust fumes. It is a device that meets the requirements of international standards as described, among others, by ECE 24, ISO 3173 and ISO (TC 22) SC 5 N650. The phenomenon of photometric absorption provides the basis for the operation of the fumes meter. The measurement system of the device consists of a measurement cell and a light source and a receiver of light radiation located at both ends of the measurement cell. Light radiation that is generated by a high-brightness diode is put through the measurement cell containing exhaust fumes. During the determination, the radiation emitted by the source does not reach the receiver at such an intensity as in the case of measurement cell filled with pure air. The part of the radiation that is not absorbed by the exhaust fumes falls onto the photocell, thus being converted into a voltage signal. The comparison of results obtained for both cells provides information on exhaust fumes opacity and enables indirect and approximate estimation of particulate matter content. The applied light wave-length of the fumes meter was 567 nm and it had been carefully selected in order to match the absorbing power of the exhaust fumes.

The statistical analysis included determination of functional relations with the use of multiple regression analysis. Regression equations were derived for the relations between the tested index and the speeds, and their corresponding indexes that determined the level of adjustment of the curves. All statistical calculations were performed with the use of Excel and Statistica programs.

RESULTS AND DISCUSSION

The influence of the kind of fuel on the ecological parameters was determined according to the results of exhaust fumes opacity tests in the function of engine speed for the tested blends of fuel on the engine load characteristics carried out in two ranges of engine speed. The changes were referred to the working points of the DF engine. In order to facilitate the test result analysis, the test results were presented in their relative form *ie* the absolute values of the measured values for the fuel blends were referred to the proper values for the reference fuel, that is diesel oil. The points of reference were engine loads graded at every 25% of the power value *ie* 25, 50, 75, and 100%.

The test results, in the form of engine load characteristics presenting the relation between exhaust fumes opacity characterised by the light adsorption factor k in the function of power produced, performed for two engine speeds are presented correspondingly for the speed $n = 2250$ r min^{-1} in Fig. 2a, and for the speed $n = 3000$ r min^{-1} in Fig. 2b.

The analysis of test results proved that an addition of FAME to diesel oil changes diesel exhaust fumes opacity. When analysing the level of exhaust fumes opacity, in the function of power produced, one can observe a significant increase of fumes opacity Z_{sp} along with the increase of engine load. The value of fumes opacity Z_{sp} for engine speed of 2250 r min^{-1} was higher than for the speed of 3000 r min^{-1}. The addition of the biocomponent results in a reduction of exhaust fumes opacity; the results, however, are visible only as late as at medium and high engine loads.

Statistical analysis proved that transitions in the fumes opacity Z_{sp} in the engine load function, at engine speeds of 2250 and 3000 r min^{-1} for all the tested fuels occurred with different dynamics in relation to DF.

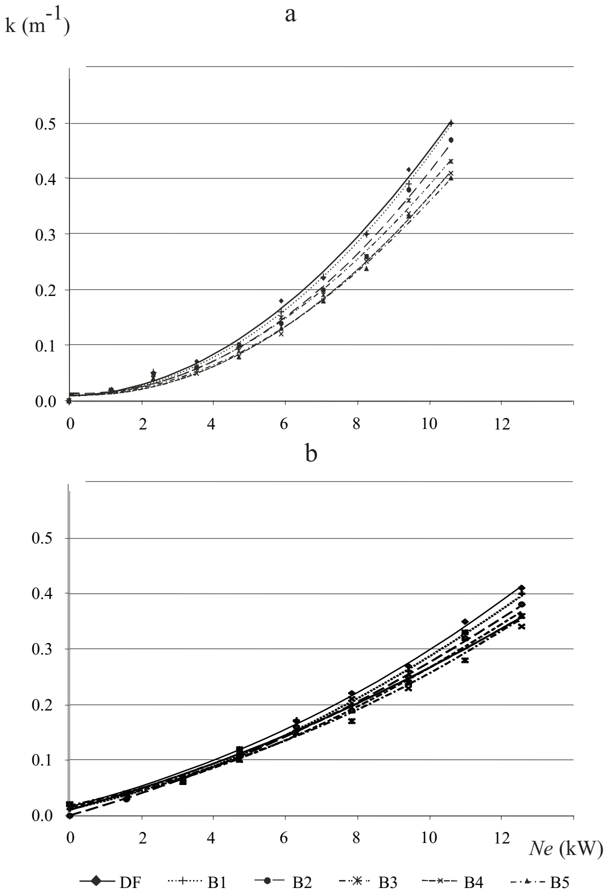

Fig. 2. Transient exhaust fumes opacity for the tested fuels in the function of engine load with n: a – 2250, b – 3000 r min^{-1}.

Table 1 presents equations for the exhaust fumes opacity Z_{sp} regression model for the particular fuels and characteristic engine speeds. The Table also takes into account determination indexes R^2.

When analysing the diagrams (Fig. 3) of relative transient fumes opacity, one can observe that the changes depend on the share of the biocomponent in the fuel blend, and on the engine speed. The most significant variations of fumes opacity were noted for the fuels B5 and B4, which amounted to *ca*. 20% at the speed of 2250 r min^{-1} and *ca*. 17% at the speed of 3000 r min^{-1}. The fuels with low content of the biocomponent – B1 and B2 – and at low and medium engine load, exhibited fumes opacity parallel to diesel fuel, whereas at higher engine loads their relative decrease amounted to a maximum of 7%.

The studies on the effect of the use of FAME and DF blends on exhaust fumes opacity showed its decrease when compared to the use of DF only. Changes were particularly visible in, typical for agricultural tractors, conditions of higher engine loads (Fig. 3) and were similar for both engine speeds. It is worth mentioning that exhaust fumes opacity of exhaust gasses emitted by engine powered with fuel containing 1 and 2% of FAME remained on a level similar to the one powered with DF. Greater changes, reaching 20%, were observed in the case of blends containing 3-5% FAME. Therefore, use of low ester content blends had no effect on exhaust fumes opacity. The observed reduction of exhaust fumes opacity resulted from the presence of oxygen in FAME which has the effect of improving combustion processes (Carraretto *et al.*, 2004; Szlachta, 2002).

T a b l e 1. Regression equations calculated on the test results for the variable Z_{sp} (m^{-1})

Engine speed (r min^{-1})	Fuel	Regression equation	Determination index R^2
2250	DF	$y = 0.000305\ Ne^3 + 0.014818\ Ne + 0.001372$	0.990072
	B1	$y = 0.000251\ Ne^3 + 0.015020\ Ne + 0.005355$	0.983465
	B2	$y = 0.000210\ Ne^3 + 0.019767\ Ne + 0.005256$	0.979143
	B3	$y = 0.000225\ Ne^3 + 0.016638\ Ne + 0.000314$	0.985395
	B4	$y = 0.000211\ Ne^3 + 0.012567\ Ne + 0.008595$	0.991977
	B5	$y = 0.000221\ Ne^3 + 0.010554\ Ne + 0.010992$	0.992608
3000	DF	$y = 0.00033Ne^3 - 0.00391Ne^2 + 0.02771Ne - 0.00404$	0.99684
	B1	$y = 0.00018Ne^3 - 0.00130Ne^2 + 0.01598Ne + 0.00091$	0.97826
	B2	$y = 0.00025Ne^3 - 0.00262Ne^2 + 0.02076Ne - 0.00131$	0.99522
	B3	$y = 0.00028Ne^3 - 0.00327Ne^2 + 0.02237Ne - 0.00212$	0.99451
	B4	$y = 0.00022Ne^3 - 0.00206Ne^2 + 0.01583Ne + 0.00030$	0.99953
	B5	$y = 0.00028Ne^3 - 0.00335Ne^2 + 0.02108Ne - 0.00222$	0.99521

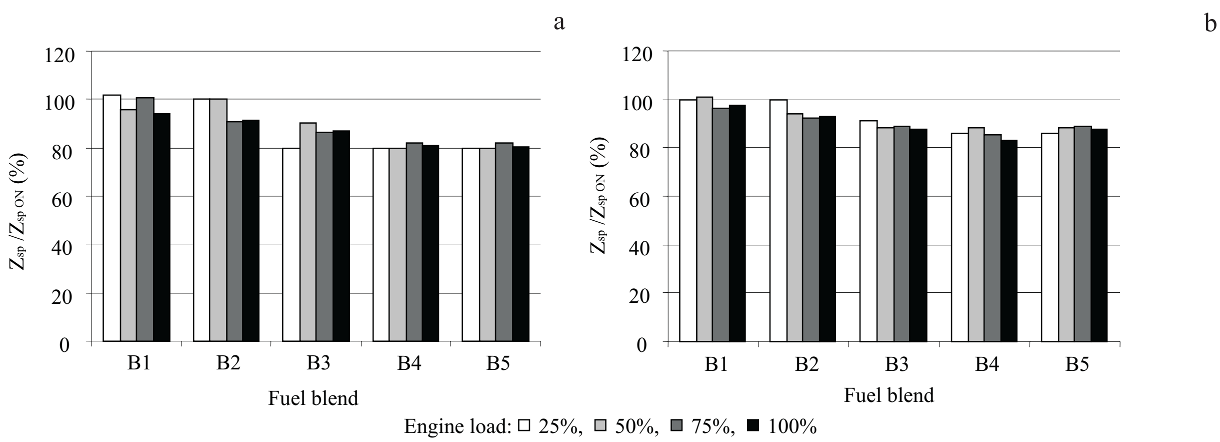

Fig. 3. Relative transition of exhaust fumes opacity for the tested fuels with *n*: a – 2250, and b – 3000 r min^{-1} and engine load graded at every 25%.

Objective evaluation of toxic components of exhaust gases emissions of diesel engine, among which are particulate matters, is a difficult task. In a diesel engine, as a result of fuel injection into a cylinder, fuel-air distribution is not homogeneous, therefore, the process of particulate matter formation is controlled by mixing air and fuel. Final effects depend also on the condition of the engine, type of combustion chamber, conditions and indicators of its work, as well as on differences in physicochemical properties of fuel. They can also be affected by the measurement method as well as the test used (Jakóbiec, 2006; Szlachta, 2002).

Obtained findings are confirmed by data found in other publications. Results of experiments, with various types of engines, in which pure biodiesel was used, showed that exhaust fumes opacity of investigated engines, when compared to engines running on DF, was 30-60% (Laforgia and Ardito, 1995; Lotko, 1997), 50-80% lower (Bhattacharyya and Reddy, 1994). In the case of blends containing 20% FAME, 25-40% (Krahl *et al.*, 2003) reduction was obtained.

Utilization of DF and FAME blends containing as little as 4-5% of esters can yield benefits for tractor engine work environment, resulting from exhaust fumes opacity reduction. Although, observed ecological effects are greater when pure biodiesel is used rather than blends, it was proven by the research (Szlachta, 2002) that when low percent blends are used no changes in traction, fuel consumption, durability and reliability of vehicle are observed.

CONCLUSIONS

1. The blend of rapeseed oil fatty acid methyl esters (FAME) with diesel fuel (DF) in the proportion of 5% by volume makes fuel fully compatible with diesel engines that meet all the requirements concerning fuel for self-ignition engines.

2. The introduction of rapeseed fatty acid methyl esters into diesel fuel in the amount of 1-5% brings about a change in the ecological parameters of an engine powered by such fuel. It has been proved that the increase in the share of the biocomponent in the fuel blend caused a decrease of fumes opacity from the maximum level of 20 for 5% share of the biocomponent. The transitions are constant throughout the entire range of engine loads.

3. Only the use of blends with the biocomponent share of 1-2% is justified economically, as such a share does not instigate any significant changes in the ecological parameters.

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