

ENGINE TESTING OF RME ADDITIVES

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Abstract

Reducing the emission of pollutants emitted from motor vehicles, and now also in greenhouse gas emissions, is a result of European Union policy. Vehicle design changes are just one way of reducing emissions of harmful substances and greenhouse gases. The second way is to change the type of fuel, by which the vehicle's engine is powered, that is the substitution of conventional fossil fuels derived from crude oil, such as gasoline or diesel fuel by so-called renewable fuels, for which the CO₂ emissions are measured not only in the engine exhaust system, but also by analysis "from the source to the wheel" WTW (Well-to-wheel) - is much smaller. As part of this task the Directive 2009/28/EC introduced for all Member States to the use of renewable energy, biofuels, alternative fuels to a certain extent share of the energy and conventional fuel by 2020.

This paper presents the results of measurements of emissions on the dynamometer with a diesel engine powered by six kinds of mixtures of diesel oil and rapeseed oil methyl ester (RME) – with esters containing 0 (clean diesel), 20, 40, 60, 80 and 100 (pure rapeseed oil methyl esters)% in the fuel. We analysed the reasons for the impact of changes in fuel composition on selected limited exhaust components. We found, that the addition of esters of rapeseed oil to the diesel fuel can be a reason of reducing the emissions of CO, CO₂, and THC in the exhaust gases of tested engine and increased emissions of NO_x and PM.

Keywords: renewable fuels, specific emissions of pollutants

1. Introduction

European Union policy in the field of reducing the mass emissions of pollutants from motor vehicles for decades concerns the limited exhaust gas components like CO, THC, NMHC, NO_x, PM and PN recently. However, for last several years the attention of ecologists is focused on greenhouse gases emissions. In the automotive industry branch the reducing greenhouse gas emissions, including mainly CO₂ emissions, goes multifaceted and at many levels. The first step in this area was obligation to measure in type approval tests CO₂ emissions in passenger and light duty vehicles. After many years of waiting, along with the introduction of Euro VI limit, this obligation was extended to the measurement of the CO₂ specific emission in approval tests of heavy duty engines. Following the implementation of the CO₂ emissions measurement, come the first forms of impose to the vehicle manufacturers, charges for the environment in case of producing vehicles having too high CO₂ emissions.

Limits of the greenhouse gas emissions from motor vehicles as a effect of appropriate structural modifications of vehicles and their engines are just one of the ways of restricting the emissions. Parallel to this one, the EU legislation requires the use of renewable fuels instead the fossil fuels. For renewable fuels the total CO₂ emissions measured not only in engine exhaust system, but on the way from the source to the wheel (well to wheel) is much smaller. The implementation of this approach is Directive 2009/28/EC, which introduced for each EU Member State the obligation to apply till the year 2020 a certain share of renewable fuels and energy on the inner markets. For Poland the target is 15%.

In Tab. 1 is shown the possible effect of a CO₂ emission reductions as a result of some alternative fuels using. One among the fuels listed in this table is biodiesel produced from rape oil seed which is essentially the rapeseed oil methyl ester (RME).

In this paper will be discussed some aspects of test bench engine testing fuelled with mixtures of diesel oil and rapeseed oil methyl esters.

Tab. 1. Reducing CO₂ emissions for produced biofuels (without net CO₂ emissions due to land use change) [1]

Type of fuel	Typical limits for greenhouse gas emissions	Standard limits for greenhouse gas emissions
ethanol from sugar beet	61%	52%
ethanol from wheat (process fuel - not specified)	32%	16%
ethanol from wheat (lignite as process fuel in CHP plant)	32%	16%
ethanol from wheat (natural gas as process fuel in conventional boiler)	45%	34%
ethanol from wheat (natural gas as process fuel in CHP plant)	53%	47%
ethanol from wheat (straw as process fuel in CHP plant)	69%	69%
corn ethanol produced in the Community (natural gas as process fuel in CHP plant)	56%	49%
ethanol from sugar cane	71%	71%
biodiesel from rapeseed	45%	38%
biodiesel from sunflower	58%	51%
biodiesel from soy bean	40%	31%
biodiesel from palm oil (technology not specified)	36%	19%
biodiesel from palm oil (technology with methane capture)	62%	56%
biodiesel from waste vegetable or animal oil	88%	83%
hydrotreated vegetable oil from rapeseed	51%	47%
hydrotreated vegetable oil from sunflower	65%	62%
hydrotreated vegetable oil from palm oil (technology not specified)	40%	26%
hydrotreated vegetable oil from palm oil (technology with methane capture)	68%	65%
pure vegetable oil from rapeseed	58%	57%
biogas from organic municipal waste as compressed natural gas (biomethane)	80%	73%
biogas from wet manure as compressed natural gas (biomethane)	84%	81%
biogas from dry manure as compressed natural gas (biomethane)	86%	82%

2. Test fuels

In the tests were used mixtures of diesel oil and rapeseed oil methyl ester, whose physico-chemical properties are shown in Tab. 2.

Tab. 2. Selected physic-chemical properties of diesel oil and rapeseed methyl esters used in vehicles tests

Property	Unit	Diesel	RME
FAME content	%(v/v)	4.5	99.1
Calorific value	MJ/kg	42.5	39.5
Cetane number	-	52.8	52.5
Density at temp. 15°C	kg/m ³	830.1	882.7
Surface tension	N/m	22.5·10 ³	25.4·10 ³
Kinematic viscosity at temp. 40°C	mm ² /s	2.693	4.463
Cold filter plugging point (CFPP)	°C	-31	-25
Chemical analysis			
- content of C (measured)	%	87.95	79.01
- content of H (measured)	%	11.94	12.85
- content of O (calculated from the balance)	%	0.11	8.14
H/C	-	1.83	1.93
O/C		0	0.08

Comparing these two test fuels the attention should be paid to the difference in their chemical composition, particularly in terms of oxygen. The content of this component in esters is about 8%, while in diesel oil it is close to zero. RME heat value expressed in MJ/kg is smaller by app. 7% in comparison to diesel oil, but expressed in MJ/dm³ only by about 1% due to the greater density of the esters. The greater contribution of the hydrogen mass fraction in ester molecules suggests the possibility of reducing the CO and THC emissions in products of combustion of this fuel.

3. Tests results analysis

The study included measurement in standard engine emission cycles on test bench equipped with a suitable measurement devices. Selected test cycles comes from different type approval regulations for vehicle engines (ESC, ETC and WHTC), off-road machineries (NRTC) and the American regulations (HDTC). The tested object was an A115DI engine type deriving from delivery truck. It met Euro III requirement.

In order to minimize the influence of random errors on the measurement results, there were made a series of emission tests, in which the tested engine was powered by six different blends of rapeseed oil methyl esters and diesel fuel containing 0% of esters (pure diesel fuel), 20, 40, 60, 80 and 100 (pure methyl esters of rapeseed oil) % of the fuel. The test results are shown on Fig. 1 and 2. The diagrams are drawn as a function of the mass fraction of the rapeseed oil methyl ester in the fuel, expressed as a decimal fraction. The values of measured emission were approximated with linear regression lines, and obtaining curves showed the emission trends as a function of fuel composition (fraction of the ester).

Figures 1 and 2 give possibility clearly to identify the trends of pollutant emission changes that occur with an increase of the ester participation in the tested fuels. This trends are symbolically shown in Tab. 3, where the arrow pointing down indicates that the emission of exhaust component in selected test decreases with the increase of esters participation in the fuel, while the arrow pointing up means the opposite tendency.

Tab. 3. Trends in changes of emissions in selected tests as a result of esters addition in diesel fuel

Test type	engine A115DI				
	CO ₂	CO	NO _x	THC	PM
ESC	↓	↓	↑	↓	No change
ETC	↓	↓	↑	↓	↑
HDT	↓	↓	↑	↓	↑
NRTC	↓	↓	↑	↑	↑
WHTC	↓	↓	↑	↓	↑

Analysing the information collected in Tab. 3 it can be concluded, that the addition of the esters to the diesel fuel will cause in tested engine increase of NO_x and PM emissions, and decrease the emissions of CO, CO₂, and THC in most of performed tests. The decline of CO, CO₂, and THC might be expected, taking into account the higher hydrogen content in the esters. The relatively smallest is the difference in CO₂ emissions, because in average it is not greater than 1-2%. However, this value is not the result of measurement error, because on the presented figures it is possible to see clearly the decreasing trend of CO₂ emissions with an increase in participation of esters in the fuel. Taking into account that methyl esters of rapeseed oil are renewable fuels, the

use of this fuel will decrease the global CO₂ emissions, calculated by the WTW (well to wheel) method by approximately 40% (Tab. 1). Analysing the other exhaust gas components, we can see that in the ETC cycle (Fig. 2) the THC emissions decreased by 32% (compared to diesel fuel to pure rapeseed oil esters), while NO_x emissions increased by 40% and PM increased by 44%.

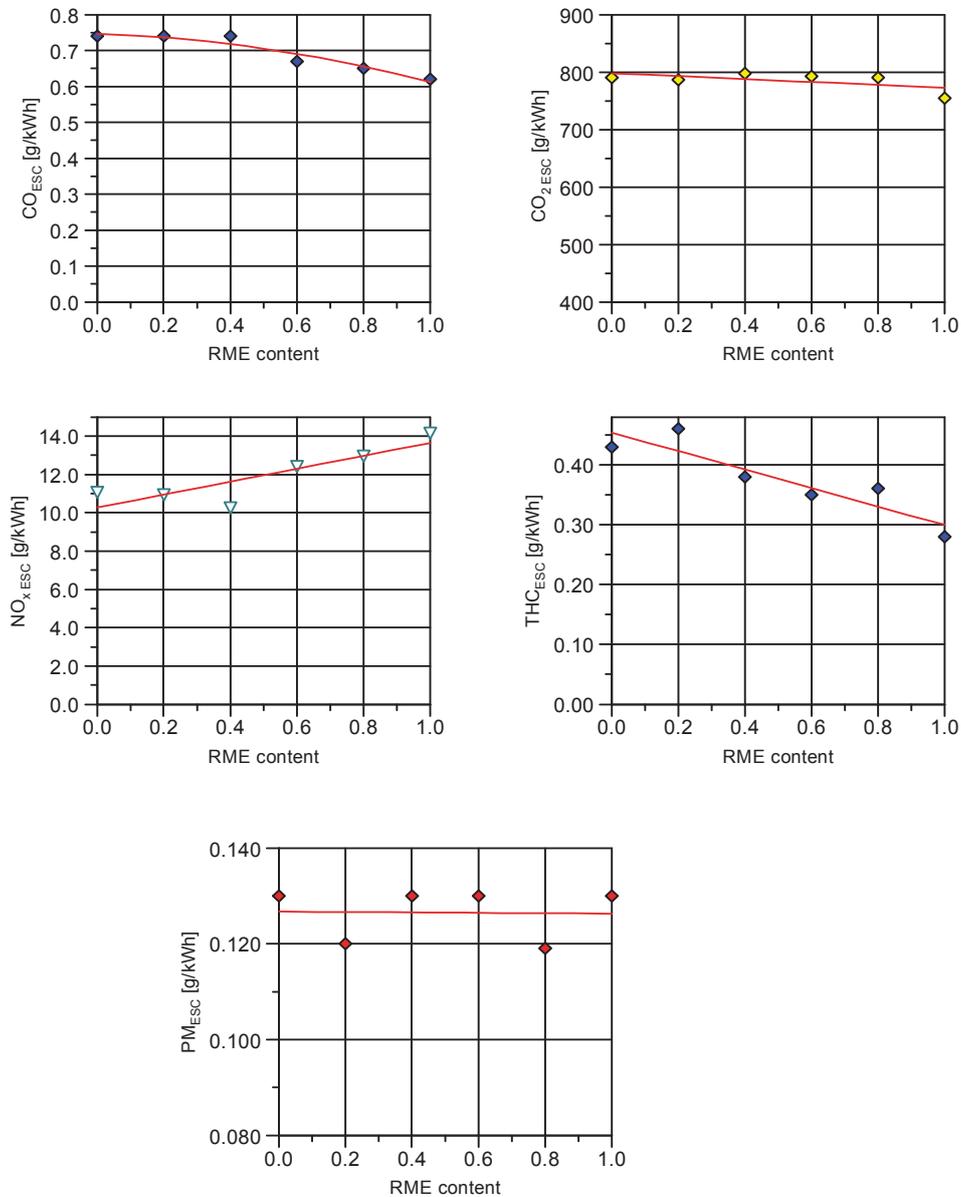


Fig. 1. Specific emission In European Steady Cycle (ESC) versus RME content in diesel oil

The major factors of the NO_x formation are high combustion temperature, rich local oxygen concentration, and long residence in the high temperature atmosphere. Obviously, with RME, the temperature in combustion chamber could be increased and amount of oxygen is also increased, which could improve combustion and lead to the formation of higher NO_x emissions.

It is well known that the diesel particle consists of soluble organic friction (SOF), dry soot and sulphate. Due to the fact that the RME contain less sulphur, compared to diesel fuel and smoke opacity of the tested engine fuelled with RME was lower than for diesel fuel, it can be expected that the particles emitted from the engine powered by biodiesel will contain less soot and sulphates. Therefore, the only explanation for the increase of particulate emissions mass would be an increase of soluble organic friction. In general, the origins of soluble organic friction in PM are partly of lubrication oil, unburned oil, and compounds created during fuel combustion.

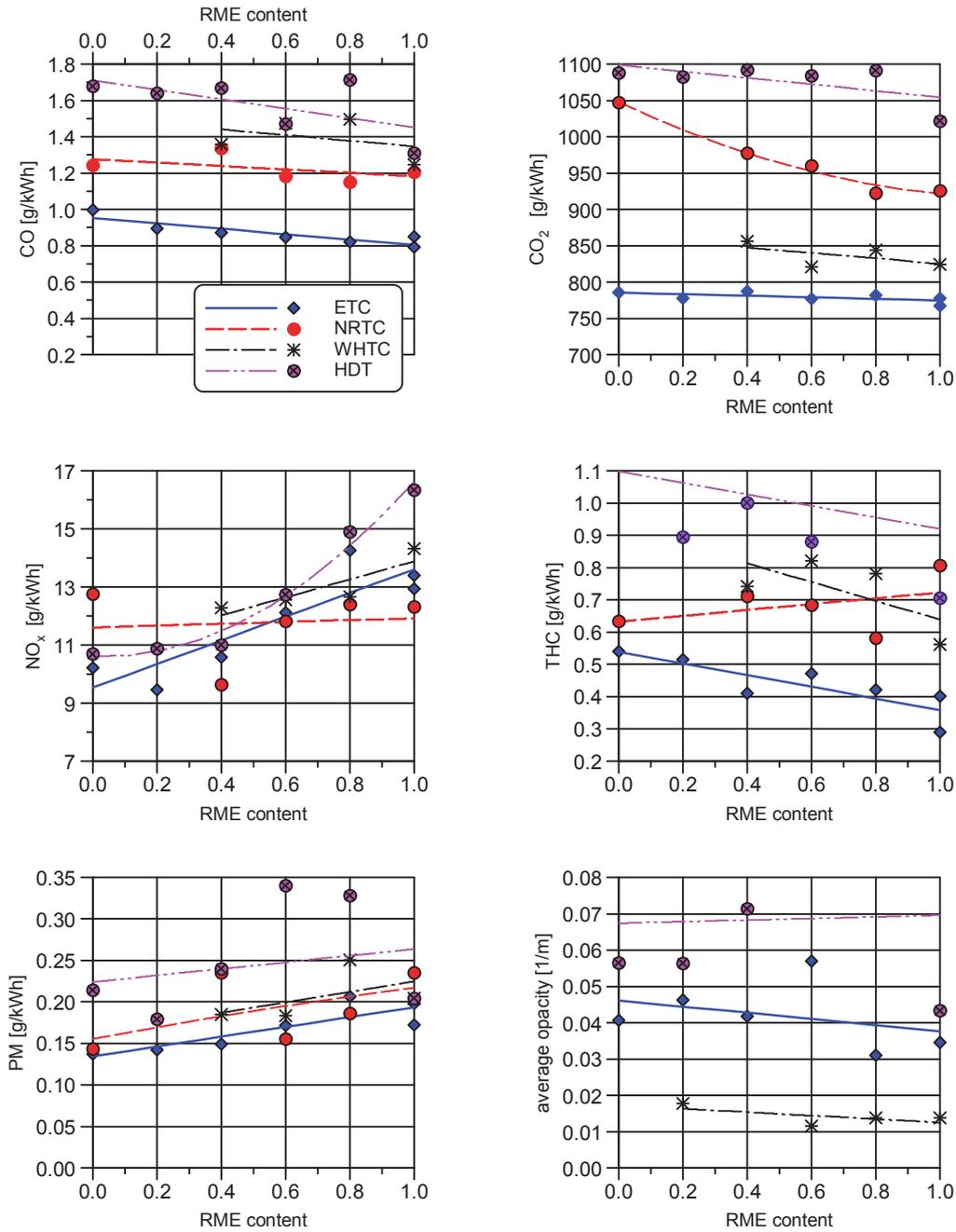


Fig. 2. Specific emissions in different transient cycles versus RME content in diesel oil

Some authors reported [5] that the higher SOF fraction observed with the biodiesel or biodiesel blends could be attributed to the low volatility of biodiesel, which was caused by the higher boiling point, higher viscosity and higher density, leading to the worse mixture of fuel and air in chamber and incomplete combustion. In the end, the unburned oil and compounds of uncompleted combustion increase with biodiesel content in fuel, and result in the increase of proportion of SOF in turn. The more the biodiesel is in the blended fuels, the lower the sulphur content will be. The most possible explanation of the observed phenomena increase of sulphate proportion is just a consequence of the sharper reductions in smoke and a slighter decrease in sulphate mass of biodiesel blends

In order to analyse the impact of fuel composition on the smoke emission, on the Fig. 2 there is provided diagrams showing the change of the average exhaust gas opacity as a function of the fuel constitution. This value is calculated as the arithmetic mean of the opacity values recorded during

corresponding cycles. Analyse of these curves indicates, that the addition of RME to diesel fuel is beneficial for reducing opacity, given that the maximum decrease of the average exhaust opacity is equal from zero to app. 20%, depending on the nature of the engine work (the type of used emission test).

The observed decrease in exhaust smoke cannot be explained by the quality of fuel atomization during the injection, because the viscosity and surface tension are greater for RME than for diesel fuel. These parameters are rather reason of worse startability at low temperatures of RME-fuelled engines [1].

In [3] is stated that the presence of the bonded oxygen could explain the decrease of smoke, which reduces the probability of soot nuclei formation in locally rich zones. When sufficient oxygen is available, soot precursors species react with oxygen or oxygen-containing radicals (like OH, O) and eventually produce CO rather than aromatics and soot. Moreover, the increase of oxygen content in blends means a decrease of carbon content, which is the major contributor of soot formation. Some researchers claim [4] that reductions of opacity can be due to the dilution of aromatics, which were considered as the soot precursors.

4. Conclusions

1. Compared with baseline diesel fuel, the biodiesel blends give higher NO_x and PM emissions.
2. RME blends give lower CO, THC, CO₂ emission compared to diesel fuel.
3. The smoke opacity of biodiesel blends decreases remarkably, in comparison with baseline diesel fuel.
4. The dry soot proportions decrease with increase in the proportion of biodiesel and the SOF and sulphate proportions increase with the percentage of biodiesel.

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