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Ecological indicators for the Perkins 1104D-44TA engine fuelled by sunflower oil methyl esters operating according to load characteristics

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Abstract. Fuels constitute one of the research areas within the scope of piston internal combustion engines. The works encompass both conventional as well as alternative fuels. Fuels are sought which will contribute to a reduction in the negative impact of transport on the natural environment and humans. These may be fuels obtained from organic raw materials of agricultural (most often) or forest origin. When it comes to compression-ignition engines, Biodiesel B100 type biofuels can be used to fuel them, which most often constitute a long chain fatty acid ester, made from plant oils or animal fats. The publication presents ecological indicator test results for a compression - ignition engine fuelled by SME Biodiesel, or sunflower oil methyl esters and commercially available diesel as a benchmark. During the tests, the engine operated according to load characteristics at two different crankshaft rotational speeds. A sunflower oil ethyl ester fuelled engine returned beneficial values for most of the tested ecological indicators as compared to a diesel fuelled engine. Concentrations of substances such as CO, CO_2, unburned hydrocarbons (THC), particulate matter (PM) were lower in the engine emissions, exhaust smoke levels were also reduced. Only nitrogen oxides (ON_x) increased.

Key words: compression-ignition engine, engine ecological indicators, load characteristics, harmful emission contents, sunflower oil methyl esters (SME), FAME Biodiesel.

INTRODUCTION

Transport is a field of human activity which consumes significant quantities of energy. Currently most of that energy comes from non-renewable sources. Fuels used to power means of transport are primarily obtained from crude oil. The use of gas fuels, primarily LPG and CNG is on the increase. Renewable fuels obtained from organic matter are also used: Biodiesel, biogas, alcohols. Plant oil esters [1,7,9,10,14] are used to fuel ompression-ignition engines. These are usually used as additives for commercially available diesels. Compression-ignition engines can also be fuelled by esters in their pure form [2,3].

One of the more important documents specifying the share of biofuels in European Union's fuel market is Directive 2003/30/EC of the European Parliament and of the Council on the promotion of the use of biofuels or other renewable fuels for transport. The objective of the Directive was for biofuels to enter into general use [4]. It imposed requirements for European Union countries to use biofuels in transport. In 2009 the European Parliament and the European Council adopted Directive 2009/28/EC on the promotion of the use of energy from renewable sources [5]. The European Union obliged member states to ensure a 10% or larger renewable energy share in final consumption of energy across all types of transport by 2020. In Poland, according to the National Indicator Targets, in 2017 all entities placing fuels on the market have to demonstrate a 7.8% or more share of biofuels and biocomponents in their overall fuel balance. Pursuant to the Act on fuel quality monitoring and control of 25 August 2006, biofuels have to satisfy quality standards. The FAME biodiesel has to comply without the PN-EN 14214 standard. Currently we may add a 7% (V/V) component of plant oil FAME fatty acids methyl esters for diesels to diesel [16].

PRODUCTION OF SME BIOFUELS IN THE PROCESS OF TRANSESTERIFICATION FROM SUNFLOWER OIL

Calculating the optimum (stoichiometric) amount of reactants needed to carry out the transesterification process usually involves the usage of simplified models [15]. However, in order to determine the appropriate amount of reactants needed to produce RME, the authors of this paper used a model developed by one of the co-authors, which makes it possible to optimally determine the quantities of methyl alcohol and the catalyst necessary for the process of transesterification - Fig. 1 [16,17].

The following ratio was used for the purpose of transesterification of sunflower oil: for each 1 dm^3 of oil, a mixture obtained from dissolution of 7.0g of KOH in 0.15 dm^3 of CH_3OH was used. Transesterification was performed in a single step, with the temperature of the start of the process being 63ºC P.a. purity CH_3OH methyl alcohol of a molecular weight of 32.04 g/mol was used for the transesterification process, along with p.a. purity KOH potassium hydroxide with a molecular weight of 56.11 g/mol as the catalyst.

Biofuel of the SME Biodiesel type (Sunflower Methyl Esters) was produced in a GW-200 reactor constructed by one of the authors (G. Wcisło) - Fig. 2. The process of transesterification was carried out in two stages and the obtained degree of oil transition into methyl esters was equal to 98.7% (m/m) [19]. The result has proved that the obtained SME biofuel complies with EN 14214 standards of biofuel for a high pressure engine, as regards the ester content in FAME (Fatty Acid Methyl Esters).

Model for receiving SME (FAME) from typical triglyceride for sunflower comprised of two oleic acids and one linoleic acid. We break down big triglyceride molecule into three small molecules, from which by transesterification using methanol, two molecules of oleic acid and one of linoleic acid are obtained. The residue marked with symbol A and three OH groups derived from breaking down the methanol molecule create glicerol.

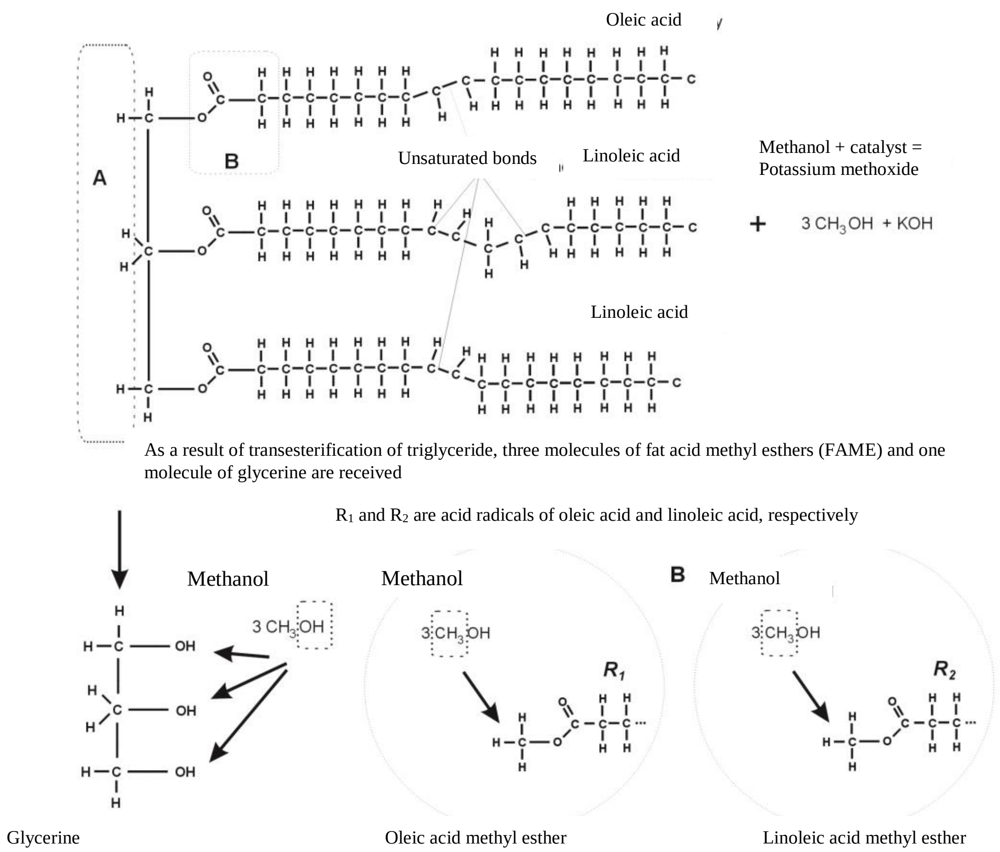

Fig. 1. Diagram of sunflower oil transesterification [17]

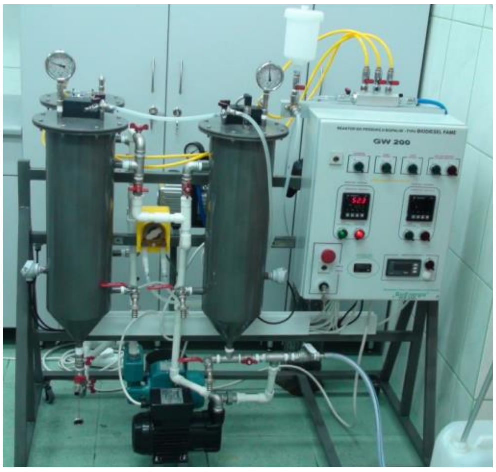

Fig. 2. Reactor GW 200 for production of Biodiesel FAME (SME)

FUELS SELECTED FOR TESTING AND TEST METHODS

Tests of the Perkins 1104D-44TA engine fuelled by SME and conventional fuel (commercially available diesel which satisfies EN 590:2014 [12] standard requirements) as benchmark were performed at an engine test stand. During the tests the engine operated according to load characteristics at a crankshaft rotational speed of 1400 rpm. This is the speed at which the engine in question generates maximum torque. Concentrations of the following substances in emissions were measured at pre-determined engine working conditions: CO, CO_2, nitrogen oxides (ON_x), total hydrocarbons (THC) content and particulate matter (PM). Exhaust smoke levels were also measured. For tests performed subject to exactly the same engine working conditions, a relative change in the concentrations of emissions was calculated subject to the engine operating on SME sunflower oil methyl esters with reference to concentrations measured when the engine was fuelled by diesel. The following relation was used to that end:

$$\Delta i = \frac{i_{SME} - i_{ON}}{i_{ON}} \cdot 100[\%] \qquad (1)$$

where: Δi – relative change to the concentration of the "i" component in the exhaust emissions of an SME fuelled engine as compared to diesel, expressed as a percentage, i_{SME} – concentration of the "i" component in exhaust emissions generated by an SME fuelled engine, i_{ON} – concentration of the "i" component in exhaust emissions generated by a diesel fuelled engine.

TEST SUBJECT

The subject was a four cylinder, inline, compression-ignition, direct injection Perkins 1104D-44TA engine. This is an industrial engine. It meets Stage IIIA and EPA Tier 3 standards within the scope of emissions standards for off-rad machines. Basic technical data of the tested engine are shown in table 1. The Perkins 1104D-44TA engine features a power system with a mechanically controlled injection pump [h]. In order to increase the level of cylinder fill in the tested engine's intake system a blowof valve controlled turbocharger connected to the engine's inlet manifold was used. The engine is equipped with a sixteen OHV valvetrain system. Four valves are dedicated to each cylinder, two intake and two exhaust valves.

Table 1. Perkins 1104D-44TA compression-ignition engine specification

Parameter	Unit	Value
Cylinder system	-	inline
Number of cylinders	-	4
Type of injection	-	direct
Fuel system	-	Delphi DP310 rotary fuel injection pump
Maximum power	kW	75
Rated speed	rpm	2200
Maximum torque	Nm	416.0
Maximum torque rotational speed	rpm	1400
Displacement	m^3	$4.4 \cdot 10^{-3}$
Compression	-	18.2
Air inlet system	-	turbocharged, aftercooled

TEST FACILITY

The tests were performed at a test stand with the PERKINS 1104D-44TA compression-ignition engine mounted. AMX – 200/6000 eddy current brake by ELEKTROMEX CENTRUM is able to take-off up to 200 kW and transfer torque of 700 Nm. The test stand was equipped with a desktop computer and Automex software to control and display test progress. An accurate measurement of liquid fuel consumption by the engine was made possible by an Automex dosage meter. Air consumption was measured using an ABB thermal mass air flowmeter. See figure 3 for a flowchart if the engine in question.

Compression-ignition engine emissions analysis was performed using MEXA-1600DEGR and MEXA-1230 PM Horiba analysers and an AVL DiCom 4000 PL analyser. The MEXA-1600DEGR analyser is used for real time continuous measurements of concentrations of five components of piston internal combustion engine exhaust gasses: carbon monoxide (CO), carbon dioxide ($CO_{2,}$), total hydrocarbons (THC), nitrogen oxides (ON_x) and oxygen (O_2) [6]. Horiba's MEXA-1230 PM particular mater analyser comprises a soot analyser and a soluble organic fraction (SOF) analyser. The analyser facilitates mass concentrations of particulate matter components: soluble organic fractions (SOF), soot as well as the total soot and soluble organic fraction mass (Total PM) [a2, a3]. Smoke levels in the tested compression-ignition engine exhaust gasses were tested using an VL DiCom 4000 PL analyser [18].

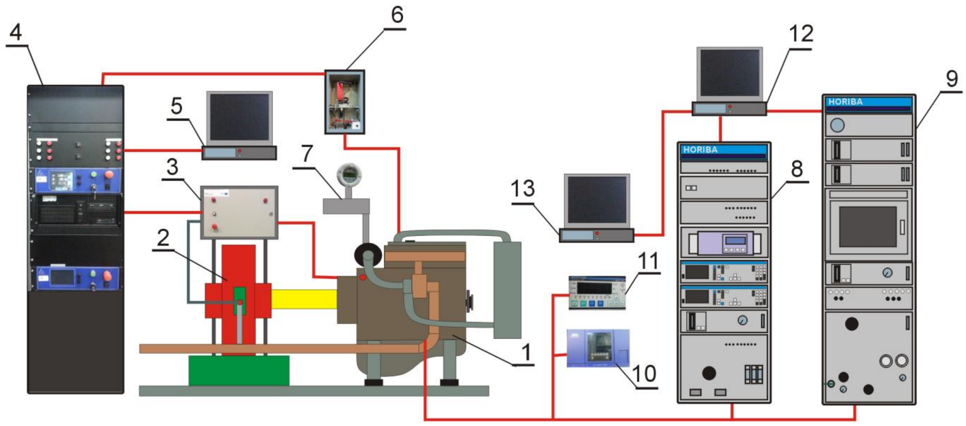

Fig. 3. Test facility, where: 1 - Perkins 1104D - 44TA engine, 2 - Automex AMX 200/6000 brake, 3 - measurement module, 4 - measurement cabinet with test facility control system, 5 - computer sued to control test facility parameters and to archive test results, 6 - Automex ATMX2040 mass fuel dosage meter, 7 - ABB mass flowmeter, 8 - Horiba Mexa 1230PM particulate matter analyser, 9 - Horiba Mexa 1600DEGR exhaust gasses analyser, 10 -AVL Dicom 4000 smoke meter, 11 - Horiba AFR Mexa-730 air to fuel ratio analyser λ, 12 - computer operating the Mexa 1230PM analyser, 13 - computer synchronising exhaust gas analysis measurements and archiving emission measurement results

TEST RESULTS AND ANALYSIS THEREOF

The Perkins 1104D-44TA engine powered by SME biofuel, operating according to load characteristics for crankshaft rotational speed of 1400 rpm generated smaller maximum torque than when powered by diesel. The reduction is slight for crankshaft rotational speed of 1400 rpm: approximately 1.4%. This is significant as the net calorific value if SME Biodiesel is approximately 10% lower.

Figure 4 depicts the results of carbon monoxide (CO) concentration measurement in Perkins 1104D-44TA engine exhaust gasses operating according to load characteristics for crankshaft rotational speed of 1400 rpm powered by SME and diesel. Carbon monoxide concentrations in the exhaust gasses produced by the tested engine were compared for measurements taken subject to the same engine working conditions. Relative carbon monoxide (CO) concentration level changes were calculated for sunflower oil ester fuel in relation to carbon monoxide concentrations measured when running on diesel. Calculation results are shown in figure 5. Using SME to fuel the engine lower carbon monoxide (CO) concentration levels were obtained in the engine's exhaust gasses than when powered by conventional fuel.

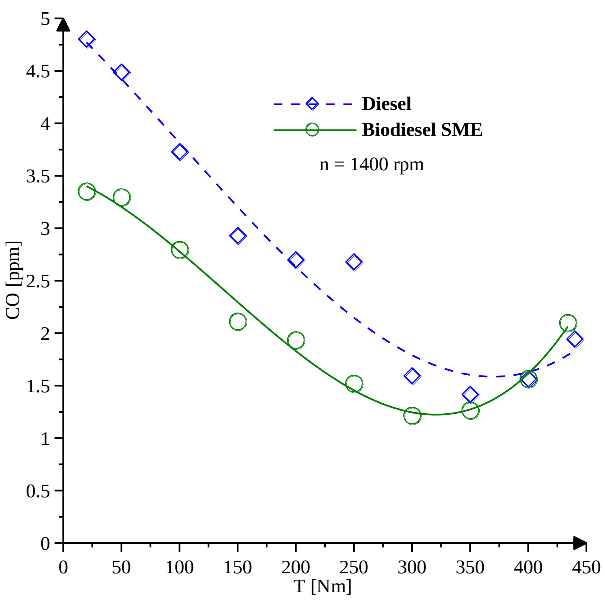

Fig. 4. A comparison of carbon monoxide (CO) concentration levels in SME and diesel powered Perkins 1104D-44TA engine exhaust gasses. Subject to load characteristics for n = 1400 rpm

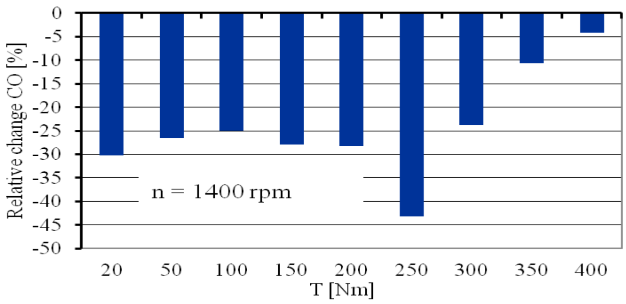

Fig. 5. Relative change to carbon monoxide (CO) concentration levels in SME and diesel powered Perkins 1104D-44TA engine exhaust gasses

Carbon dioxide (CO_2) concentrations were also measured in Perkins 1104D-44TA engine exhaust gasses. Figure 6 depicts a comparison of carbon dioxide (CO_2) concentration levels in exhaust gasses of the tested engine operating according to load characteristics for crankshaft rotational speed of 1400 rpm powered by SME sunflower oil methyl esters and diesel. For measurements performed under exactly the same loads, the relative change to carbon dioxide concentrations were calculated in exhaust gasses generated by the engine powered by SME esters as compared to the concentrations thereof in exhaust gasses produced by a diesel fuelled engine. These calculation results are shown in figure 7. Subject to the engine operating under load characteristics for n=1400 rpm and loads from 20 Nm to 250 Nm, lower concentrations of carbon dioxide were obtained with the engine powered by SME esters that when it was running on diesel. The degree of this reduction decreases as the load increases. For loads of 250 Nm and above carbon dioxide concentrations in exhaust gasses generated by the engine powered by SME esters were higher than those produced by a diesel fuelled engine.

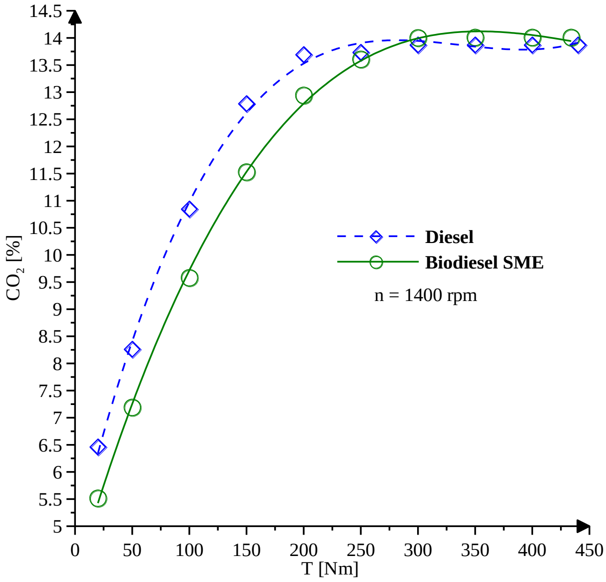

Fig. 6. A comparison of carbon dioxide (CO_2) concentration levels in SME and diesel powered Perkins 1104D-44TA engine exhaust gasses. Subject to load characteristics for n = 1400 rpm

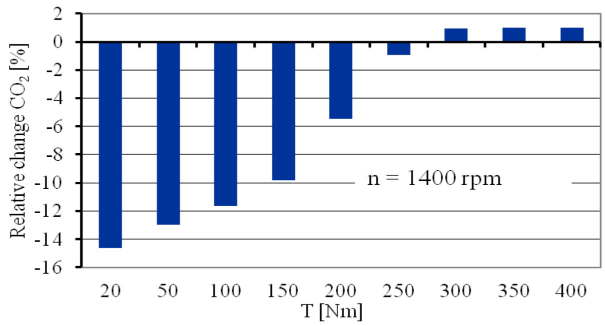

Fig. 7. Relative change to carbon dioxide (CO_2) concentration levels in SME and diesel powered Perkins 1104D-44TA engine exhaust gasses

Figure 8 shows a graphical representation of nitrogen oxides (ON_x) concentration level measurements in the Perkins 1104D-44TA engine exhaust gasses fuelled by SME sunflower oil methyl esters and diesel. A relative change to the value of nitrogen oxides (ON_x) concentration levels in the engine exhaust gasses fuelled by SME sunflower oil methyl esters as compared to those generated under diesel power (fig. 9) was calculated for the same loads. Subject to the engine operating under the smallest 20 Nm load, both load characteristics returned lower nitrogen oxides concentration levels for the engine fuelled by SME esters than when running in diesel. Under larger loads, with the exception of a single measurement point (fig. 9), higher nitrogen oxide concentration levels were obtained when the engine was fuelled by sunflower oil methyl esters than when it was running on conventional fuel.

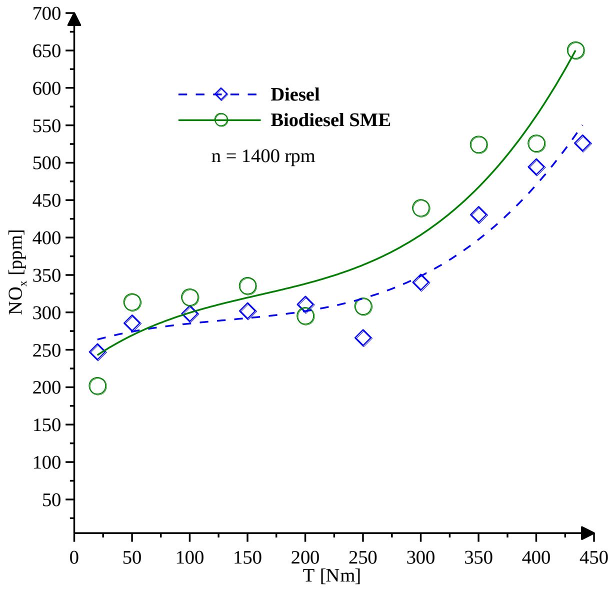

Fig. 8. A comparison of nitrogen oxides (ON_x) concentration levels in SME and diesel powered Perkins 1104D-44TA engine exhaust gasses. Subject to load characteristics for n = 1400 rpm

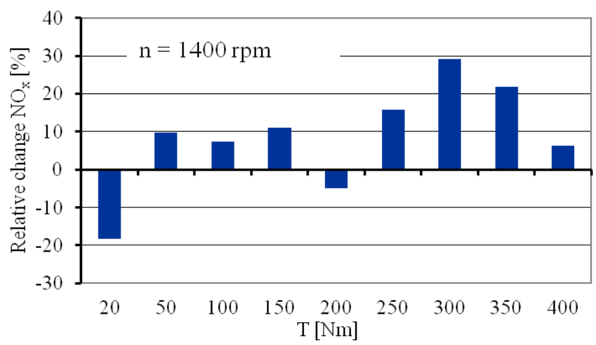

Fig. 9. Relative change to nitrogen oxides (ON_x) concentration levels in SME and diesel powered Perkins 1104D-44TA engine exhaust gasses

Figure 10 depicts a comparison of total hydrocarbons (THC) concentration in the Perkins 1104D-44TA engine exhaust gasses operating according to load characteristic for crankshaft rotational speed of 1400 rpm powered by SME sunflower oil methyl esters and diesel. Using SME esters to fuel the engine, a distinctly lower total hydrocarbon (THC) content in exhaust gasses was recorded forall measurement points than when running on diesel (fig. 11).

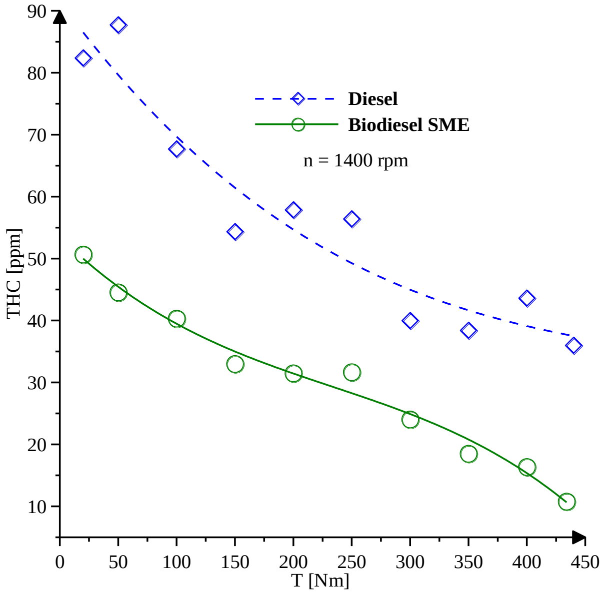

Fig. 10. A comparison of total hydrocarbons (THC) concentration levels in SME and diesel powered Perkins 1104D-44TA engine exhaust gasses. Subject to load characteristics for n = 1400 rpm

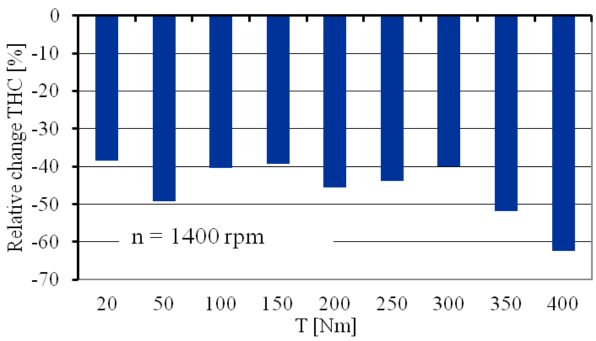

Fig. 11. Relative change to total hydrocarbons (THC) concentration levels in SME and diesel powered Perkins 1104D-44TA engine exhaust gasses

Similar results were obtained for smoke levels in exhaust gasses. The results of these measurements are shown on figure 12. A sunflower oil ethylester fuelled engine returned smaller smoke levels in exhaust gasses readings than when running on diesel (fig. 13). Average smoke levels in exhaust gasses calculated for measurement points under the engine operating subject to load characteristics for crankshaft rotational speed of 1400 rpm was more than 60%.

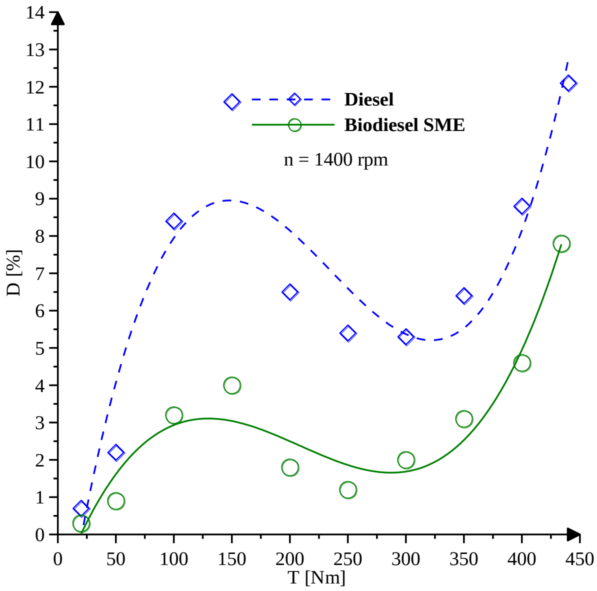

Fig. 12. A comparison of D smoke levels in exhaust gasses generated by an SME and diesel powered Perkins 1104D-44TA engine.

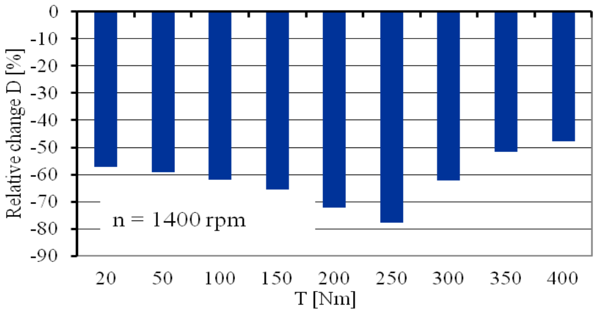

Fig. 13. Relative change in the value of D smoke levels in exhaust gasses generated by an SME and diesel powered Perkins 1104D-44TA engine

Figure 14 depicts measurement results of particulate matter concentration in the Perkins 1104D-44TA engine exhaust gasses operating according to load characteristics for crankshaft rotational speed of 1400 rpm powered by SME sunflower oil methyl esters and diesel. Only the smaller engine load under operation subject to load characteristics for rotational speed of 1400 rpm returned a larger value of particulate matter in exhaust gasses when fuelled by SME esters in comparison to diesel.

Using SME esters to fuel the engine, a distinctly lower particulate matter content in exhaust gasses was recorded for all measurement points (except one) than when running on diesel (fig. 15).

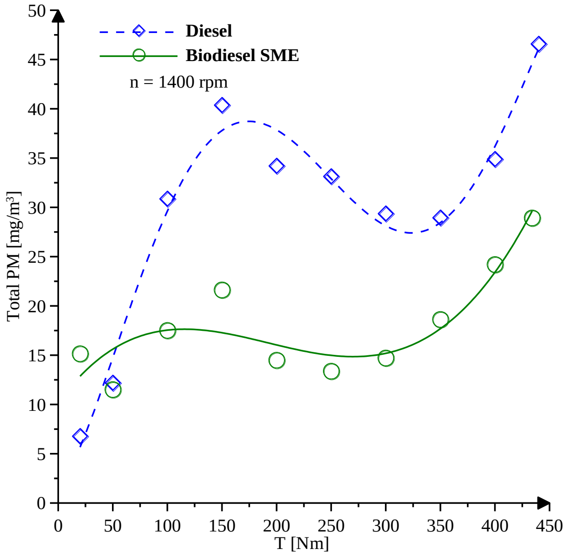

Fig. 14. A comparison of Total PM particulate matter concentration levels in SME and diesel powered Perkins 1104D-44TA engine exhaust gasses

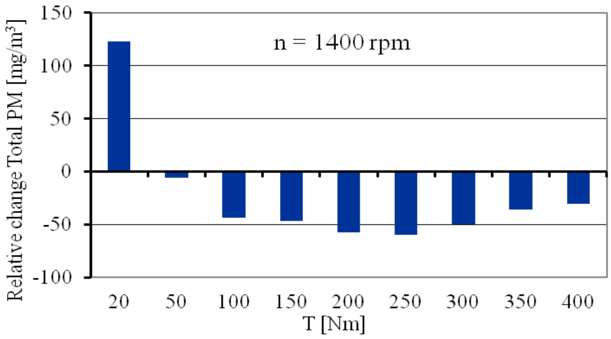

Fig. 15. Relative change in Total PM particulate matter concentration levels in SME and diesel powered Perkins 1104D-44TA engine exhaust gasses

CONCLUSIONS

The article presents ecological indicators for the Perkins 1104D-44TA engine fuelled by sunflower oil methyl esters and diesel benchmark figures. During the tests the engine operated according to two load characteristics at a crankshaft rotational speed of 1400 rpm. An ester fuelled engine generated smaller torque as compared to diesel.

Using sunflower oil methyl esters to power the Perkins 1104D-44TA engine, most measurement points returned a reduction in the concentrations of carbon dioxide in exhaust gasses as compared to diesel. On top of that, esters are a plant based fuel, and thus the carbon dioxide emission balance, the primary cause of the greenhouse effect is more favourable for this fuel than for diesel.

Using sunflower oil methyl esters to power the tested engine as compared to diesel, significantly smaller concentration levels of carbon monoxide, total carbohydrates and particulate matter in exhaust gasses were obtained. Also smoke levels in exhaust gasses for the engine running on esters were clearly less than when using diesel.

A negative consequence of using sunflower oil esters to fuel the Perkins 1104D-44TA engine as compared to diesel was the increase in nitrogen oxides emission. This is caused by the content of oxygen in the elementary composition of the plant based fuel and its higher combustion temperatures. Average nitrogen oxides emission increase

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