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External speed characteristic for the Perkins 1104D-44TA engine fuelled by sunflower oil methyl esters

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Abstract. The publication presents test results for a Perkins 1104D - 44TA engine powered by SME sunflower oil fatty acids methyl esters. The SME biofuel was manufactured in-house using a GW-200 reactor at MCOŹE "BioEnergia". The test was carried out at an engine test stand at Kielce University of Technology's Heat Engine Laboratory. During the test the engine operated according to an external speed characteristic. The tests aimed to determine the impact of using an SME type biofuel to power the engine on the engine's primary performance indicator values. A slight decrease to the brake horsepower and torque of the tested engine powered by sunflower oil esters as compared to diesel was recorded. Fuel consumption of the engine powered by plant origin fuel also increased. No operating problems were experienced associated with powering the engine using sunflower oil esters during the tests.

Key words: external characteristic harmful emission contents, sunflower oil methyl esters (SME), FAME Biodiesel.

INTRODUCTION

Conventional fuels used to power piston internal combustion engines include diesels obtained from crude oil. They exhibit good self-ignition properties expressed by cetane number values. Diesel injected under high or very high pressure into compressed air in the combustion chamber, makes a fuel - air mixture which self-ignites. Alternative fuels for compression - ignition engines should also exhibit good self-ignition properties. Currently tests are underway, and the following alternative fuels are in use with such engines: plant based oils, FAME plant based oil esters, gas fuels (natural gas, biogas, propane-butane mixture), alcohols, esters.

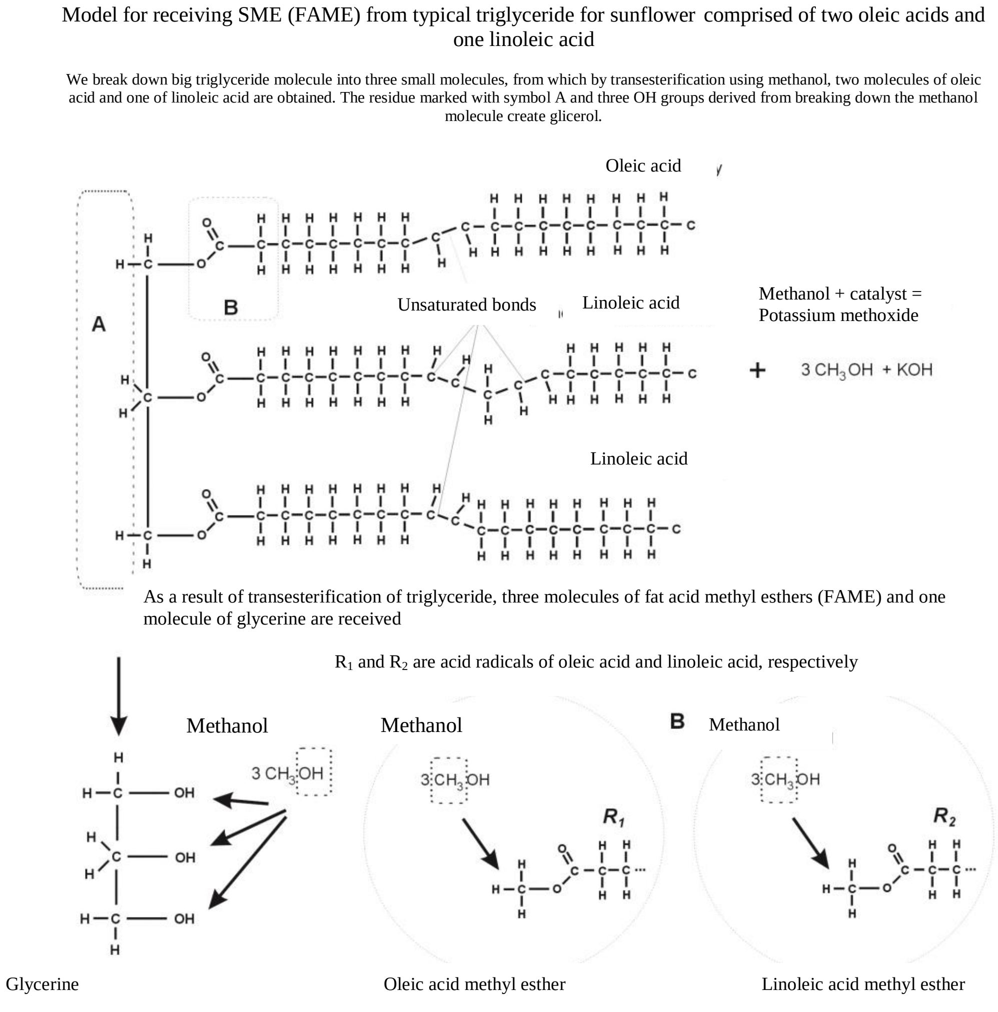
Plant based oils comprise a mixture of glycerine esters and fatty acids which contain between 14 and 24 carbon atoms in each molecule [12]. Plant based oil properties may be altered in a transesterification process [1,14]. It entails a reaction of methyl or ethyl alcohol with long chain fatty acid triglycerides in the presence of a catalyst. Plant based oil esters are obtained. During chemical reactions trivalent glycerine molecules transform into monovalent alcohol molecules which create monoesters with the remains of fatty acids [6].

FAME plant based oils fatty acids esters are currently used as an additive for diesels. They can also be used as a FAME fuel in a pure form (B100) to fuel compression-ignition engines. Their properties as fuels used to power internal combustion compression-ignition engines are normalised [10]. Currently, plant based oils esters are practically the only fuel which can be used in a pure form to power compression-ignition engines without making structural changes [1,2]. This stems from similarities in the physical and chemical properties of FAME and diesel. First and foremost, they exhibit good self-ignition properties, or a high cetane number without the need to introduce modifying additives. Plant based oils esters, when compared with diesels are denser and more viscous. Esters have a lower net calorific value than diesels due to the differences in the elementary compositions of these fuels. Esters contain approximately 11% oxygen. A weakness of esters is that they are more inclined to dissolve water and the presence of unsaturated bonds in molecules. Furthermore, as fuels, esters exhibit worse low temperature characteristics. In winter conditions esters may only be used if special additives are applied to reduce the crystallisation temperature. Similar to diesels, rapeseed oil fatty acids methyl esters contain long hydrocarbon chains. Thus, the two fuels are mutually soluble and may be mixed together in any proportions [5].

The problem with using esters obtained from different plant based oils in order to power piston internal combustion compression-ignition engines was and still does constitute the subject of tests and published papers [4,5,7,11,14]. In Poland, methyl esters are produced and manufactured from rapeseed oil. This is dictated by the prevalence of rape grown in moderate climate conditions. Various different plant based oils are used all over the world to manufacture esters. These include: soybean oil, sunflower oil, palm oil, linseed oil, peanut oil, cottonseed oil and others. This depends on the farming conditions suitable for oil seeds in the given climate.

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 [13]. 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 [15,16]. 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 63^{o}C 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.



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.

As a result of transesterification of triglyceride, three molecules of fat acid methyl esthers (FAME) and one molecule of glycerine are received

R_1 and R_2 are acid radicals of oleic acid and linoleic acid, respectively

Fig. 1. Diagram of sunflower oil transesterification [15]

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) [17]. 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).

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

TEST FACILITY

The test was performed at a test stand equipped with a PERKINS 1104D-44TA compression-ignition engine. The primary elements of the stand such as: the engine and the brake with a complete control system as well as systems necessary for the engine to operate have been assembled on a common stand. The AMX – 200/6000 type eddy current brake by ELEKTROMEX CENTRUM is able to take-off up to 200 kW and transfer torque of 700 Nm. The test stand is 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. A diagram of the test stand used for the tests is shown in figure 3.

Operation of the Perkins 1104D - 44TA engine is controlled using the test stand control module and a computer. The test stand control module can be used to alter the speed and load engine working conditions. It controls the engine and brake working conditions and diagnoses correct operation of the test stand. The computer makes it possible to record and archive the operating parameters of the tested engine, such as: crankshaft rotational speed, power, torque, fuel consumption, pressures and temperatures in engine and brake systems.

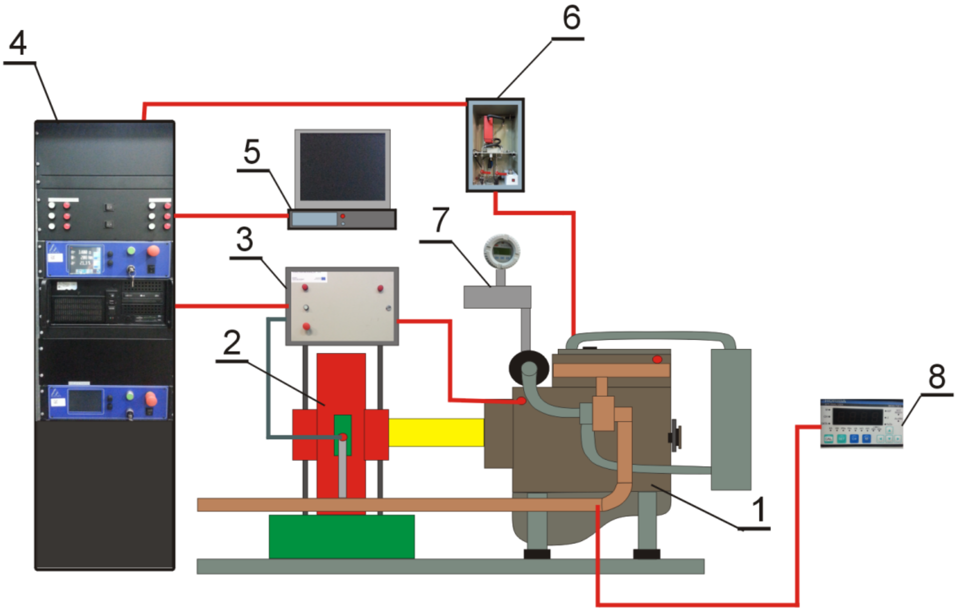


Fig. 3. Test facility, where: 1 - Perkins 1104D - 44TA engine, 2 - Automex AMX 200/6000 brake, 3 - measurement module, 4 - measurement cabinet with test facility control system, 5 - computer used to control test facility parameters and to archive test results, 6 - Automex ATMX2040 mass fuel dosage meter, 7 - ABB mass flowmeter, 8 - Horiba AFR Analizer Mexa-730 for measuring excess air λ

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.

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

The tests were performed on a Perkins 1104D - 44TA engine powered by SME sunflower oil fatty acids methyl esters. The esters used for the tests were manufactured in "BioEnergia" Małopolska Centre for Renewable Energy Sources.

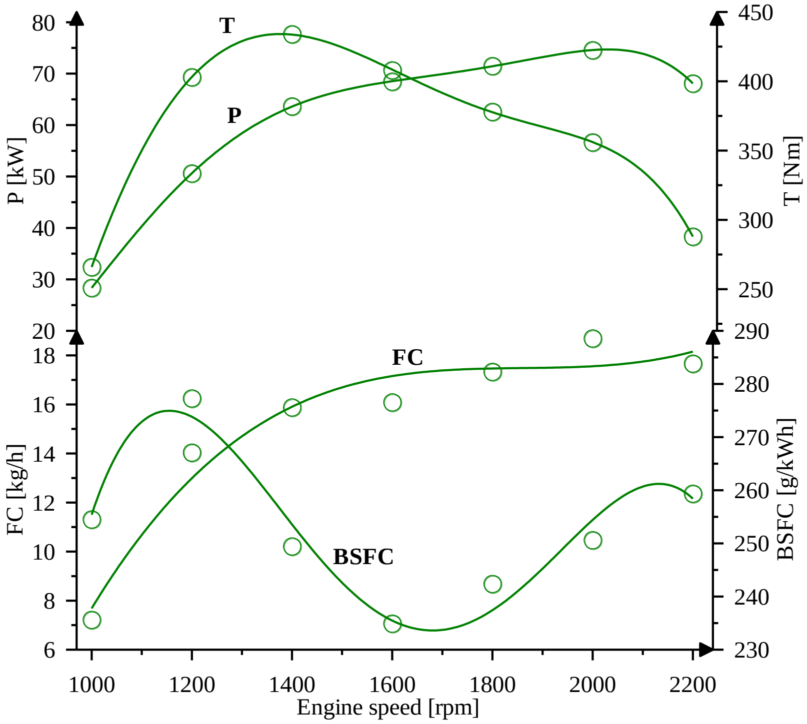
A reactor was used to that end which produces esters on a non-industrial scale and is primarily dedicated for private persons, farmers, transport companies and the like. It facilitates the production of methyl and ethyl esters from raw, refined and used plant based oils as well as animal fats.

In order to determine the impact of using sunflower oil esters on selected Perkins 1104D - 44TA engine performance indicators, the tests were also carried out with the engine running on diesel. The engine running on diesel was tested in the same working conditions as when fuelled using SME sunflower oil methyl esters. The tests were carried out under engine operation according to an external speed characteristic. The crankshaft rotational speed was varied between 1000 rpm and 2200 rpm. The tested engine generates maximum brake horsepower under rotational speed of 2200. According to manufacturer's data, maximum torque is generated with the crankshaft rotational speed of 1400 rpm. During tests in pre-determined working conditions of the tested engine, N_e brake horsepower, M_o torque and FC hourly fuel consumption were measured. Instant fuel consumption BSFC was also calculated.

PERKINS 1104D - 44TA ENGINE CHARACTERISTICS

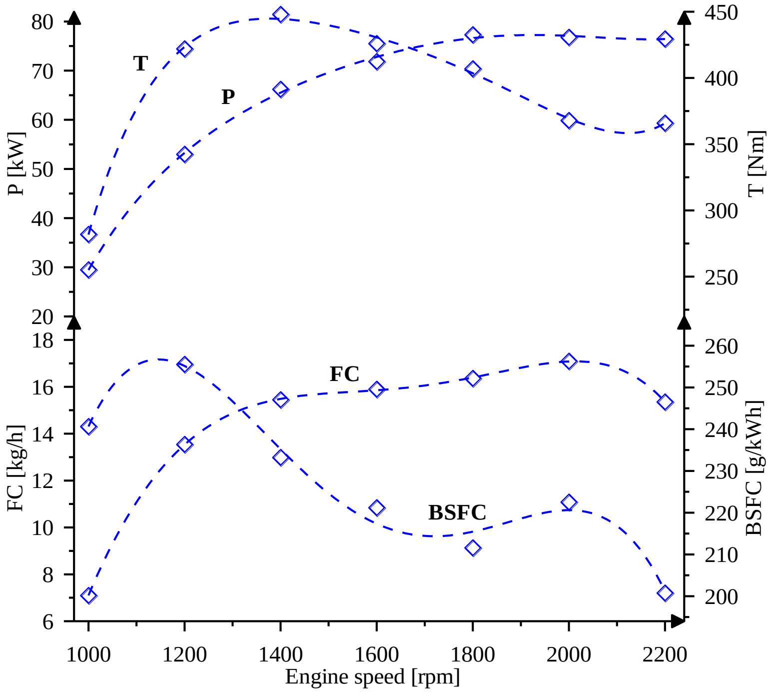
The tests aimed to determine the impact of using pure rapeseed oil fatty acids methyl esters to fuel a Perkins 1104D - 44TA engine on its basic operating parameters. Figure 4 depicts the external speed characteristic for the tested engine fuelled by SME sunflower oil methyl esters. Engine operating problems were not identified whilst determining this characteristic at a test engine stand. Figure 5 shows a Perkins 1104D - 44TA engine external speed characteristic determined when powered by commercial diesel.

Figure 6 shows Perkins 1104D-44TA engine power curves obtained when fuelled by SME sunflower oil methyl esters and diesel. When fuelled by SME esters, every measurement point returned lower engine brake horsepower values (fig. 7). The biggest engine power decrease was observed for crankshaft rotational speed of n = 2200 rpm. According to manufacturer's data the engine generates maximum power under such crankshaft rotational speed. The engine running at crankshaft rotational speed of n = 2200 rpm and fuelled by esters retuned a power reduction of approximately 11% as compared to diesel. At other measurement points under lower crankshaft rotational speeds, the brake horsepower of the engine fuelled by esters was less by between approximately 2.9% and approximately 7.5% as compared to diesel. For crankshaft rotational speed of n = 2000 rpm the power generated by a SME fuelled engine was only approximately 2.9% less than when tuning of diesel.



T – torque, P - effective power, FC - fuel consumption per hour, BSFC - fuel consumption per unit of power

Fig. 4. External speed characteristic for the Perkins 1104D-44TA engine fuelled by SME esters



T – torque, P - effective power, FC - fuel consumption per hour, BSFC - fuel consumption per unit of power

Fig. 5. External speed characteristic for the Perkins 1104D-44TA engine fuelled by diesel

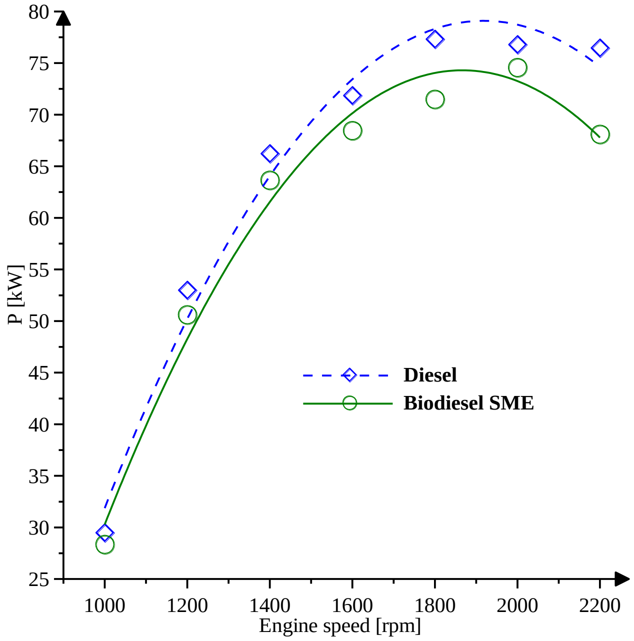


Fig. 6. A comparison of brake horsepower for the Perkins 1104D-44TA engine fuelled by SME esters and diesel, operating according to a speed characteristic.

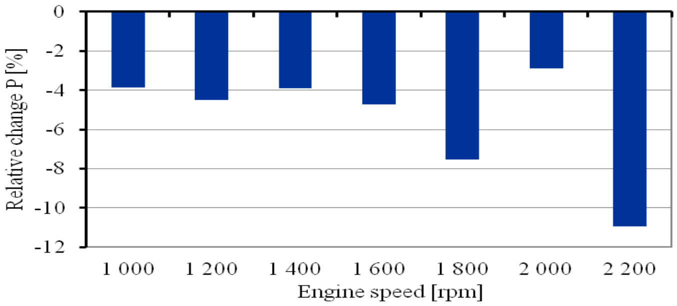


Fig. 7. The relative change of N_e brake horsepower for the Perkins 1104D-44TA engine fuelled by SME esters and diesel, operating according to an external speed characteristic.

Figure 8 shows a comparison of torque characteristics for the Perkins 1104D-44TA engine fuelled by SME sunflower oil methyl esters and diesel under operation according to an external speed characteristic. Smaller torque values were obtained at each measurement point for the engine fuelled by SME esters (fig. 9). The largest torque decrease was observed for crankshaft rotational speed of 2200 rpm. At that point, the torque generated by the engine powered using SME esters is approximately 21% smaller than the torque generated when running on diesel. At other measurement points the torque of the engine fuelled by sunflower oil esters was less by between approximately 3.1% and approximately 7.1% as compared to conventional fuel.

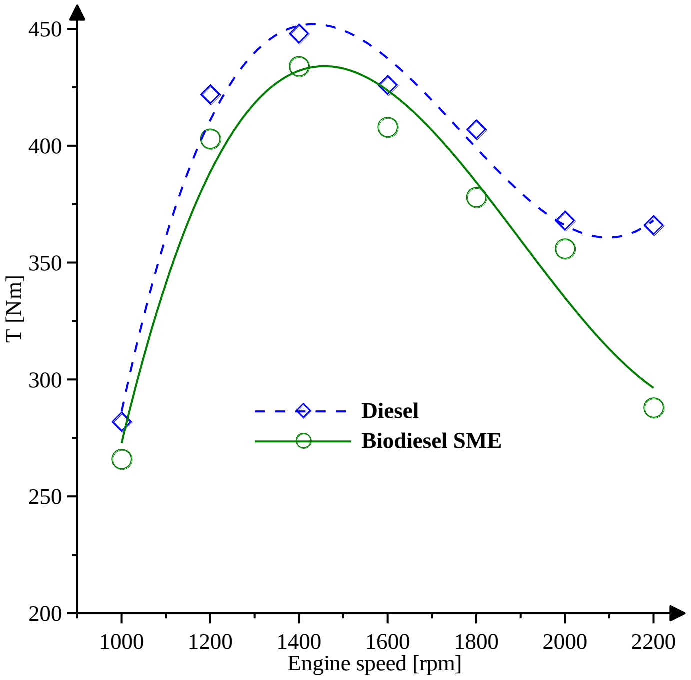


Fig. 8. A comparison of M_o torque for the Perkins 1104D-44TA engine fuelled by SME and diesel, operating according to an external speed characteristic.

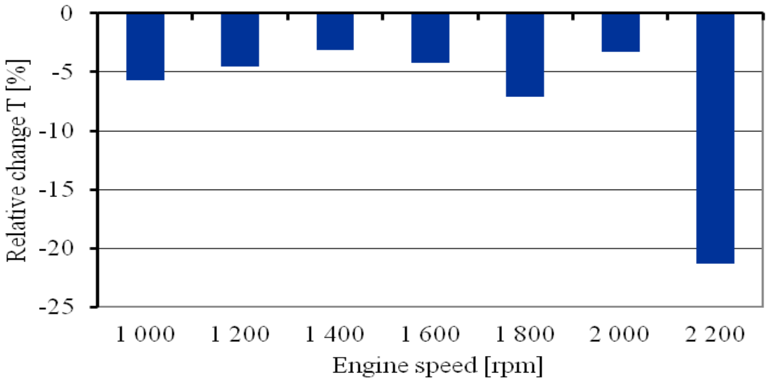


Fig. 9. The relative change to M_o torque for the Perkins 1104D-44TA engine fuelled by SME esters and diesel

During tests at a test stand, FC hourly fuel consumption was measured using a mass dosage meter. Figure 10 shows a comparison of FC hourly average fuel consumption for the Perkins 1104D-44TA engine fuelled by SME sunflower oil methyl esters and diesel under operation according to an external speed characteristic. At every measurement point, the FC hourly fuel consumption for the engine powered by SME sunflower oil esters exceeded that of the engine running on diesel (fig. 11). Powering the engine using SME sunflower oil methyl esters resulted in an increase to the hourly fuel consumption rate from approximately 1.1% to approximately 15%. However, that was to be expected, as the net calorific value of SME Biodiesel is smaller and stands at approximately 37.5MJ/kg, whilst for diesel it is approximately 43MJ/kg. The fact that within the scope of low crankshaft rotational speeds, between 1000 rpm and 1600 rpm, the increase in fuel consumption was only between approximately 1.1% and approximately 3.6%/ is noteworthy. This means that within this scope, fuel was combusted more effectively and better thermodynamic efficiency was attained. Above crankshaft rotational speeds of n = 1600 rpm the use of SME sunflower oil methyl esters increases gradually and profoundly as compared to diesel consumption. For crankshaft rotational speed of n = 2200 rpm, the consumption of esters by the tested engine was 15% more than the design consumption of diesel.

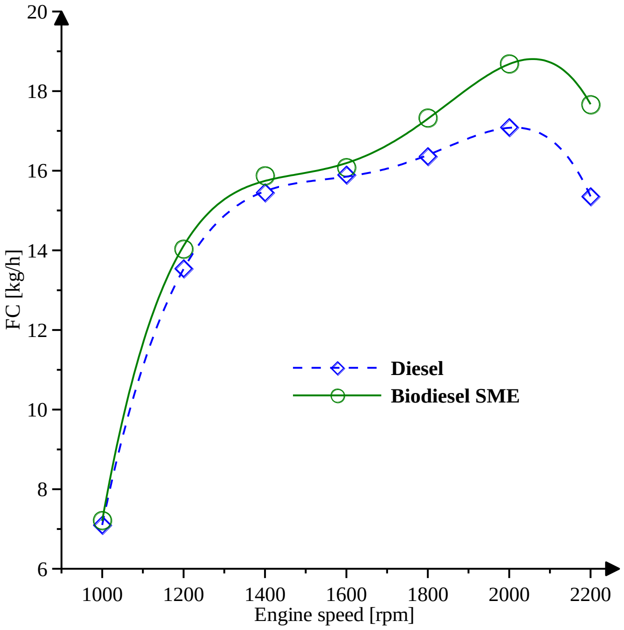


Fig. 10. A comparison of FC hourly fuel consumption for the Perkins 1104D-44TA engine fuelled by SME esters and diesel, operating according to a speed characteristic

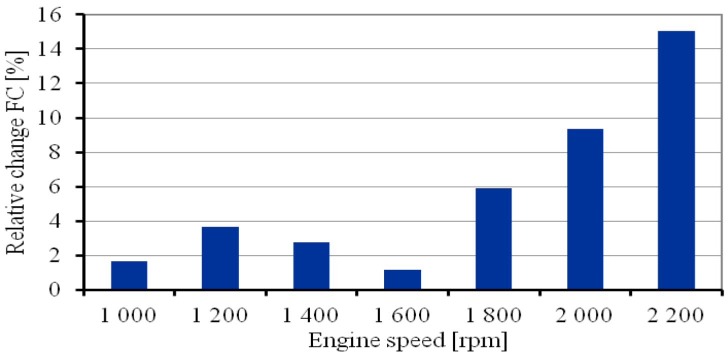


Fig. 11. The relative change of FC hourly fuel consumption for the Perkins 1104D-44TA engine fuelled by SME esters and diesel, operating according to an external speed characteristic

Instant fuel consumption BSFC was calculated using FC hourly fuel consumption and N_e engine brake horsepower figures for the Perkins 1104D - 44TA engine under operation according to an external speed characteristic. It transpired that using SME to power the engine unambiguously higher values of instant g_e fuel consumption were obtained than when running on diesel (fig. 12). Figure 13 depicts the relative change to the BSFC instant fuel consumption vale for the tested engine powered by SME esters as compared to diesel. Instant fuel consumption for the Perkins 1104D - 44TA engine increased from approximately 5.7% for rotational speed of 1000 rpm to approximately 29.2 % for crankshaft rotational speed of n = 2200 rpm. A significant increase in the BSFC instant fuel consumption for the engine powered by SME sunflower oil methyl esters as compared to diesel can be observed for crankshaft rotational speeds in excess of 1600 rpm.

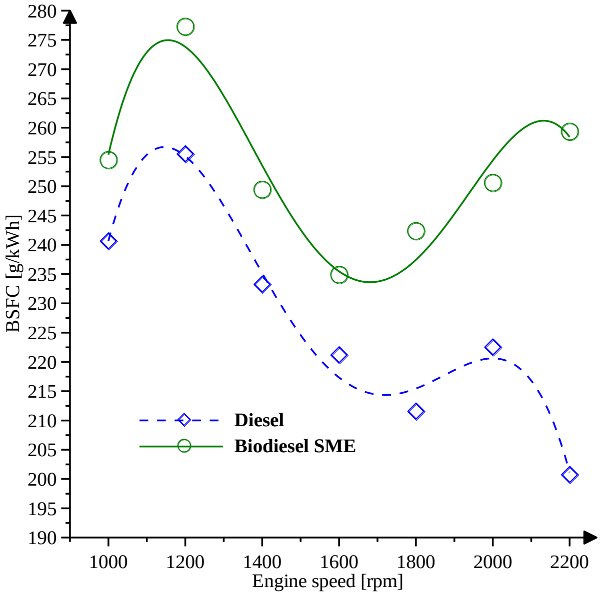


Fig. 12. A comparison of BSFC instant fuel consumption for the Perkins 1104D-44TA engine fuelled by SME esters and diesel, operating according to a speed characteristic

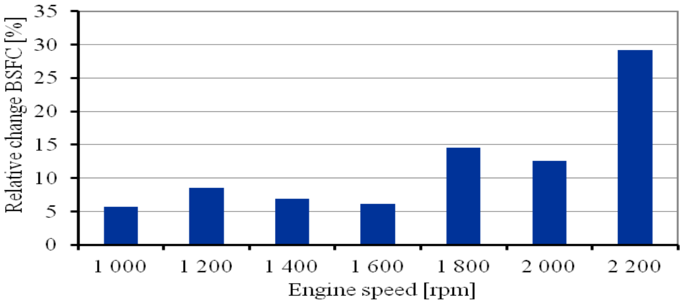


Fig. 13. The relative change of g_e instant fuel consumption for the Perkins 1104D-44TA engine fuelled by SME esters and diesel, operating according to an external speed characteristic

CONCLUSIONS

During testing at a test engine stand, a Perkins 1104D - 44TA engine operating according to an external speed characteristic was fuelled using SME sunflower oil fatty acids methyl esters and diesel as benchmark. The used sunflower oil esters were manufactured by a small non-industrial scale reactor, ideally suited for farms and to satisfy individual demand. Problems with engine operation during tests performed on an engine fuelled by sunflower oil esters were not observed.

A Perkins 1104D - 44TA engine operating according to external speed characteristics fuelled by sunflower oil methyl esters returned smaller brake horsepower and torque values at every measurement point than when running on diesel. The average reduction to brake horsepower for points at which measurements were taken was approximately 5.5%, with an approximately 7% average torque reduction. However, it should be pointed out that out of all the measurement points the biggest decrease in brake horsepower and torque was observed for crankshaft rotational speed of 2200, which is the speed at which the tested engine generates maximum power.

Hourly Perkins 1104D - 44TA engine fuel consumption, operating under external speed characteristic, was higher at every measurement point when fuelled by SME sunflower oil methyl esters than when running on diesel. The average increase in fuel consumption across all measurement points when running on SME esters as compared to diesel was 5.6%. The fuel consumption increase is larger at higher engine crankshaft rotational speeds.

Tests of the Perkins 1104D - 44TA engine fuelled by SME sunflower oil methyl esters retuned a decrease in brake horsepower and an increase in hourly fuel consumption as compared to diesel. This resulted in clearly higher instant fuel consumption figures when running on SME esters. This increase was even as much as 29.2% for crankshaft rotational speed. The average BSFC instant fuel consumption increase calculated across all measurement points for the tested engine fuelled by SME sunflower oil esters operating under an external speed characteristic was approximately 12% as compared to diesel. This correlates with SME's lower net calorific value determined using calorimetry. The net calorific value of sunflower oil esters is approximately 11% (m/m) less.

The largest decrease to the Perkins 1104D - 44TA engine brake horsepower powered by SME sunflower oil methyl esters was observed for crankshaft rotational speed of n = 2200 rpm. For that rotational speed the hourly fuel consumption increase was also the largest when running on SME esters as compared to diesel. Also for rotational speeds of 1800 rpm and 2000 rpm the hourly consumption of plant based fuel is clearly higher than for smaller rotational speeds as compared to diesel. This might indicate that under these engine working conditions the fuel - air mixture creation process, when running on esters is difficult and the combustion process is not efficient. Esters do not evaporate as easily as diesel. It could be suggested that under higher crankshaft rotational speeds, the intake valve should open earlier when the engine is powered by esters as compared to conventional fuels.

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