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ASSESSMENT OF DYNAMIC QUALITIES OF THE G9T ENGINE WITH COMMON RAIL SYSTEM, FED WITH BATTLEFIELD-USE FUEL BLENDS WITH A BIOCOMPONENT

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Abstract

The main aim of the study was to experimentally determine the influence of fuel blends of F-34 with biocomponents (rapeseed methyl esters and methyl alcohol) on the performance of an engine with high pressure fuel injection; Common Rail system was used as the example. The study included measurements of useful parameters of combustion and composition of exhaust gas. The studied engine was Renault G9T engine with Common Rail fuel system, fed with the following fuels: fuel base (diesel oil); aviation fuel, code NATO F-34; fuel blends of F-34 and rapeseed methyl esters of higher fatty acids; fuel blends of F-34 and anhydrous ethyl alcohol.

The study showed that the parameters of Renault G9T engine with high pressure injection system fed with fuel blends of F-34 with biocomponents changed in comparison to those obtained with the use of the fuel base: diesel oil.

As a result of the study it must be stated that fuel blends of F-34 with RME and F-34 with ethyl alcohol can be used as alternative fuel for diesel engines with high pressure Common Rail injection system.

***Keywords**: combustion engine, fuel system, f-34 fuel, ester*

1. Introduction

Self-ignition engine can easily be adjusted to work with other types of fuel. In order to achieve that, additional devices or special constructional solutions are implemented. The use of multi-fuel engine in military vehicles allows for operating in difficult conditions, even when the fuel base (diesel oil) is lacking. However, such solutions increase the complexity of the engine's design and its cost. Alternatively to this, universal fuel can be used for all the engines of military use. F-34 is a universal fuel of this kind; its parameters are determined in the STANAG 2536 doctrine. It has been designed for running land vehicles and land-based aircraft [1,2].

2. Aim and scope of the study

The present situation on the oil market and prognosed decrease in the natural oil resources make looking for alternative types of fuel a necessity. At the same time in military units there has been visible increase in the number of vehicles with self-ignition engines, high-pressure injection systems with fuel injection units and Common Rail type systems. Regardless of the way in which high pressure of injection is obtained, the main problem are the phenomena occurring during the injection of fuel under high pressure, their influence on the fuel and the course of its injection, combustible mixture creation and combustion. The main aim of the study was to experimentally determine the influence of F-34 fuel and blend of F-34 with a RME biocomponent on the performance of an engine with high pressure fuel system; the example used was one with Common Rail system. The study included measurements of the useful parameters of combustion, composition of exhaust gas in function rotation speed and engine load, course of combustion and determination of the engine's dynamic characteristics. The study was conducted with the engine running in transient states, in a replacing cycle labeled as the ECE R15 cycle.

3. Test bench

Figure 1 shows the scheme of test bench used for the study in transient states (ECE R15 cycle). It is impossible to run such cycle manually with the use of engine test house; for this reason it was necessary to develop specialized software for automatic control of the engine and the house's measurement systems.

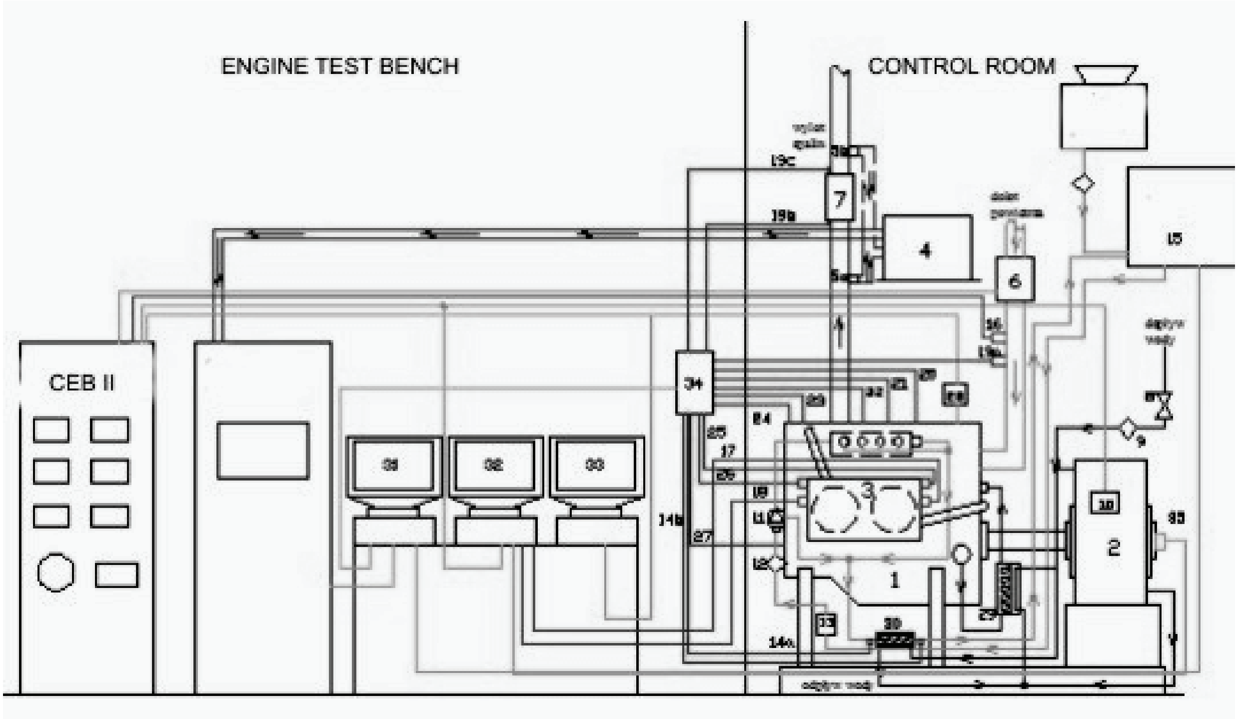


Fig. 1. The scheme of test bench for testing the engine in transient states:
1 –Renault G9T engine, 2 – electro rotation brake, 3 – air cooler, 4 – prefilter, 5a – exhaust gas intake probe before the catalytic converter, 5b – exhaust gas intake probe behind the catalytic converter, 6 – swinging flap airflow meter, 7 – catalyst converter, 8 – globe valve for water inlet, 9 – water filter, 10 – torque sensor, 11 – high pressure pump, 12 – fuel filter, 13 – fuel pump, 14a –thermocouple for fuel temperature measurement before the fuel cooler, 14b- thermocouple for fuel temperature measurement behind the fuel cooler, 15- weight for specific fuel consumption measurement, 16 – intake pressure sensor,17 – pressure sensor at the cooler's inlet, 18 – pressure sensor at the cooler's outlet, 19a – thermocouple for measuring inlet air temperature, 19b- thermocouple for temperature measurement before the catalyst converter,19c- thermocouple for temperature measurement after the catalyst converter, 20 – thermocouple for measuring the temperature of liquid coolant, 21 – thermocouple for measuring the temperature of exhaust gas before the EGR valve, 22 – thermocouple for measuring the temperature of exhaust gas behind the EGR valve, 23 – thermocouple for measuring the temperature of exhaust gas behind the turbine, 24 – thermocouple for measuring the temperature of exhaust gas before the turbine, 25 – thermocouple for measuring the temperature of air at the cooler's inlet, 26 – thermocouple for measuring the temperature of air at the cooler's outlet, 27 – thermocouple for measuring the temperature of oil, 28 – servomechanism for controlling the engine's rotational speed, 29 – water to water heat exchanger, 30 – water-gas heat exchanger, 31- computer registering specific fuel consumption, engine's temperatures and exhaust gas emission per work cycle, 32- computer registering rotational speeds and torques per work cycle, 33- computer controlling the engine's performance during the replacing cycle, 34- thermocouple connector, 35 – the engine's torque sensor

Reproducing the ECE R15 cycle with the use of the computer allowed for repeatable reproduction of the cycle. The study included constant acquisition of the most important parameters of the engine's performance. Computers no. 31 and 32 were used for registering the following data:

- hourly fuel consumption and composition of exhaust gas,
- temperature from individual thermocouples,
- torque and engine speed.

4. Results

When the engine was working with blends of the different fuels during the reproduction of the ECE R15 cycle (simulated engine running when driving in the city – UDC cycle), the study was divided into the following parts:

- working with fuel blends of F-34 and methyl ester, and fuel bases,
- working with fuel blends of F-34 and methyl alcohol.

Due to limited study possibilities (lack of chassis dynamometer and of a vehicle with G9T engine), the test was carried out at dynamometric bench with the use of engine brake. The procedure of controlling the engine and its load was carried out with the use of a computer algorithm implemented for tests of this type. On the first stage the test was carried out during cold start and the engine working while still cold. On the next stage the test was carried out on a engine warmed up to its operating temperature. At the dynamometric bench the engine's and brake's work cycle was controlled by the computer with properly calculated values of engine speed and extortion by the brake (from traveling speed). The creation of the proper algorithm for controlling the engine allowed for running driving test in the conditions in accordance to Directive 70/220/EWG. The time of every cycle was equal: 14 min (780s). The times of elementary cycles were also equal: 3.25 min (195s).

4.1. Reproducibility assessment

The first stage dealt with the assessment of the reproducibility of the results obtained. The aim was to confirm that the method developed is useful for studying the influence of the fuel used on the parameters of G9T engine's performance in transient states.

The analysis of the results began with superimposition of the engine's torques. This allowed for the assessment of the reproducibility of runs. Figure 2a shows torque changes for warmed engine working with B20 fuel, obtained in the same conditions.

The two cycles shown in Fig. 2 a), b). were conducted in the same conditions of the engine's running. It is visible that the diagrams of runs are ideally overlapping; therefore reproducibility of the measurements' results is very good in this case. Additionally, in order to assess reproducibility of the runs, mean values were calculated; they are presented in Table 1.

Tab. 1. Mean values of the engine's torque and engine speed for B20 fuel with warmed engine

Sample number	Mo [Nm] average value	n [rpm/min] average value
Attempt 1	87.1	2047.2
Attempt 2	86.4	2032.4
Attempt 3	86.8	2036.4
Attempt 4	86.7	2038.4
Maximum difference	0.75%	0.72%

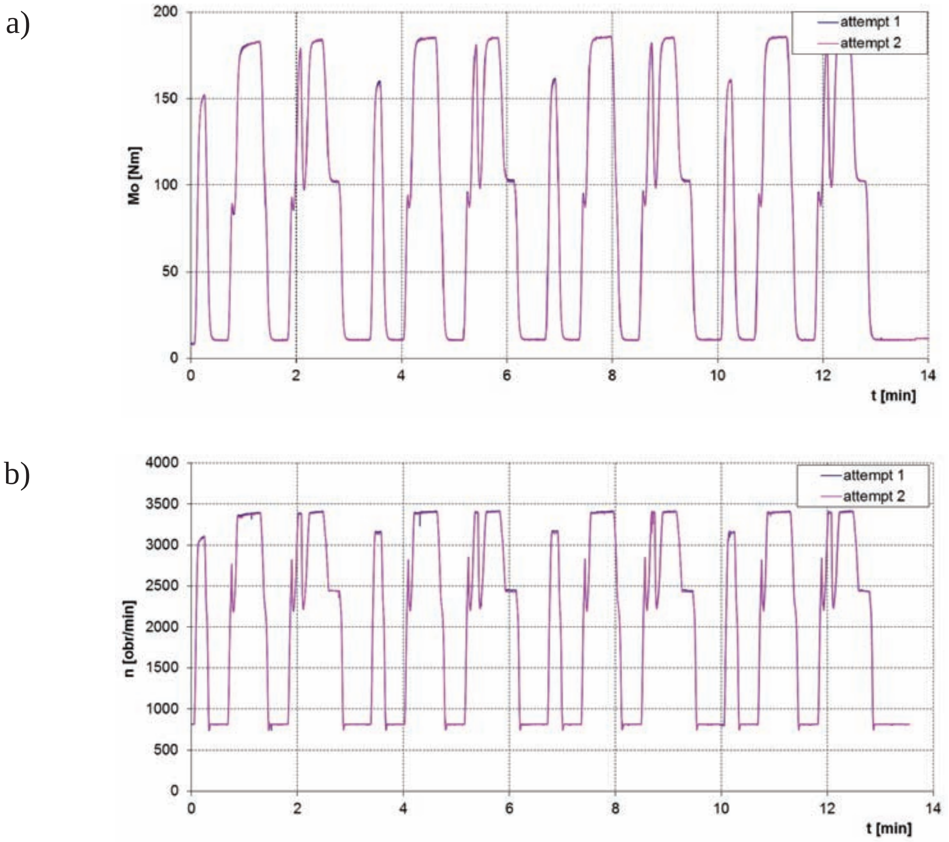


Fig. 2. Comparison of instantaneous values for B20 fuel with warmed engine: a) torque, b) engine speed

It shows that mean values of the torque changes differ by ca. 0.75% compared to the first run. The differences between mean values of engine speed changes are similarly negligible: 0,72%. Therefore it may be assumed that reproducibility of torques and engine speeds is very good in every cycle.

Reproducibility of the other values obtained was assessed in a similar way. Table 2 presents mean values of these runs. The difference in temperature T1 between mean values of runs is ca. 0.02%. This may be assumed to be admissible error; reproducibility of the runs is very good. For temperature T2 the difference between mean values is 0.1%. It is also a negative value, which is why reproducibility of the runs for this temperature can also be assumed to be very good. The difference between mean values of T3 is 0.47%: again, it may be considered satisfactory. Clearly, the difference between mean temperature values in this case is lower than 1%; reproducibility of these runs may therefore be considered satisfactory.

Tab. 2. Mean values of compounds content in exhaust gas and temperatures for B20 fuel

Sample number	NO_x [ppm]	THC [ppm]	CO2 [%]	O2 [%]	T1 [^{o}C]	T2 [^{o}C]	T3 [^{o}C]
Attempt 1	619.4	21.2	4.82	13.5	313.6	296.6	340.3
Attempt 2	619.0	21.0	4.82	13.6	313.3	296.3	341.4
Attempt 3	618.8	21.1	4.83	13.7	313.4	296.4	341.7
Attempt 4	618.0	20.8	4.84	13.8	313.2	296.3	341.9
Maximum difference	0.22%	1.76%	0.05%	0.39%	0.1%	0.02%	0.47%

For NO_x the difference between four runs is 0.22%. For hydrocarbons it is 1.76%. The differences between values for these compounds are small, considering the measurement units (ppm) pointing to negligible content of this compound in the sample. Similarly, measurements of CO_2 and O_2 do not differ substantially. The difference between mean values of CO_2 and O_2 are 0.05% and 0.39%, respectively. Such small differences may be considered negligible; therefore, reproducibility of the measurements is very good.

The measurements also included measuring hourly fuel consumption. The difference between mean values of this parameter is small, too: 1.3%.

4.2. The influence of tested fuels on the engine's performance in transient states

The analysis of the results consisted of 3 stages:

- working with fuel blends of F-34 with methyl ester and fuel bases,
- working with fuel blends of F-34 with ethyl alcohol,
- working with ternary fuel blends (of F-34 fuel, methyl ester and ethyl alcohol).

The study included the use of diesel oil as the fuel base, pure F-34 fuel and its blends with methyl esters of fatty acids: 20%, 40%, 60% and 80% of ester in F-34 fuel and 100% pure ester.

Figure 3 shows basic engine parameters for different fuels. It may be observed that increasing the amount of RME in F-34 fuel causes notable decrease in power and torque. 40% ester content causes a little (ca. 2%) increase in power compared to B-20 blend. The reason may be increased viscosity of F-34 fuel, due to which the blend reached its optimal spray coverage value and atomization. However, further increasing of the RME content caused losses in power and torque, resulting from increased fuel thickness and its inaccurate atomization. The calorific value of these fuels had notable influence on torque changes. Calorific value of RME is much lower than calorific value of diesel oil and F-34 fuel. Growing content of ester in F-34 fuel negatively influenced calorific value of the resulting blend. This was the reason for visible decrease of torque. Such decrease (ca. 6%) can also be noticed while switching from B-60 to B-80 fuel. Little ester content in F-34 compared to diesel oil did not cause any significant changes in the engine's performance. However, in comparison to pure F-34, torque was lower by 2÷3% and power by 3%.

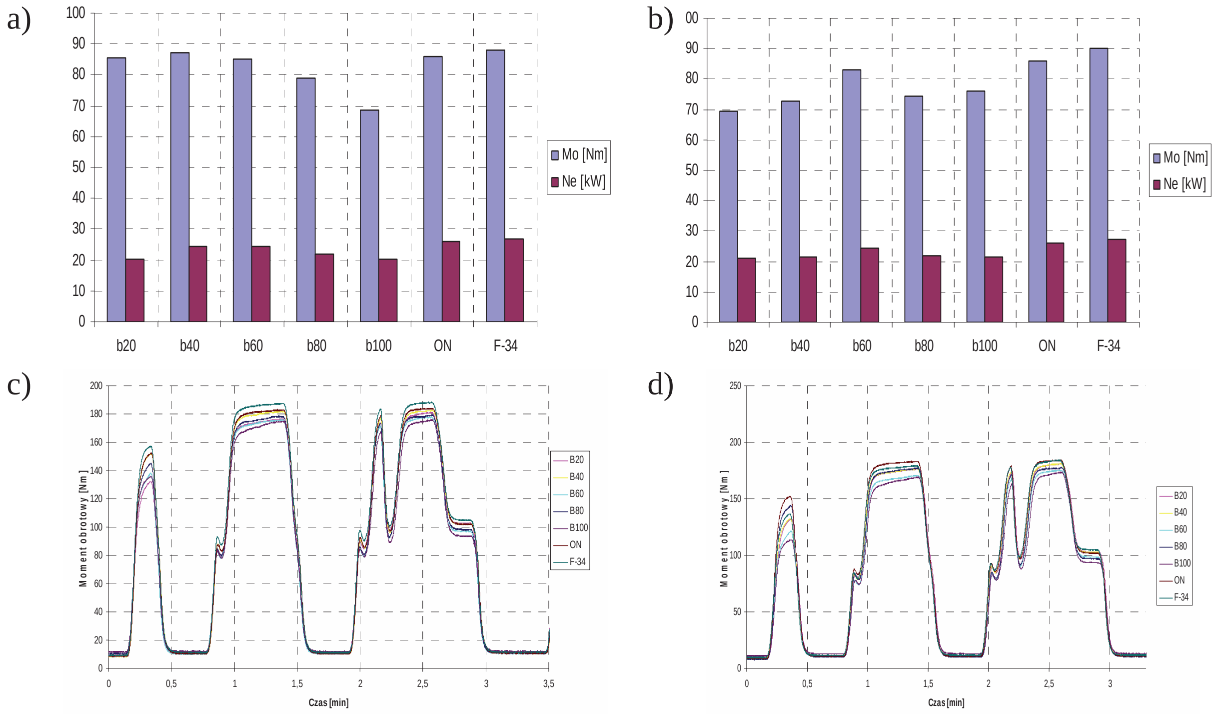


Fig. 3. Mean values of torque and effective power with the use of different fuels for: a) warmed engine, b) cold engine, a chosen phase of torque changes for: c) warmed engine, d) cold engine

The performance was worst while feeding the engine with pure fatty acids ester. This was caused by the smallest calorific value of this fuel compared to the others and by increased viscosity, which may cause problems with injectors control.

Performance of cold engine is shown in Fig. 3 b), d). When different blends of F-34 fuel are used, changes of torque and effective powers are clearly visible. The engine's performance was best for B60 blend. In the case of the other blends, changes ranged from 1 to 2%. The performance was optimal (90Nm and 27kW) when pure F-34 fuel was used. Even as little as 20% ester content caused ca. 30% loss of power and torque.

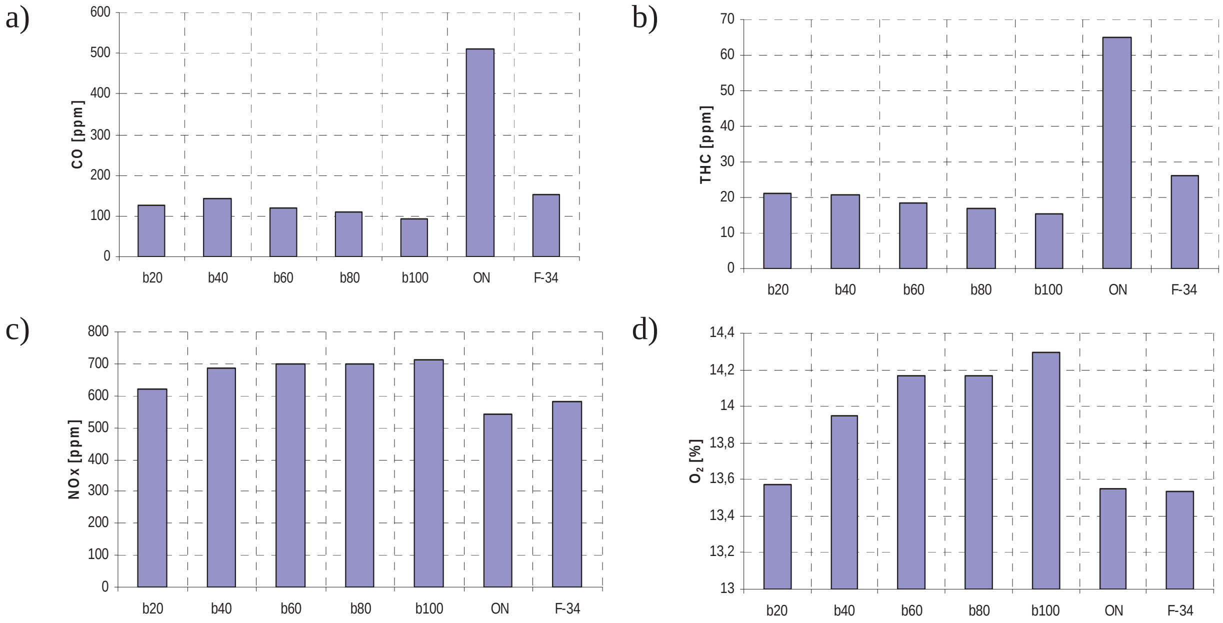
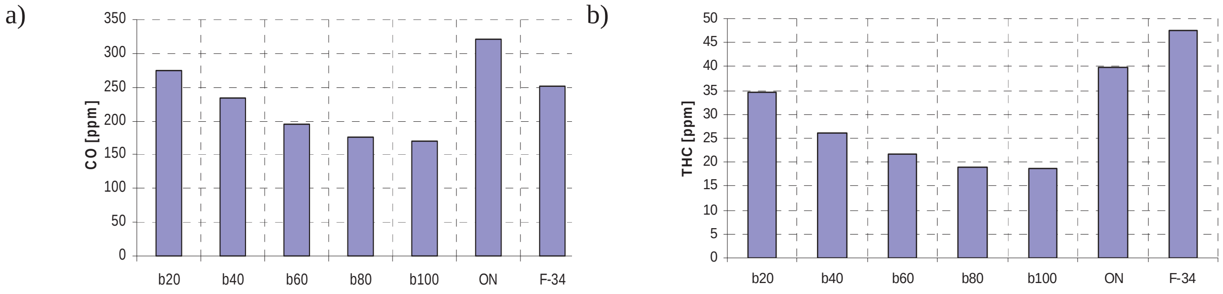


Fig. 4. Mean values of different compounds content in exhaust gas for different fuels when the engine was warmed: a) carbon monoxide, b) hydrocarbons, c) nitric oxides, d) oxygen

The greater methyl ester content in F-34, the smaller the content of carbon monoxide and hydrocarbons in exhaust gas. Increased content of methyl ester in F-34 fuel causes minor decrease of carbon monoxide and hydrocarbons content. When the engine was warmed, this content was lowest for B-100 fuel. The difference was, however, visible in comparison to diesel oil, for which the carbon monoxide and hydrocarbons content in exhaust gas was nearly three times higher. The nitric oxides content in exhaust gas was lowest for diesel oil. Compared to B-100 fuel, NO_x content in exhaust gas for diesel oil was ca. 25% lower.

Similar results were obtained when the fuel was fed to cold engine. Decrease in hydrocarbons content is visible while ester content is growing in F-34 fuel. The reason for that is increasing amount of oxygen particles in fuel and increasing cetane number, which improves the fuel's ignition characteristics and the combustion process (complete combustion). There is also visible decrease of carbon monoxide content when RME content in F-34 fuel increases. On the other hand, nitric oxides content increases, which may be caused by greater amount of molecular oxygen in the blend.



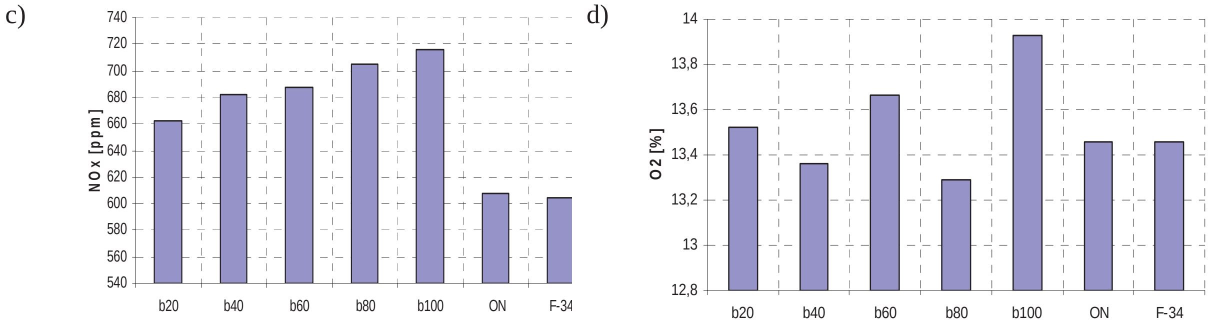


Fig. 5. Mean values of different compounds content in exhaust gas for different fuels when the engine was cold: a) carbon monoxide, b) hydrocarbons, c) nitric oxides, d) oxygen

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The change in rapeseed methyl esters content in F-34 fuel is followed by change in hourly fuel consumption. Together with increasing ester content in F-34 fuel, the hourly fuel consumption increases. In the case of diesel oil and F-34 fuel the difference in hourly fuel consumption is 1.6%. The results of the study also show that even small RME content in F-34 fuel greatly increases hourly fuel consumption (B20). Engine working with F-34 fuel has smaller hourly fuel consumption than one working with diesel oil. This is caused by greater viscosity of diesel oil compared to F-34 fuel.

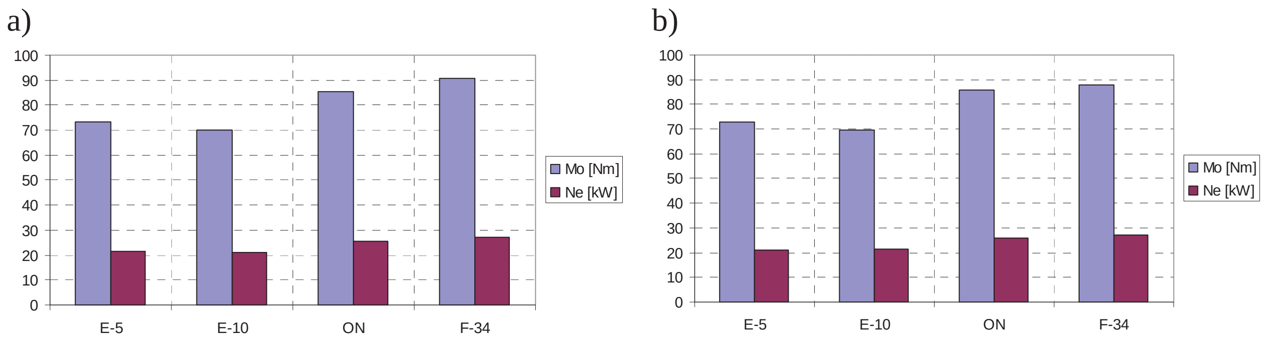
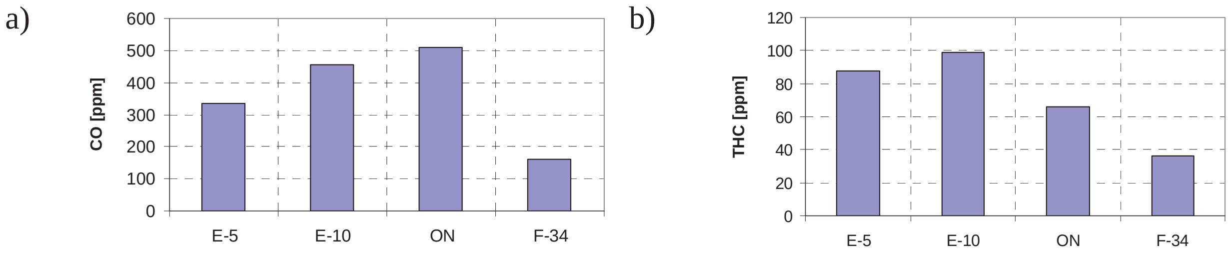


Fig. 6. Mean torque and mean effective power values with the use of different fuels: a) cold engine, b) warmed engine

The study was carried out with the use of diesel oil as the fuel base, pure F-34 fuel and its blends with 5% and 10% alcohol. The results were analyzed in the same way as for methyl ester. The description of the results obtained has been limited to presenting mean values obtained for different runs.



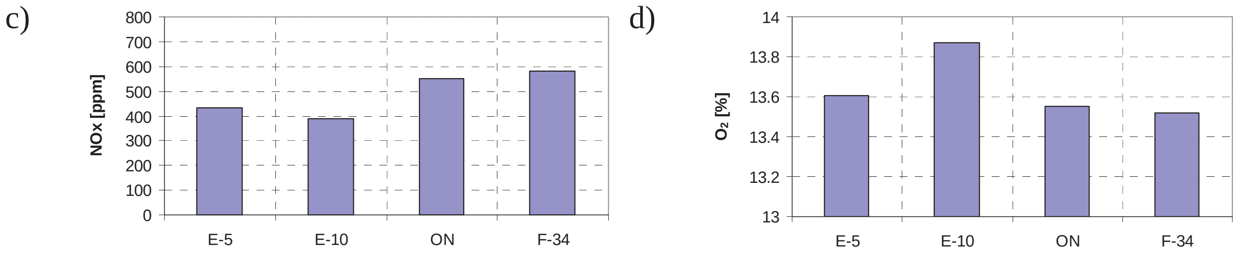


Fig. 7. Mean values of different compounds content in exhaust gas for different fuels when the engine was warmed: a) carbon monoxide, b) hydrocarbons, c) nitric oxides, d) oxygen

Adding alcohol to F-34 fuel causes notable decrease in power and torque. 5% alcohol content (E-5 blend) causes ca. 9% decrease in power, while in the case of E-5 it is ca. 13%. The reason for that is decreased calorific value of the blends following the increase in alcohol content and decrease in the engine's efficiency. Calorific value of the blends is much lower than in the case of diesel oil and F-34 fuel. Figure 7 shows mean values of CO, THC and NO_x content in exhaust gas for warmed engine.

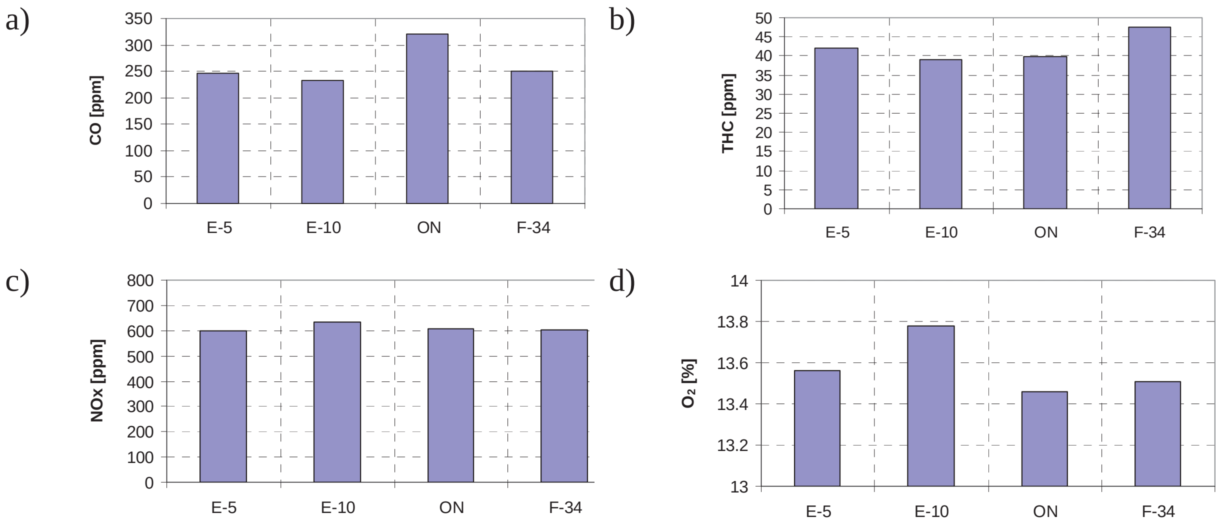


Fig. 8. Mean values of different compounds content in exhaust gas for different fuels when the engine was cold: a) carbon monoxide, b) hydrocarbons, c) nitric oxides, d) oxygen

Increased alcohol content in F-34 fuel is followed by increased carbon monoxide and hydrocarbons content in exhaust gas. CO and THC content for E-5 blend is twice (and in the case of E-10 blend thrice) as great as that of F-34 fuel. This is caused by the blend's lower cetane number fed to the cylinder, which in turn shortens the combustion process and therefore increases the content of incomplete combustion's residue in exhaust gas.

5. Conclusion

1. The study proved that the developed method of reproducing a replacing cycle is useful for studying the influence of the fuel used on the parameters of G9T engine's performance in transient states.
2. The character of fuel used has no influence on reproducibility of the runs obtained. The runs do not differ from one another by more than 1%; therefore the measurements may be assumed to have been done with satisfactory accuracy and reproducibility.
3. The use of RME, alcohol and F-34 B fuel blends caused increased mean hourly and

specific fuel consumption with accompanying decrease of mean power achieved by the engine. This is caused by decrease in calorific value in the blends fed to the cylinder. The changes are dependent upon biocomponent percentage in the blend. As the percentage increases, so do the changes.

4. The use of F-34 fuel blends with biocomponents is profitable in that it decreases carbon monoxide and hydrocarbons emission, which is caused by increased amount of molecular oxygen in air-fuel mixture.
5. The use of F-34 fuel blends with biocomponents is adverse in that it increases nitric oxides emissions.

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