ASSESSMENT OF START-UP CHARACTERISTICS OF G9T ENGINE AT LOW TEMPERATURE, FED WITH F-34 FUEL BLENDS WITH BIOCOMPONENTS

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Abstract

The main aim of the study was to experimentally determine the influence of low temperature on start-up and performance of an engine with high pressure fuel system; Common Rail system was used as the example here. The study included measurements of useful parameters of combustion and composition of exhaust gas, and determination of the influence of the fuel used on catalytic converter's performance.

The studied engine was Renault G9T engine, 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.

The process of engine's ignition relies mainly on the proper functioning of engine starting system, fuel system and devices assisting the start-up.

Keywords*: combustion engine, fuel system, f-34 fuel, ester, code NATO, Renault G9T*

1. Introduction

Engine starting system forces rotations of the engine's crankshaft and, consequently, the occurrence of all the processes accompanying the creation and firing of the air-fuel mixture. The use of battery of greater nominal capacity (170 Ah) guaranteed supplying the crankshaft with the rotation speed necessary for starting the engine in assumed conditions.

The engine is equipped with pre-ignition plugs. Their heating is controlled by block heating glow plugs. Function of heating glow plugs occurs both before and after the engine's start-up. The duration of heating before start-up is signalized by an indicator lamp and dependent on the temperature of the liquid and battery's voltage. In any case the indicator lamp can not be lighted longer than 15 seconds. After it goes off, the pre-igniters are still powered for 10 seconds.

For the assumed study conditions the use of glow plugs for starting the engine was not necessary, but it was beneficial for the assessment of the composition of exhaust gas, because of increased differences in emissions levels in the initial period of the engine's running at low temperature.

To assess the feasibility of fuel supply and engine starting at low temperature is an important value of the or Cetane index, flash point and ignition, and cold filter plugging. Of all the studied fuels ethanol is the one with especially adverse self-ignition characteristics; its Cetane number equals 8 and its self-ignition temperature is 430ºC. Rapeseed methyl esters, on the other hand, are characterized by high cold filter plugging point.

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2. Test bench

Renault G9T engine together with fittings and part of the measuring and controlling equipment was put into cold-test chamber in the Military University of Technology's Low Temperature Laboratory. The engine was put on a frame bolted to the chamber's floor.

The exhaust train together with catalytic converter is shown in Fig. 1a. The exhaust gas was removed from the chamber with the use of a fan. In order to avoid suction of the exhaust gas from the engine's exhaust train a solution was implemented, guaranteeing its free flow to the hood (Fig. 1b). Exhaust gas at the cable's disconnection was sucked by the fan together with air from the chamber.

Fuel in the tank and battery were put in the chamber and were cooled together with the engine.

a) b)

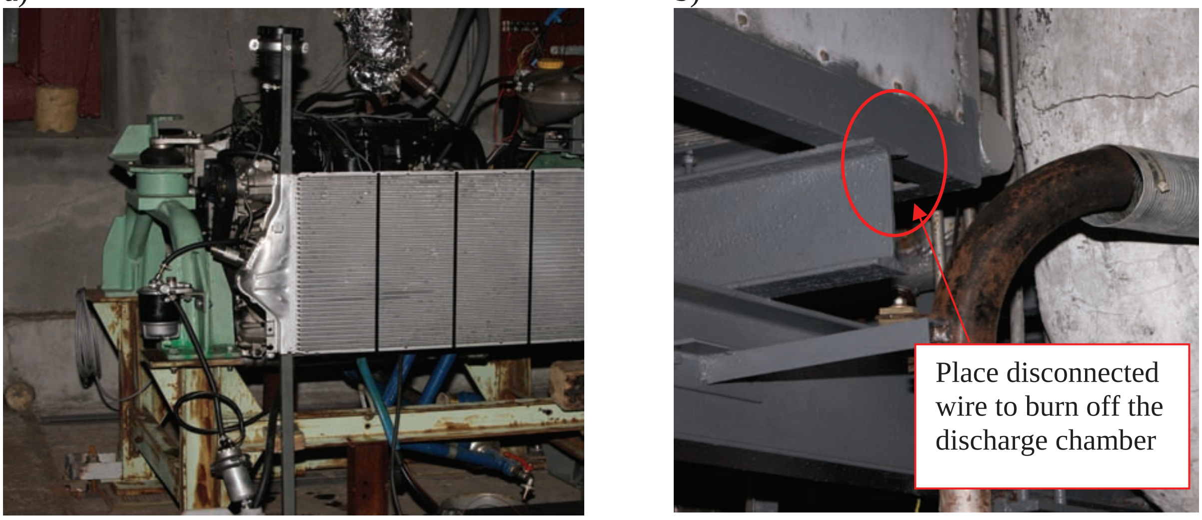


Fig. 1. G9T engine on the test bench in cold-test chamber: a) general view of the engine; b) junction between exhaust train of the engine and exhaust gas hood.

The test was run twice for every fuel in the temperature of -7ºC, in which homologation tests are carried out. The study of the influence of fuel (blends) on start-up characteristics of G9T engine and efficiency of the catalytic reactor after the start-up was done according to the following method:

1) mounting the engine in cold-test chamber, preparing it for the tests,
2) filling the engine with the tested fuel,
3) thermal stabilization of the engine and fuel in the chamber at -7ºC,
4) starting the measuring and controlling equipment ca. 1 hour before start-up of the engine,
5) start-up of the engine without pre-igniters,
6) engine's idle run according to the factory settings for 15 minutes, engine's work for 15 minutes with increased rotational speed – acceleration pedal position15%,
7) turning off the engine,
8) single repetition of steps 3-8 (double test for every fuel),
9) change of fuel in the system, the engine's work with the new fuel for at least 30 minutes,
10) repetition of steps 3 to 10 for the next fuel.

Each attempt included registering of:

- starting current,
- battery voltage,
- composition of exhaust gas,
- temperatures in different parts of the engine,

Start-up tests of G9T engine were carried out in cold-test chamber at -7°C ambient temperature. The engine's lubrication system was filled with oil of 5W/40 class viscosity. In the fuel system the following fuels were used: diesel oil, F-34 and RME blends with ethyl alcohol. The fuels were labelled BXXEY, with XX indicating RME fraction, and YY indicating ethyl alcohol fraction. The rest was F-34 fuel. Each change of fuel resulted in comprehensive cleaning of the engine's fuel system in order to remove any residue of the previously used fuel.

After placing the engine in cold-test chamber, the test bench was equipped with temperature sensors. The trial start-up included measurement and registration of changes in voltage at the battery terminal post clamps and in intensity of current input from the battery with the use of a LEM probe. Registration also concerned the injector's control signal (current); Fluke AC/DC 80i-110s (100 A) current probe was used.

Basic physical parameters of the fuels were also measured: density and dynamic viscosity were measured with the use of Hoppler viscometer in positive ambient temperature and test temperature.

As has been noted above, the engine was started without the use of pre-igniters. Its warming up was conducted according to the fixed procedures for testing the exhaust gas emissions: that is, it worked for 15 minutes with idle speed, and then acceleration pedal position was increased by up to 15%, which corresponded to ca. 1500 rpm speed for the initial fuel, which was diesel oil.

During the study the engine driving control (EDC) was supervised by KTS-570 diagnostic system.

a) b)

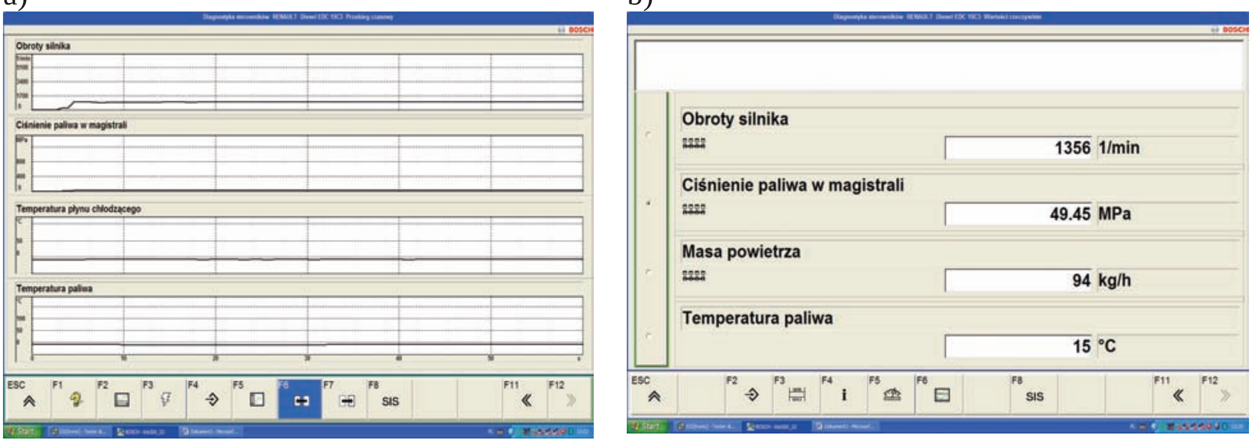


Fig. 2. G9T engine's performance parameters during the trial start-up registered with the use of KTS-570 tester: a) timings of different parameters of the engine's performance, b) instantaneous values of those parameters

3. Results of start-up tests of G9T engine

During the tests density and viscosity of the studied fuels were measured. Results for some of these are presented in Fig. 3.

Synthetic results of start-up tests of the engine fed with the previously prepared fuels are shown in Table 1. The following designations of the values measured and calculated have been used:

- I – minimum and maximum value of the battery's input current intensity while powering the crank shaft with the use of starter – [A];
- U – minimum and maximum voltage on battery terminal post clamps while current input

equals I – [V];

- n – mean value of the crank shaft's rotational speed while powering it with the starter – [rpm], (rotational speed value was calculated on the basis of current intensity timing before starting the engine);
- t – engine's start-up time – [s].

The time of the first ignition was not calculated here due to the timing of the engine's start-up. After the first ignition the crankshaft's rotational speed was increasing intensely enough for the current intensity to be decreasing monotonically to the assumed value. The time of the engine's start was the time when the engine current's intensity reached 200 A.

Tab. 1. Results of start-up tests of G9T engines fed with different fuels

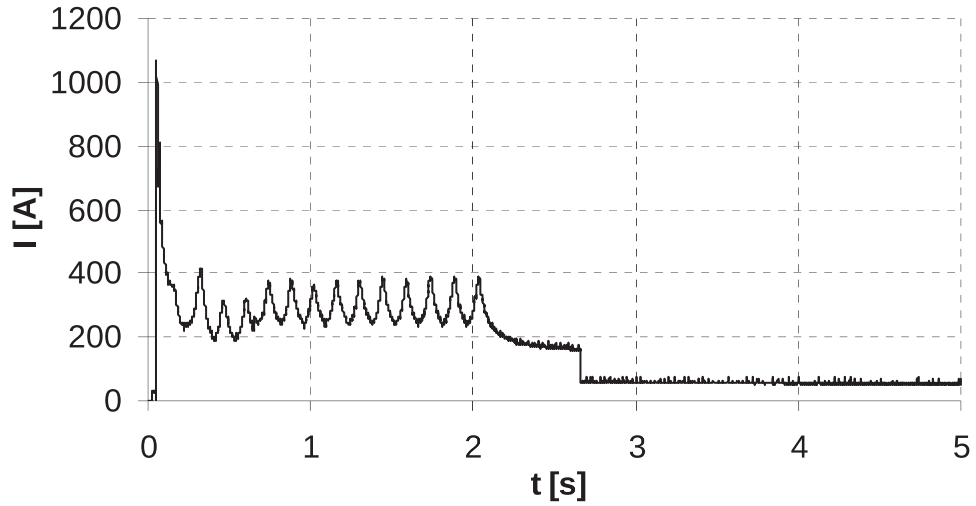
Symbol of the fuel /No attempt	I [A]	U [V]	n [obr./min]	t [s]
ON/1	190 – 355	11.4 – 12.0	207	0.9
ON/2	190 – 355	11.4 – 12.0	207	1.4
F34/1	240 – 380	11.0 – 11.4	205	2.2
F34/2	250 - 400	10.8 – 11.3	198	1.6
B20/1	250 – 400	10.7 – 11.2	196	2.8
B20/2	245 – 380	11.0 – 11.5	200	0.9
B40/1	250 – 390	10.7 – 11.2	202	2.6
B40/2	245 – 380	11.1 – 11.7	203	1.9
B60/1	250 – 390	10.6 – 11.1	198	3.4
B60/2	250 – 390	11.0 – 11.7	202	4.2
E5/1	220 – 360	11.1 – 11.6	205	1.6
E5/2	230 – 380	10.6 – 11.0	192	2.3
B9E3/1	240 – 380	11.1 – 11.6	208	1.8
B9E3/2	240 – 360	11.1 – 11.6	200	1.9
B36E8/1	240 – 370	11.5 – 11.9	208	1.9
B36E8/2	240 – 370	11.5 – 11.9	208	1.9
B48E3/1	240 – 380	10.8 – 11.8	200	2.8
B48E3/2	245 – 360	11.0 – 11.6	200	3.1
B56E8/1	245 – 380	11.3 – 11.7	198	3.9
B56E8/2	250 – 360	11.4 – 11.9	208	4.1
B45E10/1	245 – 380	10.8 – 11.6	196	3.3
B45E10-2	240 – 370	11.0 – 11.8	198	2.9

Fig. 3a presents the battery's input current intensity while starting the engine fed with F-34 fuel, attempt no. 1; Fig. 3B presents the corresponding voltage timing on the battery terminal post clamps.

When the starter begins its work, the battery input current reaches ca. 1050 A. While the crankshaft was powered before the ignition occurred, the intensity value was changing from 240 to 380 A. At the same time voltage on the battery terminal post clamps was changing from ca. 11.0 to 11.4 V, which indicates that current load was not excessive. The starter's shaft was powered with high rotational speed of ca. 205 rpm. The starter's worktime equalled ca. 2.6 s, and fixed the start-up time was 2.2 s. Notable decrease in the value of current intensity up to 1 s since the beginning of the starter's work is visible, which indicates that firings of the fuel injected to the cylinders occurred at that time.

There is visible decrease in voltage on the battery terminal post clamps, up to ca. 9.3 V, at the moment when the starter began its work. Up to 1 s since then high values of voltage result from lowered current intake caused by firings in the engine's cylinders. The following decrease in mean voltage value results from dropout in electromotive force of the battery polarization; in this period is not caused by exhaustion of the battery's capacity nor by lowering electrolyte concentration. After the starter has been turned off, battery voltage is ca. 12.2 V, which means that there has been no battery charge by the alternator at this engine speed range.

a)



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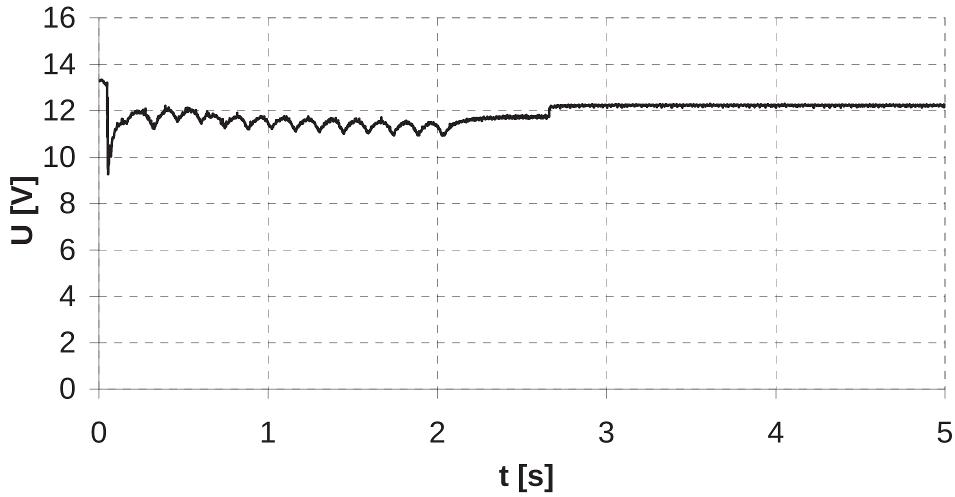

Fig. 3. Start-up parameters timing at the battery while starting the engine fed with F-34 fuel, a) starter input current, b) voltage on the battery terminal post clamps

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The engine's start-up in the case of the fuels used in assumed test conditions was similar; the only differences visible were those in length of the crankshaft powering period.
As a result of the tests carried out, the following conclusions may be noted:

– diesel oil – very fast start-up during the first firings; no phase of powering by the starter here – this is why the parameters of the start-up timing differ to some extent from those of other fuels.
– F-34 – there is some difference between the rotational speeds given here, due to their calculation just before the firings, which occurred at different times.
– B-20 – during the second trial start-up the engine was started in a very short time (analogically to the case of diesel oil), in the firings phase immediately after turning on the starter; this is why the values of voltage and intensity given here are greater. While warming up, the engine works very irregularly and tends to stop.
– B-40 – the engine started properly. While warming up, the engine works very irregularly and tends to stop a couple of times.
– B-60 – the engine started properly. The start-up time longer than for B-40 blend. While warming up, the engine works very irregularly and tends to stop a couple of times. The fuel is turbid; troublesome viscosity measurement.
– B-80 – the engine started, its run was supported by the starter for 4 s, then it became impossible to repeat the start-up. Fuel filter blocked.
– B-100 – the test was not carried out, as already in the case of B-80 blend it was impossible to start the engine.
– E-5 – at -8ºC the fuel in the engine's plastic container and viscometer became turbid, although nothing of this kind happened in the measuring cylinder used for density measurement. During the first attempt the engine was turned on twice. After its speed increased up to 1.7 s, it would not work on its own; it was necessary to turn on the starter again for 1.3 s. The start-up here was assumed 0.6 s after the starter was turned on.
– B9E3 – engine fed with this fuel did not stop. Already at -2ºC the fuel in the engine's plastic container and viscometer became turbid, although nothing of this kind happened in the measuring cylinder used for density measurement. Without delamination, in all its volume, it became turbid at -8ºC.
– B36E8 – at ca. 17ºC the fuel was transparent. However, notable volume of alcohol was liberated both at the viscometer and at the bottom of the measuring cylinder (1.5 – 2 cm diameter) below it. While measuring the viscosity, this volume was moving downwards, which means that its density was greater than that of the remaining fuel volume. While measuring the viscosity as -1.4 ºC the liberated volume was moving upwards, not downwards, which indicates change in the densities. In the measuring cylinder one of the liberated volumes appeared at the bottom, and the other above.
– B48E3 – after the start-up the engine worked properly; some turbidity at viscosity measurement; start-up time longer than that of F-34 and diesel oil.
– B56E8 – notable volume of alcohol was liberated both at the viscometer and at the bottom of the measuring cylinder (1.5 – 2 cm diameter) below it. While measuring the viscosity, this volume was moving downwards, which means that its density was greater than that of the remaining fuel volume. The engine's run was instable and stopped a couple of times, which made it necessary to turn it on again.
– B89E3 – the test was not carried out, as already in the case of B-80 blend it was impossible to start the engine; delamination of the blend and particulate matters precipitation.

During the tests in Cold-Test Chamber the influence of the fuel used on the composition of exhaust gas and the catalytic converter's performance was assessed as well. In the course of the start-up tests the following temperatures were measured: T_1 – the temperature of the liquid cooler, T_2 – the temperature of the oil, T_3 – the temperature of exhaust gas at the engine's outlet, before the turbocompressor, T_4 – the temperature of exhaust gas behind the turbocompressor, T_5 – the temperature at the EGR pipe, before the mixing valve, T_6 – the temperature in the engine intake manifold– behind the EGR valve, T_7 – air temperature before the inlet air cooler, T_8 – air temperature behind the inlet air cooler, T_9 – the temperature of exhaust gas at the catalytic converter's inlet, T_{10} – the temperature of the element with catalyst support – external housing, T_{11} – the temperature of exhaust gas at the catalytic converter's outlet.

The tests also included measurements of the composition of exhaust gas (CO, CO_2, THC) at the catalytic converter's in and outlet. Figures 4 to 7 present sample timings for different fuels, registered during the trial start-ups.

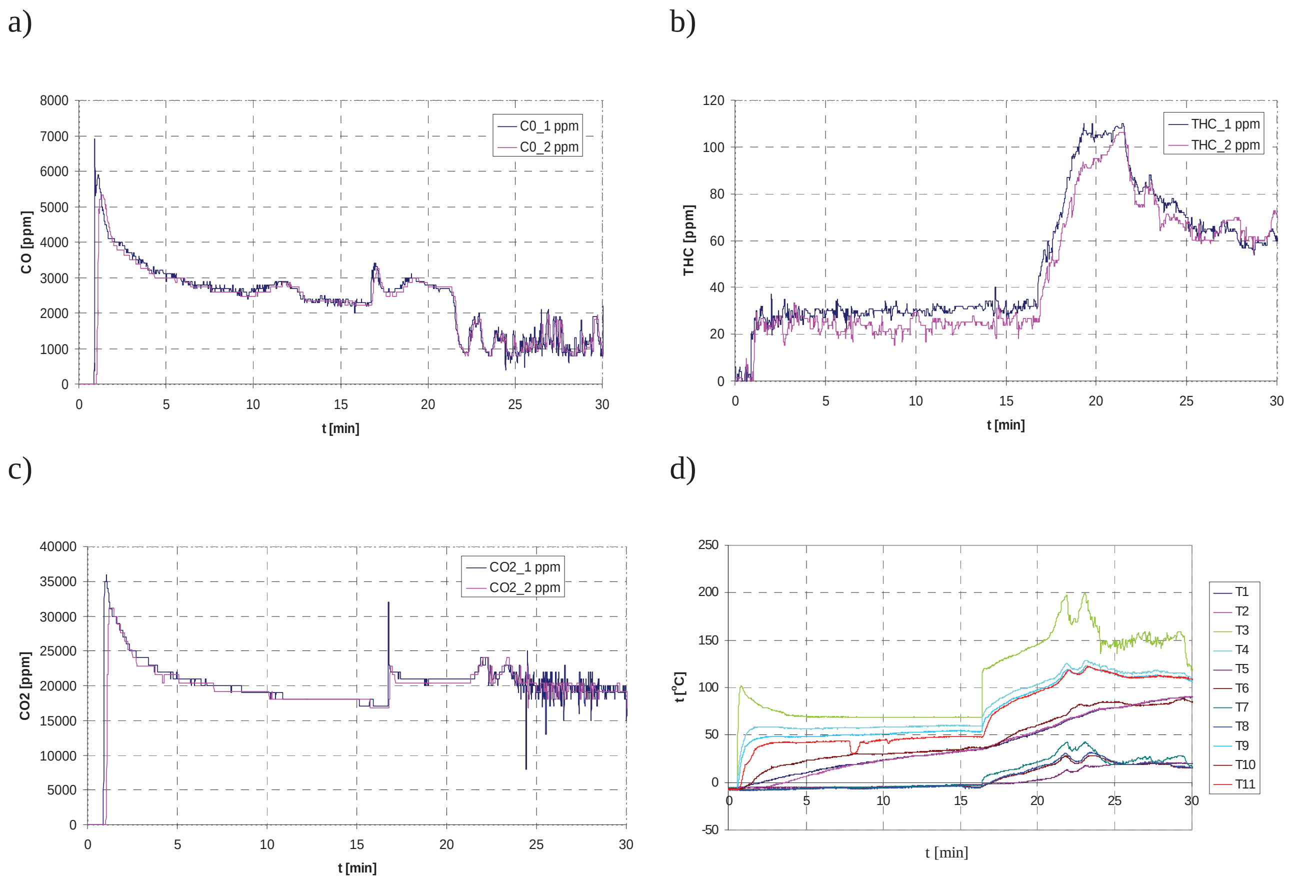

Fig. 4. Timings of the composition of exhaust gas and temperature for F-34 fuel: a) CO, b) THC, c) CO_2, d temperature at different parts of the engine

Figure 4 presents timing for F-34 fuel. After the engine's start-up increased emission of carbon monoxide was observed. This was caused by low temperature in the combustion chamber and increased volume of fuel needed for maintaining the increased idle speed. When the engine works at increased rotational speed, this is also accompanied by increased temperature of the exhaust gas at the engine's outlet (T_3). The engine's warming up occurs together with decrease in its rotational speed and in CO and CO_2 content in the exhaust gas. The hydrocarbon content remains unchanged (Fig. 4b). Immediately after the start-up the temperature of exhaust gas at the engine's outlet reaches the level of 100-120ºC, depending on the fuel used. This is followed by loss of exhaust gas temperature, caused by decreased amount of fuel and rotational speed.

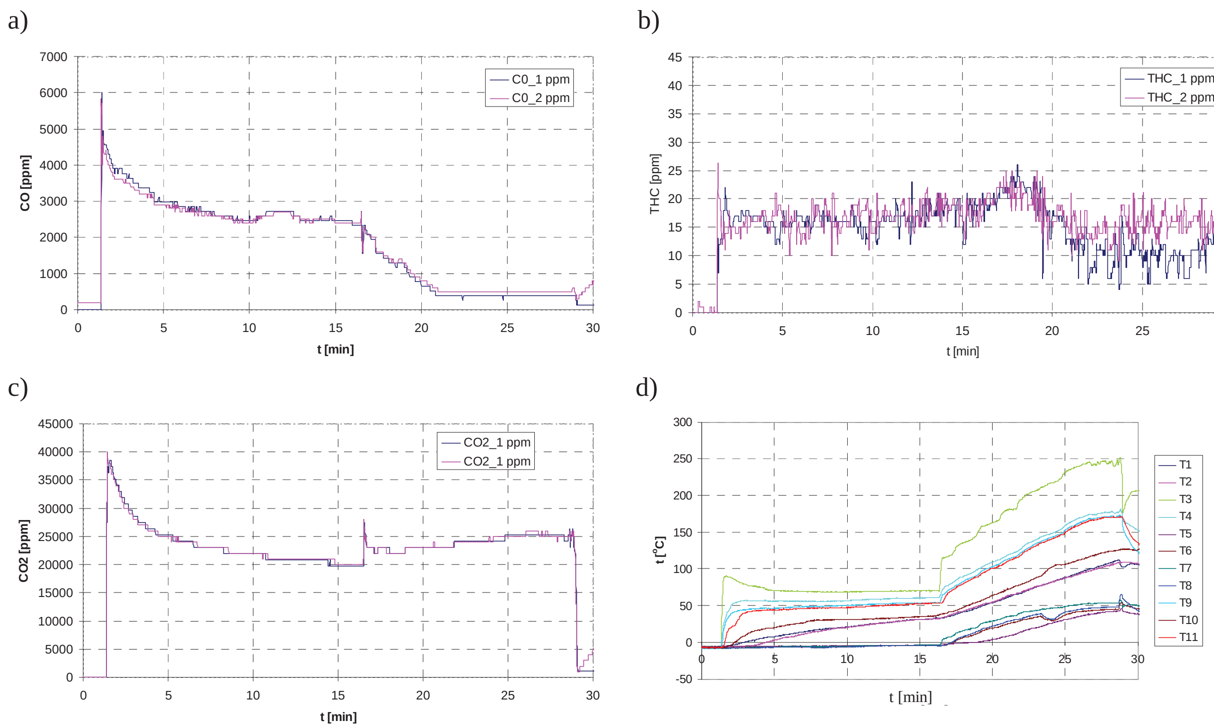

Fig. 5. Timings of the composition of exhaust gas and temperature for diesel oil: a) CO, b) THC, c) CO_2, d) temperature at different parts of the engine

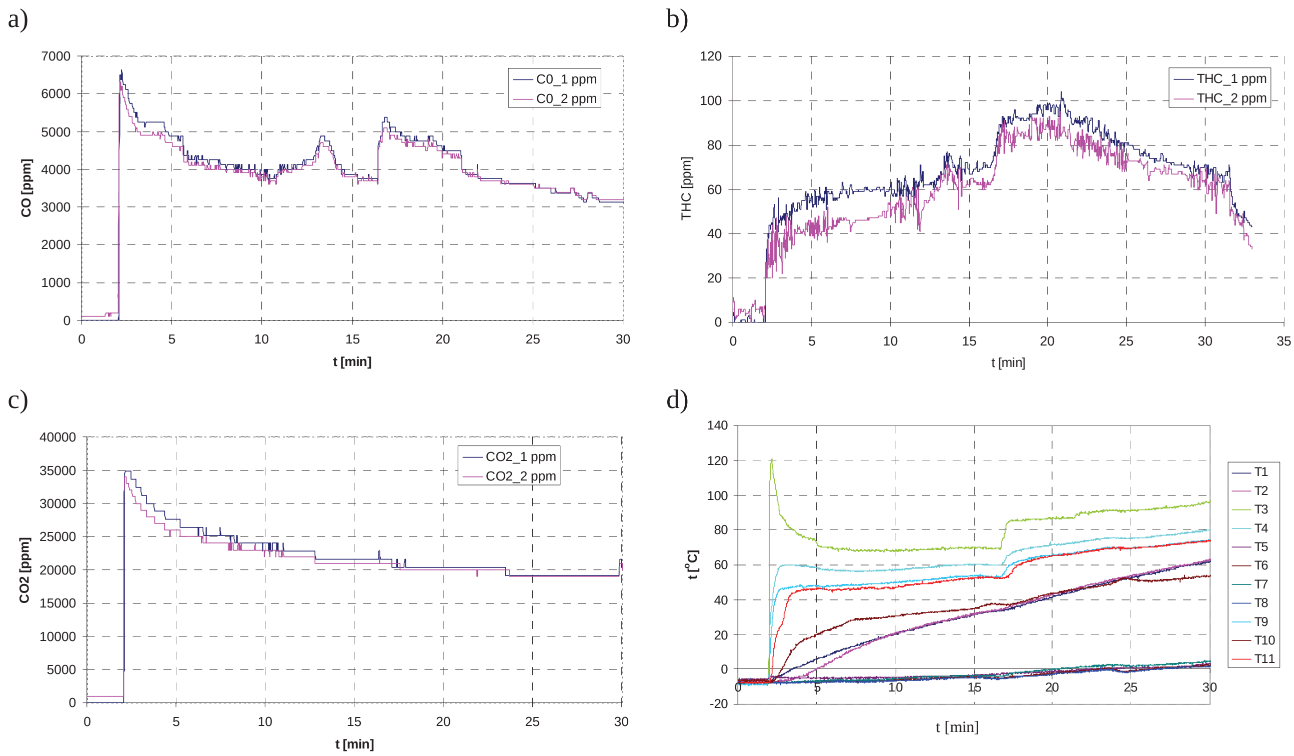

Fig. 6. Timings of the composition of exhaust gas and temperature for B36E8 fuel: a) CO, b) THC, c) CO_2, d) temperature at different parts of the engine

After 15 minutes since the start-up the temperature of the element with catalyst support (T_{10}) reaches ca. 40°C. It is too low for the catalytic converter's proper performance. When the rotational speed is increased to 1500 rpm, after 15 minutes of the engine's running, the temperature reaches 90°C – again, too low for the catalytic converter's proper performance. That the catalytic converter's efficiency equals 0 is visible in the registered timings of gas components in the exhaust gas. The timings of CO, THC and CO_2 at the catalytic converter's in and outlet overlap. On the basis of the timings registered it is impossible to determine the influence of the fuel used on the performance of the catalytic converter after the start-up at low temperatures – the temperature of exhaust gas and, consequently, of the element with the catalyst support, is too low for the catalytic converter to work properly.

When the rotational speed is increased to 1500 rpm, the exhaust gas temperature increases and both CO and HC contents decrease.

The comparison of compositions of exhaust gas after G9T engine's start-up shows that introduction of biocomponents to F-34 fuel causes increases content of incomplete combustion residues in the exhaust gas. Despite 30 minutes' work, the catalytic converter did not reach the temperature necessary for its proper performance.

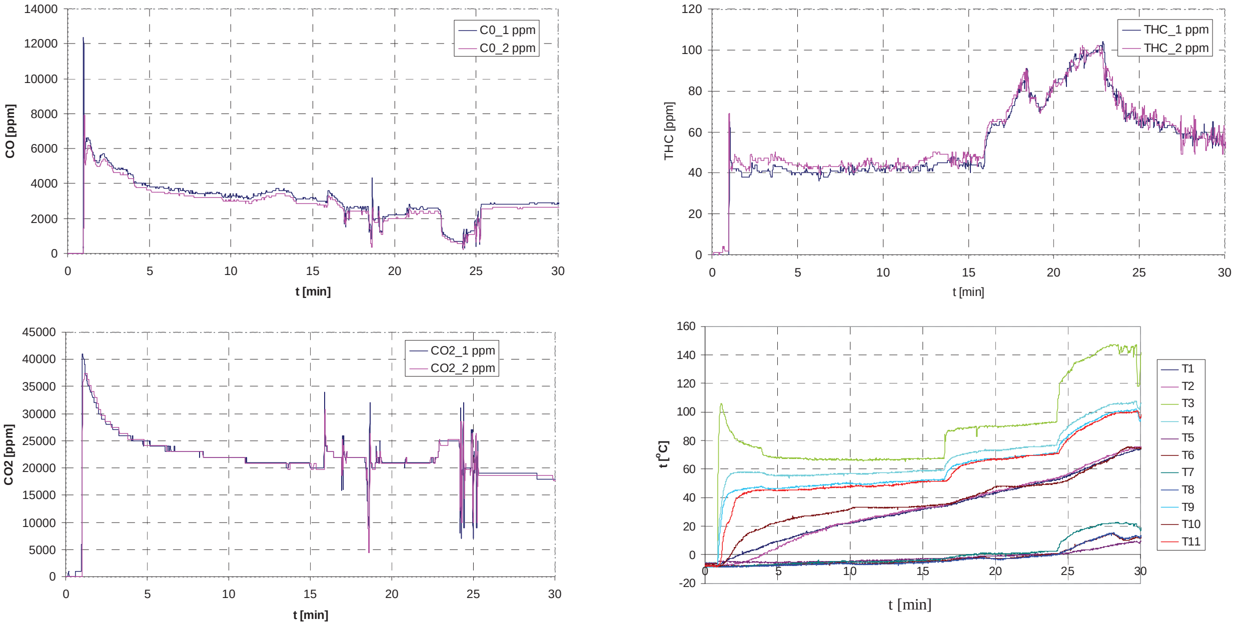

Fig. 7. Composition of the exhaust gas. Timing of the battery's input current intensity during the start-up of G9T engine fed with B9E3 fuel

4. Conclusion

The performed start-up tests of G9T engine fed with F-34 fuel with biocomponent content in low ambient temperature of -7°C have shown that such conditions do not cause significant differences in the start-up. For each of the fuels used the start-up took less than 5 s; therefore it was immediate, which is why the start-up parameter is not significant here for assessing the difficulty of starting the engine. Increased biocomponent content in F-34 fuel causes increase in the time needed for the engine's start-up.

Fuels of notable (over 60%) RME content are not suitable for powering a diesel engine at low temperatures. The filter is blocked and the engine stops.

The comparison of compositions of exhaust gas after G9T engine's start-up shows that introduction of biocomponents to F-34 fuel causes increases content of incomplete combustion residues in the exhaust gas. The catalytic converter does not reach the temperature at which the incomplete combustion residues are burnt out.

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