INVESTIGATION OF DIESEL ENGINE WITH THE SUPPLY SYSTEM TYPE COMMON RAIL SUPPLIED FUEL F-34 AND BIOFUEL

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Abstract

Problems of the power supply in military vehicles grow with the growing number of vehicles in armies. Moreover, biocomponents additions which are added to the basic fuels change its properties. Therefore undertaking work to adopt engines to supply them with fuels coming from renewable sources is essential.

The purpose of that research is indicating the influence of fuel feeding system on useful parameters and composition of exhaust exhaust gases of self-igniting engine Renault G9T with high pressure injection mechanism „Common Rail. The researches were conducted while the engine was supplied with six kind of the fuel: basic fuel which was diesel oil, aviation fuel coded NATO F-34, fuel mixtures: F-34 methyl esters of higher fatty acids from rapeseed oil. In the result, it can be stated that the achievements of the engine Renault G9T with high pressure injection system feed with F-34 fuel and mixtures have hanged partly.

Conducted examination has showed the essential influence between the fuel and performance of Renault G7T engine with high-pressure injection system feed with F-34 fuel mixtures with methyl esters of higher fatty acids. The increase of EMKOR share in F-34 fuel caused the decrease of useful power, increase of fuel consumption and decrease of combustion smoke.

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

1. Introduction

Liquid fuel is one of the most important sources of energy in the present field of fight. Fuel husbanding decides about the mobility of armies, efficiency of armament and different equipment using and suitable quantity of delivery. The fulfilment of the growing demand of fighting armies in motive materials is one of the most difficult problems of the logistic protection on the field of fight. It can be calculated that the average demand of motive materials and greases for one soldier per day comes to about 30 kilos. Delivering such a big amount of these materials in war conditions is extremely difficult. Therefore, this is the aim to standardize different kind of fuels in the army and the example of this is introducing the uniform fuel F-34 on the field of fight in NATO.

It was decided to standardize fuel to stroke engines and turbine mechanic vehicles and aircrafts stationing on land. Fuel f-34/35 was introduced. That fuel has identical base as the fuel JP8 and its final proprieties come from additions introduced before pouring the fuel to the fuel tank.

At present the fuel F 34/35 (the code NATO) is traded as the uniform fuel on the field of fight to all engines with self-igniting in NATO. For many years that fuel was examined precisely in engine with inline and distributor-type injection pumps. Applying that fuel in vehicles and stationary airplanes results from simplification the logistics supply chain, among which fuel represents about 40% of the total weight of cargo shipped fighting forces.

The equipment of engines changed united research into that fuel started instead of piston injection pumps, nowadays high-pressure injection Common Rail systems are used and much less extent Unit Injector System. In these systems the fuel pressure is raised to 140…200 MPa and the pressure is kept for majority of work time. That feature changes fuel thermal conditions fundamentally before injection to combustion chamber and its temperature is much higher in the composition with the fuel temperature in piston pump. The excess of fuel flows to fuel tank and its constant circulation causes fuel cooling in lines and fuel tank.

CR injection systems are applied universally in the engines of car, delivery vans, lorries, locomotives, ships and combat vehicle. For example, engines MTU of the series of MT 880 are equipped with these systems instead of injection systems with piston pumps which were applied in initial versions.

Using fuel F34 to the engine with CR system can cause essential changes in parameters in engine work. The own examinations of engine G9T with CR system showed distinct decrease of its maximum torque in medium rotary speed range, decrease the share of NOx in exhaust exhaust gases and increase of unitary fuel consumption. That feature indicates deterioration of the process of burning fuel F34 in engine with CR system.

Tab. 1. Chosen physical and chemical properties of fuels applied during researches

Parameter	**Unit of measure**	**ON IZ-40**	**RME**	**Fuel F-34**
Density in temp. 15°C	g/cm^3	0.831	0.881	0.804
Calorific value	MJ/kg	43.2	38.3	42.8
Ignitron temperature	°C	66	177	57
Temperature of blocking cold filter	°C	-31	-9	-54
Stickiness in 40 ° C	mm^2/s	2.35	4.6	1.27
Contents of the sulphur	mg/kg	350	19	3000
Cetane Number	-	50	43	45
Course of the distillation • beginning, • 50%, • end.	°C	178 255 353	300 339 360	167 202 238

The fuel F-34 and F-35 in comparisons with diesel oil characterize better low-temperature parameters, lower viscosity, lower Cetane number, lower heating value. Technical advantages of uniform fuel are: conformity with civil fuel in airplanes, witch production will be raised about 10% annually because of increasing number of transport, smaller susceptibility to pollution, availability on airports of the whole world, better low-temperature properties, decrease of the fire risk in comparison with vilely fractions fuels, reduction of pollution. Logistic advantages: using only one kind of fuel in the whole army, simplification of fuel delivery, uniform of storehouse infrastructure.

Disadvantages of the uniform fuel are: growth of demand for fuel based on based on kerosene, decrease of another kinds of fuels and the fuel price can go down, the fall of engine powers for the sake of decrease of the mass in the dose of fuel, necessity of equipment modernization.

Different properties concern fuel made up of methyl esters of rapeseed oil witch include oxygen (about 12%) apart from carbon and hydrogen. The content of oxygen is conducive to better self-ignition and complete combustion. Molecular oxygen contained in fuel displays higher activity than molecular oxygen contained in air that causes higher Cetane number of this fuel. Better course of combustion process allows decreasing the contents of toxic compounds in exhaust exhaust gases and decrease of smoke. Drawback of methyl esters of rapeseed oil is high content of water and aggressive influence on rubber elements and coatings. The fuel has breath density and stickiness therefore its addition to the standard fuel F-34 causes similarity of fuel F-34 properties to diesel oil.

2. The purpose and range of the examination

Fuel situation on the world and prediction of petroleum natural resources decrease force to search new kinds of fuel. That situation concerns also supply of military vehicles. Despite that NATO has accepted fuel F-34 as basic fuel, it is necessary to consider possibility to complete that fuel with products do not come from petroleum processing. At the same time, the growth of the number of vehicles equipped with compression-ignition engines with injection systems based on Unit Injector System and „Common Rail". Irrespective of how to obtain a high injection pressure are the primary problem of phenomena occurring during the injection of fuel into the high pressure, their effect on fuel injection and the course of his, the creation of the combustible mixture and combustion is observed. The basic aim of the work is examination of fuel F-34 influence and mixtures of F-34 fuel with biocomponents in form of esters of rapeseed oil on performance of engine with high pressure engine injection basing on the example of Common Rail system on engine performance.

3. The object, methodology and the range of the examination

The object of the examination has been four-cylinder compression-ignition engine G9T Renault engines, with power 95 kW at n = 2500 rpm and 280 Nm at the time of 1750 rpm used to delivery truck. This is four-cylinder engine with direct fuel injection to combustion Comoros toroidal, equipped with fuel injection with high longitudinal tray. The engine is charged with a turbocharger and supercharge air is cooled (Fig. 1). A set of two fans for the cooler air allows the air temperature control system intake engine. The engine was equipped with a power-type Common Rail, Bosch production, made up of the following:

- controller EDC 15A53,
- feed pump EKP3,
- High pressure pump CR/CP1S3/L70/10-1S.

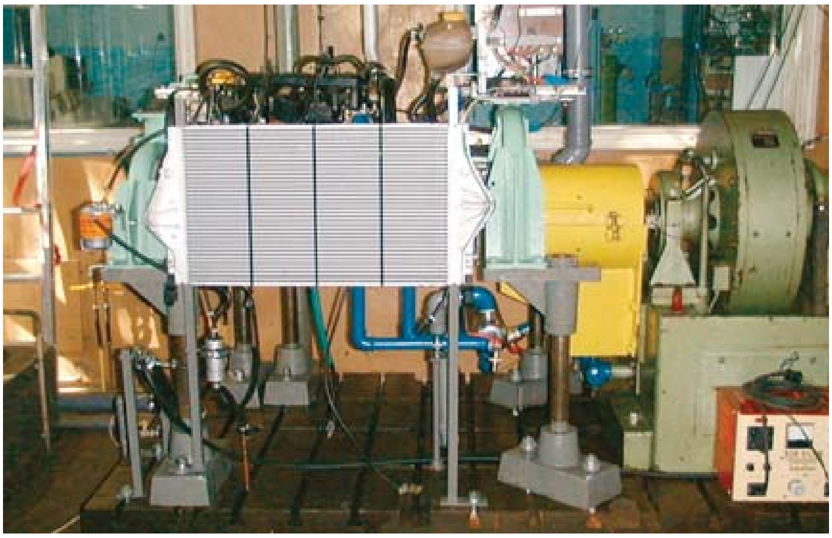

Fig. 1. The engine G9T on the investigative position

The range of the examination has included measurement of the parameters in the process of burning and the exhaust gases composition in function as a function of engine speed and engine load for the established operation of the engine.

The examination has been conducted supplying different kinds of fuel to the engine:

- diesel oil ON,
- fuel F-34,
- the mixture of F-34 and methyl esters of higher fatty acids from rapeseed oil labelled B-20, B-40, B-60 and B-80 where the figure after the letter B is the mass share in a mixture of methyl esters.

The examination has been conducted in different work states of the engine, changing its load depending on the speed: 1000, 1500, 2000, 2500, 3000 and 3500 rpm. During the examination useful parameters of engine operating temperature (coolant, oil, exhaust gas turbocharger in front of and after, before and after EGR valve, the air in front of and after the air cooler and at the intake collector), air pressure in front of and after the air cooler, the shares in the exhaust gases: CO_2, O_2, CO, HC, NO_x and smoke has been measured.

On the basic of the analysis it can be stated that the engine achieves the larges power for diesel oil (Fig. 2a). Application of F-34 has caused insignificant decrease of Ne (about 1-2%) Addition of esters to the fuel f-34 has caused gradual decrease of the power engine (about 7-8%) depending on the mixture composition (percent of esters). The reason for that is the increase of mixture density of F-34 and EMKOR and decrease of its heating value the difference of the power raises along with the engine speed.

The lowest hourly fuel consumption is observed for diesel oil (Fig. 2d) witch is the basic fuel applied for that engine, although its properties are similar with F-34 (substitute fuel). Application of methyl esters of higher fatty acids application causes increase of ge consumption (about 3-5%) – depending on mixture composition and rotary speed. It is caused b low heating value of mixtures with esters.

The lowest unit fuel consumption is observed for fuel F-34 (similar results with ON, Fig. 2c), which amounted 232.7 g/kWh (235.9 g/kWh) for the speed of n = 1500 rpm. Addition of esters o fuel F-34 caused increase of ge, and for B-20 amounts 252.7 g/kWh and for B-80 amounts 253.1 g/kWh (increase of 10%). The higher fuel consumption is caused by lower fuel values and stickiness of EMKOR Lower viscosity causes better atomization and higher homogeneity of fuel stream, what is conducive to complete combustion of mixture.

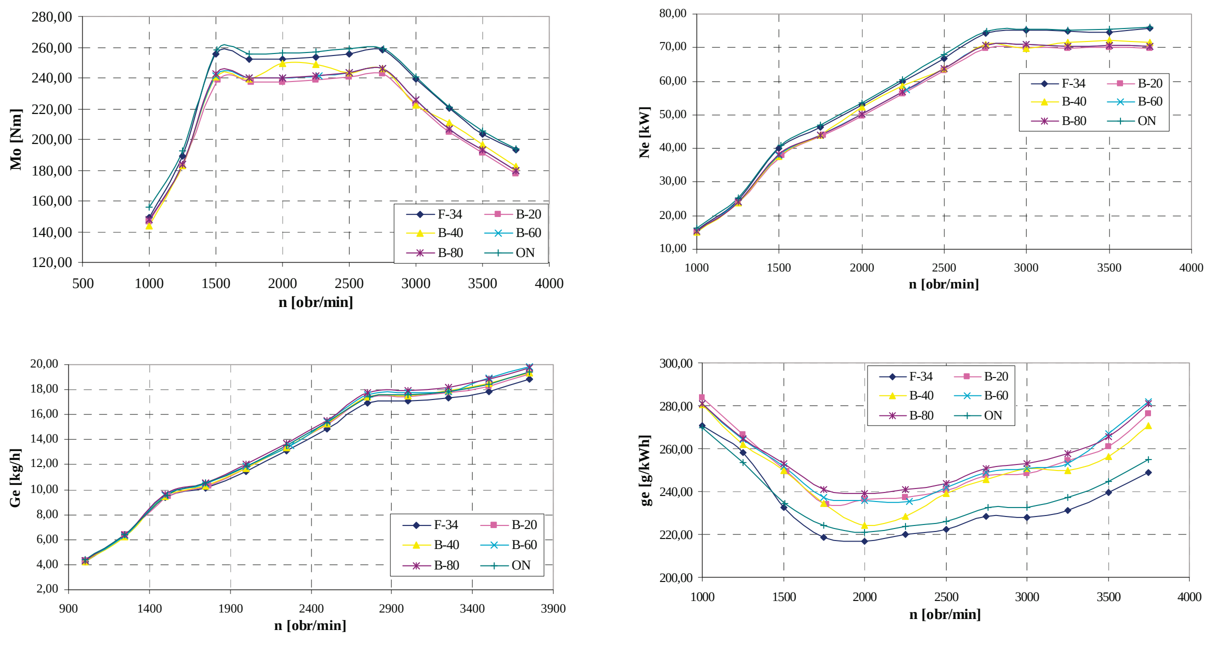

Fig. 2. The external profiles of the engine Renault G9T, a) torque, b) useful power, c) the hourly consumption of the fuel, d) the unit consumption of the fuel

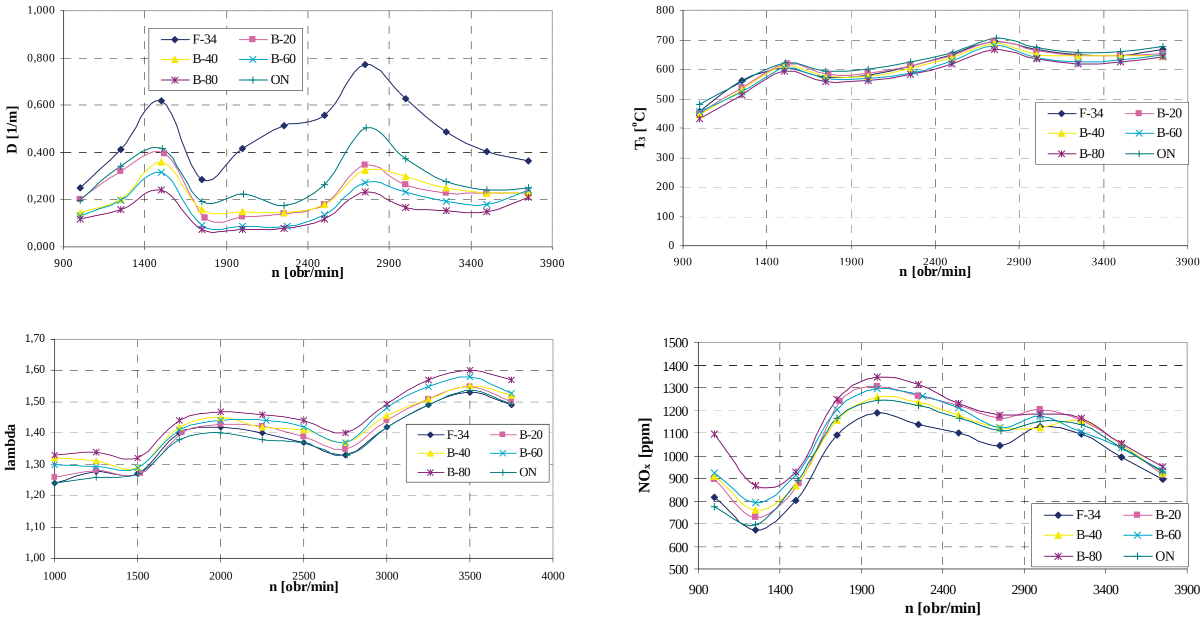

Fig. 3. The external profiles of the engine Renault G9T: a) the fogging the exhaust gases, b) the temperature of exhaust gases behind compressor, c) the coefficient of the excess of the air λ, d) part NOx in the exhaust gas

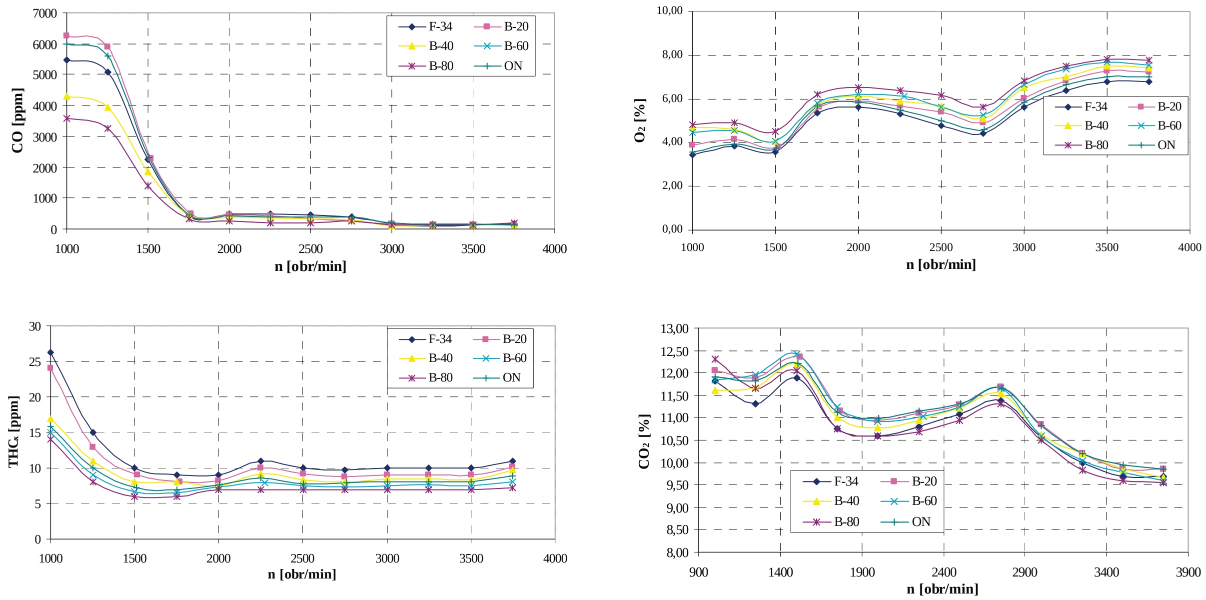

Fig. 4. The external profiles of the engine Renault G9T: a) the part of CO in exhaust gases, b) the part O_2 in exhaust gases, c) the part THC in exhaust gases, d) the part CO_2 in the exhaust gas

Mixture F-34 with esters has favourable influence on combustion smoke. The highest combustion is observed for the engine supplied by fuel F-34 (similar for ON), and then as a result of increasing of esters share in mixtures combustion is nearly 2..3 times lower. Such tendency is kept in the whole rotary speed range. Decrease of combustion smoke engine powered EMKOR make it possibility to reduce the emissions of nitrogen oxides by reducing the angle of the start of fuel flow.

The exhaust gases temperature at the point of exit from the engine is the highest for ON and amounts 622°C for n=1500 rpm (Fig. 3b). The lowest exhaust gases temperature has the mixture B-80 and amounts 592°C for n=1500 rpm, and the 5% temperature fall is visible. The exhaust gases temperature falls along with the increase of EMKOR in the fuel.

The lowest value of the excess of air λ is for fuel F-34 (Fig. 3c). Esters addition enlarges the ratio λ and for mixture B-90 that increases amounts about 25%. It is caused by oxygen content in molecular methyl esters of higher fatty acids from rapeseed oil and consequently, less demand for oxygen during combustion.

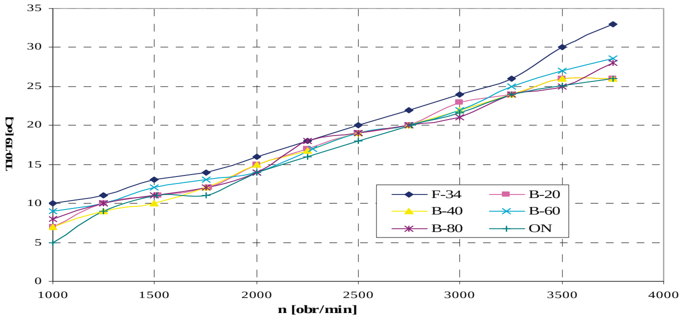

Fig. 5. The influence of the speed of engine on the increase of the temperature of fuel in the arrangement of the power supply

The NOx share in the exhaust gases is the lowest for fuel F-34 and for ON in the whole range of rotary speed (Fig. 4c). The increase of NOx (about 10-15%) is observed when the mixtures with EMKOR are applied. It is caused among other things by the oxygen content in methyl esters fatty acids from rapeseed oil. Moreover that fuel has greater susceptibility to spontaneous combustion / ignition (higher Cetane number). That increase of temperature inside of the cylinder creates more nitric oxide caused by just that phenomenon.

The big emission of CO is observed for low rotary speed the increase of speed causes significant decrease of CO content in exhaust gases. The biggest emission of CO is observed for diesel oil and fuel F-34, the ester addition to the fuel causes reduction of CO emission about 10-15% (Fig. 4a) for the higher rotary speed. The lower content of CO in exhaust gases for the fuel with biocomponents indicates its better / faster combustion with relation to fuel F-34 and ON. The EMKOR addition has positive influence on CO emission for the low rotary speed. The CO emission is kept on invariable level for the speed over 1500 rpm and for all kinds of the fuel.

The O2 content in exhaust gases is similar to the value of excess of air. The lowest value is for fuel F-34 and for ON and the largest for the mixture B80 (increase about 20-25%), Fig. 4b.

The THC share in exhaust gases is lower to 50% for the fuel B80 in the whole for the all rotary speed (Fig. 4c). Like in case of CO, lower share of THC in exhaust exhaust gases while feeding the engine with B80 fuel lower share of THC in exhaust exhaust gases while feeding the engine with B80 fuel is a result of better combustion and increased content of oxygen in fuel-air mixture.

The parameters for CO2 content are different than oxygen content. The lowest values / results are for fuel F-34 and the highest (about 6-10%) for the mixtures with EMKOR (Fig. 4b).

The temperature increase of the fuel leaving the engine varies with the increase of rotary speed of engine and mixtures of fuel. The temperature difference between the fuel F-34 and the fuel B-80 amounts 3^{o}C an n=3500 rpm. Information in the Figure 5 shows that the fuel F-34 heats itself most of all. It causes the lowest stickiness and weak lubricating parameters. It is difficult to define the influence of different kinds of the fuel on the temperature in feeding system for the sake of lack of exact stabilization at the engine entrance.

Than weight-bearing characteristics were prepared. Performed characteristics of the rotational speed of n = 1500 rpm (range Mo_{max}) and n = 3000 rpm (range Ne_{max}). At that speed the engine works the most often. On that basis the influence of applied fuel and its ecological properties was defined. The range of changes is different for the individual parameters what was descended below.

The lowest fuel unit consumption is for the fuel F-34 and for diesel oil. At n=1500 rpm it amounts 225 g/kWh (for ON 227 g/kWh) with a torque of 180Nm.

The lowest fuel consumption at n = 3000 rpm amounts 274.4 g/kWg at 90 Nm. Methyl esters addition to the fuel F_34 causes increases of the fuel consumption. Depending on mixture consumption (ester content) that increasing varies from 8% to 16% for the B80 mixture (Fig. 6a). It is caused by lower calorific value for higher stickiness of EMKOR.

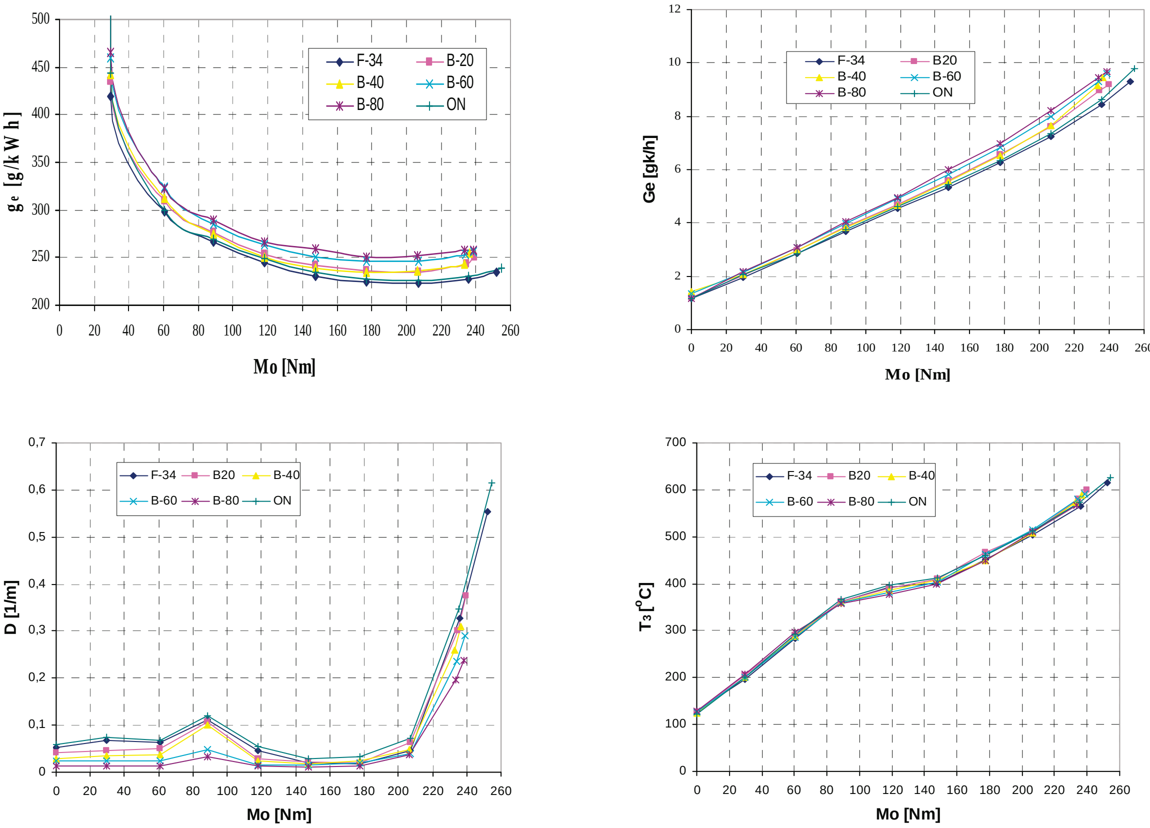

Fig. 6. The weight-bearing characteristics of the engine Renault G9T, n = 1500 rpm, a) the unit consumption of the fuel, b) the hourly consumption of the fuel, c) the fogging the exhaust gas, d) the temperature of exhaust gas before turbocharger

At lower loads, engine consumption for the F-34 and Diesel was lower than the consumption of fuel blends EMKOR. It was probably causes by low temperature in the consumption chamber too, it has made EMKOR evaporation difficult. The opposite phenomenon is observed for large load, because the process of combustion is intensified by additional oxygen in molecules of methyl esters from rapeseed oil.

The measurements were collected at the same value of Mo. It was observed that the lower result was for the fuel F-34 and ON 3.66 kg/h and 3.76 kg/h (for n=1500 rpm) and 7.77 kg/h and 8.00 kg/h (for 3000 rpm). Hourly fuel consumption is rising about 10-12% (Fig. 6b) for the salve of ester addition. It night be caused by higher fuel stickiness which involves worse spraying, evaporating and fuel combustion in the engine.

The EMKOR addition to the fuel F-34 has caused lower combustion smoke and it has a positive influence on the ecological properties of the engine. For n-1500 rpm and for the mixture B80 combustion smoke it twice as low (Fig.6c).

The lowest temperature of exhaust gases was observed for the mixture B80 357oC (n=1500 rpm) and the highest for diesel oil 367^{o}C, what indicates the increase about 2% (Fig. 6d).

The lowest values of the excess of air λ is for the maximum load both for n=1500 rpm and n=3000 rpm. The lower values were observed for the fuel F-34 and for ON and the highest for the mixtures B80 (increase about 5%). That phenomenon is caused by the big amount of oxygen in methyl esters and what fallows lower demand for oxygen during combustion in engine chamber.

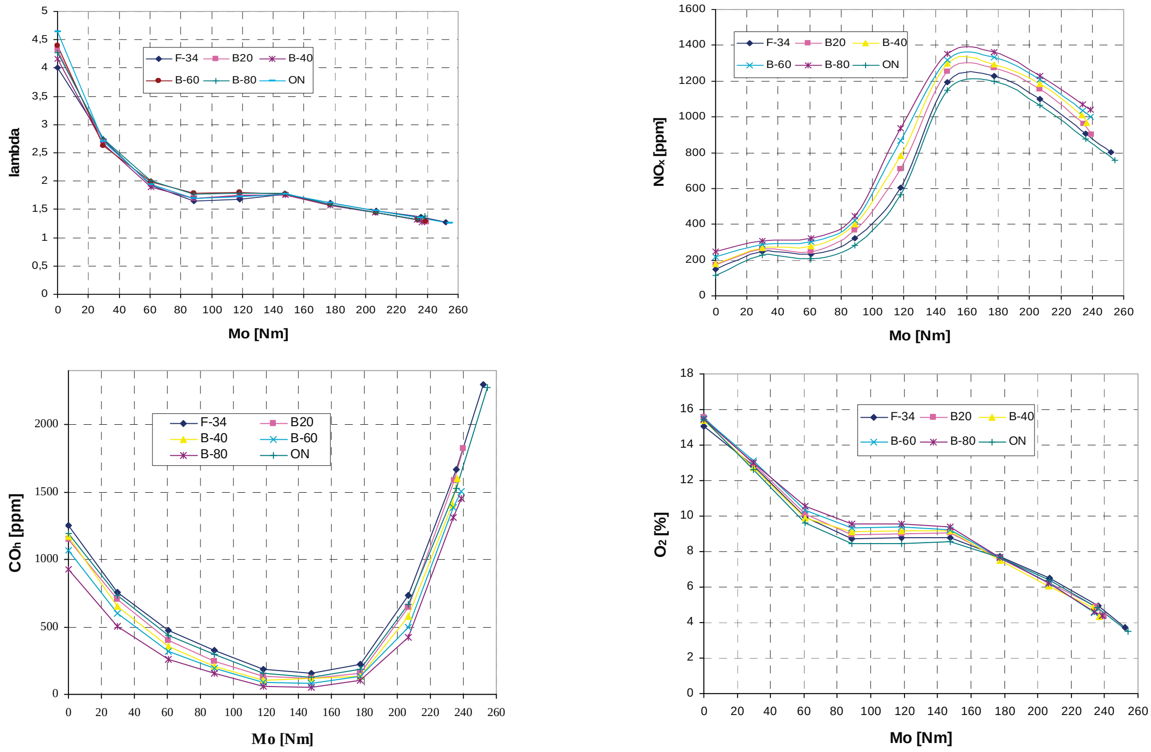

Fig. 7. The weight-bearing characteristics of the engine Renault G9T, n = 1500 rpm, a) the coefficient of the excess of the air λ, b) the part NOx in exhaust gas, c) the part of CO in exhaust gas, d) the part O2 in exhaust gas

The lowest NOx share in exhaust gases in the whole load range is for the basic fuel (ON and F-34) (Fig. 7b). Mixtures with EMKOR cause increase of NOx emission (about 10-15%). Among other things it is caused by oxygen content in w methyl esters of higher fatty acids from rapeseed oil. Additionally that fuel has greater susceptibility to spontaneous combustion higher Cetane number and it causes that the most of the fuel is burned in a compression stroke The temporary high temperature inside the cylinder is conductive to creation of nitric oxide.

The large CO emission for n=1500 rpm and n=3000 rpm is for low as well as maximum engine loads. Medium torque range of CO remains on low level. The larges CO emission is for diesel oil and fuel F-34, ester addition to the fuel causes significant decrease of CO emission (for n=1500 rpm, about twice more) (Fig. 7c). The lowest CO share in exhaust gases for the fuel with biocomponents indicates its better combustion with relation to F-34 fuel and ON.

The lowest O_2 content in exhaust gases is observed when the engine is supplied by diesel oil (for n=1500 rpm and M=90Nm amounts 8.46%) whereas supplying by the mixture B80 is 9.57% (increase of 13%), Fig. 7d. The highest oxygen emission during the process of burning combustion is for the mixtures with EMKOR. It is caused by high oxygen content in molecules of methyl esters of higher fatty acids from rapeseed oil.

THC share in exhaust gases is lower to 50-60% for the mixtures with EMKOR than fuel F-34 (for n=1500 rpm and n=3000 rpm) in the whole load range Like in case of CO, lower share of THC in exhaust exhaust gases while feeding the engine with fuel supplemented with esters is a result of better combustion.

Conclusion

1. Conducted examination has showed the essential influence between the fuel and performance of Renault G7T engine with high-pressure injection system feed with F-34 fuel mixtures with methyl esters of higher fatty acids.

2. While the engine was supplied by the mixtures F34 with EMKOR, the fall of the power was observed (about 8% with relation to ON, which is the basic fuel for those kinds of engine).
3. The unit fuel consumption is about 16% higher for the fuel with methyl esters of higher fatty acids, especially in the high speed and high engine loads (lower calorific value EMKOR) with relation to supplying the engine by ON.
4. EMKOR addition to the fuel F-34 has caused reducing of combustion smoke nearly threefold with relation to supplying the engine by ON.
5. It was started that the coefficient of the excess of air λ has raised about 25%. It was caused by methyl esters of higher fatty acids from rapeseed oil.
6. NO_x share in exhaust gases increased about 10-15% when the engine was supplied with the B60 and B80 mixtures, which is caused higher tendency to self-ignition of the fuel (higher Cetane number).
7. The leadership of more far investigations purposeful is over the use of fuels with the part EMKOR, because as received results, propriety of such mixtures illustrate they change in the profitable way. It is also necessary to examine low temperature properties of these mixtures.

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References

[1] Ambrozik, A., Kruczyński S., Jakubiec J., Orliński, S., *Wpływ zasilania silnika spalinowego o zapłonie samoczynnym paliwem mineralnym i roślinnym na proces wtrysku oraz rozpad strugi paliwa*, Journal of KONES Powertrain and Transport, European Science Society of Powertrain and Transport Publications, vol. 13 / No. 3, Warsaw, 2006.

[2] Baczewski, K., Kałdoński T, Walentynowicz J., *Sprawozdanie z realizacji pracy n-b „Opracowanie koncepcji wdrożenia jednolitego paliwa do lotniczych silników turbinowych i silników wysokoprężnych"*, Warszawa, WAT, 2001.

[3] Baczewski, K., Kałdoński, T., *Paliwa do silników o zapłonie samoczynnym*, Warszawa, WKŁ, 2004.

[4] Boecking, F., Dohle, U., Hammer, J., Kampmann, S., *PKw- Common-Rail-Systeme für künftige*, Emissionsanforderungen. MTZ 7-8/2005, 2005.

[5] Daisuke, K., Hajime, I., Yuichi, G., Akira, N., Yuzo, A., *Application of Biodiesel Fuel to Modern Diesel Engine*, SAE Technical Papers, 2006-01-0233, 2006.

[6] Horn, U., Egnell, R., Johansson, B., Andersson, O., *Detailed Heat Release Analyses With Regard To Combustion of RME and Oxygenated Fuels in an HSDI Diesel Engine*, SAE Technical Papers 2007-01-0627, 2007.

[7] Karczewski, M., Wilk, M., *Problemy zasilania silnika G9T paliwem F-34 oraz jego mieszaninami z biokomponentem*, Międzynarodowa konferencja motoryzacyjna, Motoryzacja w dobie zrównoważonego rozwoju świata, Szczawnica, 2008.

[8] Mayer, A., Czerwiński, J., Wyser, M., Mattrel, P., Heitzer, A., *Impact of RME/Diesel Blends on Particle Formation, Particle Filtration and PAH Emissions*, SAE Technical Papers 2005-01-1728, 2005.

[9] Szlachta, Z., *Zasilanie silników wysokoprężnych paliwami rzepakowymi*. WKŁ, Warszawa, 2002.