In-use investigations of the changes of lubricant properties in diesel engines

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Summary. The paper discusses the results of comparative investigations of the changes of the dynamic viscosity and dielectric constant of lubricants as a function of temperature and fuel consumption in diesel engines fueled with Ecodiesel Plus 50B under actual operating conditions. The oil change intervals recommended by the engine manufacturers due to a difficult to define variability condition do not always correspond with the actual needs. When realizing a periodical diagnosis of the selected oil parameters for given operating conditions we can determine new criteria, which would be economically justified – particularly in professional applications.

Key words: diesel fuels, engine oils, dynamic viscosity, dielectric constant.

INTRODUCTION

The basic functions of the engine oil are: lubrication, cooling, cleaning, engine sealing etc. [17]. Very difficult to identify in practice are the changes of the lubrication conditions of critical pairs resulting from a continuous deterioration of the engine oil parameters, dissolution and dispersion of contaminants and fuel leakage through piston-piston and ring-piston sleeve pair [16]. That is why during operation under actual conditions it is recommended to frequently monitor the condition of the engine oil in the whole period between oil changes. The oil change intervals recommended by the manufacturers due to a difficult to define operating conditions variability do not always reflect the actual needs. By carrying out periodical comparative tests of the properties of the lubricants in the oil sump at given operating conditions we can determine new criteria of oil change and obtain measurable benefits in the form of savings in the operating costs [2].

The design, technological history of the materials and parts in the friction pairs as well as mutual triboligical interactions during operation – very much dependent on the quality of the applied oils and fuels – determine the course of the decrement processes in the friction pairs of diesel engines fitted in vehicles and self propelled machinery. The selection of oil for the central lubrication systems, including, in particular its properties, for the actual operating conditions may have key impact on the durability and reliability of diesel engines [2, 6, 7, 13, 17, 18, 19].

An important problem related to the durability of sliding critical pairs in diesel engines in operation, indicated by many authors in recent publications is the application of bio- and eco- fuels that used according to the requirements of the increasingly more stringent emission standards [1, 9, 10, 11, 20, 21, 22, 23]. Diesel engines are particularly sensitive to fuel quality and the use of such fuels can lead to changes in the lubrication parameters (not only in the kinematic pairs of the fuel system but also in the centrally lubricated kinematic pairs) of consequences that are difficult to determine in terms of the deterioration of the whole engine [6, 7, 8, 9, 10, 11].

In relation to the presented conditions, the authors attempted to explain in comparative investigations whether the amount of used fuel under actual conditions of operation has influence on the changes of the rheological and quality properties of the engine lubricants in diesel engines fitted in farm tractors. The authors attempted to explain whether the observed changes of the selected parameters of the engine oil resulting from the consumption of a certain amount of fuel may lead to the verification of the oil change intervals and in extreme cases to a development of pathological wear processes in the critical friction pairs – particularly sliding friction pairs.

OBJECT AND METHODS OF INVESTIGATIONS

The object of the investigations were oil samples taken between the oil change intervals from 5 Z 8602.1

engines (engine operation time to date approximately 300÷600 mth after rebuild – Ursus farm tractors) and 5 T4/SIIIB engines utilizing the PowerTech Plus technology (engine operation time to date approximately 700÷1000 mth, new engines John Deere 7430) fueled with the same kind of fuel– ON Ekodiesel Plus 50B.

Right before the tests were initiated the lubricating systems were filled with oil recommended by the engine manufacturers [5, 14]:

- U engines (Z 8602.1) –SAE 15W/40, API CG-4, ACEA E2/B2/A2,
- JD engines (T4/SIIIB) –SAE 15W/40, API CI-4, ACEA E4.

Then, the diagnostics of the engine condition was performed as per the manual. Based on the obtained results of the inspection the engines were deemed as technically operative.

All the engines assigned for comparative investigations were operated in similar weather, soil and terrain conditions – in the periods from the end of March to the end of November (agro-technical season) 2010 in two adjacent villages. The engines were used typically for their power output class. The oil samples were taken according to a preset procedure - the same for each engine. The first sample was taken from the oil container where it was stored before application. Subsequent samples were taken every 200 dm^3 of the consumed fuel until next oil change. The samples were taken through the dipstick access by a syringe ending with a rubber hose ($50 \cdot 10^{-6}$ m^3 in capacity) with the accuracy of $5 \cdot 10^{-7}$ m^3, immediately after the tractor ended operation. Immediately after the samples were taken the syringe and the hose were thoroughly cleaned in a solvent and dried. The oil decrement was topped up. In the period when the experiment was conducted the amount of consumed fuel was recorded based on the readouts of the fitted flow meters with the accuracy of +1% from the measured value.

For the determination of the viscosity a digital rotary viscometer was used (Brookfield DV-II+ with an ultra-thermostatic chamber, PC computer controlled based on Rheocalc 32 software). The measurement was conducted according to the standard [24] and recommendations of the manufacturer of the viscometer with the accuracy of $\pm 10^{-2}$ mPa·s [3]. For the determination of the qualitative changes of the oil a Lubrisensor was used. Thanks to the measurement of the relative changes of the value of dielectric constant ε (with the accuracy of $\pm 10^{-1}$ $F \cdot m^{-1}$) the Lubrisensor recognized 3 groups of engine oil operation contaminants (I group– oxides, sediments, dirt, fuel combustion products, acids; II group – water, coolant, metal parts; III group – fuel). Dielectric constant ε grows or decreases proportionally to the change of the concentration of the contaminants present in the fuel. The direction of the indicator towards '+' or '–' and the readout determine the group of the contaminants and their amount. The assessment of the conditions of the tested oil consists in calibrating of the device on a base sample (fresh oil) and measuring of the changes of dielectric constant ε for the tested samples taken from the engine [4, 12]. In the whole test cycle the total of 30 oil samples were taken from the U engines (6 from each engine) and 45 samples from the JD engines (9 from each engine). For each of the taken samples the measurement of the changes in the ε value in the temperature of 293K was carried out three times as well as the measurement of the dynamic viscosity for the temperatures in the range (273÷368) K stepwise every 5K. Next, the average values and standard deviations were calculated. The obtained results were subjected to statistical analysis on the significance level of $\alpha = 0,05$.

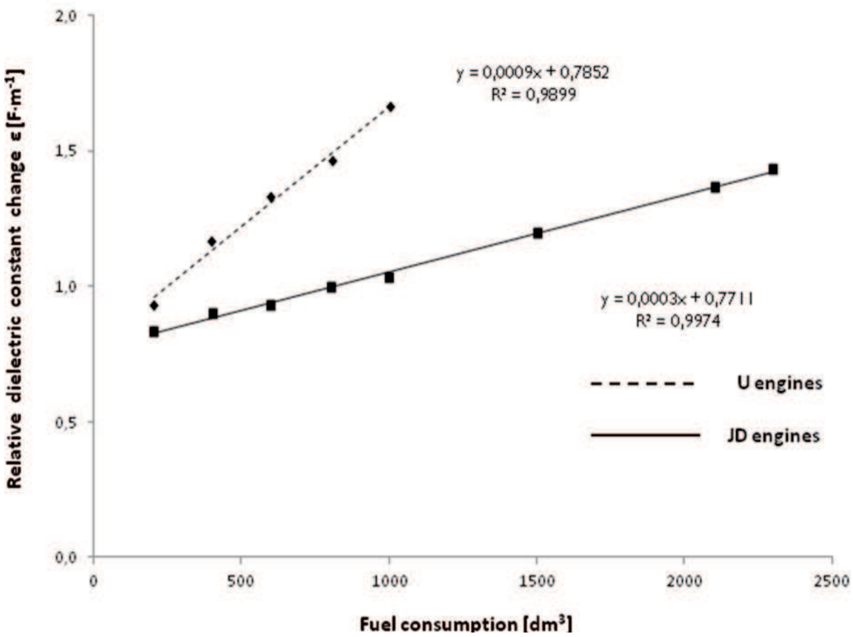

Fig. 1. Comparison of the relative regression lines of the changes of the dielectric constant of the tested engine lubricants as a function of fuel consumption (constant measuring temperature T = 293 K)

DISCUSSION OF THE TEST RESULTS

Based on the statistical analysis of the test results a significant influence of the amount of consumed fuel on the changes of the dielectric constant was observed of the engine oils SAE 15W/40, API CG-4, ACEA E2/B2/A2 and SAE 15W/40, API CI-4, ACEA E4. A very strong positive correlation was observed between the changes of the ε values and the amount of consumed fuel (Fig. 1). The comparison of the direction coefficients of the lines of regression indicates that the unit increment of the ε value as a function of consumed fuel for the engine lubricant SAE 15W/40 API CG-4 (Fig. 1, dotted line) is approximately 3 times greater than for the engine lubricant SAE 15W/40, API CI-4 (Fig. 1, solid line).

During the comparative in-use tests of the qualitative changes of the engine oils with the use of Lubrisensor in the case of all the samples taken directly from the oil pan in the period of operation under analysis only contaminants from group I were detected. No contaminants from groups II and III (water, coolant, metallic parts, fuel) were detected by the device. This may confirm the earlier formulated assumption regarding the conditions of full parametric usability of the engines, adopted in the beginning of the comparative tests after carrying out of the diagnostic procedures as recommended by the manufacturer. An important effect of the conducted tests is the increment of the value of the dielectric constant clearly seen in Fig. 1 (as compared to the base oil) already in the first samples taken from the engines after consuming approximately 200 dm^3 of fuel. Such a significant change already after the first examination may indicate an excessive amount of contaminants (exhaust carbon, deposits, sludge) in the interior parts of the engine and oil ducts and indicate the need for flushing of the system before oil change.

Fig. 2 presents the sequential graphs of the changes in the dynamic viscosity of the monitored engine oils as a function of temperature and fuel consumption obtained based on the results of the performed in-use tests.

In the whole agrotechnical season of the field works and transport works with the fuel consumption of approximately 2400 dm^3 (for the JD engines) and approximately 1200 dm^3 (for the U engines) the authors did not observe

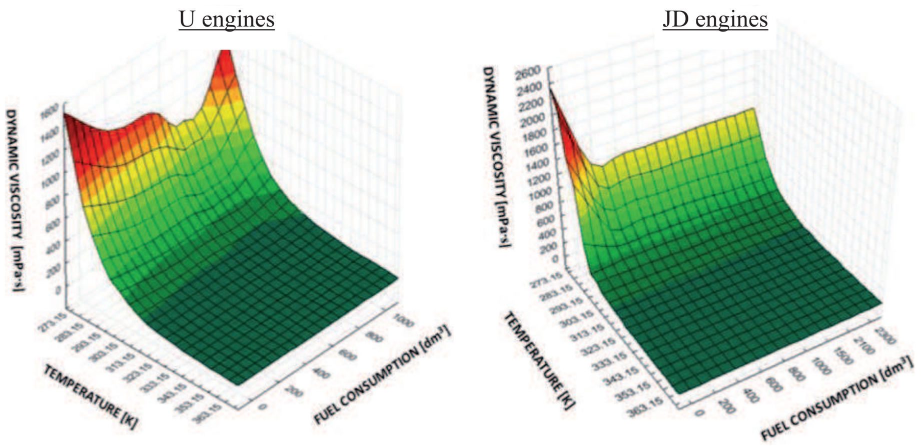

Fig. 2. Sequential charts of the changes in the dynamic viscosity of the tested oils as a function of temperature and consumed fuel: U engines (SAE 15W/40 API CG-4), JD engines (SAE 15W/40, API CI-4)

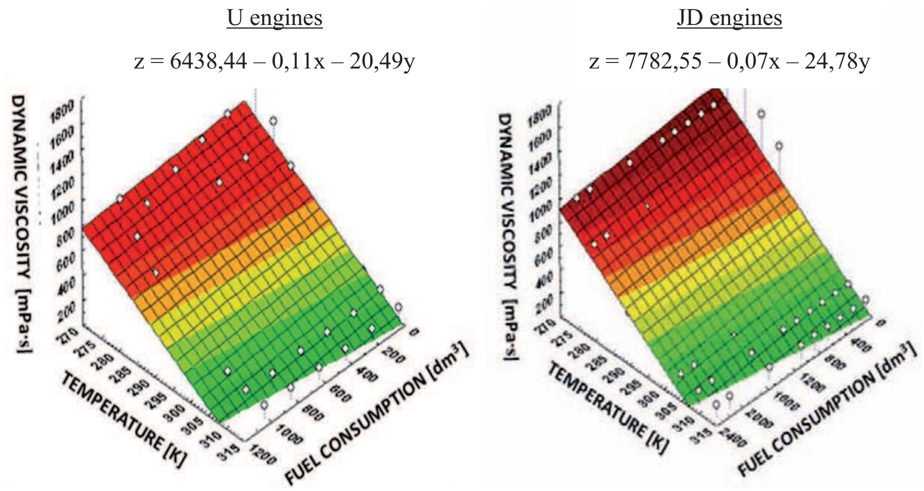

Fig. 3. Surface charts with regression equations of the changes in the dynamic viscosity of the engine oils as a function of temperature and consumed fuel: U engines (SAE 15W/40 API CG-4), JD engines (SAE 15W/40, API CI-4) (interval estimation for the conditions of start-up and cold operation in the temperature range of 273K to 313K)

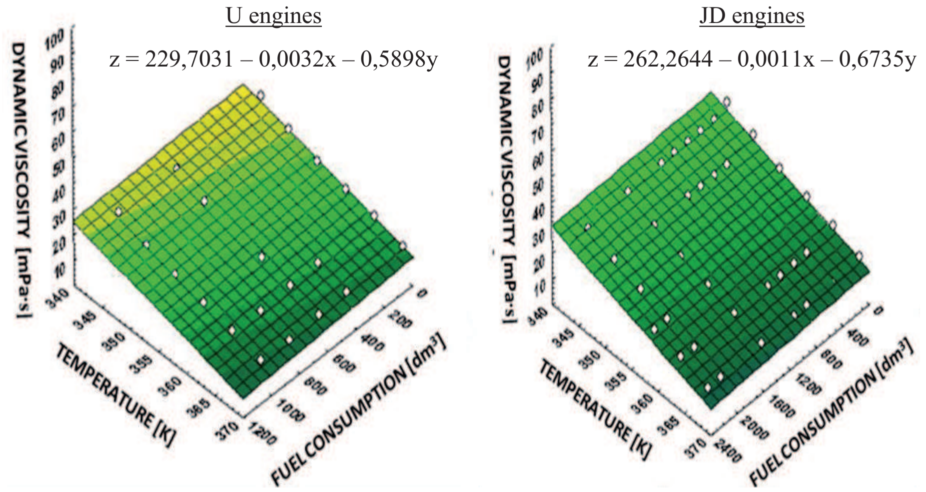

Fig. 4. Surface charts with regression equations of the changes in the dynamic viscosity of the engine oils as a function of temperature and consumed fuel: U engines (SAE 15W/40 API CG-4), JD engines (SAE 15W/40, API CI-4) (interval estimation for the conditions of start-up and cold operation in the temperature range of 343K To 368K)

an excess of the admissible values of the dynamic viscosity (Fig. 3 and 4) and the dielectric constant (Fig. 1) as compared to the fresh oil.

Based on the discussed nature of the changes of the values of the dynamic viscosity and the dielectric constant of the monitored oils: SAE 15W/40 API CG-4 and API CI-4 as a function of the amount of consumed fuel a supposition was formed that the oil change interval be extended until the boundary values are reached defined in the variability range of ±25% (dynamic viscosity) [2] and (3,5÷4,0) $F \cdot m^{-1}$ (dielectric constant) [15].

CONCLUSIONS

1. The changes in the dynamic viscosity of the oil show a strong (U engines) and very strong (JD engines) negative correlation as a function of time and amount of consumed fuel. The greatest observed unit drops of the dynamic viscosity, as a function of temperature, were observed on the base samples (fresh oil) and the smallest on the samples right before the oil change. In the temperature range (273÷313) K – for start-up and cold engine operation– the unit drop in the dynamic viscosity as a function of the consumed fuel in the T4/SIIIB engines is approximately 40% smaller and as a function of temperature approximately 20% greater than in the Z 8602.1 engines. In the range of operating temperatures (343÷368) K the unit drop in the dynamic viscosity as a function of consumed fuel in the T4/SIIIB engines is approximately 3 times smaller and as a function of temperature approximately 14% greater than in the Z 8602.1 engines.
2. The changes in the dielectric constant of the oil in the Z 8602.1 and T4/SIIIB engines indicate a very strong positive correlation as a function of the growth of the consumed fuel. Based on the analysis of the regression model of the relative change of the dielectric constant in the temperature of 293K the authors observed that the unit ε increment as a function of the consumed fuel in the Z 8602.1 engines is approximately 3 time greater than in the T4/SIIIB engines.
3. It is possible to extend the oil change intervals in the SAE 15W/40 API CG-4 and API CI-4 classes in relation to the specifications of the Z 8602.1 and T4/SIIIB engine manufacturers as the relative change in the dielectric constant is smaller than (3,5÷4)$F \cdot m^{-1}$ and the change in the dynamic viscosity in the whole range of analyzed temperatures and consumed fuel does not exceed (25÷30)% as compared to the fresh oil, which is deemed as admissible [6, 7, 24]. An additional argument confirming the purposefulness of this possibility is the fact that in none of the analyzed samples were there any contaminants from groups II and III that are responsible for developing of pathological wear processes in the sliding pairs.

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BADANIA EKSPLOATACYJNE ZMIAN WŁAŚCIWOŚCI OLEJÓW SMARNYCH W SILNIKACH Z ZAPŁONEM SAMOCZYNNYM

S t r e s z c z e n i e. W pracy omówiono wyniki badań porównawczych zmian lepkości dynamicznej i stałej dielektrycznej oleju smarnego w funkcji temperatury i zużycia paliwa, w silnikach z zapłonem samoczynnym, zasilanych paliwem Ekodiesel Plus 50B w rzeczywistych warunkach eksploatacji. Terminy wymian zalecane przez producentów silników, ze względu na trudną do zdefiniowania zmienność warunków pracy, nie zawsze są zgodne z rzeczywistymi wymaganiami. Realizując okresowe diagnozowanie wybranych parametrów oleju silnikowego, dla określonych warunków eksploatacyjnych, można wyznaczyć nowe kryteria wymiany, co ma ekonomiczne uzasadnienie – szczególnie w zastosowaniach profesjonalnych.

S ł o w a k l u c z o w e: paliwa do silników z zapłonem samoczynnym, oleje silnikowe, lepkość dynamiczna, stała dielektryczna.