Specifications of Wear of Oils in Two-Fuel Systems

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Article focuses on the monitoring of motor wear of vehicles powered by a dual-fuel diesel-vegetable oil system. The introductory part focuses on the use of biofuels for combustion engines and tribotechnical diagnostics for wear testing. Analysis of engine oil samples from vehicles with different fuels is carried out. Fuel is diesel fuel, biodiesel and a two-fuel system with two fuels – rapeseed oil and diesel fuel. The abrasion wear of biodiesel is increased. Wear in dual fuel system is within the standard exchange interval in the zone of emergency wear of metallic particles and carbon. The article evaluates the adjustment of the oil exchange interval to limit negative effects on wear surfaces. Shortening the interval to the optimum level for biodiesel is 1/3, for dual fuel system is 1/2. Vegetable oil in engine oil causes a change in the character of lubrication. Shortening the interval to 1/2 is necessary to minimize negative effects.

Keywords: Biofuel, Biodiesel, Engine Oil, Wear Particles, Nomogram the Wear

1 Introduction

Interest in renewable fuels has begun to arise in the context of strong dependence on the countries of the Middle East and other strongly politically and economically unstable states. States tried to find their own fuel source, which would secure the state in the event of sharp fluctuations in oil prices. Alternative fuels have other benefits, such as lower emissions and rural development [1].

Biofuels have become an integral part of the everyday life of modern society. Bioethanol and fatty acid methyl esters form a common part of gasoline and diesel fuels and the pressure to intensify the replacement of fossil fuels by bio-constituents is steadily increasing [1,2]

Fuels for diesel engines on the EU market:

- Diesel fuel (B7) according to standard EN 590;
- Biodiesel (B100) according to standard EN 14214;
- Diesel fuel-biodiesel blend (B30);
- Purified rapeseed oil.

The basic component of oils and fats is 90-98% w/w. of triglycerides (esters of higher fatty acids + glycerol), monoglycerides, diglycerides and free fatty acids. Most natural oils are a mixture of different triglycerides from C_9 to C_{29}, most commonly C_{15} and C_{17}. The melting point and boiling point is therefore within a wide range of temperatures.

Chemical transformation due to different physical chemical parameters (compared to diesel fuel) is necessary. The result of chemical transformation is FAME Fatty Acid Methyl Ester. According to the raw material we can distinguish, for example [1-3]:

- FAME Fatty Acid Methyl Ester (MEMK) according to standard EN 14 214;
- RME Rapeseed Methyl Ester ;
- SFME Sunflower Methylester;
- SME Soya Methyl Ester;
- AFME Animal Fat Methyl Ester;
- REE Rapeseed Ethyl Ester.

Vegetable oil can be used without chemical treatment. The fuel system has to be modified with respect to the different fuel parameters - especially the kinematic viscosity and adaptation to the fuel properties (Fig. 1).

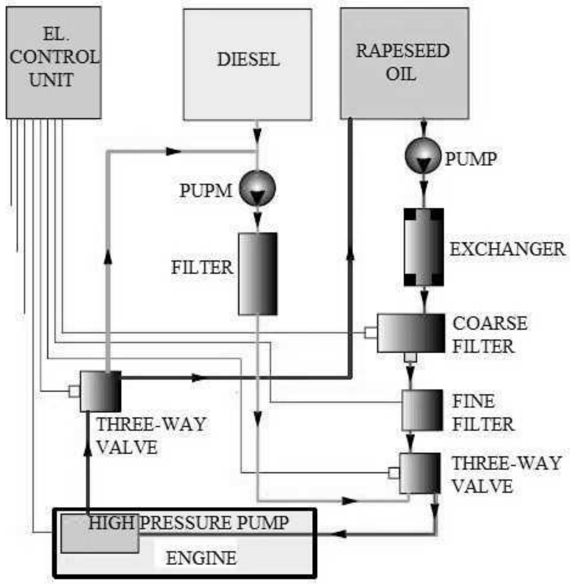

***Fig. 1** Dual Fuel System Diesel-Vegetable oil [3]*

The two-fuel system of Figure 1 consists of two tanks with a low-pressure branch. Vegetable oil is heated in the system and if the temperature is at least 60 ºC it is possible to switch fuel from diesel fuel to rapeseed oil. The kinematic viscosity at this temperature corresponds to the viscosity of the diesel fuel [3].

Operation must be terminated on diesel fuel and fuel must be switched in time.

The physical properties of rapeseed oil are different compared to diesel fuel. Rapeseed oil has lower calorific value, viscosity and flash point. Table 1shows that direct use in a conventional diesel engine is complicated [2,3]

Tab. 1 *Comparison of basic fuel parameters of rapeseed oil and diesel fuel*

		Rapeseed oil		Diesel fuel	
Parameter	Units	min	max	Min	max
Density at 15 °C	$kg.m^{-3}$	910.0	925.0	820.0	845.0
Kinematic viscosity at 40 °C	$mm^2.s^{-1}$	-	36.0	2.0	4.5
Calorific value	$MJ.kg^{-1}$	36.0	-	about 42.6	
Flash point	°C	101	-	55	-
Oxidation stability at 110 °C	h	6.0	-	20	-

Reasons for application of vegetable oils as fuel

- biodegradability (within about 3 weeks)
- reducing dependence on crude oil;
- local renewable fuel source;
- positive energy balance;
- support for rural development
- lower emissions of GHG;
- absence of polyaromatic hydrocarbons;
- economical and ecological land use;
- handling safety. [3]

Methods of tribotechnical diagnostics were applied for the measurement of wear particles of metals in a two-fuel system. Tribotechnical diagnostics monitors the state of the oils in the lubrication system. Diagnostics monitors wear of machine parts that come into contact with friction and evaluates their technical condition. The aim of tribotechnical diagnostics is:

- determination of oil life - the degree of wear and degradation and secondary pollution is evaluated;
- monitoring the wear of moving and non-moving parts - increase of abrasive metals, monitoring of the mechanical condition of the engine, verification of the suitability of the recommended lubricant;
- determining the optimum lubricant exchange interval [4-6]

2 Materials and methods

For measuring were chosen:

- analysis of the metal particles were carried out on the PMA-90 magnetic analysator;
- determination of carbon impurities by Thin Layer Chromatography (TLC).

The TLC method measures the degree of opacity of the central zone of drop test according to amount of carbon pollution. The Canon Cano-Scan 9950F professional scanner was used to measure the degree of dimming. The results were digitally evaluated using Photoshop version 8.

Measurement of the samples was performed on a PMA-90 capillary ferrograph, which is able to detect the amount of metal abrasion particles in engine oil using two sensors and an electromagnet. The analyzer divides the particles into small D_S and large D_L and sensors will evaluate their amount. These two values are recorded and further counted according to the following relationships (1–5).

Specific concentration (1)

$$WPC = D_L + D_S \quad (1)$$

To construct a nomogram the wear should be carried out to correct the *WPC* to WPC_K, taking into account also the amount of new oil added for the full rexchange interval (2,3)

$$WPC_K = WPC \cdot K_C \quad (2)$$

$$K_C = K_M \cdot K_{NM} \quad (3)$$

and the value of K_M, K_{NM} calculated according to equation (4,5)

$$K_M = \frac{V_k + V_{tu}}{V_k} \quad (4)$$

$$K_{NM} = \frac{M_{ntu}}{M_{stu}} \quad (5)$$

where: V_k (l) – the volume of oil in the casing; V_{tu} (l) – the amount of oil added in the whole interval exchange; M_{ntu} (l) – standardized fuel consumption; M_{stu} (l) – actual fuel consumption.

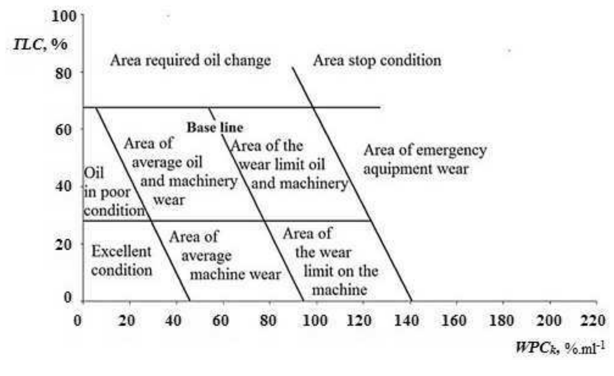

Fig. 2 *Construction of nomogram the wear*

Discrimination analysis serves as a classification process (Fig.2). Horizontal axis *x* shows wear level *WPC* in $\%\text{-}ml^{-1}$ and main vertical axis y is showing opacity of central zone *TLC* in %. "Centroid of all values *B*" (Fig. 3–8) is calculated by calculating the arithmetic mean of all values. This point divides the whole group into two sets of points: "good" and "bad". From the remaining values of both sets, we calculate the arithmetic averages of the so-called "Centroid of good machines *A*" and "Centroid of bad machines *C*" (Fig. 3–8). The basic line of BASE-LINE is perpendicular to the trend line of points *A*, *B* and *C*. Next, we create parallels with the *x*-axis passing through the A value and the C value. The final step in the graphical processing of the nomogram is the construction of the parallel with the BASE-LINE passing through points *A* and *C*. On the basis of discriminatory analysis is determined the dependence of two main variables: opacity of central zone *TLC* [%] and wear level *WPC* [$\%.ml^{-1}$] [3,7-9]

The graph shows the distribution of values to individual zones for practical purposes (Fig.2):

Engine oil samples from 5 vehicles Škoda Octavia with different fuels were monitored to assess operational reliability. Samples are labeled with working titles:

Diesel1 – diesel fuel vehicle 1 - Škoda Octavia TDi 77 kW, the sample was taken after 7,000 km; 12,000 km; 18,000 km; 28,000 km;
Diesel2 – diesel fuel vehicle 2 - Škoda Octavia TDi 96 kW, the sample was taken after 9,000 km; 14,000 km; 20,000 km; 30,000 km;
Biodiesel1 – biodiesel vehicle 1 - Škoda Octavia TDi 77 kW, the sample was taken after 8,500 km; 15,000 km; 21,000 km; 30,000 km;
Biodiesel2 – biodiesel vehicle 2 – Škoda Octavia TDi 66 kW, the sample was taken after 7,000 km; 16,000 km; 21,000 km; 25,500 km;
D-RO1 I – dual fuel system diesel fuel + rapeseed oil – vehicle 1, I. oil change interval, the sample was taken after 9,000 km; 15,000 km; 20,000 km; 23,000 km;
D-RO2 – dual fuel system diesel fuel + rapeseed oil – vehicle 2, the sample was taken after 9,000 km; 16,000 km; 20,000 km; 24,000 km;
D-RO3 – dual fuel system diesel fuel + rapeseed oil – vehicle 3, the sample was taken after 7,000 km; 15,000 km; 20,000 km; 22,000 km;
D-RO1 II – dual fuel system diesel fuel + rapeseed oil – vehicle 1, II. oil change interval, the sample was taken after 8,000 km; 15,000 km; 18,000 km; 22,000 km;

The prescribed oil change interval by manufacturer for all samples and vehicles is 30,000 km. Two oil change intervals for vehicle D-RO1 were analyzed – the interval II follows the interval I. The vehicles were operated mainly in urban traffic in Prague by one company. Samples were taken continuously from September 2014 to July 2018.

3 Results

Fuel is always mixed with the engine oil during the combustion process as a result of imperfect sealing of the cylinders by piston rings. The hot flue gas penetrates the crank mechanism and degrades the engine oil there. Fuel changes viscosity and reduces lubrication of the oil. Fuel and oil consumption is increasing and damage of the engine (piston damage, engine seizure) may occur [9,10]. The most important parameter is the amount of abrasion metal particles that is labeled as WPC_K in the article.

The nomogram of wear is shown in Fig. 2–5. The horizontal axis *x* shows *WPCk* [$\%.ml^{-1}$], the vertical axis *y* represents opacity of the sample *TLC* [%]. The value *B* in Fig. 2 (Centroid of all values) is the average of all values and is intersected by the BASE-LINE. BASE-LINE represents the value of the optimum oil change interval. The *A* value represents the Centroid of good machines, the *C* value represents the Centroid of bad machines and both divide the nomogram into the specific areas (Fig. 1 and 2).

Figures 2–5 show the results of tribotechnical analysis of engine oils. All tested fuels together are shown in Figure 2. The results in Figure 2 are important to compare with the areas in Figure 1 above.

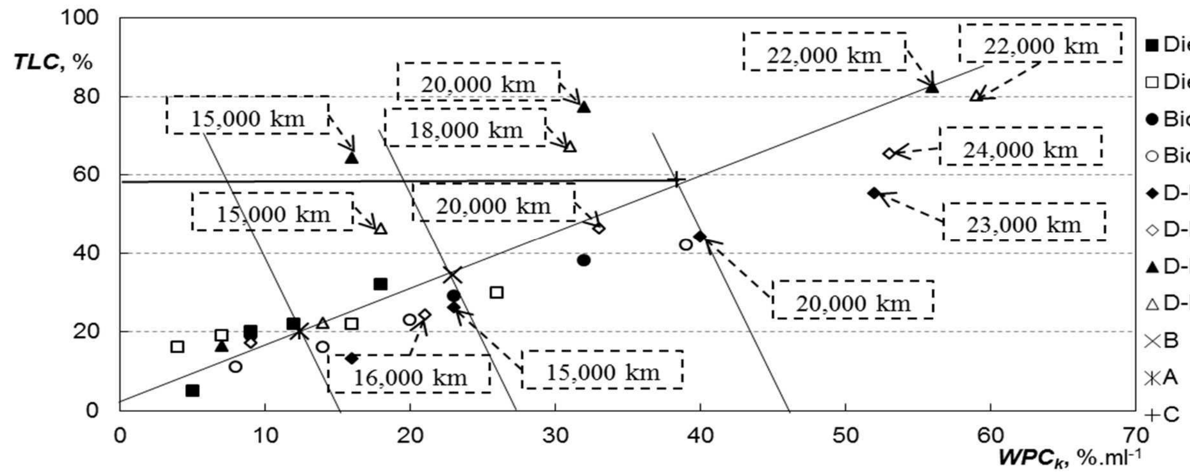

***Fig. 2** Nomogram the wear of engines and oil condition of all fuels*

Figure 2 also shows the number of kilometers per oil interval for dual-fuel systems. The exchange interval is 30,000 km according to the oil manufacturer. The BASE-LINE in Figure 2 and Figures 3–5 represents the optimal exchange interval. All vehicles driven by vegetable oil in combination with diesel fuel reach an optimum exchange interval of approximately 15,000 km.

The optimal exchange interval for diesel fuel samples Fig. 2 and 3 is about 30,000 km, which corresponds to the oil manufacturer's requirements.

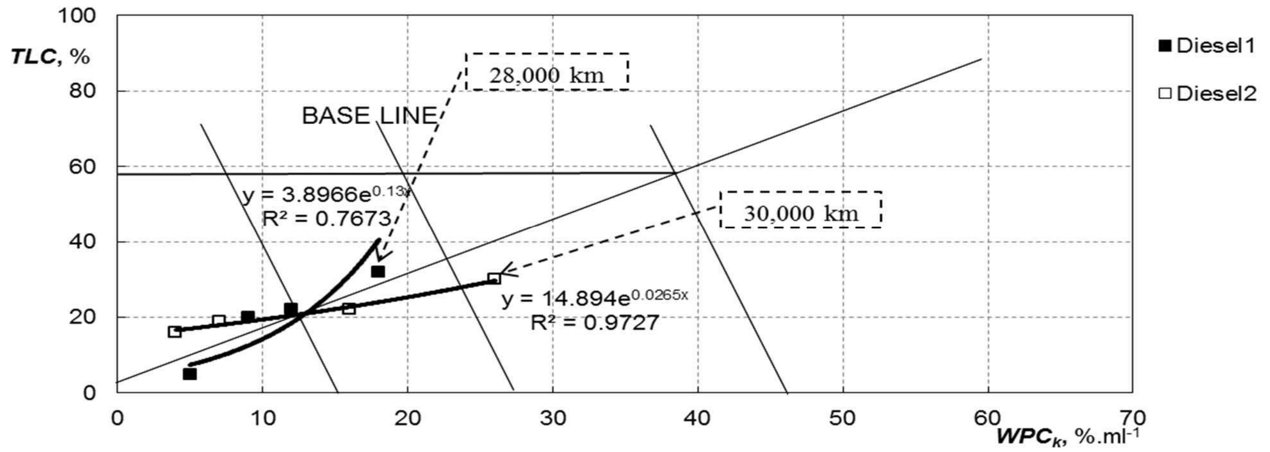

Fig. 3 Nomogram the wear of engines and oil condition of diesel fuel

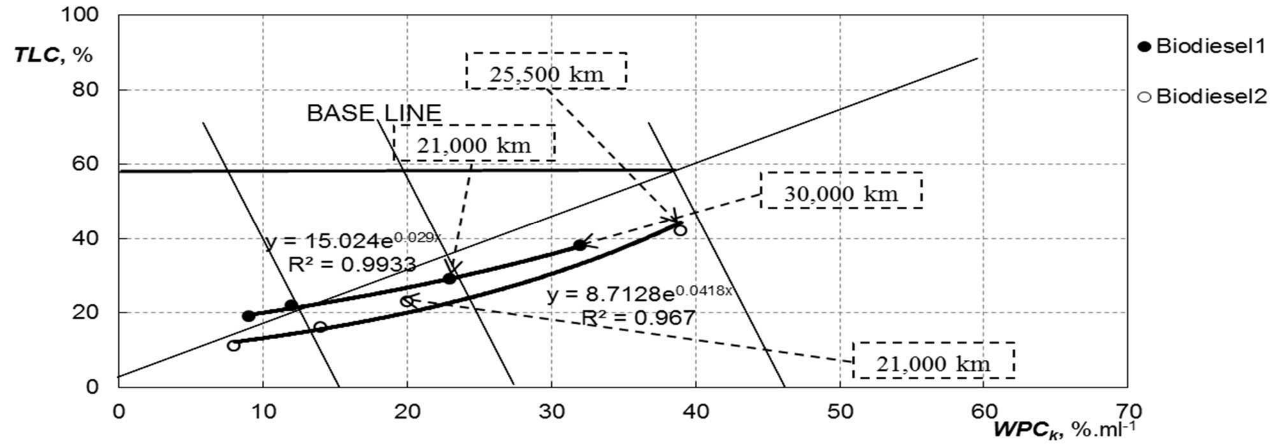

Fig. 4 Nomogram the wear of engines and oil condition of biodiesel fuel

Breakthrough of unburnt biodiesel into the oil means faster degradation. The degree of dilution can be tolerated up to 20% of the biodiesel (FAME) content of special motor oils. However, the use of special motor oils developed for biodiesel operation is necessary.

Therefore, the exchange interval with 100% biodiesel must be reduced by approximately 1/3 as shown in Figure 4. The optimal exchange interval for biodiesel fuel is approximately 20,000 km.

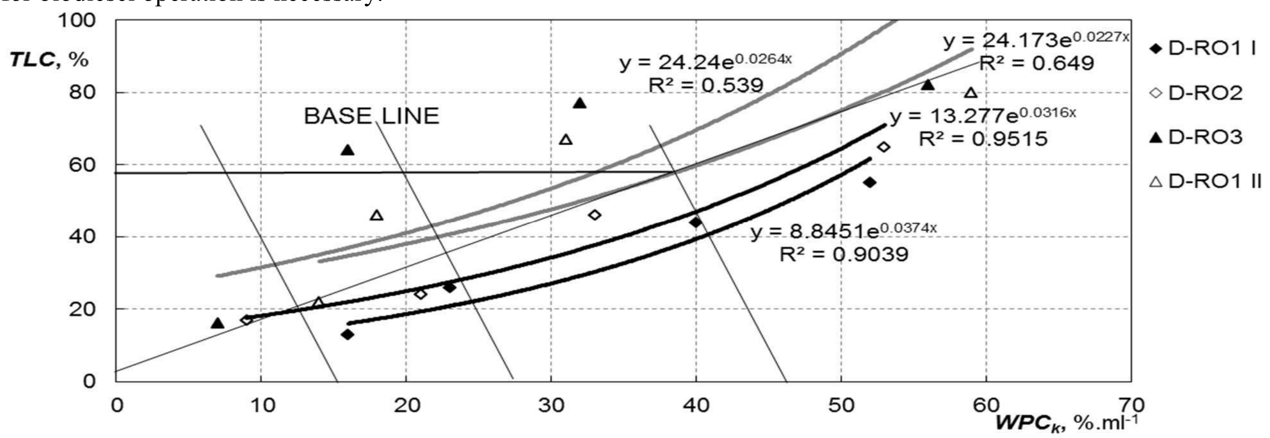

Fig. 5 Nomogram the wear of engines and oil condition of dual fuel system diesel fuel-rapeseed oil

A major problem arises from the formation of relatively large drops of oil and its low evaporation. This leads to the formation of carbon and the change in viscosity when the engine oil is diluted by rapeseed oil. Another problem may be blocking of the injectors and piston ring grooves, which is the cause of the loss of compression. [11,12]

The maximum mileage range for 30,000 km of oil was not realistic when using a dual-fuel system. Figures 2 and 5 show that wear of approximately 20,000 km is in the area of emergency wear. This is due to the high proportion of metal particles (*WPC*) and increased carbon content (*TLC*). The optimal sample interval occurs at approximately 15,000 km. The exchange interval by using the two-fuel system must be reduced to 1/2 to minimize the negative effects of abrasion metal particles. Shortening the interval also prevents excess fuel in engine oil.

4 Conclusions

Vegetable oil is a fuel with a relatively high cetane number. The fuel is from local sources and is biodegradable and can be used in protected landscape areas. Its burning produces minimal emissions and harmful substances. However, the rapeseed oil kinematic viscosity is significantly higher than diesel fuel, and it is necessary to use dual fuel system vegetable oil-diesel fuel.

When engine oil is contaminated with rapeseed oil, the amount of metal particles increases and the viscosity of the engine oil varies. This causes its degradation and increased wear on the lubricated parts. It is therefore necessary to shorten the oil change interval.

Normal oil change intervals are 15,000 km or 30,000 km according to the type of the oil. Test samples for diesel-fueled vehicles corresponded to this interval. The optimal for diesel is up to 30,000 km. The degree of dilution by the biodiesel can be tolerated to 20% biodiesel content in special motor oils.

Reducing the oil fill interval by 1/3 seems to be a better solution with regard to the results of the analyzes. The wear is greater due to the failure of the continuous lubrication layer of the engine components. The results of the analysis show that the shortening of the interval to 1/2 is optimal.

High-percentage biofuels represent a long-term sustainable energy source. However, the motors are designed for fossil fuels and it is necessary to adjust the oil change interval for trouble-free operation and to minimize the negative effects.

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