ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume 65 51 Number 2, 2017
https://doi.org/10.11118/actaun201765020481

DEFINITION OF A MOTOR OIL CHANGE INTERVAL FOR HIGH-VOLUME DIESEL ENGINES BASED ON ITS CURRENT CHARACTERISTICS ASSESSMENT

Marie Sejkorová[1], Ivana Hurtová[1], Josef Glos[2], Jan Pokorný[3]

[1]Department of Transport Means and Diagnostics, Jan Perner Transport Faculty, University of Pardubice, Studentská 95, 532 10 Pardubice, Czech Republic
[2]Department of Combat and Special Vehicles, Faculty of Military Technology, University of Defence, Kounicova 65, 662 10 Brno, Czech Republic
[3]Educational and Research Centre in Transport, Jan Perner Transport Faculty, University of Pardubice, Doubravice 41, 532 10 Pardubice, Czech Republic

Abstract

SEJKOROVÁ MARIE, HURTOVÁ IVANA, GLOS JOSEF, POKORNÝ JAN. 2017. Definition of a Motor Oil Change Interval for High-Volume Diesel Engines Based on its Current Characteristics Assessment. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis,* 65(2): 481–490.

Evaluation of motor oils is given a big attention due to a fact that during the years it was proven that lubrication is a key factor influencing a service life of vehicles and industrial engines. Motor oil must fully serve in various operational conditions (such as city traffic with frequent braking and acceleration) as well as in different climatic conditions (arctic winters or tropical summer heat). Therefore, the change of the motor oil should be optimized in order to ensure proper engine efficiency and extend its service life.

The article presents result of testing of two types of used motor oils with the same specification ACEA E4/E7, SAE 10W-40, from two different suppliers. These oils were used in a high-volume diesel engine of IVECO CITY BUS. The sales representatives recently offered a more expensive motor oil (in the text marked oil B) claimed that in their oil can extend the change interval from 40,000 km to 80,000 km.

Evaluation of selected parameters did not prove that after exceeding of change interval 40,000 km, the more expensive motor oil would ensure all required functions as it had been declared by the supplier's sales representative.

Keywords: motor oil, change interval, lubricant analysis, lubricant quality, degradation, FTIR spectrometry, emission spectrometry, particles analysis, measurement

INTRODUCTION

Reliability and a length of a service life of vehicles or other machines depend not only on operational use of the given device but also on features of the oil that is. A type of the motor oil and its current condition influences not only efficiency parameters of the engine and its wear but also its consumption and emissions production.

Components used for a motor oil production, ie. basic oil and chemical additives, their amount and mutual proportion ratio, must be chosen in a way so that the required features of the oil are in a balance and no feature of the oil is highlighted to a detriment of another feature (Sejkorová, 2013). Refining chemical additives that are added to the basic oil are: metallic detergents, ash-free dispersants, oxidation and wear protection additives, friction modifiers, viscosity modifiers, foam removal additives and additives preventing the oil to congeal. Tracking the volume of these additives in the oils is important for a predictive maintenance as well as for extension of the engine service life.

Generally, it can be said that recommendations of producers of engines and other machinery related to minimum quality and change interval of the oil that is used should be followed. Quality of the motor oil is determined by its performance specification. However, a higher performance specification of the oil does not automatically mean its longer change interval.

One of the most important issues influencing the oil service life is the engine construction and further its chemical degradation and contamination (Mihalčová, 2013; Sejkorová *et al.*, 2014).

The oil service life in a diesel or gasoline engine and its change interval is affected by many factor, therefore it is not easy to define an optimum mileage for one oil change cycle for a specific vehicle. Producers usually recommend a maximum time period or a mileage limit; however, it may not correspond to operational conditions of that given vehicle because this limit does not reflect a specific mode of the vehicle usage. For example, during a repeatedly operation in a city traffic in winter, the engine is not running long enough to warm up sufficiently and is turned off and on again, sediments tend to appear on the inner fix parts of the engine and on a surface of the movable parts that get into contact with the oil. These sediments decrease a throughput of lubrication channels, oil filter or strainer. If in this situation a hot highway operation follows, these sediments turn into solid particles and scale that then come adrift from the surface. Then it is just a matter of time when the oil system gets blocked for example by clogging the strainer. This can lead to immediate and unexpected engine failures.

In order to be able to define the optimal oil change interval and a non-disassembly diagnostics of the lubricated system, it is critical to analyze the lubricant quickly and precisely. An efficient oil analysis programme is often based on an off-line oil analysis, performed in laboratories where all oil properties are analysed. Among the most basic observed parameters of the engine oils that have a direct relation with their performance and therefore also with their change interval, we can include viscosity, viscosity index (VI), total base number (TBN) (Král *et al.*, 2014; Mihalčová and Al Hakim, 2008) and a total acid number. For purposes of evaluation of quality parameters of the lubricant being used, analysts use instrumental methods such as infrared spectrometry with Fourier transformation (FTIR spectrometry) (Caneca e al., 2006; Sejkorová, 2013; Trčka *et al.*, 2015; Al-Ghouti *et al.*, 2010; Hnilicová *et al.*, 2016; Marinović *et al.*, 2012; Van De Voort *et al.*, 2006) and electrochemical methods (Tomášková *et al.*, 2014). Atomic emission and absorption spectrometry (Kumbár *et al.*, 2014; Mihalčová and Rimár, 2015, Sychra *et al.*, 1981) are a technique for detecting and quantifying metallic particulates in used oil arising from wear, contamination and additive packages. Analytical ferrography (Hönig and Hromádko, 2014; Machalíková *et al.*, 2007) is a technique which separates magnetic wear particles from oil. Particle Count is a method used to count and classify particulate in a fluid according to accepted size ranges (Kučera *et al.*, 2016; Juránek *et al.*, 2011).

Glos and Sejkorová (2016) analysed by combining the instrumental methods of tribotechnical diagnostics the setting of oil change intervals in buses.

Based on application of modern tribodiagnostics methods Kučera *et al.* (2013), Bekana *et al.* (2015), Kosiba *et al.* (2013) and Tulík *et al.* (2013) evaluated biolubricants that are used in agriculture and transport machinery.

Tippayawong and Sooksarn (2010) have assessed the degradation of lubricating oil used in a small motorcycle engine fuelled with gasohol. Bulsara *et al.* (2015) predicted of residual life of lubricant oil in four stroke engine. Severa *et al.* (2010) dealt with evaluation of changes in flow of oil in motorcycle engines during their life cycle.

With respect to a fact that research in automotive industry focuses primarily on safety and quality of cars and decreasing their operational costs, some car producers have established systems of prolonged services intervals for their brands. Motor oil ("long-life" oil) change intervals for those cars are somewhere between 30,000 and 50,000 km. Král *et al.* (2014) tested long-life motor oils if they were used in unfavorable or difficult conditions.

Aldajah *et al.* (2007) studied an effect of exhaust gas recirculation (EGR) contamination of diesel engine oil on wear. The effect of biofuels on the quality and purity of engine oil evaluated Veselá *et al.* (2014).

Based on the research above, we can say that thanks to development of new analysis methods, and their effective usage it is possible to set an optimal oil change intervals and thus increase efficiency of the oil usage having economical as well as ecological effects. Nováček (2004) reported that optimal setting of change intervals can save up to 20 % of financial costs.

MATERIALS AND METHODS

The work below presents results of quality testing of two types of worn motor oils of the same performance and viscosity specification but from two different producers. This testing was requested by a transport company for purposes of potential extension of oil change intervals and change of the motor oil vendor. Motor oils of the same specification – ACEA E4/E7, SAE 10W-40 – from two individual producers (motor oil A and B) were used in a high-volume diesel engine of Iveco Citybus. Qualitative parameters of new oils are stated in Table I and Table II. Volume of oil needed for this bus type is 25 l and the bus producer recommends the oil to be changed after every **40,000 km** mileage at most (see below).

For purposes of testing, relatively same operational conditions of the bus were ensured for

I: *Parameters of new motor oils*

Parameter	Motor oil A	Motor oil B
SAE classification	10W-40	10W-40
ACEA classification	E4/E7	E4/E7
Density at 15°C [kg.m^{-3}]	867	-
Flash point [°C]	220	210
Viscosity at 40 °C [mm^2.s^{-1}]	90	95
Viscosity at 100 °C [mm^2.s^{-1}]	14.2	14.5
Viscosity index	162	155
Pour point [°C]	< -36	-35
TBN [mg KOH.g^{-1}]	-	11.5

II: *Summary of individual partial oil samples A and B*

oil sample A	odometer reading [km]	mileage [km]	oil sample B	odometer reading [km]	mileage [km]
1	470,387	21,371	**1**	556,948	20,541
2	480,272	31,256	**2**	566,518	30,111
3	492,036	43,020	**3**	581,195	44,788
4	496,491	47,475	**4**	586,914	50,507
-	-	-	**5**	593,826	57,419

both types of oil. Laboratory tests also tracked oil parameters providing information about operation conditions (eg. fuel in the oil as a result of cold starts etc.) that may have a negative impact on the motor oil characteristics.

In case of ***oil A***, a change interval was extended by 7,475 km and in case of ***oil B*** by 17,419 km (see Tab. II) behind a limit of 40,000 km that is recommended by the bus producer as maximum. During the given mileage period, the oil was being refilled.

Evaluated parameters of quality of the tested oil samples were:

- Kinematic viscosity

Experiments were carried out using Stabinger viscometer SVM 3000. It is a modified rotation viscometer being used for measurements of viscosity and density of oils and liquid fuels in accordance with ASTM D7042 standards. Based on the measured values of a dynamic viscosity and density, the device automatically computes the kinematic viscosity and viscosity index in accordance with ASTM D 2270/ISO 2909 standards.

- Flash point

A method of assessment in the open cup according to Cleveland (ČSN EN ISO 2592) was used.

- Conradson carbon residue

This parameter defined in accordance with ČSN ISO 6615 standards describes the oil's tendency to produce coke substances at high temperature.

- Water presence

Determination of water content was made by distillation testing in line with ČSN 65 6062 standards. Water in the motor oil may cause for example condensation of some additives in form of sediments, or hydrolysis of detergents etc.

- Atomic emission spectrometry

An atomic emission spectrometer Spectroil Q100 (Spectro Inc., USA) with a rotary disk electrode (AES/RDE) was used to determine concentration of evaluated abrasion metals and elements related to contaminants.

- Particles analyzer

Laser analyzer of particles LNF Q200 Laser Net Fines (Spectro Inc., USA) was used to determine the total amount of wear particles in a 1 ml sample of worn oil as well as to classify particles per type of wear based on their morphology characteristics.

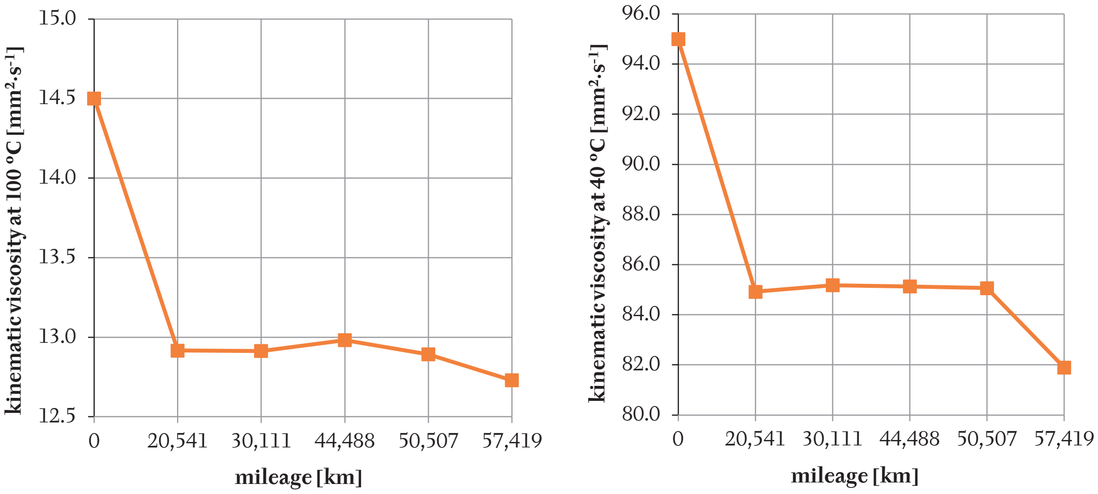
- FTIR spectrometry

Chemical degradation of the motor oil, its contamination, penetration of contaminants and loss of additives were determined on a qualitative basis through comparison of IR spectra of new and worn oils. For this purposes, we used a spectrometer Nicolet iS10 (Thermo Scientific, Inc., USA) with ATR extension head (ZnSe crystal); spectral range 4,000–650 cm^{-1}, resolution 4 cm^{-1}, number of spectrum accumulations 64.

RESULTS AND DISCUSSION

The paper presents results of analysis mainly oil samples after exceeding the recommended motor oil change interval 40,000 km.

The most important motor oils characteristic is the viscosity defined as a measure of inner friction which works as a resistance to the change of molecule positions in fluid flows when they are under the impact of shear force (Perić *et al.*, 2014).



1: *Results of determination of kinematic viscosity at 100 °C and 40 °C for oil A (authors)*

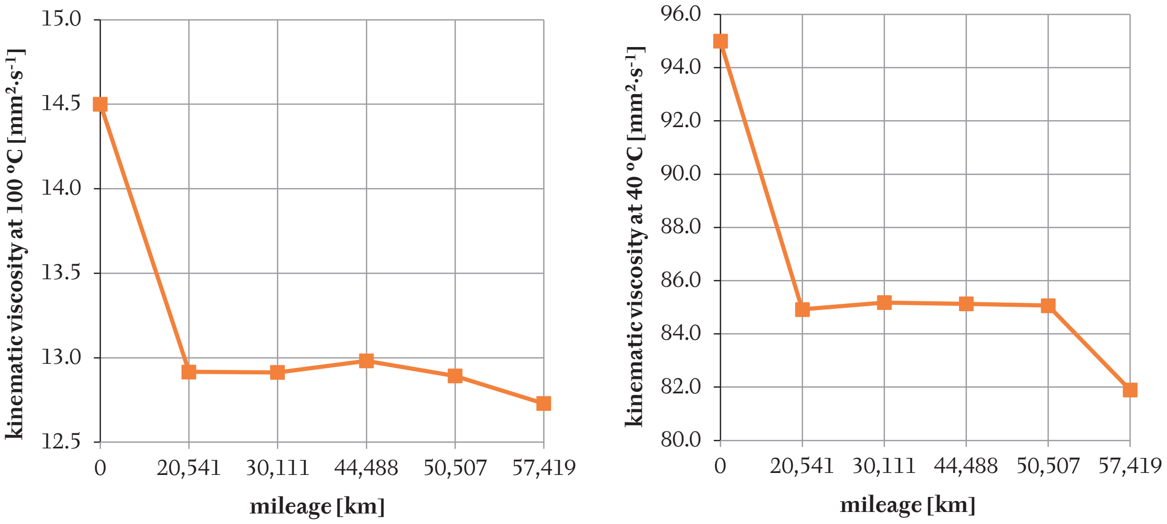
Values of the kinematic viscosity at 100 °C and 40 °C for individual samples of the motor ***oil A*** are presented in Fig. 2. It can be clearly seen that during the use of the oil, its kinematic viscosity decreased to a level of approximately 88–90 % of the kinematic viscosity of the new oil filling. It was noted already for the sample after 21,371 km mileage. According Nedić *et al.* (2009) the fall of viscosity is evident during the first 10,000 km, and after this period, viscosity remains approximately constant until the end of the interval changes of oil charge. The same conclusions have been made by Černý and Václavíčková (2006); according to them, a rapid change of viscosity occurs at the beginning of the oil usage, especially in case of oils of SAE xW-40 class as a result of shear mechanical stress. Also, a reason for the viscosity decrease may be an intrusion of fuel into the oil that can occur naturally in a limited scope. Low viscosity of the oil means too thin oil film and therefore low load capacity. Consistency of the film is then disrupted which then may result in higher wear of the device. The lower viscosity, the higher wear occurs.

As it can be seen in Fig. 1, even in case when the oil change mileage was exceeded by 7,475 km, the used oil viscosity value was not more than 20 % higher than that of a new oil when the oil was supposed to be changed.

Also in case of the motor ***oil B***, when the oil change interval was exceeded by 17,419 km, its viscosity did not differ by more than ±20 % (see Fig. 2) compared to viscosity of a new oil.

Compared to the value for new oil, the limit values for viscosity at 100 °C are equal: warning limit −5 %; +15 %, critical limit −10 %; +20 % (Timotijevic *et al.*, 2013).

Based on determination of an **flash point** and **water content** (see Tab. III) oils samples ***A*** and ***B***, in case of which the oil change limit was exceeded, it can be stated that they do not show such concentration



2: *Results of determination of kinematic viscosity at 100 °C and 40 °C for oil B (authors)*

III: *Results of oil samples A and B analyses*

sample	carbon residue [wt. %]	flash point [°C]	water content [%]
4 (oil A)	2.44	199	0.15
5 (oil B)	2.88	197	0.14

of contaminants that might lead to a collapse of additives or that might indicate an excessive content of fuel in the oil. Allowable concentration of water in the oil is 0.2 % (Nedić *et al.*, 2009). A rapid decrease of the flash point (for diesel engines, the limit value is stated to be 180–190 °C) would indicate that a bigger volume of fuel intruded into the oil filling due to a damage of injector nozzles, injection pump or piston rings. Volume of the fuel in oil is also affected by an operating temperature of the engine as well as a temperature inside the crankcase. In a cold engine, the fuel vapors condensate and flow down into the oil in much higher extent than in case of engines at operating temperature. An acceptable limit of the fuel content in oil is usually determined not to exceed 4 %.

Even after exceeding the oil change interval, a value of the **Conradson carbon residue** did not exceed a level of 4 % of the mass which is a value set as a limit for compression ignition engines. According to Perić *et al.* (2014) allowable values of deviation limits of individual characteristics of the oil are conditioned by the type of oil, working conditions and internal recommendations of the manufacturer of lubricants and users. Deviation of only one source changes characteristics of oil filling, no matter of what a characteristic is about.

Kumbár and Dostál (2013) state that in order to evaluate a current quality of the motor oil, results of oil viscosity, results of emission spectrometry analysis of abrasion metals and monitoring of detection of amount, type and size of abrasion particles using the particles counter are perfectly sufficient.

Also **elements analysis** of the oils using an **atomic emission spectrometry** allows to track a level of concentration of elements that are related to the oil contamination (eg. Si, Na, B), the level of additives (eg. P, Zn, Ca, Mg, Ba etc.) and elements (eg. Fe, Cu, Sn etc.) of abrasion metals of the main construction parts of the engine.

Tab. IV clearly shows that in case of ***oil A***, exceeding the oil change interval led to an increase of concentration of Iron (Fe) which is the basic chemical element used for constructing engines. Content of iron is the below warning limits. Timotijevic *et al.* (2013) published as warning limit 100 mg.kg^{-1} and critical limit 120 mg.kg^{-1} Fe in used oil. The origin of Iron in the motor oil may be wear of bearings, cylinder liners, piston ring, valve lifter, camshaft, crankshaft (Nedić *et al.*, 2009). Other values of chemical elements concentration correspond to a standard wear.

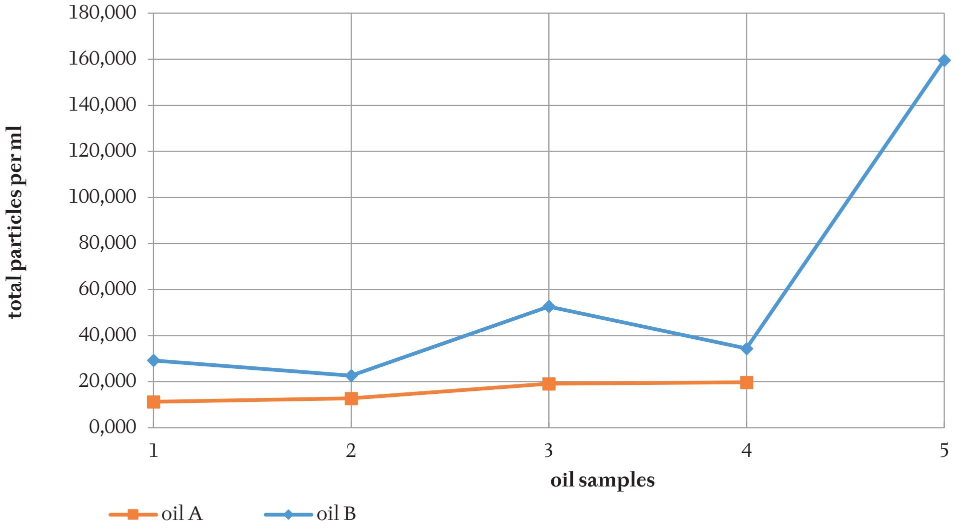
The 5th sample of the ***oil filling B*** shows an almost dangerous concentration of Silicon (Si). Silicon is a part of a dust particles intruding into the oil from outside; therefore, its higher concentration signals a need for maintenance with a probability of the air filter failure. The higher concentration of Fe probably probably relates to the increased level of these hard silica particles that get abrased into the engine and cause its excessive wear. Iron is the most common metallic material. It is usually refined with other metals in order to increase its hardness, increase its slide characteristics or to add an anti-corrosion protection. Copper (Cu) can be found in materials used for production of bearings or slide bearings sheath. Composites containing lead are also used for production of slide bearings. An increased of concentration of chromium may come from chromium coated piston rings or cams.

A **particles analyzer LNF** was used to indirectly determine wear of the most exposed surfaces through detection of number of particles in 1 ml the oil sample (see Fig. 3). The analyzer detects particles with size of 5 to 100 µm (Valach *et al.*, 2013). Based on morphological characteristics of the particles, majority of them are related to fatigue (wear from fatigue occurs often on valves) and abrasion processes. The sample no. 5 of the ***oil*** filling ***B*** shows a rapid growth of the total amount of particles in 1 ml of the oil (Fig. 3). Such a high amount of particles indicates an increased and dangerous wear of the engine with a risk of its failure.

Results given by the particles analyzer correspond to AES analysis also showing the increased concentration of the iron. Therefore, it can be concluded that exceeding the recommended oil change interval by 17,419 km in case of ***oil filling B***

IV: *Results of a chemical elements analysis using AES/RDE method*

sample	Fe [mg.kg^{-1}]	Cu [mg.kg^{-1}]	Cr [mg.kg^{-1}]	Pb [mg.kg^{-1}]	Si [mg.kg^{-1}]	Al [mg.kg^{-1}]
4 (oil A)	56.22	7.53	3.15	19.43	15.12	6.35
new oil A	2.28	0.19	0.00	0.00	8.32	3.39
5 (oil B)	67.85	9.19	3.88	18.53	24.73	6.46
new oil B	2.26	0.15	0.00	0.00	8.77	3.93



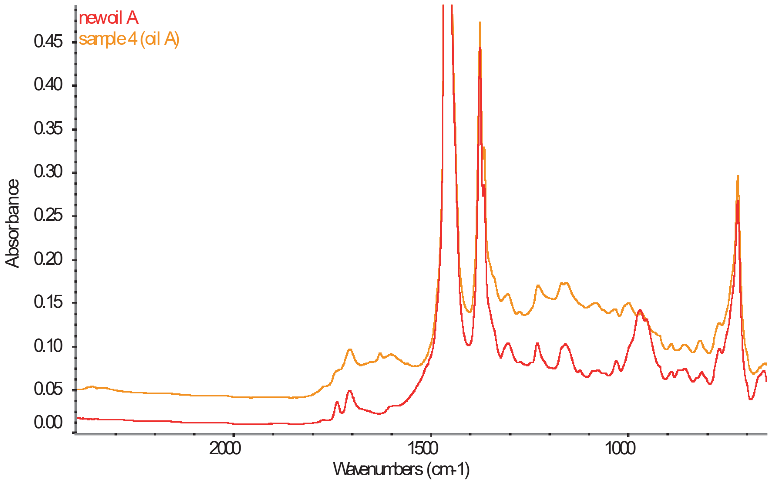
3: *Total amount of particles trend in oils A and B (authors)*

(the engine producer recommends to change the oil every 40,000 km) is not economically effective from the perspective of the total engine wear.

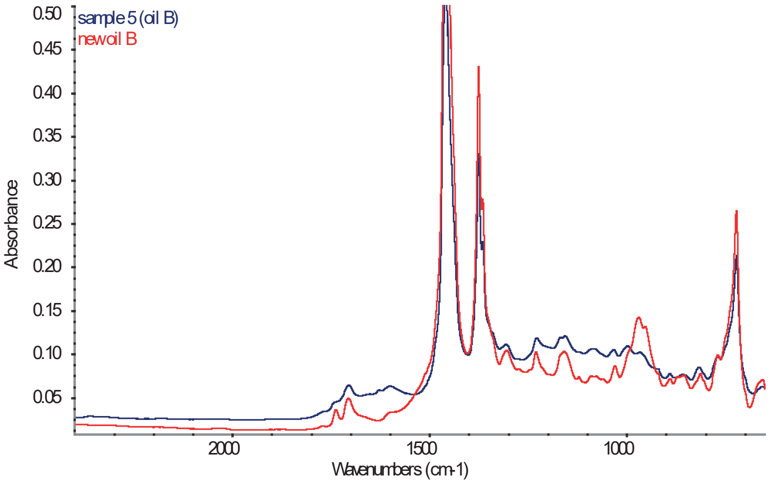
FTIR spectrometry was used for observing degradation of the oil, its contamination and additives depletion. Comparison of IR spectrum of new and used oils in case of a 4th sample of ***oil A*** (Fig. 4) has proved an almost complete depletion of a basic antiwear and antioxidation additive zinc dialkyldithiophosphates (ZnDDP) being indicated by absorbance loss around 1,050–950 cm^{-1}. An oil filling is recommended to be changed when a concentration of this additive falls to 80 % of the original value of the new oil. A significant fall of volume of a detergent additive (a band around 1,230 cm^{-1}) was not registered; a significant fall of volume of this additive together with a rapid fall of concentration of additive ZnDDP may indicate of a fall of alkalinity value (TBN) of the motor oil.

Growth of absorbance in an area between 1,650 and 1,600 cm^{-1} (Fig. 5) indicates a presence of organic nitro compounds due to penetration of gases from a combustion area. In Fig. 5, there is an obvious increased absorbance of a basic line around 2,000 cm^{-1} that is indicated by a shift of the whole spectrum of the worn oil against the one of the new oil. Darkening effect is related to a production of polymeric or polycondensation substances at higher temperatures and with presence of impurities (especially carbon/soot). This effect is normal for compression-ignition engines in a standard operation. There was no significant contamination with fuel – an increase of the band around 800–750 cm^{-1} is negligible. This result is in line with determination of the flash point whose value did not drop below 190 °C.

From details of ***oil B*** spectrum (Fig. 5) it is apparent that already after 57,419 km mileage, there was a significant depletion of basic anti-abrasion and antioxidant additives by approximately 95 % which is indicated by a decrease of a primary band in area of 1,050–950 cm^{-1} and secondary



4: *Spectrum of a new oil and the 4th sample of the motor oil A (authors)*



5: *Spectrum of a new oil and the 5th sample of the motor oil B (authors)*

band with peak around 660 cm^{-1} (P = S link). According to information published by Černý *et al.* (2007), contemporary motor oils show a very good lubricity that does not decline during the oil service life. It is probable that the good lubricity is reached with contribution as polar products of oxidation reactions. Authors (Černý *et al.*, 2007) have experimentally proved that the motor oils at the end of their service life showed better lubricity characteristics than new oils and therefore state that lubricity and anti-abrasion or anti-wear characteristics of the oil are not factors that limit the service life of the motor oils).

There is a negligible absorption zone around 1,630 cm^{-1} that indicates the oil nitration being caused by a contact of the oils film with combustion products (Fig. 5). Intrusion of fuel into oil indicated by a growth of line around 800–750 cm^{-1} has not been confirmed. A shift of the base line towards higher values of absorbance in an area around 2,000 cm^{-1} is an indication of contamination of the oil with soot (Robinson, 2000) penetrating into the oil around the piston. The higher temperature causes the formation of insoluble particles and more intensive oil carbonisation.

Summary

The efficient use of lubricants is linked to determination of how fasts the oil filling gets depreciated, to a level of lubrication quality and wear of the lubricated parts.

One of presumptions for setting optimal oil change intervals is determination of a current status of the oil as well as the lubricated device from which the oil sample was taken. For this purpose, various laboratory diagnostics methods with various degrees of applicability were used as shown on specific situations in this work.

A goal of the study is to present results of testing of quality parameters of two different brands of used motor oils with the same viscosity and performance specification with focus on oil fillings when a maximum recommended **40,000 km** mileage was exceeded. In case of the motor oil marked as ***A***, the change interval was exceeded by approximately 18 %, in case of the motor ***oil B*** approximately 42 %. These two samples of motor oils were tested in buses of a city mass transportation system. In case of the more expensive motor oil (in text marked as ***B***), a vendor declared that its change interval can be prolonged to a double of the recommended mileage, ie. 80,000 km.

Results of experimental determination of motor oils parameters tested in the high-volume engines of buses show that when the mileage gets closer to the one recommended by the producer for the oil change, the anti-oxidation and anti- abrasion additives on a basis of ZnDDP get rapidly depleted even despite the oil was refilled during time. Also, the analyses proved a higher concentration of abrasion metals, especially of *Fe* – in case of ***oil B***, the significant change in concentration of Fe is probably related to intrusion of hard *Si* particles from outside. These particles get stuck in the engine and cause its extensive wear. Based of their shape characteristics, these particles have been identified as particles related to fatigue abrasion processes.

As a result of shear instability of viscosity modifiers, viscosity of the oils decreased; however, the values did not exceed a limit of ±15–20 % which is usually an acceptable limit for a change of viscosity for motor oils during service life. Even exceeding the mileage of the oil change interval did not cause significant growth of amount of products of heat and oxidation processes in the oil as well as intrusion of such amount of soot into the oil that would cause a significant increase of viscosity.

Results of the analyses of both motor oil samples with specification ACEA E4/E7, SAE 10W-40 show that it is possible to prolong their change intervals but they cannot be doubled as it was declared by the vendor of the more expensive motor oil. The results are in accordance with results of study of Timotijevic *et al.* (2013). They testing motor oils with specification ACEA E4/E7, SAE 10W-40 used in buses of a city transportation system in Beograd (Serbia) and coming to a conclusion that the oil change interval can be prolonged by up to 30 %. Authors say that particular operational conditions of the engine are the most important factor impacting oil degradation and engine wear. Also, Nedić *et al.* (2009) assessed the motor oil VALVOLINE, API CF and ACEA E4, gradation SAE 10W-40 during its use in engines of EURO 2 category buses with an oil change interval recommended by a producer at every 30,000 km. All observed physicochemical parameters of oil and oil wear products (Fe a Cu) were below the maximum limits during the whole period of operation.

Monitoring of motor oils taken from tractors was performed by Bekana *et al.* (2015). Based on analyses they also came to a conclusion that a recommended oil change interval of 250 motor-hours is not determined properly because the tractors were in a good condition and a high reliability of the engine was ensured. They propose to perform a further research based on which the oil change interval can be optimized with respect to operational conditions of a device.

CONCLUSION

A goal of the paper was to present results of analysis of two samples of worn motor oils ACEA E4/E7, SAE 10W-40. The oils were used in IVECO CITY buses even after the oil change interval of 40,000 km, recommended by the bus producer, was exceeded. The testing was requested by the city transportation authority in order to verify if it is possible to double the recommended maximum oil change interval of the more expensive oil (in tests marked as B) as it was declared by the oil distributor's sales representative.

Based on the analyses (determination of viscosity, flash point, Conradson carbon residue, volume of water, wear particles using AES spectrometry and laser particles counter, FTIR spectrometry), it was recommended to stay with the current motor oil provider. The offered more expensive motor oil showed a significant increase of amount of wear particles after exceeding the recommended motor oil change interval (40,000 km) by approximately 42 %. This indicates insufficient friction conditions among moving parts of the engine, ie. increased engine wear.

Acknowledgmets

The research has been supported by the project SGS_2016_008. The authors thank University of Pardubice for financial support.

REFERENCES

ALDAJAH, S., AJAYI, O. O., FENSKE, G. R. et al. 2007. Effect of exhaust gas recirculation (EGR) contamination of diesel engine oil on wear. *Wear*, 263(1): 93–98.

AL-GHOUTI, M. A., AL-DEGS, Y. S. and AMER, M. 2010. Application of chemometrics and FTIR for determination of viscosity index and base number of motor oils. *Talanta*, 8(3): 1096–1101.

BEKANA, D., ANTONIEV, A., ZACH, M. et. al. 2015. Monitoring of Agricultural Machines with Used Engine Oil Analysis. *Acta Univ. Agric. Silvic. Mendelianae Brun.*, 63(1): 15–22.

BULSARA, M. A., HINGUZ, A. D. and PATEL, K. 2015. Prediction of residual life of lubricant oil in four stroke engine. In: *Proceedings of International Conference on Advances in Materials and Product Design (AMPD 2015)*. 409–413. [Online]. Available at: https://www.researchgate.net/profile/Mukesh_Bulsara/publication/271072642_Prediction_of_residual_life_of_lubricant_oil_in_four_stroke_engine/links/54bce1300cf253b50e2d80a9.pdf [Accessed: 2016, November 27].

CANECA, A. R., PIMENTEL, M. F., GALVÃO, R. K. H. et. al. 2006. Assessment of infrared spectroscopy and multivariate techniques for monitoring the service condition of diesel-engine lubricating oils. *Talanta*, 70(2): 344–352.

ČERNÝ, J., BUČKO, L. and VÁCLAVÍČKOVÁ, I. 2007. Lubricating and anti-abrasion characteristics of motor oils. [in Czech: Mazivostní a protioděrové vlastnosti motorových olejů] In: *Aprochem 2007: Odpadové fórum*. 16. – 18. 4. 2007, Milovy. 1433–1438. [Online]. Available at: http://www.petroleum.cz/upload/aprochem2007_169.pdf [Accessed: 2016, November 27].

ČERNÝ, J. and VÁCLAVÍČKOVÁ, I. 2006. Shear stability of motor oils. *Goriva i maziva*, 45(5): 323–330.

GLOS, J. and SEJKOROVÁ, M. 2016. Tribo-diagnostics as and input for the optimization of vehicles preventive maintenance. In: *Intelligent Technologies in Logistics and Mechatronics Systems, ITELMS 2016 – Proccedings of the 11th International Conference*. Panevėžys, April 28–29. Bologna, Italy: MEDIMOND, 83–90.

HNILICOVÁ, M., KUČERA, M. and PAVLŮ, J. 2016. Analysis of Hydraulic Oil in Handling Lines Baljer & Zembrod using the Methods of Tribotechnical Diagnostics. *Key Engineering Materials,* 669: 451–458.

HÖNIG, V. and HROMÁDKO, J. 2014. Possibilities of using vegetable oil to power diesel engines as well as their impact on engine oil. *Agronomy Research*, 12(8): 323–332.

JURÁNEK, R., MACHALÍK, S. and ZEMČÍK, P. 2012. Research on image features for classification of wear debris. *Machine Graphics & Vision*, 20(1): 1–22.

KOSIBA, J., TKÁČ, Z., HUJO, Ľ. et al. 2013. The operation of agricultural tractor with universal ecological oil. *Res. Agr. Eng*, 59: 27–33.

KRÁL, J., KONEČNÝ, B., MADAČ, K. et al. 2014. Degradation and chemical change of longlife oils following intensive use in automobile engines. *Measurement*, 50: 34–42.

KUČERA, M., ALEŠ, Z., IVANDIĆ, Z. et al. 2013. Possibility of hydraulic fluids with a low environmental impact application in agriculture and transport machinery. *Journal of Central European Agriculture*, 14(4): 1575–1584.

KUČERA, M., ALEŠ, Z., PAVLŮ, J. et al. 2016. Applying of Automatic Laser Particle Counter as Technique to Morphology Assessment and Distribution of Wear Particles during Lifetime of Transmission Oils. *Key Engineering Materials*, 669: 417–425.

KUMBÁR, V. and DOSTÁL, P. 2013. Oils degradation in agricultural machinery. *Acta Univ. Agric. Silvic. Mendelianae Brun.*, 61(5): 1297–1303.

KUMBÁR, V., GLOS, J. and VOTAVA, J. 2014. Monitoring of Chemical Elements During Lifetime of Engine Oil. *Acta Univ. Agric. Silvic. Mendelianae Brun.*, 62(1): 155–159.

MÁCHAL, P., MAJDAN, R., TKÁČ, Z. et al. 2013. Design and verification of additional filtration for the application of ecological transmission and hydraulic fluids in tractorc. *Acta Univ. Agric. Silvic. Mendelianae Brun.*, 61(5): 1305–1311.

MACHALÍKOVÁ, J., SEJKOROVÁ, M., LIVOROVÁ, M. and KRTIČKA, F. 2008. Assessment of Morphology of Wear Particles in Oils for Vehicles. *Transactions on Transport Sciences*, 1(4): 185–192.

MARINOVIĆ, S., JUKIĆ, A., DOLEŽAL, D. et al. 2012. Prediction of used lubricating oils properties by infrared spectroscopy using multivariate analysis. *Goriva i maziva*, 51(3): 205–215.

MIHALČOVÁ, J. and AL HAKIM, H. 2008. Tribotechnical diagnostics in waste oil operation I-methods of evaluation of wear particles in oils [in Slovak: Ttribotechnická diagnostika v prevádzke použitých olejov I. – metódy hodnotenia častíc opotrebovania v olejoch]. *Chem. listy*, 102: 358–362.

MIHALČOVÁ, J. 2013. Tribotechnical diagnosis in aircraft engine practice. *Applied Mechanics and Materials*, 308: 57–62.

MIHALČOVÁ, J. and RIMÁR, M. 2015. Control of Activity of Aircraft Engines by Analysis of Wear Debris Particles in Terms of Shape and Size. *International Journal of Engineering Research in Africa*, 18: 136–143.

NEDIĆ, B., PERIĆ, S. and VURUNA, M. 2009. Monitoring physical and chemical characteristics oil for lubrication. *Tribology in industry*, 31(3–4): 59–66.

NOVÁČEK, V. 2004. Tribodiagnostics rigmarole [in Czech: Peripetie v tribodiagnostice]. In: *Proceedings conference Reotrib 2004 – Quality of fuels and lubricants*. Velké Losiny, May 19–21. Praha: VŠCHT Praha, 85–88.

PERIĆ, S.; NEDIĆ, B. and GRKIĆ, A. 2014. Applicative Monitoring of Vehicles Engine Oil. *Tribology in industry*, 36(3): 308–315.

ROBINSON, N. 2000. Monitoring oil degradation with infrared spectroscopy. *Technical Bulletin*, 18: 1–8.

SEJKOROVÁ, M. 2013. Determination of total alkalinity of motor oil by FTIR spectroscopy [in Czech: Stanovení čísla celkové alkality motorového oleje metodou FTIR spektrometrie]. *Chem. Listy,* 107(8): 643–647.

SEJKOROVÁ, M., POKORNÝ, J. and JILEK, P. 2014. The usage of modern instrumental methods in diagnostics of quality of operated engine oils. In: *Proceedings Deterioration, Dependability, Diagnostics.* Brno: University of Defence, 255–262.

SEVERA, L., HAVLÍČEK, M. and ČUPERA, J. 2010. Changes of engine oil flow properties during its life cycle. *Acta Univ. Agric. Silvic. Mendelianae Brun.*, 58(4): 203–208.

SYCHRA, V., LANG, I. and ŠEBOR, G. 1981. Analysis of petroleum and petroleum products by atomic absorption spectroscopy and related techniques. *Prog. Anal. At. Spectrosc.* 4: 341–426.

TIMOTIJEVIC, Z., BACEVAC, S. and CORSI, S. 2013. *Evaluation of oil drain interval for buses in urban traffic with respect to local operating conditions*. World Tribology Congress 2013.Torino, Italy,September 8 – 13, 2013. Available at: http://www.nisotec.eu/sites/default/files/files/Biblioteka/Evaluation%20of%20oil%20drain%20interval%20for%20buses%20in%20urban%20traffic%20with%20respect%20to%20local%20operating%20conditions.pdf. [Accessed: 2016, December 27].

TIPPAYAWONG, N. and SOOKSARN, P. 2010. Assessment of lubricating oil degradation in small motorcycle engine fueled with gasohol. *Maejo Int. J. Sci. Technol*, 4(02): 201–209.

TOMÁŠKOVÁ, M., CHÝLKOVÁ, J., JEHLIČKA, V. et. al. 2014. Simultaneous determination of BHT and BHA in mineral and synthetic oils using linear scan voltammetry with a gold disc electrode. *Fuel*, 123: 107–112.

TRČKA, M., KLIMKOVÁ, L., FILIPI, B. et al. 2015. The influence of transformer oil aging on its safety parameters [in Czech: Vliv stárnutí transformátorového oleje na jeho bezpečnostní parametry]. *Chem. listy*, 109(12): 957–959.

TULÍK, J., HUJO, Ľ., STANČÍK, B. et al. 2013. Research of new ecological synthetic oil-based fluid. *Journal of Central European Agriculture*, 14(4): 1384–1393.

VALACH, M., MAREČEK, J., HLAVÁČOVÁ, Z. et al. 2013. Determination of impurities in biofuels with use of particle size analyzer. *Acta Univ. Agric. Silvic. Mendelianae Brun.*, 61(3): 813–817.

VAN DE VOORT, F. R., SEDMAN, J., COCCIARDI, R. A. et. al. 2006. FTIR condition monitoring of in-service lubricants: ongoing developments and future perspectives. *Tribology Transactions*, 49(3): 410–418.

VESELÁ, K., PEXA, M. and MAŘÍK, J. 2014. The effect of biofuels on the quality and purity of engine oil. *Agronomy Research*, 12(2): 425–430.

Contact information

Marie Sejkorová: marie.sejkorova@upce.cz
Ivana Hurtová: ivana.hurtova@student.upce.cz
Josef Glos: josef.glos@unob.cz
Jan Pokorný: jan.pokorny@upce.cz