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ANALYSIS OF DEGRADATION OF MOTOR OILS USED IN ZETOR TRACTORS

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Abstract

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The durability of motor oil and then the change interval are influenced by numerous factors and it is not easy to determine optimal mileage for a specific means of transport or a machine. The manufacturer proposes a maximum limit, but it is not always suitable since operating conditions influence the process significantly.

Using FTIR spectrometry and analytical ferrography methods we evaluated used motor oils collected from older types of ZETOR tractors. Change intervals were extended for most tested oil fills.

The analysis results showed that when the tractors were exposed to a considerable everyday load during autumn tasks, the lubrication and friction processes in their motors were affected negatively which resulted in increased wear. Therefore it is not advisable to extend the change interval as proposed by the ZETOR manufacturer.

Keywords: tractors, motor oil, analysis, degradation, particles, FTIR spectrometry, ferrography

INTRODUCTION

Efficient and reliable technical equipment is a key element when it comes to completing agricultural production tasks. There is a tendency to achieve higher performance of the tractor motors at lower specific petrol consumption, better thermal efficiency at lower emission of exhaust fumes (Pexa *et al.*, 2010, Sejkorová, 2015). The dependability and the durability of these motors depend not only on careless or careful handling a certain machine, but also on the current properties of the used oil fill. When manufacturing motor oil, the purpose is to assure maximum durability of the motor and preserve all motor properties as long as possible. The basic motor oil functions are as follows (Sejkorová, 2013; Enchev and Delikostov, 2013; Sascha, 2011; Černý and Mašek, 2010):

- protecting a motor against the effects of heat, pressure, corrosion, oxidation, and pollution,
- providing a sufficiently thick oil film between the interfaces of moving parts of a combustion engine so that the friction and the wear could be reduced,
- cleaning the inside of the motor by removing the products of thermal oxidation reactions in the oil, the fuel and other pollutants, and preventing their sedimentation on the surfaces washed by the oil in the form of sludge and carbon,
- motor cooling by dissipating engine run heat,
- tightening the gap between piston rings and a cylinder wall so that the leakage of compressed gases and pollutants around the piston would be as low as possible.

Lubricant is extremely important to preserve optimum motor performance and dependability. Therefore it is essential to monitor the oil state so that the excessive wear and the failure of important parts in lubricated equipment could be prevented.

The durability of an oil fill is affected by numerous factors, e.g. a motor design, the content of sulphur in fuel, and load on a motor (velocity, machine load, etc.). (Bekana *et al.*, 2015).

Other factors influencing the durability of motor oils and the loss of the function properties of lubricated systems are as follows (Mihalčová, 2013; Sejkorová *et al.*, 2014):

- degradation – thermal and oxidative, as a result of decrease in antioxidant, anti-abrasive and detergent additives efficiency owing to the destruction of polymer viscosity modifiers,
- contamination – combustion products, by solid particles such as dust, outer contaminants, abrasive metals, water and a cooling liquid, by diluting the oil by unburned fuel.

One of the most important factors affecting the motor oil change interval in farm machines is the engine case volume – motor performance ratio. (Bekana *et al.*, 2015).

The observation of physio-chemical parameters in operated motor oils and their contamination is based mostly on standardized analytical procedures which provide general information on the oil state. However, these procedures are time consuming and require relevant laboratory apparatus. Therefore, when evaluating the current lubricant state and its residual durability, we use instrumentation methods, such as Fourier Transform Infrared Spectrometry (FTIR Spectrometry) (Glos and Svoboda, 2015; Hnilicová *et al.*, 2016; Král *et al.*, 2014; Sejkorová *et al.*, 2014) combined with chemometric software (Al-Ghouti *et al.*, 2010; Caneca *et al.*, 2006; Sejkorová, 2013; Van de Voort *et al.*, 2006), electro-chemical methods (Tomášková *et al.*, 2014), emission and absorption spectrometry (Glos and Sejkorová, 2012; Mihalčová, 2014; Kumbár *et al.*, 2014), a particle analysis using particle counters (Juránek *et al.*, 2011; Kučera *et al.*, 2016), and ferrography (Mihalčová and Rimár, 2015; Machalíková *et al.*, 2008; Roylance, 2005).

The evaluation of the degradation of the oils used in the New Holland CX 860 threshing machine was based on the observation of dynamic viscosity and the particle analysis of additives and abrasion metals (Kumbár and Dostál, 2013). Based on application of modern tribodiagnostics methods (FTIR spectrometry and particles counter LaserNet Fines), Kučera *et al.* (2013) evaluated biolubricants that are used in agriculture and transport machinery. Along with the techniques introduced above the sensors used for evaluating the oil state are applied too (Capone *et al.*, 2008; Jakoby, 2003; Latif *et al.*, 2011; Wang, 2001). During road tests the sensor was used to observe the motor oil degradation which might be divided into three phases: (1) good oil state, (2) rapid acid products increase in the oil (evaluation based on the total base number – TAN), and (3) rapid viscosity increase (Wang, 2001).

In the article there are the results bringing the experimental evaluation of the degradation of oil fills used in the ZETOR tractors after they reached or almost exceeded the change interval. There is also the evaluation of the influence the current oil fill quality has on the wear pattern of a lubricated system.

Monitoring of motor oils taken from tractors was performed also by Bekana *et al.* (2015). Based on analyses they 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. Máchal *et al.* (2013) dealt with a proposal of additional filtration of hydraulic oils used in tractors which would help to decrease a level of wear of lubricated parts of the tractors and degradation of the oil and also to extend the oil interval change. Kosiba *et al.* (2013) presented results of research of properties of hydraulic ecological oil MOL Farm UTTO Synt in operational conditions when used in Zetor Forterra 11441 tractor. They monitored pollution of the oil, lubrication quality of the oil and its influence on a level of wear of a hydraulic pump of the tractor during operation. Also, Tulík *et al.* (2013) tested this hydraulic oil with use of a cogwheel of a hydrostatic pump that is being used in the latest models of Zetor Forterra tractors. During the test, flow values were statistically evaluated and graphically displayed in a form of flow characteristics and the loss of flow efficiency. Severa *et al.* (2010) dealt with evaluation of changes in flow of oil in motorcycle engines during their life cycle.

MATERIALS AND METHODS

The oils analysed were the motor oils Mogul M7ADS III and M6ADS collected from the tractor motors ZETOR of earlier year of manufacture (Tab. I). The change interval was extended for most of the collected oil samples.

The current physio-chemical state of the operated oil fills was evaluated by the FTIR spectrometry method.

Analysing particles wear we can observe indirectly mechanical changes in the system in which the lubricant is applied. The method suitable for the qualitative description of morphology and size characteristics of particles wear is ferrography (Mihalčová, 2015; Machalíková *et al.*, 2008).

FTIR spectrometry

Infrared spectra were recorded by the VECTOR 22 (Bruker) spectrometer with ATR attachment (crystal ZnSe) using a fully reduced reflectance technique. The spectra of the measured motor oil samples ranged from 4,000 to 600 cm^{-1}.

Measuring parameters: resolution 4 cm^{1}, the number of spectrum accumulations 32. Recorded spectra were later processed by the OPUS computer programme.

Using the FTIR spectrometry we can evaluate the level of motor oil wear comparing the difference between the original oil spectrum and the degraded oil spectrum. It is possible then to evaluate

I: *Technical specifications of tractors and operated oil fills*

Marking tractors ZETOR	7340	9540	9641	10641 A, B	11441	12145
Engine type	turbo diesel					
Number of cylinders	4	4	4	4	4	6
Cooling	liquid					
Speed	40					30
Production year	1998	1996	2005	2001	2005	1984
The recommended oil change interval [Mth]	200	200	300	200	250	150
Operation of engine oil charge [Mth]	230	295	298	A – 196 B – 213	295	ca. 200
Overall operation [Mth]	8,835	22,095	598	A – 4,999 B – 4,803	1,185	Not known
Marking engine oil	M7ADS III					M6ADS

the content of oxidative, nitrative, sulphating products, the content of water, fuel, cooling liquid, and anti-oxidant additives decrease, etc. The typical vibrations of the observed functional sub-systems might be found in relevant literature (Sejkorová, 2015).

Ferrography

The oil fills were analysed by the REO1 (Reo Trade Ostrava, Czech Republic) ferrograph, and the obtained ferrograms were examined by the bichromatic binocular microscope H6000 (Intraco Micro Tachlovice, Czech Republic) and the digital camera Nikon Coolpix 4500 connected to the THOMSON television. For a dimensional evaluation of the observed particles we used stage micrometer one division = 10 µm (L.E.T. Optomechanika Prague Ltd., Czech Republic).

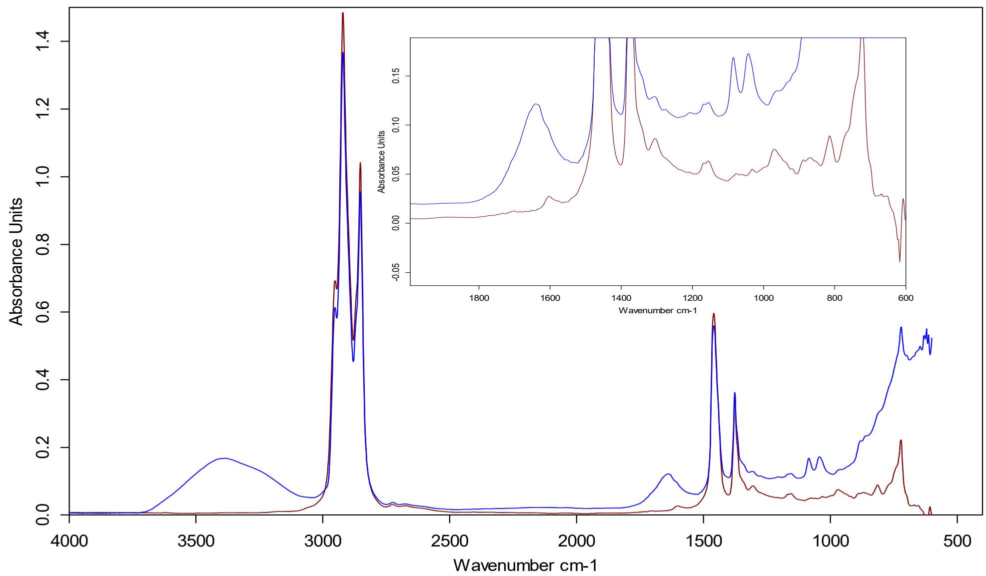
In order to get a representative sample of the oil fill, the collected samples were heated to 65 °C and homogenized for five minutes by shaking before the actual ferrography analysis was performed.

RESULTS AND DISCUSSION

FTIR spectrometry results

The oil sample of the ZETOR 12145 tractor represents the oil fill after the exactly specified number of Mth because of the system failure which is registered by tractor mileage. The oil change (M6ADS III) was based on personal judgement of the operator and performed after about 200 Mth of operating time. A technical manual says that the interval of the motor oil change is 150 Mth.

The primary interval in the wave number range of 3,600–3,100 cm^{-1} and the secondary interval in the wave number range of 1,550–1,750 cm^{-1} (Fig. 1) belong to the hydrogen bridge bonding belonging to water. Due to the fact that in the spectrum there is a significant double interval with the peaks in the point of 1,080, 1,040 cm^{-1} belonging to ethylene glycol bonding, we might presume that the cooling liquid of the ethylene glycol aqueous solution got into the oil fill because of broken sealing under the motor head, or due to ring (rubber band) coking on piston protectors. Aqueous solution glycol based cooling liquid appearing in the oil is a very undesirable contaminant. Water has a corrosive effect on single parts of the motor, accelerates oil degradation and weakens the effect of additives. Anti-freeze liquids are doped mainly by the substances which should prevent the cooling system corrosion. However, glycols with these additives react with motor oil a lot more intensely than bare water. Even at low concentrations they cause serious and irreversible changes to the oil – the oil gets dark, loses its fluidity, can be degraded by insoluble sludge and sediment. These degradation products are difficult to be removed during a common oil change and can affect significantly the quality of a new oil fill (Černý and Mašek, 2010). Based on the differential infrared spectrometry results it might be stated that the oil viscosity also changed. The oil viscosity is one of the most observed motor oil parameters, since cooling liquid, soot and the processes of oil oxidative degradation result in deterioration in low temperature viscosity characteristics, an increase in viscosity, and an aggravation of oil pumping. The spectra (see Fig. 1) show us that in the point of 2000 cm^{-1} there is no significant shift in the basic line of the used oil spectrum towards higher absorbance values (the shift is circa 0,020 A. u.), therefore there is no higher soot content in the oil. Conversely, the viscosity is decreased by petroleum



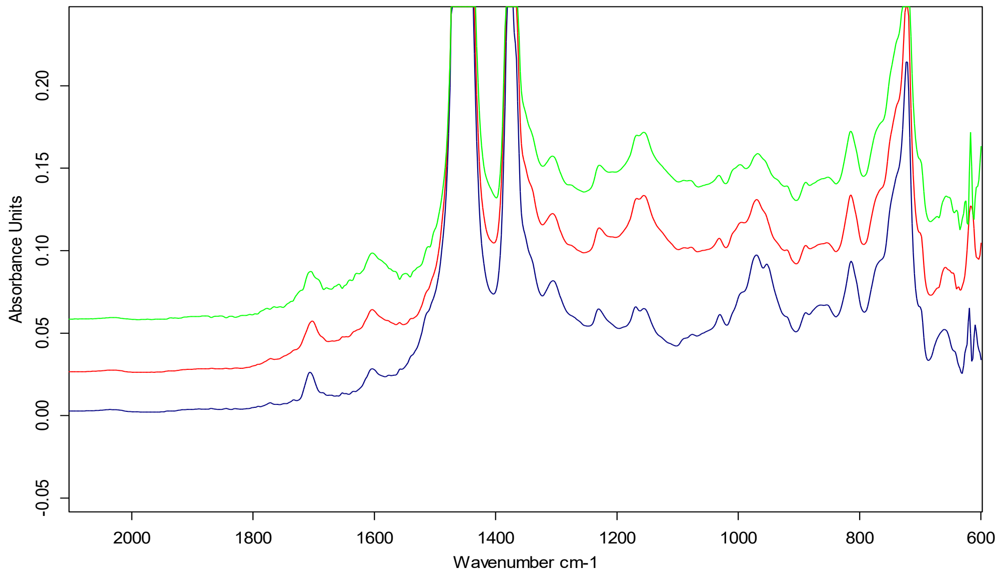
1: *Spectrum of new oil and the oil after motor failure*

leakage into the oil which would be manifested in infrared spectrum as an increase in absorption band in the point of 750 cm^{-1}. Due to the leakage of a great amount of cooling liquid into the oil fill, the absorption intervals overlapped and the basic line shifted towards higher absorbance values in the range of about 1,000–600 cm^{-1}. Therefore it is not possible to assess whether the oil contains petroleum and whether the content of ZnDDP (zinc diethyldithiophosphate) based lubricating and anti-abrasive additives decreased – that would be manifested by the interval in the wave number point of 970 cm^{-1}. Due to a high concentration of water which was manifested by a secondary absorption interval in the range of 1,550–1,750 cm^{-1} it is impossible to determine from the spectrum whether oxidative degradation processes occurred in the oil fill (it is manifested by an absorbance increase in the range of 1,710–1,750 cm^{-1}), or there were processes related to organic nitrocompound occurrence (it is manifested by an absorbance increase in the range of 1,580–1,650 cm^{-1}).

In Fig. 2 there are the spectrograms of a new oil and used oils M7ADS III in ZETOR 10641 tractors of the same type (Tab. I) – in one of the tractors the period of oil fill change was shortened by circa 4 Mth, and in another tractor the oil change interval was extended by about 3 Mth.

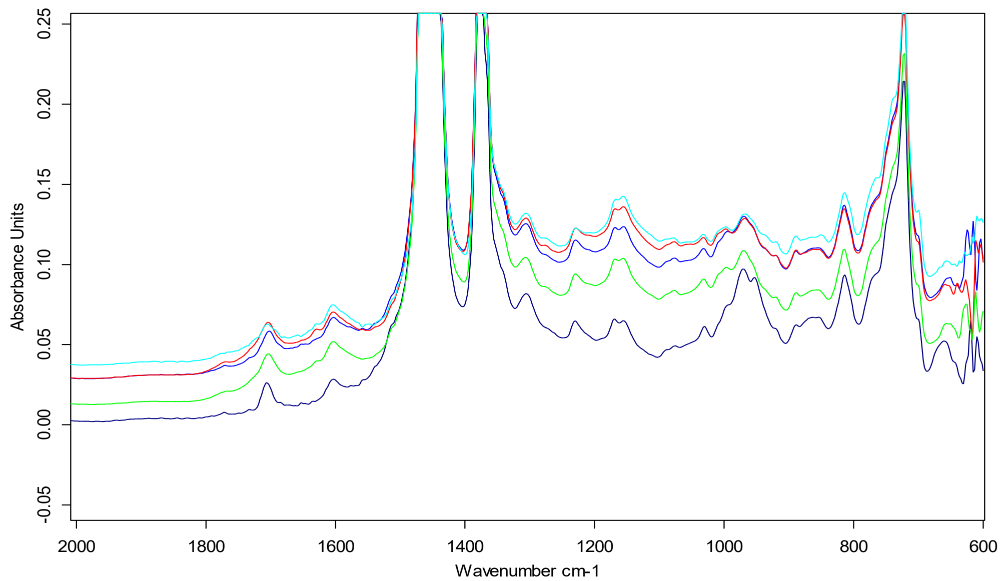
The motor oil Mogul M7ADS III is a multi-grade oil used in highly supercharged Diesel engines with high thermal load and high temperatures of a piston group. Fig. 2 shows that in no oil fill there was cooling liquid leakage. As for the motor oil with the extended change interval, there was significant soot leakage into the oil fill; in the infrared spectrum this factor was manifested by an increase in the basic spectrum line in the point of 2000 cm^{-1} by about 0,06 A.u. relative to the basic line of a new oil. The contamination of oil by soot might indicate piston groups wear. The higher amount of soot can result in an increase in viscosity and aggravation of oil pumping. There was slight thermo-oxidative degradation in both operated oils. In the range of 1,180–1,120 cm^{-1}we could observe a growth of the sulphate interval – the neutralization of alkaline additives in the motor oil occurred. In the oil with the extended change interval there was a higher decrease in anti-oxidative additive (interval peaking at 970 cm^{-1}). In Fig. 3 there are the infrared spectra of the Mogul M7ADS III oil fills operated in ZETOR 7340, 9641, 9540, 11441 tractors. The tractors are of different age and during their design only one type of aggregate, which had been further modified (by compression change, drilling, stroking, etc.) into single types, was used. The interval of oil change was set by the manufacturer according to the tractor type ranging from 200 to 300 Mth. Overall tractors mileage and oil fill mileage are put in Tab. I.

There was no contaminant leakage in the form of glycol water solutions into any oil fill. No connection was found between the oil fill tractor mileage and the soot content in the motor oil. The content of soot in the oil with the change interval extended by 95 Mth was the same as the content of soot with the change interval shorted by 2 Mth. The most significant changes which can be put in the spectra are those which have a connection with the content of the basic ZnDDP anti-oxidative additive. Running-out of the additive is manifested by a decrease in absorbance in the range of 1,050–950 cm^{-1} and 650 cm^{-1}. Due to the running-out of the anti-oxidants the original



Legend:
— new motor oil M7ADS III
— used motor oil 106 41 A (shortened change interval)
— used motor oil 106 41 B (extended change interval)

2: *Spectrum of a new oil and used oils with shortened and extended change interval*



Legend:
— new motor oil M7ADS III
— used motor oil from Zetor 7340 (extended change interval by 30 Mth)
— used motor oil from Zetor 9641 (shortened change interval by 2 Mth)
— used motor oil from Zetoru 9540 (extended change interval 95 Mth)
— used motor oil from Zetoru 11441 (extended change interval by 45 Mth)

3: *Spectrum of a new oil and used oils with shortened and extended change intervals*

lubricating and anti-abrasive additives also run out, since both oil properties are mostly ensured by the same additive-zinc dithiophosphates. This is manifested by a slow increase in friction coefficient and also engine sound (Černý and Václavíčková, 2006). The increased friction will later result in higher fuel consumption.

At 9540 and 11441 tractors the concentration of ZnDDP dropped below 20 % of its content in a new oil, i.e. the change interval should not have been extended.

Results of ferrographic analysis

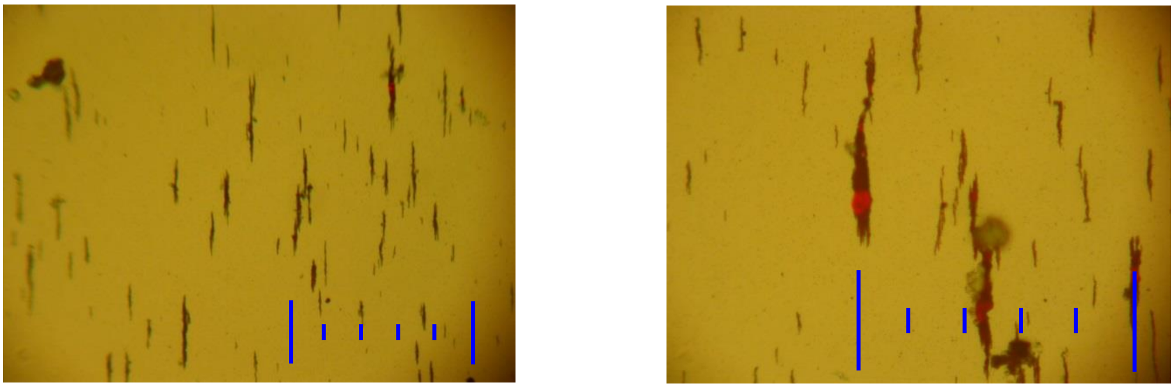
The ferrographic analysis was used to assess morphological characteristics of deposit particles. This method shows how the cooling liquid leakage affected the overall wear of the ZETOR 12145 motor. In ferrograms (Fig. 4a, b) there were no bigger particles of abrasive wear. There were only very small particles of common adhesive wear arranged into strings. These strings follow the direction of force lines of the magnets placed under the foil (Machalíková *et al.*, 2008). Based on the ferrographic analysis results it might be stated that the oil change was performed immediately after the failure, therefore no increased wear of motor contact surfaces occurred.

A certain level of the concentration of wear particles is quite normal and common. The number and the size of single wear particles in the oil depend on the type of a motor, oil mileage and oil filter efficiency. Even if the operation is normal and the engine run is smooth, there is a contact between metal surfaces, mainly in highly stressed parts of the motor. During regular operation the size of wear particles is smaller than 1 µm (Sychra *et al.*, 1981) and the amount of the particles is relatively low.

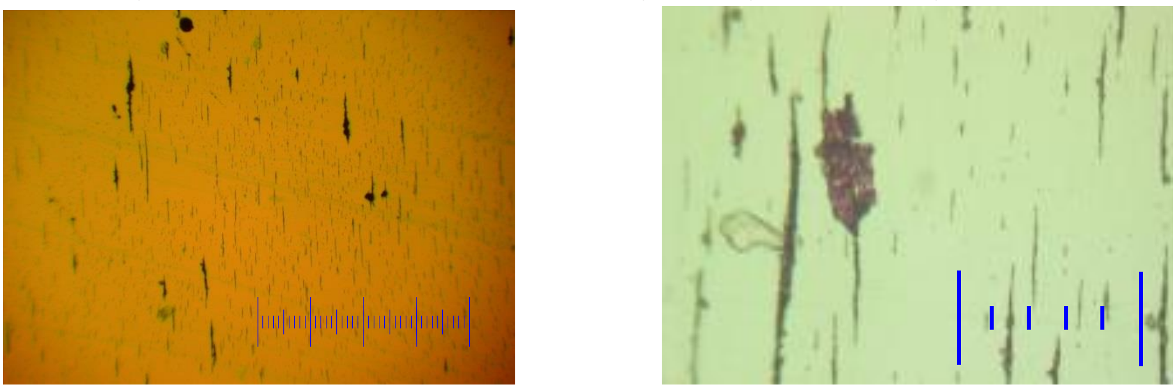
By the ferrographic analysis performed for the oil fills in the ZETOR 10641 tractor we separated fine adhesive flake-shaped particles which arranged into strings owing to magnetic force lines (Fig. 5a). In the oil where the change interval was extended and where, by using the FTIR spectrometry, a significant decrease in an anti-adhesive additive and an increase in soot concentration were found, we separated adhesive wear particles and sporadically the abrasive wear particles of about 40 µm in size (Fig. 5b).

The extended motor oil change intervals negatively affected the course of the wear of other tested motors (Fig. 6–9).

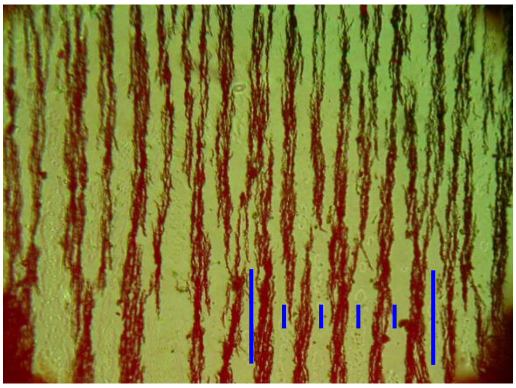
The most significant wear occurred in the oil operated in the ZETOR 11441 tractor (Fig. 9). Very thick adhesive abrasion and also relatively large particles of abrasive wear (about 60 µm) were observed. This shows that the friction and lubricating conditions of the motor quite loaded during seasonal agricultural work were rather unfavourable.

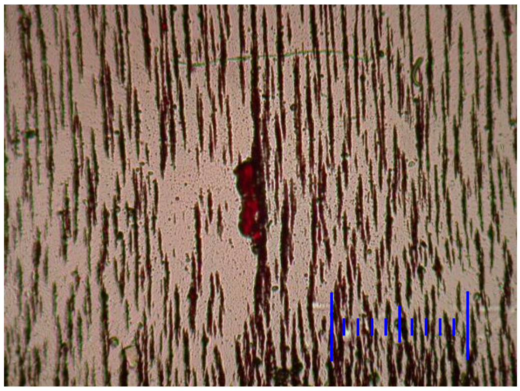


4: *a – Oil ferrogram of the 12145 tractor – adhesive particles arranged into strings, zoomed 250 × (1segment = 10 µm)*
b – Oil ferrogram of the 12145 tractor – detail of adhesive particles arranged into strings, zoomed 400 × (1segment = 10 µm)

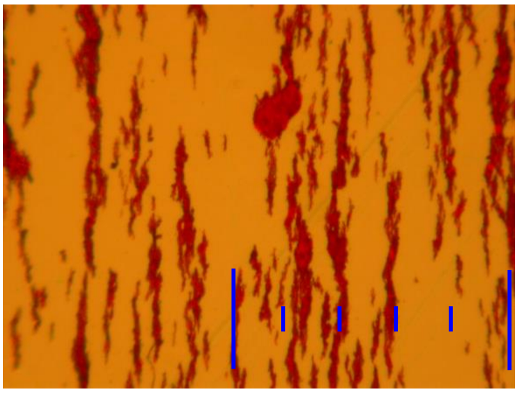


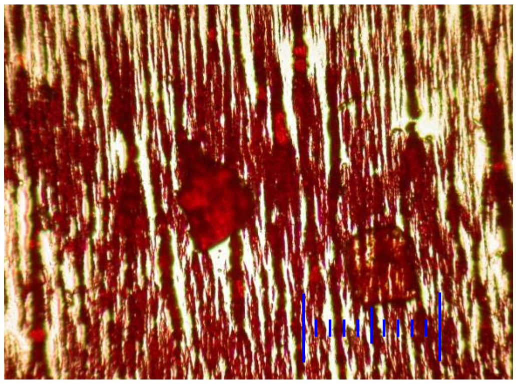
5: *a – Oil ferrogram from ZETOR 10641A – particles of common adhesive wear, zoomed 40 × (1segment = 10 µm)*
b – Oil ferrogram from ZETOR 10641B – fine abrasion of adhesive wear with abrasive particles of about 40 µm in size, zoomed 250 × (1segment = 10 µm)





6: *Oil ferrogram from ZETOR 9641 – thick adhesive abrasion, zoomed 250 × (1segment = 10 μm)*
7: *Oil ferrogram from ZETOR 9540 – thick adhesive abrasion, zoomed 100 × (1segment = 10 μm)*





8: *Oil ferrogram from ZETOR 7340 – adhesive wear particles arranged into strings forming cascades, zoomed 400× (1segment = 10 μm)*
9: *Oil ferrogram from ZETOR 114 41 – thick adhesive abrasion with abrasive particles of about 60 μm in size, zoomed 100 × (1segment = 10μm)*

CONCLUSION

In the article we introduced the results of the assessment of current condition of the Mogul M6ADS III and M7ADS III motor oils operated in the ZETOR tractors manufactured in 1974–2005. The FTIR spectrometry was used for observing degradation changes and the leakage of contaminants into the oil fill. By ferrography with a strong changing magnetic field we separated metal (and non-metal) particles from the used oil on a plastic mat and evaluated them using a microscope. Kumbár *et al.* (2013) state that when evaluating the current quality of a vehicle motor oil, the results of oil dynamic viscosity, the analysis of abrasive metals by emission spectrometry, and the detection monitoring of the amount, type and size of abrasive particles by particles counter are perfectly sufficient.

In most introduced cases the oil change interval suggested by the Zetor tractor manufacturer was extended. There was one case when the FTIR spectrometry detected significant leakage of cooling liquid into the oil fill which indicates a failure-sealing ruptured under the motor head, or the rubbers were coked. The devalued oil fill is believed to be collected immediately after the failure, since the ferrographic footmark showed common adhesive abrasion arranged into strings. The particles of abrasive wear appeared only sporadically.

As for the rest of the analysed samples we could observe that the longer the mileage, the stronger soot leakage into the oil – soot might increase its viscosity. There was also high decrease in ZnDDP-based anti-oxidative and anti-abrasive additives which are to prevent metal with metal contact by forming a protective layer on parts. By the ferrographic analysis we found a very thick adhesive abrasion as well as relatively big particles (they even reached the values over 50 μm) of abrasive wear. This shows that the friction and lubricating conditions of tractor motors exposed to harsh everyday operation during agricultural work were unfavourable and the extension of oil change interval as required by the Zetor manufacturer is undesirable.

Bekana *et al.* (2015) who tested motor oils collected after 250 Mth from relatively new tractors came to a conclusion that the recommended change interval is not adequate for a good condition of the evaluated used oils. Following the data introduced above the authors of this paper share the same opinion stating that it is necessary to optimize the period of changing motor oils used in agricultural vehicles depending on their specific working conditions.

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