Agronomy Research **14**(4), 1351–1360, 2016

Detection and characterization of wear particles of universal tractor oil using a particles size analyzer

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Abstract. Oil contamination is the most common and serious source of machine failure. Therefore, lubrication oil testing and analysis is one of the most important condition monitoring (CM) techniques for machinery maintenance and failure diagnosis. Oil analysis consists of determination of physical-chemical properties, contamination and wear debris analysis (WDA). One of the modern methods how to detect wear particles is LaserNet Fines (LNF). The technology is an extension of effective laboratory microscope analysis and was developed specifically to address the shortfalls of monitors that measure only particle size or elemental concentration. Universal tractor oil (UTTO) is the multipurpose oil for the lubrication of the transmission, rear axle, differential, wet brakes, and hydraulic system fed by the common oil reservoir.
The aim of this work is detection and characterization of friction particles during lifetime of two different universal tractor transmission oils samples with using of laser particle counter LaserNet Fines-C and their comparing, synthetic ester-based UTTO oil and mineral-based UTTO oil.

Key words: contaminants in oil, counting particles, image analysis, oil condition monitoring.

INTRODUCTION

Condition monitoring and maintenance are two essential components of the modern industry (Perić et al., 2013; Vališ et al., 2015). The purpose of condition monitoring is to detect faults occurring in machinery maintenance; on the other hand, is defined to maintain and extend, the lifetime of machinery. With regard to monitoring methods, oil analysis has been considered as an and effective approach because of its capability to reveal the wearing condition of the machinery through the analysis of oil properties and wearing particles (Raadnui, 2005; Yuan et al., 2005; Gonçalves et al., 2010; Kumar et al., 2013). Tribotechnical diagnostics examines wear products and lubricants used by the objectification of the technical state of the monitored object and evaluation of quality lubricants.

Wear is one of the major factors that contribute to the creation of failures and with this is connected generation of wear particles. Wear particles come into in lubrication system, where they cause contamination and degradation of lubricating properties and consequently it may result in major failure of machines (Kučera et al., 2013; Hönig, 2015). Wear particles analysis, based on particle size, shape and surface texture examination, have an important role in the diagnosis of machine wear. The size, shape and surface texture of wear particles are affected by the variations in machine running conditions. With increasing wear increases as their size and shape (Mihalčová & Hekmat, 2008; Henneberg et al., 2015). Important information about wear modes, wear mechanisms and wear severity can be obtained from the analysis of particle morphology and operating costs can be greatly reduced if the onset of machine failure can be predicted (Stachowiak et al., 2008; Leemet et al., 2014; Novák et al., 2014).

Tractors usually work in highly specific conditions including extremely high or low temperatures, in differnt position and slopes, under the influence of thick dust and exposed to different chemical agents and often work many hours under full load. Universal tractor transmission oils (UTTO) are designed for hydraulic and transmission systems of agricultural and forestry tractors. The main functions of the UTTO oils are: lubrication of gearbox, rear axle and gears; power transfer and hydraulic system lubrication; providing adequate cooling and friction wet brakes.

It is estimated that, at present, approximately 60% of all lubricants end up in soil and water (Majdan et al., 2014; Pexa et al., 2015). More than 95% of these materials are mineral oil based compounds, which have become prominent ever since the discovery of petroleum as they have superior quality at an affordable price. In view of their high ecotoxicity and low biodegradability mineral oil-based lubricants constitute a considerable threat to the environment (Kučera & Rousek, 2008; Tkáč et al., 2014). Possibilities of improving the condition of the environment and decreasing the level of its pollution by fillings of gearboxes and hydraulic circuits of agricultural and forest machinery replacing mineral oils by biodegradable oils. The impact of these fluids to different parts of the gear and hydraulic circuit of the machinery has not been fully clear yet. Therefore, it is necessary to perform more laboratory and field testing (Kosiba et al., 2013; Kumbár & Dostál, 2013; Máchal et al., 2013; Majdan et al., 2013; Valach et al., 2013; Veselá et al., 2014; Zhu et al., 2015). This paper describes the use automatic particle counter and classifier LNF-C for determination of friction particles of tested transmission oils.

This device is not only used for classification of particles the oil, but also for the direct analysis of wear and contamination according to the standardized code purity.

MATERIALS AND METHODS

For the purpose of the operational experiments were used two samples of oils, biodegradable fully synthetic transmission oil EP Gear Synth 150 – Panolin and mineral-based transmission oil Gyrogate CLP 150. A detailed description of the samples of operating oils is shown in Table 1. Transmission oil EP Gear Synth 150 is fully synthetic, biodegradable high-performance oil for industrial gear boxes, roller bearings and slide bearings. Oil contains additives against oxidation, corrosion and wear. It has excellent high pressure properties and excellent oxidation stability at high temperatures. Due to its outstanding anti-wear properties, reduces micro-wear of surface roughness on friction surfaces in aggregates. In case of any leakage fully decomposed by soil or water micro-organisms, without affecting the environment and practically free of deposits (methods OECD 201 to 203). Biodegradability according to OECD 301 B and OECD 306 is more than 60%. Transmission oil Gyrogate CLP 150 is primarily recommended for lubricating enclosed gear units working under severe shock operating conditions as well as constructing and farming machineries working under high pressure at high speed and low torque. This oil is formulated from carefully selected base stocks sulphur/phosphorous extreme pressure (EP) additives.

Table 1. Description of samples of tested oils

Oil code	Type of oil	Performance class	Viscosity $mm^2\ s^{-1}$ v 40 °C	Viscosity $mm^2\ s^{-1}$ v 40 °C	Viscosity Index	FZG Load Stage
SE	Universal (tractor oil)	GL-4	150	18.8	142	12
MO	Universal (tractor oil)	GL-4	135–165	13.6	> 95	12

Rear gearboxs of wheel tractor Zetor 12145 were used for experiment (Fig. 1). Mineral transmission oil was filled to the left hand side end rear gearbox, biodegradable transmission oil was filled to the right hand side end rear gearbox.

There are several methods how to assess the technical condition of lubricating oil. LaserNet Fines-C (LNF-C) was used for the carried out long-term stability test of biodegradable transmission oil and mineral transmission oil used in tractor end rear gear boxes dependent on operating time (the test period 450 days). LNF-C is an automated optical oil debris device, which combines the functions of a highly accurate particle counter as well as a particle shape classifier. The basic operating principle of the LNF-C is illustrated in Fig. 2.

Figure 1. Tooth gear of end gear box (Aleš, 2009).

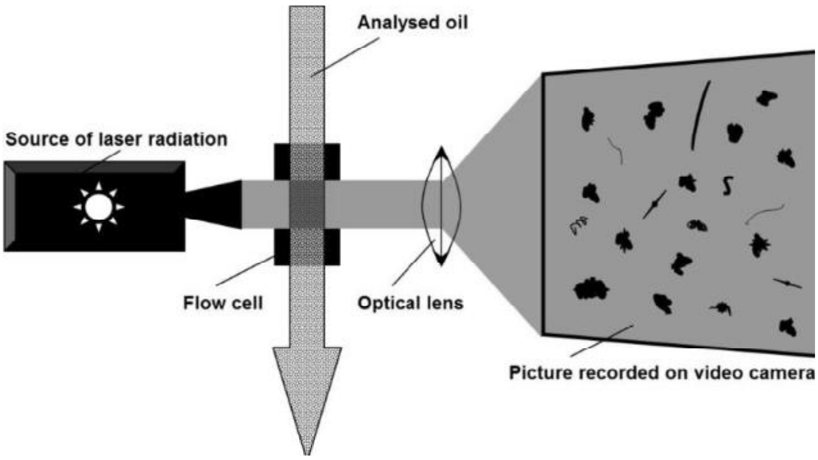
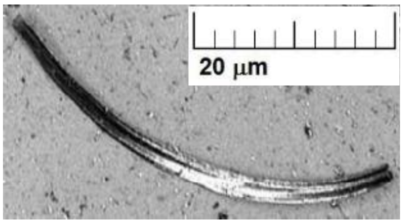
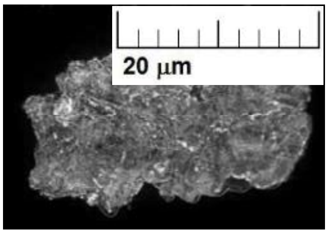


Figure 2. The basic principle of the measuring device LNF-C.

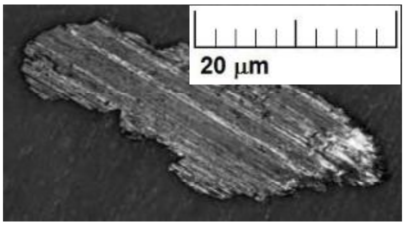
A representative oil sample is taken from the lubricating system and brought to the instrument. The oil is drawn through a patented viewing cell that is back-illuminated with a pulsed laser diode to freeze the particle motion. The coherent light is transmitted through the fluid and imaged onto a digital CCD camera. Each resulting image is analyzed for particles, with several thousand images ultimately used to determine the characteristics of the suspended particles and to obtain good counting statistics. Concentrations are measured for particle sizes between 4 μm to over 100 μm. These images are analyzed using Neural Network Artificial Intelligence and machine learning to automatically classify particles larger than 20 μm into categories such as: fatigue wear, sliding wear, cutting wear and non-metallic particles (sand and dirt), Fig. 3. The whole process of analysis takes about three minutes and the results of the analysis are displayed to the operator of the analyzer after the evaluation of the oil sample.



Cutting wear particle



Fatigue wear particle



Severe sliding wear particle

Figure 3. Classifications of Wear Debris Particles.

Particles are sized directly and results can be displayed by ISO Code (> 4 μm, > 6 μm, and > 14 μm), or other codes such as the NAS Code (5–15 μm, 15–25 μm, 25–50 μm, 50–100 μm and > 100 μm). The direct imaging capability of this instrument eliminates the need for calibration with a test dust. Air bubbles greater than 20 μm are ignored and the laser is powerful enough to process heavily sooted (black) oils.

Measurement results from the laser particle counter are quite complex and therefore it is important to select only those data that suitable describes particles resulting from wear. The most widespread approach of measuring the number of particles is a standardized method of measuring the cleanliness code according to ISO 4406:1999.

Methodology of taking oil samples was according to standard procedures, immediately after stopping the tractor. Oil sampling were carried out at irregular intervals, because it was an operational test and there was taken into consideration the needs of the operation of the tractor.

Seven oil samples (Gyrogate CLP 150, EP Gear Synth 150) were taken from the end gear boxes of wheel tractor during the long-term experiment (450 days).

RESULTS AND DISCUSSION

According to the results mineral transmission oil contained twice more particles in comparison with biodegradable transmission oil. The total amount of 1,026,851 particles was detected in one *ml* of transmission oil Gyrogate CLP 150 after the first sampling. In the seventh sample was detected in 1 *ml* of oil 4,754,078 particles, what from the first sampling represents an increase in the number of particles by 463%. In case of transmission biodegradable oil EP Gear Synth 150, the total amount of 1,508,561 particles was detected in 1 ml after the first sampling, in the seventh sample was already in one *ml* of 3,336,710 particles, what from the first sampling represents an increase in the number of particles by 221% (Fig. 4). The most frequent particles and their mean and maximum sizes are listed in Tables 2–5. The increase and large number of fatigue particles is of particular concern. The LNF-C image map of particle silhouettes was electronically filtered to show only fatigue particles. Selection of detected particles is shown in Figs 5, 6.

Table 2. The most frequent particles present in used mineral transmision oil (sample 1)

	Number of particles (ml^{-1})	Size of particles – Std.Dev. (μm)	Size of particles – Mean (μm)	Size of particles – Max (μm)
Cutting	2,053,5	16.1	31.2	153.9
Severe sliding	6,379,6	12.0	29.3	156.8
Fatigue	13,606,7	12.5	29.4	189.2
Non-metallic	9,150,3	10.1	27.7	145.9
Unclassified	608,6	30.3	42.2	257.3
Fibers	397			

Table 3. The most frequent particles present in used mineral transmission oil (sample 7)

	Number of particles (ml^{-1})	Size of particles – Std.Dev. (μm)	Size of particles – Mean (μm)	Size of particles – Max (μm)
Cutting	1,492,7	7.5	25.3	129.4
Severe sliding	6,708,9	6.0	25.0	76.5
Fatigue	17,800,1	7.2	25.7	122.0
Non-metallic	8,489,9	5.1	23.9	85.7
Unclassified	669,7	12.2	28.1	91.0
Fibers	205			

Table 4. The most frequent particles present in used biodegradable transmission oil (sample 1)

	Number of particles (ml^{-1})	Size of particles – Std.Dev. (μm)	Size of particles – Mean (μm)	Size of particles – Max (μm)
Cutting	4,340,4	15.6	28.9	356.8
Severe sliding	6,585,7	12.2	28.7	160.0
Fatigue	5,895,6	13.9	28.9	193.8
Non-metallic	19,625,5	11.1	29.3	145.6
Unclassified	733,6	26.7	35.4	200.3
Fibers	904			

Table 5. The most frequent particles present in used biodegradable transmission oil (sample 7)

	Number of particles (ml^{-1})	Size of particles – Std.Dev. (μm)	Size of particles – Mean (μm)	Size of particles – Max (μm)
Cutting	1,492,1	7.7	26.6	86.2
Severe sliding	6,255,5	8.1	26.2	138.6
Fatigue	25,910,0	8.2	26.7	190.5
Non-metallic	10,614,9	6.0	24.4	101.5
Unclassified	736,4	14.3	29.9	115.6
Fibers	123			

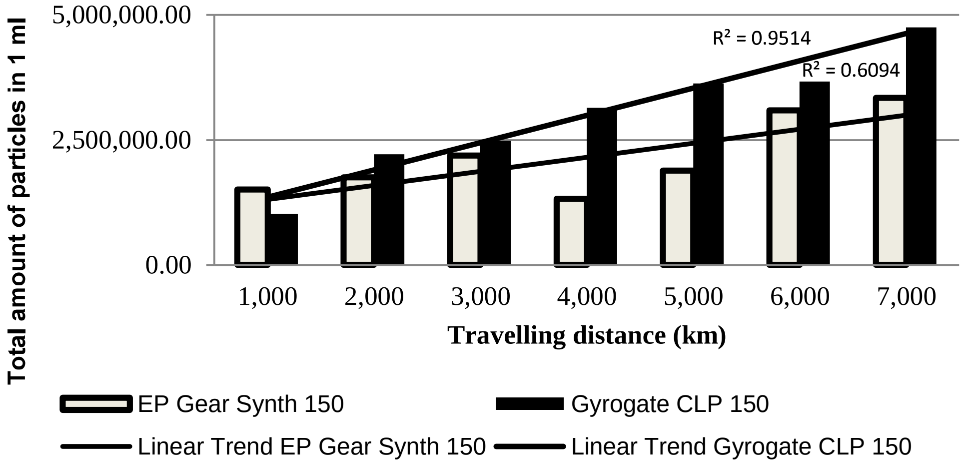


Figure 4. The course of the total amount of particles: 1 – mineral transmission oil, 2 – biodegradable transmission oil.

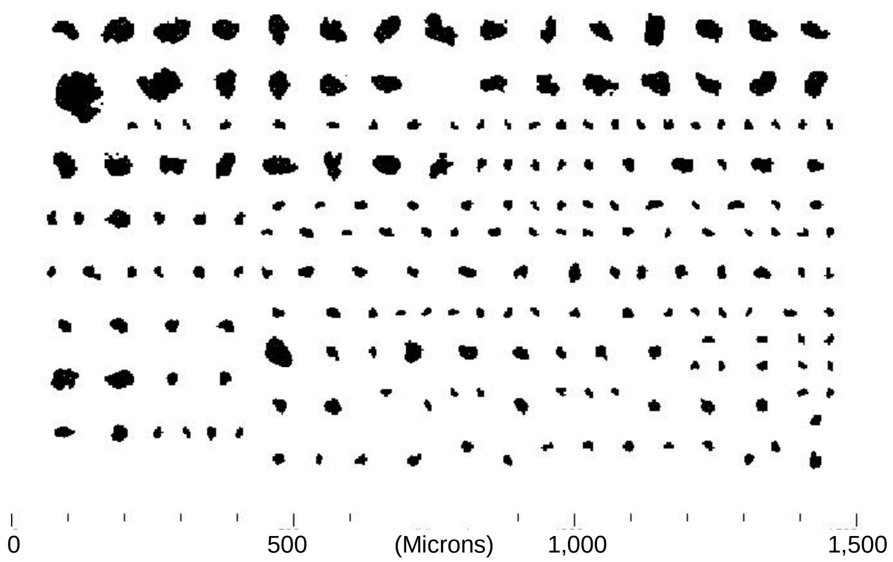


Figure 5. Record of fatigue particles detected in mineral transmission oil.

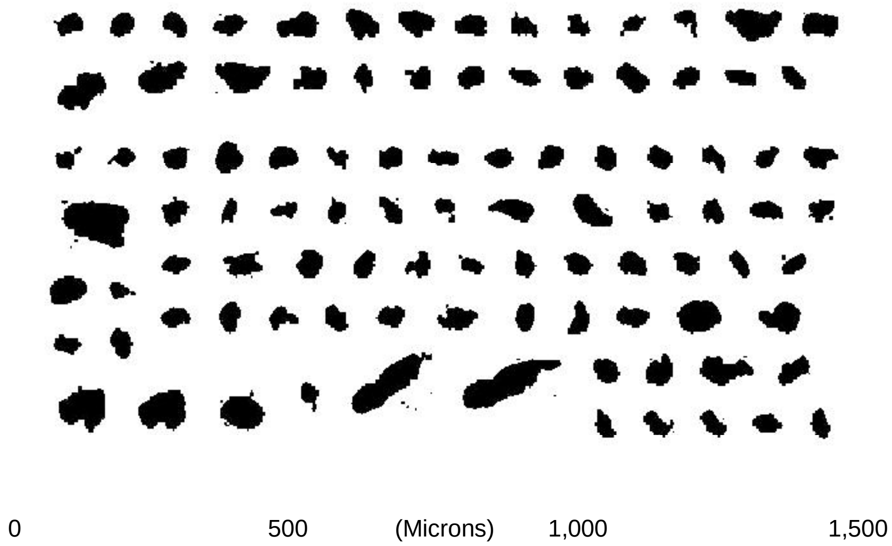


Figure 6. Record of fatigue particles detected in biodegradable transmission oil.

More transparent information on distribution of particles in the mineral transmission oil provides a Fig. 7. Describes the percentage of each type of particles in the size range of 20–25 μm. The biggest change is visible in the proportion of fatigue particles constituting the individual oil samples, which showed an increase from 18% to 53%. Conversely, the proportion of non-metallic particles decreased from 49% to 28%.

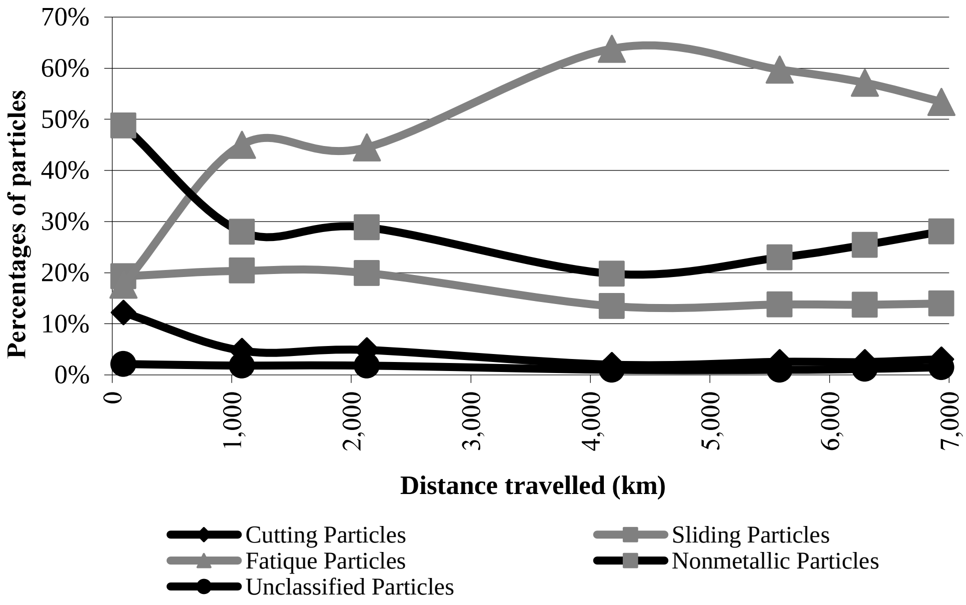


Figure 7. Percentage representation of different particles in the size range 20–25 μm (mineral transmission oil).

Fig. 8 provides information on distribution of particles in the biodegradable transmission oil. The data presented shows that already after the first receipt of a sample containing 41% of particles of fatigue. Such a high proportion of particles may have occurred by particles in an end gear box there still the experiment was run. A sample of seven shows a 48% particle fatigue, an increase of 7%.

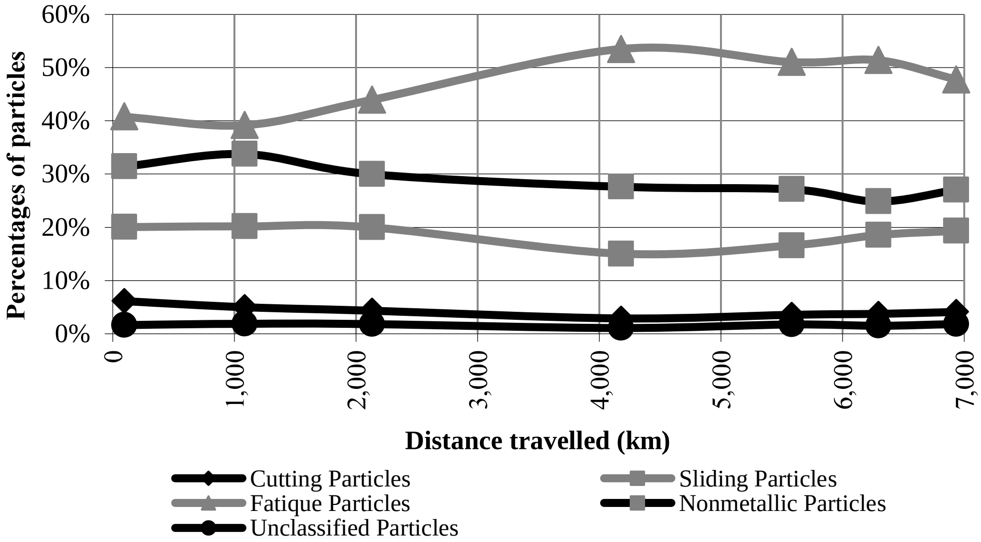


Figure 8. Percentage representation of different particles in the size range 20–25 μm (biodegradable transmission oil).

Decrease of number of wear particles may be partly due to measurement error. Important consideration of wear particle contamination of gear oil is also focused on trend of cleanliness code according to ISO 4406: 1999. Cleanliness code changed during the experiment from value 28/26/22 to >28/27/23.

CONCLUSIONS

The experiment was aimed to compare the conventional mineral oil and biodegradable oil. The measuring device MPH II was used for a precise monitoring of operating time of the end gear boxes. The information on the travelling distance is the most important parameter of the data obtained in the case of the exact operating time monitoring. For experiments, the attention paid to the creation of particles during a period of operation. For evaluation it was used desktop laser particle counter and classifier LNF-C. LNF-C has been applied to the detection of mechanical wear in diesel engines and particulate contamination in transmission systems. The ability of LNF-C to identify and quantify particle types allows its results to be used for fault identification, root cause analysis and recommendation of remedial action.

The measurement results showed a faster increase in the particle wear when compared to mineral oil biodegradable transmission oil. In view of the increase in the percentage of particles over the 20 μm flavor seems the biodegradable oil. Even in this respect it can be concluded that the biodegradable oil equivalent to petroleum-based oils.

For more accurate evaluation of the results, it would be appropriate to do an experiment that would include both approaches, i.e. chemical-physical analysis as well as determination of the technical state machine based on the analysis of the components in universal tractor transmission oil.

ACKNOWLEDGEMENTS. Ministry of Education, Science, Research and Sport of SR supported this work, Contract VEGA No. 1/0676/14.

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