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Possibility of hydraulic fluids with a low environmental impact application in agriculture and transport machinery

Možnosť využitia hydraulických kvapalín s nízkym vplyvom na životné prostredie v poľnohospodárskej a dopravnej technike

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Abstract

Agricultural and transport equipment is ideally suited to use hydraulic oils. After engine oils, hydraulic fluids are the second most important group of lubricants. More than 85 % of these materials are currently mineral oil-based. In view of their high ecotoxicity and low biodegradability, mineral oil-based lubricants constitute a considerable threat to the environment. In contrast, most hydraulic fluids based on plant oils have a low environmental impact and are completely biodegradable. Moreover, lubricants based on plant oils display excellent tribological properties and generally have very high viscosity indices and flash points. For this reason, therefore, particularly soybean, sunflower and rapeseed seem to possess the relevant properties as a potential hydraulic fluid. There are several tribotechnical methods how to assess the current technical state of used lubricants (viscosity, water content, flash point, acidity). One of the modern methods how to detect wear particles is LaserNet Fines, which is a suitable technique for machine condition monitoring. The ageing of test oils is analysed by the Fourier transform infrared spectroscopy (FT-IR); for determining anti-wear properties of hydraulic oils, the standard STN EN ISO 20623:2004 indicates 1 hour under an applied load of 150 N. The objective of the paper is to show the description and examples of modern tribotechnical methods used for determination of the technical state of used biolubricants utilized in agriculture and transport machinery.

Keywords: ageing of hydraulic oils, hydraulic oils with low environmental impact, long-term stability, physicochemical properties, wear particles

Abstrakt

Poľnohospodárske a dopravné zariadenia sú vhodné pre použitie hydraulických kvapalín. Po motorových olejoch sú hydraulické kvapaliny druhou najvýznamnejšou skupinou mazív. V súčasnej dobe je viac ako 85% kvapalín vyrábaných na báze minerálneho oleja. Vzhľadom na ich vysokú ekotoxicitu a nízku biologickú odbúrateľnosť predstavujú značnú hrozbu pre životné prostredie. Oproti tomu, väčšina hydraulických kvapalín vyrábaných na rastlinnej báze má nízky vplyv na životné prostredie. Navyše mazivá na báze rastlinných olejov vykazujú vynikajúce tribologické vlastnosti a všeobecne majú vysoké viskozitné indexy a body vzplanutia. Hlavne kvapaliny vyrábené najmä zo sóje, slnečnice a repky majú príslušné vlastnosti ako potenciálne hydraulické kvapaliny. Existuje niekoľko tribotechnických metód ako zhodnotiť technický stav používaných mazadiel (viskozita, obsah vody, bod vzplanutia a číslo kyslosti). Jednou z moderných metód ako vhodne monitorovať častice opotrebenia nachádzajúce sa v kvapaline a tým technický stav stroja je LaserNet Fines. Oxidácia skúšaných kvapalín je hodnotená pomocou Fourierovej transformácie infračerveného žiarenia (FT-IR). Pre stanovenie odolnosti voči opotrebeniu hydraulických kvapalín sa vychádza z normy STN EN ISO 20623:2004. Podľa tejto normy je kvapalina zaťažovaná po dobu 1 hodiny zaťažením 150 N. Príspevok sa zaoberá popisom a príkladom moderných tribotechnických metód pre stanovenie technického stavu použitých biologických kvapalín využívaných v poľnohospodárskej a dopravnej technike.

Kľučové slová: častice opotrebenia, dlhodobá stabilita, ekologické kvapaliny s nízkym vplyvom na životné prostredie, fyzikálno-chemické vlastnosti, oxidácia hydraulických kvapalín

Introduction

The main objective for present companies is to ensure reliability and operation of machines with minimal costs. These factors are associated with monitoring the technical condition of machinery. The maintenance strategy used for addressing complex machinery has been improved by the development of technical systems, automation and complex elements (Plaščák et al., 2010; Sloboda, 2010). Equipment maintenance is an interdisciplinary activity which involves experts from different fields of mechanical engineering, electrotechnics, electronics and other scientific branches in order to ensure the most favourable maintenance as well as to improve, modernize, develop, and reconstruct the existing equipment (Emert et al., 1995). The technical condition of machinery can be, for example, evaluated on the basis of analysis of used lubricants, within the tools of tribotechnical diagnostics (Machalíková et al., 2008; Perič, 2009). Rigorous application of tools of tribotechnical diagnostics can properly ensure reliability and increase of maintenance efficiency. In terms of condition monitoring, it is necessary to find out the extension and type of concrete wear. Even with simple methods it is possible to reveal serious problems which could cause damage of machines (Vališ et al., 2012). Furthermore, in case of damage of machinery, lubricants have a negative influence on the environment, especially in the context of soil, water and food chain contamination (Dado and Hnilica 2009; Tkáč et al., 2012). Today’s technology of high performance hydraulic power systems is closely connected with the high development level of hydraulic fluids. A good hydraulic fluid should have the following characteristics: power transmission with a minimum loss, lubrication of surfaces moving against each other and corrosion protection of metal surfaces (Mendoza et al., 2011). Numerous fluids used as hydraulic oils are mineral oil-based. Because of their low biodegradability and high toxicity, mineral oils are not environmentally friendly. The environment is becoming increasingly contaminated with numerous kinds of pollutants, so any reduction is beneficial (Salih et al., 2011; Kržan and Vižitin, 2006).

Oils with low environmental impact have most of the required properties as potential candidates for hydraulic applications, except that they have poor low temperature flow behaviour and poor oxidation and hydrolytic stability. However, this can be overcome with the use of additives and by modifying the fatty acid composition of the basestock (Kržan et al., 2010; Gustone et al., 2007). Structural limitations of naturally occurring basestocks restrict the application of vegetable oil hydraulic fluids to moderate temperatures (Schneider, 2006; Majdan et al., 2011; Tkáč et al., 2010).

It is reported that a triglyceride structure provides desirable qualities for boundary lubrication. It is due to their long and polar fatty acid chains, which provide high strength lubricant films that interact strongly with metallic surfaces, reducing both friction and wear (Matthew et al., 2007; Petyuk and Adams, 2010). The polarity of fatty acids produces oriented molecular films, which provides oiliness and imparts anti-wear properties. Fatty acids are thus believed to be key substances with regard to lubricity (Helena et al., 2001; Maleque et al., 2003).

Materials and Methods

Tested lubricants

In order to check the properties of the bio-hydraulic fluid in comparison with the reference mineral fluid, several tests have been performed with the aim of evaluating the most important physicochemical parameters required for common hydraulic fluids. The composition of the tested formulation is shown in Table 1.

Table 1: Tested fluids

Oil code	Base oil type	Oil type	Additives
R	Unsaturated ester	Rapeseed oil	Ester + standard additives
M	Mineral oil – reference lubricant	Paraffin mineral oil	Standard additives package

Test methods

Hydraulic systems for agricultural and transport applications will work efficiently if the hydraulic oil used has low compressibility. Moreover, viscosity at operating temperature and at cold start temperature are also important properties. The viscosity at 40 °C and 100 °C have been measured according to STN EN ISO 3104+AC and the viscosity index (VI) was calculated. At the same time, this type of oils must have a low pour point and a reasonable level of acidic content; these parameters have been measured following the ASTM-D97 (pour point) and STN 65 6070 (acid number) standards respectively. Another important parameter is oxidative stability; this property has been measured by means of the DSC test (Differential Scanning Calorimetry). The stability has been analysed using an isothermal method under 20 bars of oxygen pressure maintaining the temperature at 145 °C for 120 minutes. The onset parameter is the time at which oil oxidation starts.

Particle analyser. LaserNet Fines-C is a bench-top analytical instrument that combines oil analysis techniques of particle shape classification (basic ferrography) and particle counting in one instrument. This analytical equipment can analyse the hydraulic fluids and other lubricating oils from different types of machinery and on the basis of the analysis to assess their current technical condition and suggest possible measures for their maintenance. The observation is based on evaluation of morphology and wear particles number generated during the operation of machinery and equipment. An algorithm sorts particles into categories such as cutting, fatigue, severe sliding, non-metallic and fibres. LaserNet Fines-C consists of two components. The first part is the analyser which analyses the taken samples, the second part is a personal computer which is necessary to analyse and evaluate the data from the analyser. Preparation of the oil sample for analysis is thorough agitation and removal of air bubbles in an ultrasonic bath.

The analysis is carried out after removing the sample from the bath and entering the necessary data about the oil sample into computer. Then, the oil is sucked into the LNF analyser and the laser beam is radiating through the oil sample in the flow cell (Fig. 1). The formed picture is zoomed and captured on video camera. All captured pictures are processed in computer via software. The whole process of analysis takes about three minutes and the results of the analysis are displayed to the operator of the analyser after the evaluation of the oil sample. One of the results of the analysis is cleanliness code according to ISO 4406:1999 that describes the particle number in fluid – oil. According to this standard, particles are divided into three categories: >4 µm, >6 µm and >14 µm. The standard describes the particle number per one millilitre of the oil sample. It is possible to obtain the cleanliness code by manual counting on appropriate microscope or using an automatic measurement device. Automatic measurement devices are commonly based on optical detection of particles, or based on flow/pressure rate measurements while the sample is flowing through the defined filter. LaserNet Fines-C was used for the carried out long-term stability test of biodegradable hydraulic oil and mineral hydraulic oil used in tractor depending on operating time (Aleš et al., 2012).

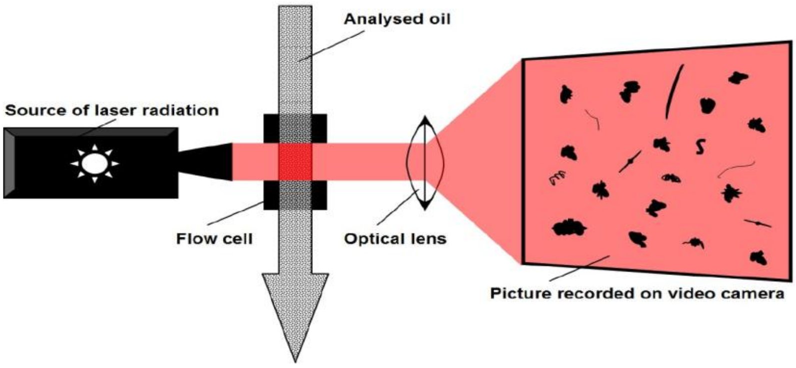

Figure 1: Principle of LNF analysis

Infrared spectrometry. The analyses were performed using an FT-IR spectrometer Thermo Scientific Nicolet iS^{10} in the spectral range of 650 – 4,000 cm^{-1}, with the resolution of 4 cm^{-1} and with the scan number 64 by means of the ATR technique (ZnSe crystal), Figure 2.

Figure 2: Spectrometer Thermo Scientific Nicolet iS^{10}

Four-ball Tribotester (extreme pressure test). The four-ball tests have been made according to the standard STN EN ISO 20623. The standard STN EN ISO 20623:2004 is the Slovak Republic adoption by the endorsement method of the standard EN ISO 20623:2003 Petroleum and related products – Determination of the extreme-pressure and anti-wear properties of fluids – four-ball method (European conditions). The components of mechanical design of the testing area, as required by this standard, are shown in Figure 3. The test balls are lime-polished, chrome-alloyed steel balls of ϕ 12.000 ± 0.0005 mm, conforming to requirements of ISO 683-17: 1999, type 1. For controlling the duration of the test, an electronic timer is used, capable of reading to the nearest 0.2 s. The vertical driving spindle rotated the upper ball with a speed of 1,475 ± 2 rpm, equivalent to a sliding speed of 548 mm*s^{-1}. The applied load was 150 N as the standard STN EN 20623:2004 requires.

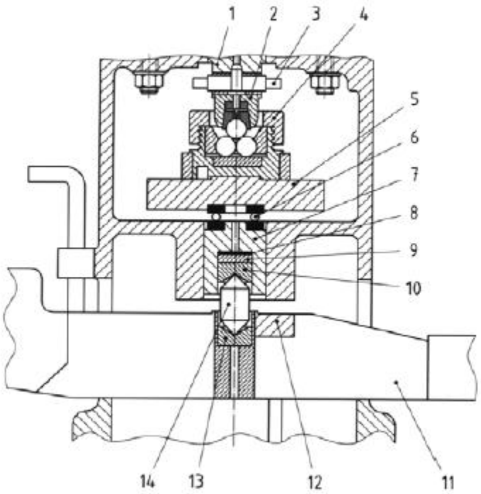

Figure 3: Illustration cut four-ball device for testing lubricants

1 – ball chuck holder; 2 – ball chuck; 3 – cam for removing ball chuck; 4 – ball pot assembly; 5 – ball pot mounting disc; 6 – trust bearing; 7 – gross head; 8 – brass shims; 9 – rubber disc; 10 – step bearing; 11 – counter-weighted level arm; 12 – fulcrum; 13 – step bearing; 14 – pressure pin

Results and Discussion

Table 2 shows the results obtained in the different physicochemical test performed in order to characterize the most relevant properties of the fluids developed. It is important to note the high viscosity index of the reference hydraulic fluids. This is an inherent property which is naturally present in the vegetable base oils. Concerning the acid content, this value is acceptable in the vegetable-based formulations in comparison with the reference oil.

Table 2: Physicochemical tests results

Oil	η at 40ºC (mm^2*s^{-1})	η at 100 ºC (mm^2*s^{-1})	VI	AC (mgKOH*g^{-1})	Pour point (ºC)	OIT (min)
R	45.6	10.1	215	0.78	- 18	54
M	46.2	8.5	165	0.54	- 30	>120

In experiments of anti-wear properties, the seizure load measured for the fluids is not very high (150 N) because high requirements of this property are not needed in the applications for which they have been designed. The values obtained for the biolubricants fulfil the requirements of the reference mineral oil. Concerning the friction, the vegetable base oils have a natural tendency to lubricate well and this property is reflected in low levels of friction measured, even lower than the reference mineral fluid (Table 3).

Table 3: Friction and wear test results

Oil	Coefficient of friction λ (Mean)	Microweldings	Ball Wear Scar Diameter (µm)
R	0.10	No	621
M	0.11	No	526

During the experiment, the operating time was monitored and kept tracked almost a year and a half depending on calendar time. Oil samples (PARAMO HV 46, BP Biohyd 46) were taken from the hydraulic system during this period. The realized analyses with the particle counter LaserNet Fines are very complex. According to the results, mineral hydraulic oil PARAMO HV 46 contained more particles in comparison with biodegradable hydraulic oil BP Biohyd 46. A deeper analytical view in Figure 4 shows that mineral hydraulic oil PARAMO HV 46 has lower ability to form a proper boundary oil layer compared to the other hydraulic oil. That is apparent due to higher increase of fatigue particle fraction during the experiment.

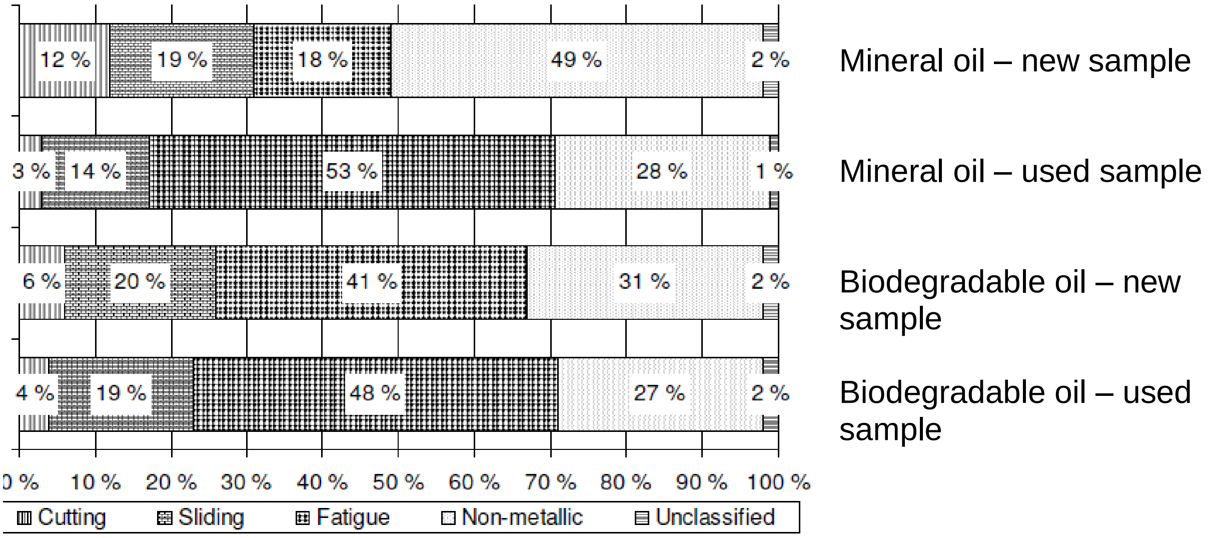

Figure 4: Percentage fraction of different particles in hydraulic oil samples analysed by LaserNet Fines

The FTIR spectroscopy method was used to analyse the hydraulic oil samples from operating (50, 100, 250, 500, 750, 1000, 1500, 2000 Mth) and comparative samples of unused oil, Figure 5 and 6. Changes in the IR spectra of oil samples compared with the new oil were only slight. In the areas around 1,730 cm^{-1} and 850 cm^{-1}, it is possible to monitor the depletion of anti-wear additives and viscosity index improvers. It can be stated that the intensity of oil degradation under the same operating conditions is dependent on a correctly determined quality of the oil used.

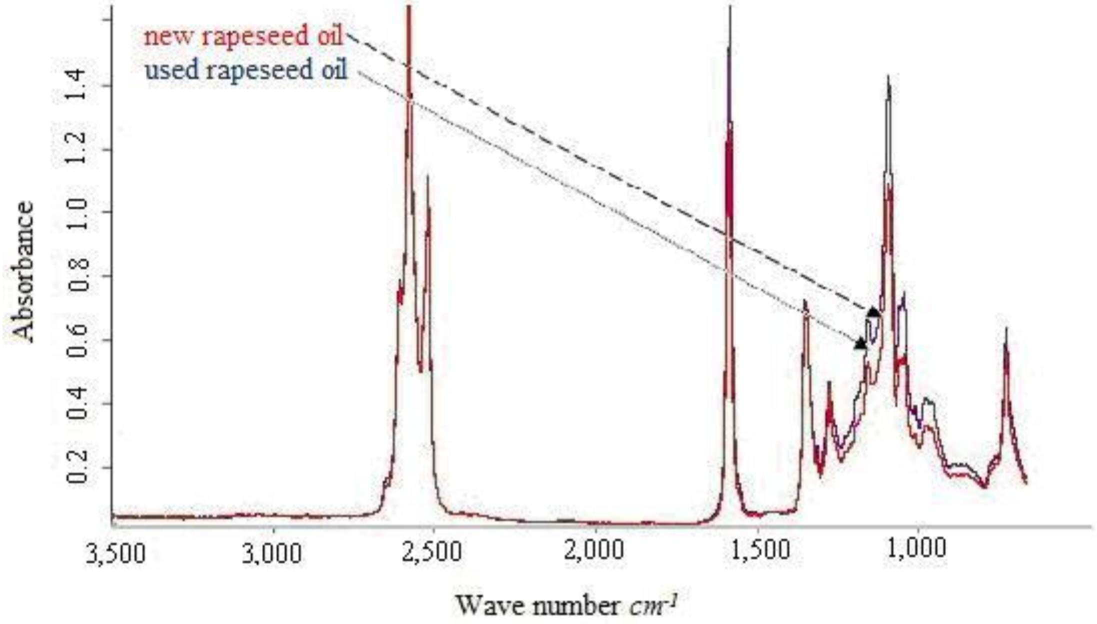

Figure 5: FTIR spectra of rapeseed oil BP Biohyd 46 (tractor)

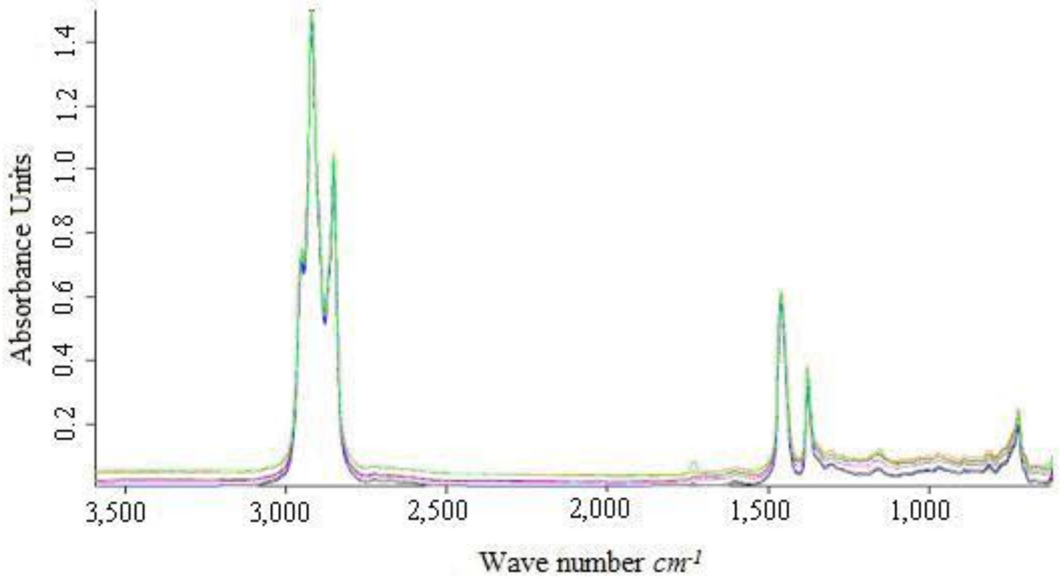

Figure 6: FTIR spectra of mineral oil PARAMO HV 46 (tractor) lower spectrum (new oil); upper spectrum (used oil)

Conclusion

Tribotechnical diagnostics use lubricants as media that help obtain information about processes and changes in the systems that they lubricate. If tribodiagnostics are applied properly and thoroughly, they result in significant savings in many areas; for example, they contribute to an increase of the lifetime of machines and devices, to a decrease of consumption of energy, to limiting the idle time due to failures and subsequent repairs, to a decrease of investment as well as operational costs (especially the machine maintenance and repair costs), to an increase of the safety of operation and to a reduction of negative influences of transport on the environment. They are based on monitoring the course of progressive wear of lubricants as well as mechanical parts.

Its main advantage lies in the fact that this diagnostic method does not necessitate disassembling of the engine. On the basis of analysis of particles in exploited lubricant, it allows evaluation of the wear regime in the given mechanism. The evaluation of the number, morphology and composition of abrasion particles permits prediction about the onset of limit or emergency wear; in some cases, it is also possible to determine the origin of abrasion particles and differentiate between the types of materials from which the abrasion particles were produced.

References

Aleš Z., Pexa M., Pavlu J., (2012). Tribotechnical diagnostic of agricultural machines. Engineering for Rural Development. pp. 88-92.

Dado M., Hnilica R., (2009). Control measurements for minimizing exposure to metalworking fluid aerosols. Josra, Nr. 3, p. 5.

Emert R., Jurić T., Filipović D., Štefanek E., (1995). Maintenance of tractors and other agricultural machinery. University of J.J. Strosmayer in Osijek, Agricultural Faculty, Osijek.

Gustone F.D., Harwood J.L., Dijkstra D.J., (2007). The lipid handbook. Boca Raton, Florida, USA: CRC Press.

Helena W., Rolf L., Theo M., (2001). Lubricant base fluids based on renewable raw materials their catalytic manufacture and modification. Applied Catalysis A: General 2001, 221, pp. 429–442.

Kržan B, Čeh B., Iztok K., Vižitin J., (2010). Study on the tribological performance of vegetable oils. Goriva i maziva, 49 (4), pp. 352-367.

Kržan B, Vižitin J., (2006). Tribological properties of lubricants derived from renewable resources. Goriva i maziva 45 (5), pp. 293-313.

Machalíková J., Sejkorová M., Livorová M., Krtička F., (2008). Assessment of morphology of wear particles in oils for vehicles. Transactions on Transport Sciences, 1 (4), pp. 185-192.

Majdan R., Kosiba J., Tulík J., Kročková D., Šinský V., (2011) The comparison of biodegradable hydraulic fluid with mineral oil on the basis of selected parameters. Research in Agricultural Engineering, vol. 57, pp. 43–49.

Maleque M.A., Masjuki H.H., Sapuan S.M., (2003). Vegetable-based biodegradable lubricating oil additives. Industrial Lubrication and Trialogy, 55, pp. 37–43.

Matthew T.S., Nader S., Bigyan A., Lambert A.D., (2007). Influence of fatty acid composition on the tribological performance of two vegetable-based lubricants. Journal of Synthetic Lubrication, 24, pp. 101–107.

Mendoza G., Igartua A., Fernandez-Diaz B., Urquiola F., Vivanco S., Arguizoniz R., (2011). Vegetable oils as hydraulic fluids for agricultural applications. Grasas y aceites, 62 (1), pp. 29-38.

Perić S., (2009) Modern methods of oil analysis in technical system. Vojnotechnički glasnik, broj 1/2009, pp. 83-112.

Petyuk A.M., Adams R.J., (2010). Oxidation stability and tribological behavior of vegetable oil hydraulic fluids. Tribology & Lubrication Technology, 66 (1), pp. 42-48.

Plaščák I., Jurić T., Emert R., (2010). Application of ferrography in condition based maitenance. Strojárstvo 52 (2), pp.233-240.

Salih N., Salimon J., Yousif E., (2011). The physicochemical and tribological properties of oleic acid based triester biolubricants. Industrial Crops and Products, 34, pp. 1089-1096.

Schneider M. P., (2006). Plant-oil-based lubricants and hydraulic fluids. Journal of the Science of Food and Agriculture, 86, pp. 1769-1780.

Sloboda J., (2010). Mechanical systems wear and degradation processes modeling. Transaction of FAMENA, 5 (4), pp. 248-264.

Tkáč Z., et al., 2010. Hodnotenie vlastností hydraulických kvapalín na základe skúšok s použitím hydrogenerátora (Evaluation of properties of hydraulic fluids based on tests with using hydrostatic pump). Nitra: SUA in Nitra.

Tkáč Z., Majdan R., Tulík J., Kosiba J., (2012). Study of ecological fluid properties under operational conditions of tractors. TEAM, 4 (1), pp. 295-298.

Vališ D., Koucky M., Zak L., (2012). On approaches for non-direct determination of system deterioration. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2012, 14 (1), pp. 33–41.