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Proposal for filtration system for biodegradable lubricants in agricultural tractors

R. Majdan[1,*], Z. Tkáč[1], R. Abrahám[1], M. Szabó[1], M. Halenár[1], M. Rášo[2] and P. Ševčík[2]

[1]Slovak University of Agriculture in Nitra, Faculty of Engineering, Department of Transport and Handling, Tr. A. Hlinku 2, SK 94976 Nitra, Slovak Republic
[2]Slovnaft, a.s., member of MOL Group, Vlčie hrdlo 1, SK 82412 Bratislava, Slovak Republic
[*]Correspondence: radoslav.majdan@gmail.com

Abstract. This paper presents a filtration system for universal tractor transmission oils (UTTO) to eliminate contamination, namely all kinds of particles and water. The aim of the research is the proposal of a universally useful filtration system for increasing the cleanliness level of biodegradable oils. The filtration systems consist of a filter housing with filter element, hoses, quick couplings and a measurement device to set the flow rate and pressure of the filtered oil. A measurement device (CS 1320) was used to monitor the cleanliness level of oil during filtration. The quality of the filtration system was evaluated according to kinematic viscosity at 40 °C, total acid number, concentration of additives (Ca, S and Mg) and content of chemical elements (Fe, Cu, Si, Al, Pb, Ag, Ni and Mn). The filtration system was designed for all tractor types because it can be connected to implement hydraulic circuit by houses and quick couplings. The filtration system was tested in the new type of tractor Zetor Forterra 11441 after completing 900 engine hours (oil contamination exceeded limits). On the basis of the performed filtration, it can be concluded that this a simple and affordable filtration system reduces the concentration of the most dangerous contamination: iron (Fe) by up to 32.95% and silicium (Si) by up to 22.23%. There was only a slight decrease in the concentration of additives recorded after use of the filtration system. The kinematic viscosity and the total acid number didn't exceed the prescribed limits.

Key words: ecological oil, lubricants contamination, agricultural tractor, lubricating properties.

INTRODUCTION

Environmental regulation has forced users and producers of machineries to use ecological oils in hydraulic systems that come into the contact with the environment Drabant et al. (2010). Biodegradability has become one of the most important design parameters both in the selection of base fluids and in the overall formulation of the finished lubricant (Mendoza et al., 2011). The cleanliness level is one of the most important conditions affecting the application of biodegradable oils in agricultural tractors. The universal tractor oils in transmission and hydraulic systems are polluted by residues of old fillings from attachments (such as ploughs, trailers, etc), contamination from environment and wear particles. At present tractors are fitted with filters that provide sufficient filtration for mineral and synthetic oil types. A standard filtering capacity of the tractor filters is 20 µm, in most cases., Hujo et al. (2012), Kosiba et al.

(2012) and Majdan et al. (2014) described the contamination of universal tractor oils in many tractors operating in agriculture. The application of biodegradable oils requires a higher cleanliness level in comparison with conventional oils. Contamination and moisture affect the decomposition of biodegradable lubricants, which lose their properties and so cannot meet requisite functions. Therefore, the highest possible cleanliness level is the base condition for the use of biodegradable oils.

Tractor use significantly affects economic effectiveness as well as environmental pollution in agriculture (Korenko & Žitňák, 2008). The UTTO in the hydraulic and transmission system of a tractor is the connecting link between various parts, and as it is operated it absorbs contamination, moisture and heat, which can cause a decrease in lubricant properties. The reliability of all hydraulic and transmission systems in tractors depends on lubricant oil properties. If the lubricant cannot meet the requisite functions, abnormal wear and malfunction can occur. Ileninová et al. (2008), Tóth et al. (2012) and Tóth et al. (2014) confirm this fact in their works.

Because of frequent accidents in operational location, ground contamination with liquid lubricants is very probable. For these reasons, the designs of machines make an effort to lubricate with biodegradable lubricants (Rédl et al. 2012).

Using the filtration system, a high cleanliness level of universal tractor oil can be provided. The filtration system was designed to realize additional filtration to increase the cleanliness level of universal tractor transmission oil as a base condition for the use of biodegradable oil types. The function of the filtration system was verified during test operation in a 11441 tractor.

MATERIAL AND METHODS

The filtration system consisting of a filtration device (3), and measurement device (2) HT 50 A (XPS Corporation, USA) is connected to the implement hydraulic circuit of the tractor by hoses (18), Fig. 1. Strainer (7) is a standard tractor filter with filtering capacity 20 μm (in the case of most tractors). This is the sufficient filtering capacity for mineral and synthetic oils. A filter element (13) realizes the second stage of oil filtration. It is a paper filter element type H 1081 (Mann+Hummel, GmbH., Germany) with filtration capacity 10 μm and the ability to remove water from oil. Therefore, the smaller particles of contamination are removed during the second stage of oil filtration. This is the way in which reach a higher cleanliness level for the use of biodegradable oils.

The tractor hydraulic pump (4) pumps the universal tractor transmission oil through the filtration device (3). Thus, the filtration device does not need to be equipped with a pump, making its construction easier. In this case, a low-pressure filter housing (up to 0.2 MPa) of FS 02 type (Kovolis Hedvikov, a. s., Czech Republic) was used. The filtration device needs to have the flow adjusted to ensure a low pressure. To test the filtration device we used the tractor Zetor Forterra 11441 which does not have a regulating hydraulic pump so it is not possible to set the desired flow rate in the hydraulic circuit. Consequently, a measuring device (2) was connected to the filtration device in series. Requisite flow value 0.2 $dm^3 s^{-1}$ was set using a restrictor (17) of this device (2). The measuring device HT 50A was used for hydraulic heating of the tractor oil fill before filtration and for setting the desired flow during filtration. The measuring device mentioned above can be replaced with a simple throttle valve and flow meter. Filtration efficiency was monitored by measuring the cleanliness level of the oil that enters the filter. A part of the oil entering the filter flows through the measuring device (3) CS 1320 (Hydac Ltd., Germany), which measures the cleanliness level according to ISO 4406 (1999). This device continuously counts the particles in the oil using the optical principle. To measure the cleanliness level, only a low oil flow was used. The low flow rate was set by a throttle valve (15) in this device. The cleanliness level according to ISO 4406 (1999) is determined by counting the number and size of particles in the oil. The standard defines the cleanliness level of particles larger than 4 µm, 6 µm and 14µm.

As an example: if 15 particles (in 100 ml of oil) larger than 4 µm, 5 particles (in 100 ml of oil) lager than 6 µm and 3 particles lager than 14 µm are counted, the ISO 4406 (1999) code level is 4/3/2. Cleanliness level definition per ISO 4406 (1999) are shown in Table 1. The step to the next cleanliness level means double or half the number of particles.

Table 1. Cleanliness levels per ISO 4406 (1999)

Number of particles per 100 ml	Number of particles per 1 ml	Cleanliness levels
1–2	0.01–0.02	1
2–4	0.02–0.04	2
4–8	0.04–0.08	3
8–16	0.08–0.16	4
etc.	etc.	etc.

The filtration system has been designed so that it can be made using different types of filter housings, which are available on most farms. The advantage of the system is its connection by quick couplers (9) to the implement hydraulic circuit of the tractor. Connection does not need additional assembly, which is characterized by simplicity. It is universally applicable to different types of tractors.

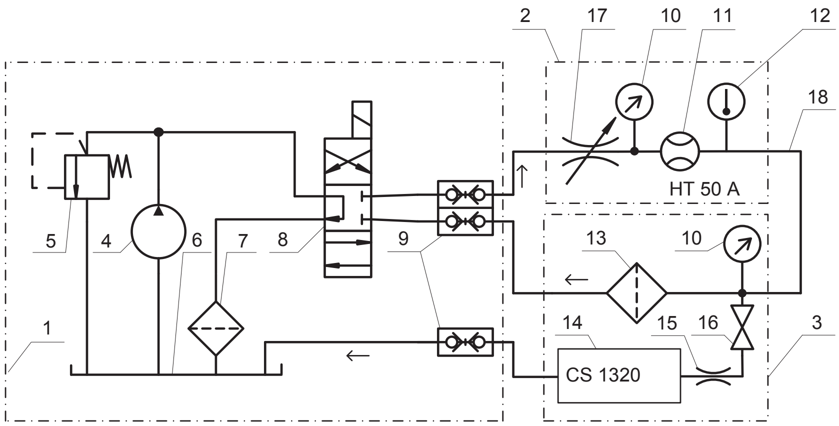

Figure 1. Filtration system: 1 – hydraulic system of tractor; 2 – measuring device type HT 50 A; 3 – filtration device; 4 – tractor hydraulic pump; 5 – pressure relief valve; 6 – tank; 7 – strainer; 8 – directional control valve; 9 – quick coupling; 10 – pressure gauge; 11 – flow meter; 12 – temperature sensor; 13 – filter element of filtration device; 14 – measuring device type CS 1320; 15 – throttle valve; 16 – shut-off valve; 17 – restrictor; 18 – hose.

Specification of filtered oil

The oil, which was used in a Zetor Forterra 11441 tractor, is a newly developed biodegradable oil made from poly-alpha-olefins synthetic base oil. This oil was chosen, because it has high chemical stability and miscibility with mineral oils that are in common use. The oil is part of the group of universal tractor transmission oils (UTTO) designed for tractors and produced by MOL Group, Hungary. The oil mentioned above is not commercially available because it is only in its testing phase at present.

The main specifications of the oil are as follows:

– kinematic viscosity at 100 °C: 10.22 $mm^2 s^{-1}$;
– kinematic viscosity at 40 °C: 58.14 $mm^2 s^{-1}$;
– viscosity index: 165;
– pour point: -42 °C (Tulík et al., 2013).

This type of oil was tested under laboratory conditions before its application in the agriculture tractor. Tulík et al., (2013) present more information about the biodegradable oil's properties and its test under laboratory conditions.

Evaluation of filtering quality

Using the agricultural tractor under operating conditions, the function of the filtration device and filtering quality were evaluated. Oil filtration was tested after 900 engine hours of tractor operation. The filtration of the oil filling the tractor transmission and hydraulic system was evaluated according to the following procedure:

Monitoring of particle contamination in the oil was realized on the basis of the cleanliness level during filtration. Device CS 1320 was used to evaluate particle contamination on the basis of the ISO 4406 (1999) standard.

After filtration particle contamination was stated from the oil sample in the accredited laboratory Wearcheck (Hungary). Using ICP (inductively coupled plasma) spectrometry, particle contamination was stated according to the content of chemical elements (Fe, Cu, Si, Al, Pb, Ag, Ni and Mn) which represent the wear of transmission and hydraulic system. Vähäoja et al. (2005) and Kučera et al. (2014) determine the presence of chemical elements (mentioned above) as markers of wear.

Changes in the chemical and physical properties of the filtered oil were evaluated according to kinematic viscosity at 40 °C and total acid number (TAN). The concentration of additives was evaluated on the basis of the chemical elements content (Ca, S and Mg). The ICP spectrometry method was used.

All these parameters were analysed from oil samples in an accredited laboratory (Wearcheck, Hungary) after filtration.

The cleaning of the transmission and hydraulic system oil fill makes sense only if the chemical and physical parameters of the fluid meet the prescribed technical limits. Lubricating properties of fluids can be best evaluated on the basis of kinematic viscosity (physical parameter of fluid) which has a decisive influence on the formation of an oil film. Stachowiak & Bachelor (2005) confirm this fact about kinematic viscosity.

Kinematic viscosity is evaluated based on the positive or negative tolerance of the value measured after the filtration in comparison with the value of new oil. Therefore, the kinematic viscosity of new oil must be evaluated. The deviation of kinematic viscosity is calculated by using the formula:

$$\Delta_{KV} = \frac{\nu_N - \nu_F}{\nu_N} \cdot 100 \quad (1)$$

where: Δ_{KV} – deviation of kinematic viscosity, %; ν_N – kinematic viscosity of the new oil, mm^2 s^{-1}; ν_F – kinematic viscosity after the filtration, mm^2 s^{-1}.

The total acid number (TAN) is the parameter which evaluates the chemical properties of lubricating oil. Its value describes oil's ability to eliminate acid compounds by virtue of alkaline additives. This parameter is used to evaluate the degradation processes of the oil. Therefore, the measurement of total acid number is very important in stating the technical properties and durability of filtered oil.

Additives concentration was monitored on the basis of the relevant content of chemical elements (Ca, S and Mg). The concentration of three elements that characterize the complex of additives, namely calcium, sulphur and manganese was measured before and after filtration to calculate changes in their content. A decrease in the content of these elements in an oil sample is calculated by using the following formula:

$$\Delta_{AD} = \frac{AD_{BF} - AD_{AF}}{AD_{BF}} \cdot 100 \quad (2)$$

where: Δ_{AD} – decrease of chemical elements representing the additives, %; AD_{BF} – content of chemical elements (Ca, S or Mg) before filtration, mg kg^{-1}; AD_{AF} – content of chemical elements (Ca, S or Mg) after filtration, mg kg^{-1}.

A decrease in the content of chemical elements which represent fluid contamination is calculated on the basis of information on polluted and filtered oil. Impurity content represents fluid contamination. A decrease in the content of chemical elements which represent fluid contamination is calculated by using the formula:

$$\Delta_C = \frac{C_{BF} - C_{AF}}{C_{BF}} \cdot 100 \quad (3)$$

where: Δ_C – decrease in chemical elements content representing particle contamination, %; C_{BF} – content of chemical elements of particle contamination before filtration, mg kg^{-1}; C_{AF} – content of chemical elements of particle contamination after filtration, mg kg^{-1}.

Oil samples were taken after completing 150, 450 and 900 engine hours during the tractor operation and after filtration. A representative sample of new oil was taken before filling the tractor transmission and hydraulic system with oil. This sample was marked as new oil. Oil filtration was realized after competing 900 engine hours when the particle contamination exceeded limits stated in the internal documents of the Wearcheck, laboratory, Hungary.

RESULTS AND DISCUSSION

The filtration device (Fig. 2) was made by simply placing the filter housing on the stand with hose adapters for connecting, and it was designed at the Department of Transport and Handling. A filter cartridge was placed in the aluminium housing of the filtration device. The filtration capability of the paper element was 10 µm.

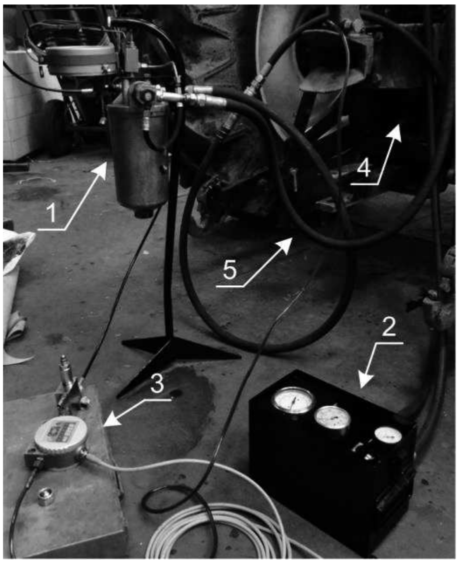

Figure 2. The filtration and measuring devices connected to the agricultural tractor type Zetor Forterra 11441: 1 – filter housing with filter element, 2 – measuring device type HT 50 A, 3 – measuring device type CS 1320, 4 – agriculture tractor type Zetor Forterra 11441, 5 – hoses.

The design of the low-pressure filter housing required the setting of a relatively low flow rate through the filtration device (0.2 dm^3 s^{-1}). Despite this low flow value, one filtering of the whole oil fill (in our case 120 dm^3) took about 10 minutes only. We filtered the oil fill three times to improve the quality of filtration. If a pressure filter housing designed for the hydraulic pump flow of a given tractor type was used, it would be possible to filter the oil fill without the restrictor. The filtering system would be simplified and filtration time shortened.

Máchal et al. (2013) published the design of a filtration device which cleans the UTTO during tractor operation continually. In this case the filtration device is placed on the tractor and requires a tractor hydraulic system with the possibility of flow setting. This filtration device is suitable only for tractors with relatively low level of oil contamination due to high quality maintenance, because filtration capability is only 2 μm. The high level of oil filtration is not suitable for all operating conditions. Máchal et al. (2013) presented a more expensive and less universal concept of a filtration device compared with the filtration device described in this paper.

Singh & Suhane (2014) suggested another filtration concept to eliminate contamination from the hydraulic oil in a tractor. To remove contaminants (mainly magnetic particles) a modification in the tractor hydraulic system was proposed. In the proposed hydraulic system a magnetic filter is fixed in the suction line of the hydraulic system before the suction filter. Our filtration method doesn't require modification of tractor because filter housing with filter element uses the oil from the implement hydraulic circuit. It is only necessary to connect the quick couplers. The suggested filtration system is able to remove all kinds of oil contamination thus also non-magnetic particles and water in contrast to the filtration concept presented by Singh & Suhane (2014).

Kinematic viscosity (Fig. 3) is a parameter that can decrease or increase during operation. In this case, a decrease in kinematic viscosity was calculated Δ_{KV} = 6.89% according to Eq. (1). The decrease of kinematic viscosity does not exceed the limit of 10% which is prescribed for the UTTO. Thus, kinematic viscosity was within the prescribed limits after filtration.

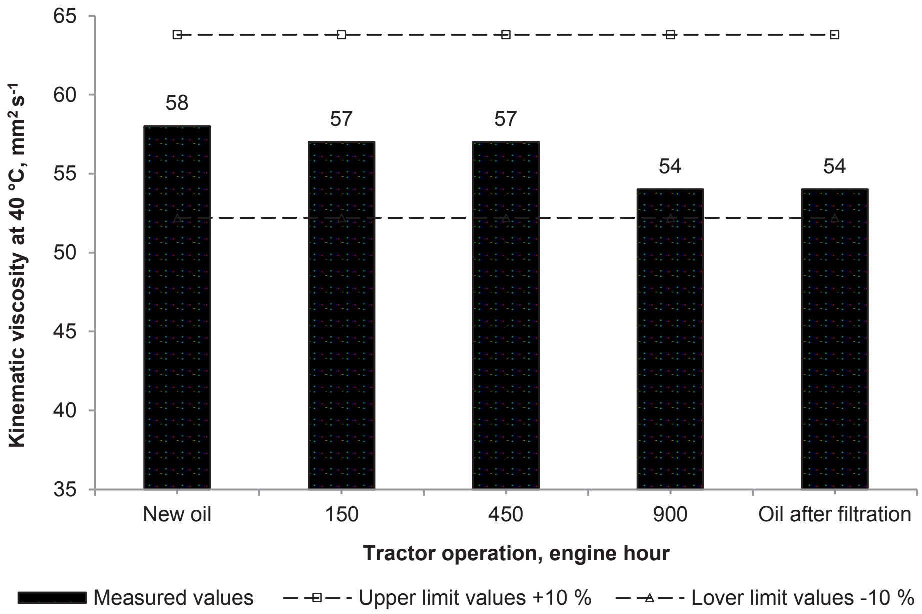

Figure 3. Kinematic viscosity of oil during the tractor operation and after filtration.

A gradual increase in total acid number (Table 2) represents a process of oil degradation. During tractor operation, the limit value 3.5 mg KOH g^{-1} wasn't exceeded. The producer of the oil (MOL Group, Hungary) stated the limits for its universal tractor transmission oils (UTTO). The value of total acid number is the same before and after filtration. Therefore, the process of filtration doesn't influence the chemical properties of the lubricating oil in tractor. The total acid number together with kinematic viscosity was measured to state the physical and chemical properties of the filtered oil because some types of oil filters could eliminate some additives and thus degrade the lubricating oil. In this case the filtration device doesn't change the properties mentioned above and so fulfils the base condition of oil filtration.

Table 2. The results of total acid number

Tractor operation, engine hour	0	150	450	900	After filtration
Measured total acid number, mg KOH g^{-1}	1.19	1.42	3	3.2	3.2
Limit value for total acid number, mg KOH g^{-1}	3.5				

The correct design of filtration device removes contamination from the oil and doesn't reduce the content of additives which improve the chemical and physical properties of the base oil. The content of additives is one of parameters describing the technical state of oil. Therefore, it is very important to evaluate the quality of filtration on the basis of concentration of chemical elements which represent additives in oil. A decrease in the concentration of chemical elements that represent additives Δ_{AD} was calculated according to Eq. (2) using measured values shown in Fig. 4.

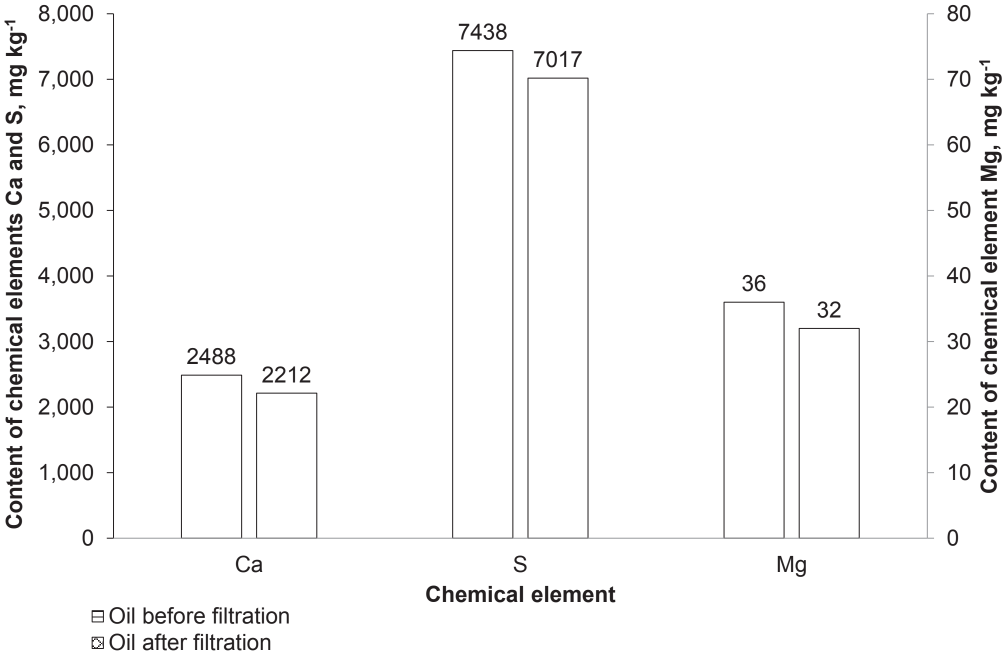

Figure 4. Decrease in chemical elements, which represent additives in oil after filtration.

The largest decrease was observed in the measurement of manganese 11.11% and calcium 11.09%. In the case of sulphur a decrease of only 5.66% was measured. Therefore, in the monitored oil, there was only a slight decrease in the concentration of additives recorded.

The physical and chemical properties of the ecological oil UTTO, as quality evaluation parameters, were monitored during tests performed by Vižintin & Kržan (2003). The authors focused on kinematic viscosity, additive content and oxidative stability. Based on these parameters, they evaluated the properties of the sunflower-oil-based fluid UTTO with AW and EP additives. In operating tests, they did not notice any exceeding of limits in the physical and chemical parameters of the used oil.

Mendoza et al. (2011) present the results of using the ecological fluid in the Agria agricultural tractor. During this oil test, the author evaluated the physical and chemical properties of the oil as a base condition for its application in an agricultural tractor.

Kučera & Rousek (2008) evaluated the kinematic viscosity of the oil type NAPRO-HO. This oil did not exceed the limit viscosity value of 10% during tests.

In our case, we evaluated the same oil parameters because they are important in the evaluation of an oil's technical parameters, which influence the reliable operation of agricultural tractors.

Fig. 5 shows an increase in the concentration of particles in oil during tractor operation. Contamination reaching high concentrations of iron and copper was observed after completing 900 engine hours. Therefore, filtration was performed with the designed filtration device. This figure also shows a decrease in the concentration of polluting chemical elements after filtration. This decrease was calculated according to Eq. (3). The decrease in concentration of the most dangerous elements reached value: 32.95% for iron, 22.23% for silicon, 6.66% for copper and 33.34% for aluminium. The other elements didn't reach a concentration considered dangerous for the lubricated system because they didn't exceed limits. The concentration of these elements, namely chrome, tin and lead, reached only a low value before filtration and therefore their elimination due to filtration was not important. The accredited laboratory Wearcheck (Hungary) together with the oil producer stated the levels of oil contamination and limit values according to technical information presented by Evans (1997).

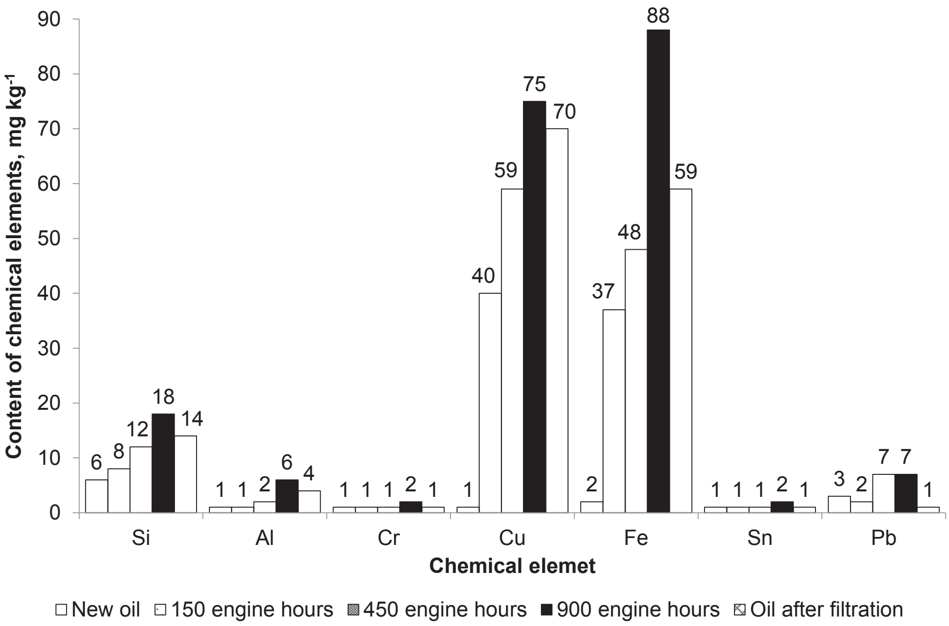

Figure 5. The content of chemical elements, which represent oil contamination before and after filtration.

Table 2 shows the results of cleanliness level measurements using the device CS 1320, which was connected to the filtration device during filtration. During filtration, a decrease in the concentration of particle contamination occurred in three stages. They are identified in Table 3 as measurements no. 1, 2 and 3. The stage represents one filtration of the whole oil fill. The table shows three measurements of cleanliness level during oil filtration. The next measurement didn't show changes in comparison to one before. It was realized to ensure that the filtration was completed. Measurement results of the cleanliness level show a reduction in the largest particles (> 14μm), which are the most dangerous for the transmission and hydraulic system of the tractor.

Table 3. Results of cleanliness level according to ISO 4406 (1999) during the oil filtration

Size of particles		Measurement 1.	2.	3.
> 4 μm	ISO class	24	24	24
	number of particles per 0.1 dm^3	8,000,000–16,000,000		
> 6 μm	ISO class	23	23	23
	number of particles per 0.1 dm^3	4,000,000–8,000,000		
> 14 μm	ISO class	10	9	8
	number of particles per 0.1 dm^3	500–1,000	250–00	130–250

CONCLUSION

This contribution deals with the design and use of a filtration system designated to ensure the reliable operation of agricultural tractors with regard to an application of ecological lubricants which require a clean oil fill. The designed filtration system ensures a clean fluid during its operation in the tractor. Removing particle contamination, the filtration system can be used for all types of oils to increase cleanliness level.

The filtration system can be used easily for different types of tractors because it is connected to the implement hydraulic circuit. It can be universally used for the newest tractor types, too. It can be made from the various filter housings available on most farms. Based on the measurements, we can conclude that the designed filtration system is suitable for cleaning universal tractor transmission oils used in tractors. The manufacturing of the filtration system is simple and affordable.

Fig. 5 shows the progress of fluid contamination up to completing 900 engine hours and a significant decrease in the most dangerous contaminants after filtration. A positive filtration effect was shown during cleanliness level measurement, too. Table 3 shows a reduction in the largest particles (> 14μm) from class 10 to class 8 (according to standard ISO 4406 (1999)) due to the filtration.

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REFERENCES

Drabant, Š., Kosiba, J., Jablonický, J. & Tulík, J. 2010. The durability test of tractor hydrostatic pump type UD 25 under operating load. *Research in Agricultural Engineering* **56**, 116–121.

Evans, J. 1997. Wear limits versus trends. *Technical bulletin of Wearcheck* **15**, 1–2.

Hujo, Ľ., Kosiba, J., Jablonický, J. & Tulík, J. 2012. Load characteristics of three-point tractor linkage. In*: Naučni trudove – zemedelska technika i technologii, agrarni nauki i veterinarna medicina, remont i nadeždnosť.* University of Rousse, Rousse, pp. 172–176 (in Bulgaria).

Ileninová, J., Mihalčová, J. & Košťáliková, D. 2008. Evaluation of hydraulic fluid properties in aero-engine. In*: Reotrib 2008.* Institute of Chemical Technology, Prague, pp. 118–122 (in Czech Republic).

ISO 4406 1999. Hydraulic fluid power – Fluids – Method for coding the level of contamination by solid particles.

Tulík, J., Hujo Ľ., Stančík, B. & Ševčík, P. 2013. Research of new ecological synthetic oil-based fluid. *Journal of Central European Agriculture* **14**, 1384–1393.

Kosiba, J., Varga F., Mojžiš M. & Bureš, Ľ. 2012. Load characteristics of tractor Fendt 926 Vario for simulation on experimental bench). *Acta Facultatis Technicae* **17**, 63–72.

Korenko, M. & Žitňák, M. 2008. Machines utilization during harvest and transport of straw bales for energetic purpose. In*: Perspective in Education Process at Universities with Technical-Orientation in Visegrad Countries: International Science Conference*. SUA in Nitra, Nitra, pp. 275–279. (in Slovak Republic).

Kučera, M. & Rousek, M. 2008. Evaluation of thermooxidation stability of biodegradable recycled rapeseed-based oil NAPRO-HO. *Research in Agricultural Engineering* **54**, 163–169.

Majdan, R., Tkáč, Z., Stančík, B., Abrahám, R., Štulajter, I., Ševčík, P. & Rášo, M. 2014. Elimination of ecological fluids contamination in agricultural tractors. *Research in agricultural engineering* **60**, 9–15.

Kučera, M., Bujna, M., Korenková, M. & Hass, P. 2014. Possibilities of using ecological fluid in agriculture. *Advanced Materials Research* **1059**, 61–66.

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**, 29–38.

Máchal, P., Majdan, R., Tkáč, Z., Stančík, B., Abrahám, R., Štulajter, I., Ševčík, P. & Rášo, M. 2013. Design and verification of additional filtration for the application of ecological transmission and hydraulic fluids in tractors. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis* **61**, 1305–1311.

Rédl, J., Váliková, V. & Kročko, M. 2012. Mathematical Model of Sliding Couple Lubricated With Biolubricants. *Acta technologica agriculturae* **15**, 46–52.

Singh, D. & Suhane, A. 2014. Modification of hydraulic system of tractor for removal of magnetic particles from hydraulic oil. *International Journal of Engineering Research and Development* **10**, 56–60.

Stachowiak, G.W. & Bachelor, A.W. 2005. *Engineering Tribology*. Elsevier, Burlington, 801 pp. (in USA).

Tóth, F., Rusnák, J. & Kadnár, M. 2012. Monitoring of geometric cylindricity tolerance changes on a test sliding pair using the oils Madit PP 80 and Mobil Mobilube SHC. *Acta technologica agriculturae* **15**, 100–102.

Tóth, F., Rusnák, J., Kadnár, M. & Čavojský, P. 2014. Effect of selected ecological lubricants on the wear of defined sliding bearing. *Acta technologica agriculturae* **17**, 13–16.

Vähäoja P., Välimäki, I., Heino K., Perämäki P. & Kuokkanen K. 2005. Determination of Wear Metals in Lubrication Oils: A Comparison Study of ICP-OES and FAAS. *Analytical Sciences* **21**, 1365–1369.

Vižintin, J. & Kržan, B. 2003. Tribological properties of vegetable based universal tractor transmission oil. In*:* Rotrib ′03. University 'Dunarea de Jos' of Galati, Galati, pp. 221–227 (in Serbia).