Elimination of ecological fluids contamination in agricultural tractors

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Abstract

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This contribution presents the elimination of pollution for ecological fluids of UTTO (universal tractor transmission oils) type in agricultural tractors. The common oil filling of the transmission and hydraulic system is polluted by residues of old fillings from attachments such as ploughs, trailers, etc. In the tractor Zetor Forterra 114 41, a newly developed synthetic ecological fluid HEPR (VDMA 24568) was applied. The oil showed pollution limits after completing 900 engine hours. For this reason, a filtration device was designed to clean mainly biodegradable fluids UTTO. On the basis of fluid application evaluation and performed filtration, it can be concluded that a simple and affordable filtration system reduces the concentration of the most dangerous contamination particles (particles lager than 14 μm) by up to 30%.

Keywords: ecological oil; cleanliness level; filtration; viscosity; hydraulic pump

Considering the character of agricultural production, the transport in agriculture significantly affects the economic effectiveness as well as environmental pollution (Korenko, Žitňák 2008; Žitňák, Korenko 2008). Mineral oils designed for hydraulic and transmission systems of agricultural tractors reliably meet all the requirements of operating conditions in most cases. Properties of mineral oils are verified by many years of use. Machine manufacturers have rich experience with mineral and synthetic oils and therefore they widely use them at present. Sloboda and Sloboda (2002), Jobbágy et al. (2003), Ileninová et al. (2008) and Tóth et al. (2012) confirm this fact in their works. However, a slow but steady move towards the use of environmentally friendly or more readily biodegradable lubricant fluids has taken place during the last decade. 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).

Because of frequent accidents at a working place, ground contamination with liquid lubricants is very probable. For these reasons, constructions of rotating components and systems make an effort to lubricate with biolubricants (Rédl et al. 2012).

Universal tractor transmission oils (UTTO) are designed for hydraulic and transmission systems of agricultural tractors. These fluids provide lubrication functions in the gear box and transmission of energy in the hydraulic system of the tractor. Currently, tractor hydraulic systems are quite complicated. These systems use mainly gear or piston hydraulic pumps and motors which transform

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pressure energy into mechanical work. Besides the energy transfer, universal oils must lubricate, dissipate heat, and they must be compatible with sealing materials and metal components of the system.

It was reported that over 60% of all lubricants end up in soil and water. Hydraulic line breaks are extremely common. If not attended to, these releases can cause contamination of the soil, ground and surface water. Many equipment operators do not clean up spills, thereby introducing pollutants to the environment. Using a fluid that is biodegradable reduces the cost of clean-up as well as the potential for polluting the environment (Cauffman et al. 2006).

The UTTO requires care and monitoring of operating parameters such as every part of the agricultural tractor. That applies even more in case of ecological fluids. Ecological fluids are more sensitive to a change in operating conditions compared with mineral oils. Fluid cleanliness is one of the most important features. Often, the cleanliness and technical condition of the UTTO are frequent causes of failures of the transmission and mainly hydraulic system of the tractor. A contaminated fluid creates a risk to the machine in terms of wear and failure. Pollution is dangerous because it accelerates the degradation and oxidation processes in the fluid. If the fluid is contaminated with dirt above the permitted level, it must be replaced. The fluid needs to be replaced even if it has good physical and chemical properties expressed by viscosity or acid number. However, in the case of expensive ecological fluids, such a solution is not economical. Therefore, the elimination of pollution from fluid by using filtration is an ecological as well as economical solution.

MATERIAL AND METHODS

The newly developed biodegradable synthetic oil-base fluid HEPR according to VDMA 24568 (1999) was applied in the agricultural tractor Zetor Forterra 114 41 (Zetor, a.s., Brno, Czech Republic). The fluid was developed by Slovnaft, a.s., a member of the MOL group, Hungary. The fluid was tested under laboratory conditions. It was cyclically loaded under a nominal pressure of 20 MPa. Laboratory testing conditions and practices of the biodegradable fluid mentioned above were described by Drabant et al. (2010), Hujo et al. (2012a,b), and Kosiba et al. (2012a,b). The fluid was loaded by cyclic pressure at temperature 65°C, which was measured during the tractor operation as stated by Kosiba et al. (2010). After successful tests, the fluid was used in the agricultural tractor. The physical and chemical properties and pollution of the fluid were evaluated during the operation test. A filtration device was designed and tested due to exceeding the pollution limits of the fluid. The filtration device was designed to ensure a reliable operation of the tractor with ecological fluids.

Filtration device. The main parts of the filtration device (developed by Department of transport and handling, Faculty of engineering, Slovak University of Agriculture in Nitra) are the filter housing with a filter element. The filtration device is connected to the implement hydraulic circuit of the tractor by hoses (Fig. 1). The tractor hydraulic pump pumps the universal transmission and hydraulic oil through the filtration device. 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 was used (up to 0.2 MPa) of FS 02 type (Kovolis Hedvikov, a.s., Hedvikov, Czech Republic). The filtration device needs to have the flow adjusted to ensure a low pressure. The tractor Zetor Forterra 114 41 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 (6) HT 50 A (XPS Corporation, Owatonna, USA) was connect-

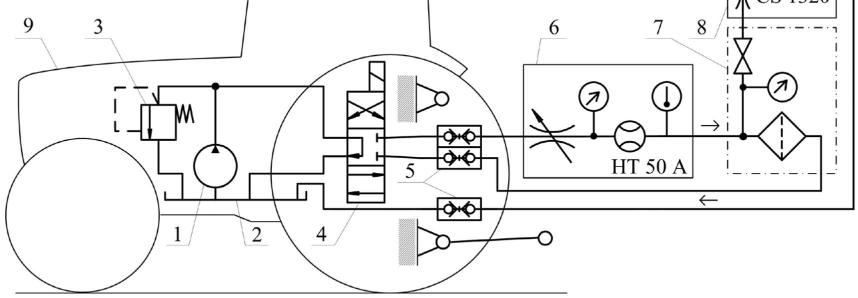

Fig. 1. Connection scheme of filtration device

1 – tractor hydraulic pump; 2 – gear and hydraulic oil supply; 3 – pressure relief valve; 4 – hydraulic valve; 5 – quick couplings of implement hydraulic circuit; 6 – measuring device; 7 – filtration device; 8 – device for measuring cleanliness level; 9 – tractor

ed to the filtration device in series. Flow value of 0.2 dm^3/s was set using a throttle valve of this device. 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. The 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 CS 1320 (Hydac Ltd., Sulzbach, Germany), which measures the cleanliness level according to the ISO 4406 (1999). To measure the cleanliness level, a low oil flow was only used. The low flow rate was set by a jet in this device.

The filtration device was designed so that it can be made using different types of filter housings, which are available in a particular farm (Fig. 2). The advantage of the device is its connection by quick couplers 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. The design of the low-pressure filter housing required setting a relatively low flow rate through the filtration device (0.2 dm^3/s); the throttle valve has thus to be used to set the required flow rate (Fig. 1). This throttle valve was placed to the measuring device. The flow meter EVS 31000 (Hydac Ltd., Sulzbach, Germany) was installed to check the right value of flow rate during the filtration. One filtering of the whole oil fill (in our case 120 dm^3) took about 10 minutes. We filtered the oil fill two times to improve the quality of filtration. If pressure filter housing designed to the hydraulic pump flow of a given tractor type is used, it would be possible to filtrate the oil fill without the flow control valve. The filtering system would be simplified and filtration time shortened.

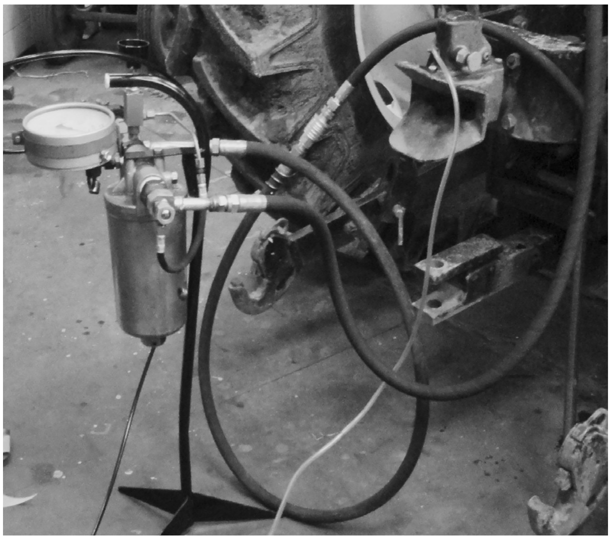

Fig. 2. Filtration device connected to the tractor

The filtration capability of a paper element was 10 μm. The filter cartridge was placed in an aluminium housing of the filtration device. The filtration device was made by simply placing the filter housing on the stand with hoses adapters for connecting; it was designed at the Department of Transport and Handling, Faculty of Engineering, Slovak University of Agriculture in Nitra, Slovak Republic. The filtration device is connected to the implement hydraulic circuit by pressure hoses and quick coupling.

Evaluation of the technical condition of ecological fluid. The technical condition of the monitored fluid was necessary to be evaluated before filtration. The following parameters were evaluated:
– kinematic viscosity at 40°C,
– concentration of additives on the basis of the chemical elements content (Ca, P and Zn) (ICP spectrometry method was used),
– depletion of antioxidants on the basis of FTIR spectroscopy.

These parameters were analysed from oil samples in an accredited laboratory (Wearcheck, Hungary).

Kinematic viscosity is evaluated based on the positive or negative tolerance of the measured values 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:

$$\Delta V = \frac{\nu_N - \nu_U}{\nu_N} \times 100 \quad (\%) \tag{1}$$

where:
ΔV – deviation of kinematic viscosity (%)
ν_N – kinematic viscosity of the new oil (mm^2/s)
ν_U – kinematic viscosity of the used oil (mm^2/s)

Additives concentration was monitored on the basis of relevant content of chemical elements (Ca, P and Zn). A decrease in the content of these elements in an oil sample is calculated by using the following formula:

$$\Delta A = \frac{A_N - A_U}{A_N} \times 100 \quad (\%) \tag{2}$$

where:
ΔA – decrease of chemical elements representing the additives (%)

A_N – content of chemical elements representing the additives in new oil (mg/kg)

A_U – content of chemical elements representing the additives in used oil (mg/kg)

The filtration of oil filling of the tractor transmission and hydraulic system was evaluated according to the following procedure:

– Online monitoring of the pollution decrease on the basis of the filtered oil cleanliness level during filtration. The device CS 1320 was used to evaluate the pollution on the basis of the Standard ISO 4406 (1999).

– Offline pollution assessment on the basis of analyses of oil samples after filtration. This was done in the accredited laboratory Wearcheck (Almásfüzitö, Hungary). Pollution was evaluated according to the concentration of chemical elements Fe, Cu, Si, Al, Pb, Ag, Ni and Mn. The contents of these chemical elements were analysed by inductively coupled plasma (ICP) atomic emission spectrometry.

A decrease in the content of the 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:

$$\Delta Z = \frac{Z_U - Z_F}{Z_U} \times 100 \quad (\%) \qquad (3)$$

where:

ΔZ – decrease in chemical elements content representing pollution (%)

Z_U – content of chemical elements representing pollution in used oil (mg/kg)

Z_F – content of chemical elements representing oil pollution after filtration (mg/kg)

Oil samples were taken after completing 150, 450, 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 0 engine hours.

RESULTS AND DISCUSSION

The cleaning of the transmission and hydraulic system oil fill makes sense only if the fluid parameters meet the prescribed technical limits. Lubricating properties of fluids can be best evaluated on the basis of kinematic viscosity which has a decisive influence on the formation of an oil film. Fig. 3 shows the course of the kinematic viscosity of oil during the tractor operation.

Kinematic viscosity is a parameter that can decrease or increase during operation. In this case, the decrease in kinematic viscosity was calculated $\Delta V = 6.89\%$ according to Eq. (1), based on the value of new oil $\nu_N = 58$ mm^2/s and value of used oil after 900 engine hours $\nu_U = 54$ mm^2/s. The decrease of kinematic viscosity does not exceed the limit of 10% which is prescribed for the UTTO. Kinematic viscosity was thus within the prescribed limits before the planned filtration.

Fig. 4 shows the FTIR spectrum of ecological oil used in the agricultural tractor. The FTIR analysis can detect the depletion of antioxidants that protect the oil from degradation. In the case of antioxidants depletion, the oil must be replaced or depleted antioxidants must be added. Therefore, it was necessary to carry out the measurement of antioxidants. The wavenumber of 3,650 cm^{-1} and 3,620 cm^{-1} is typical for phenolic antioxidants and

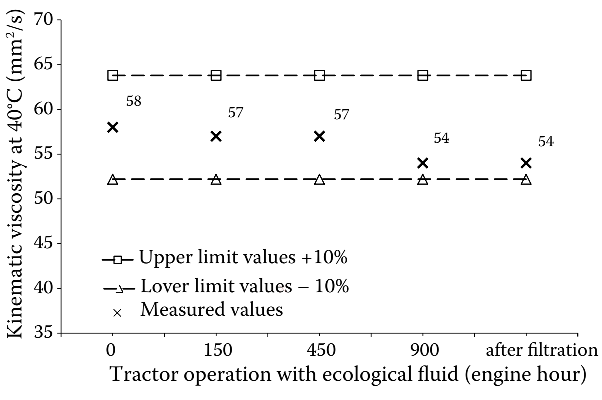

Fig. 3. Kinematic viscosity of oil during the tractor operation

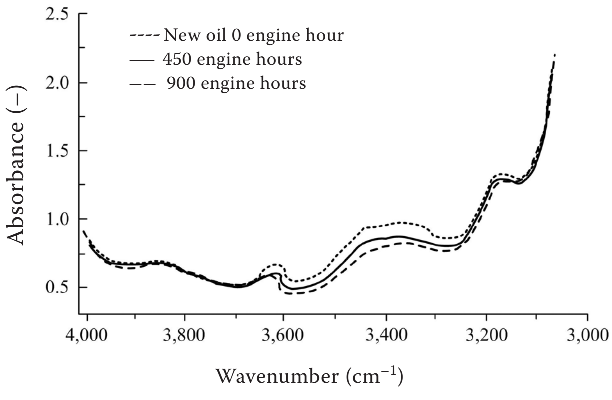

Fig. 4. Determination of antioxidant concentration using FTIR spectroscopy

Table 1. Concentration of chemical elements (mg/kg) representing the additives

Chemical element	Time of tractor operation (engine hours)				ΔA (%)
	0	150	450	900	
Ca	3,171	3,245	2,615	2,488	21.54
P	1,276	1,119	1,114	1,105	13.41
Zn	1,381	1,364	1,129	1,264	8.48

ΔA – decrease of chemical elements representing the additives (%)

the wavenumber of 1,437 cm^{-1} for amine antioxidants. Fig. 4 shows a slight decrease in the concentration of both types of antioxidants. Therefore, there is a gradual depletion of antioxidants in the oil. The remaining concentration of antioxidants can also protect the oil from degradation. Therefore, it was possible to clean the oil from mechanical impurities by using filtration.

Information on the technical condition of the tractor transmission and hydraulic oil fill after completing 900 engine hours are supplemented by information on the quantity of additives that improve the properties of used fluid.

Table 1 shows the three base elements that characterize the complex of additives, namely calcium, phosphorus and zinc. The concentration of these chemical elements decreases due to a gradual depletion of additives in the oil. A decrease in the concentration of chemical elements that represent additives ΔA was calculated according to Eq. (2). The largest decrease was observed in the measuring of calcium at 21.54%. In the monitored oil only a slight decrease was recorded in additives concentration.

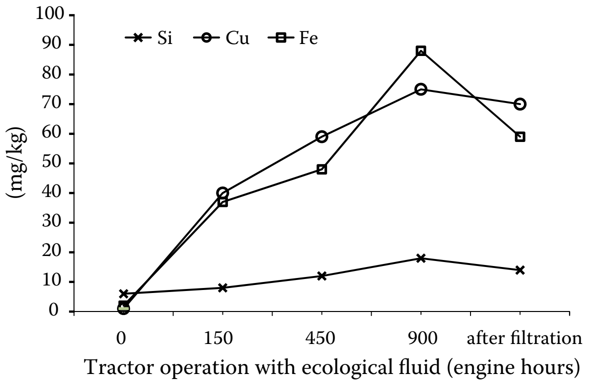

Fig. 5. Concentration (mg/kg) of iron, copper and silicon in oil samples during the tractor operation

The physical and chemical properties of the ecological oil UTTO, as the quality evaluation parameters, were monitored during the tests performed by Vižintin and Kržan (2003). The authors focused on the kinematic viscosity, additive content and oxidative stability. Based on these parameters, they evaluated the properties of the sunflower oil-base fluid UTTO with AW and EP additives. Mendoza et al. (2011) present the results of using the ecological fluid in the agricultural tractor Agria, model 9100. In operating tests, they did not notice any exceeding of limits in the physical and chemical parameters of the used oil Biogir-06. Kučera et al. (2008) evaluated the kinematic viscosity of the ecological oil NAPRO-HO. This oil did not exceed the limit viscosity value of 10% during tests.

Table 2 and Fig. 5 show an increase in the concentration of pollution particles in oil during the tractor operation. The contamination which exceeded the permitted concentrations of iron and copper was observed after completing 900 engine hours. Therefore, filtration was performed with the designed fil-

Table 2. Concentration (mg/kg) of chemical elements characterizing the mechanical contaminants

Chemical element	Time of tractor operation (engine hours)				After filtration	ΔZ (%)
	0	150	450	900		
Fe	2	37	48	88	59	32.95
Cu	1	40	59	75	70	6.66
Si	6	8	12	18	14	22.23
Al	1	1	2	6	4	33.34
Pb	3	2	7	7	7	–
Ag	2	1	2	1	1	–
Ni	< 1	< 1	< 1	1	1	–
Mn	< 1	< 1	< 1	1	< 1	–

ΔZ – decrease in chemical elements content representing pollution (%)

Table 3. Cleanliness level during the oil filtration

No.	Cleanliness level according to ISO 4406 (1999)					
	> 4 μm		> 6 μm		> 14 μm	
	ISO class	particles/0.1 dm^3	ISO class	particles/0.1 dm^3	ISO class	particles/0.1 dm^3
1	24	8,000,000	23	4,000,000	10	500–1,000
2	24	–	23	–	9	250–500
3	24	16,000,000	23	8,000,000	8	130–250

No. – measurement number

tration device. Fig. 5 shows a decrease in the concentration of major polluting chemical elements such as iron, copper and silicon after filtration.

Table 3 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 pollution occurred in three stages. They are identified in Table 3 as the measurements Nos 1, 2 and 3. Measurement results of the cleanliness level show a reduction in the largest pollution particles (> 14 μm) which are the most dangerous for transmission and hydraulic system of the tractor.

CONCLUSION

This contribution deals with the application and pollution of the ecological fluid UTTO in the transmission and hydraulic system of the tractor. Design and use of filtration devices designated to ensure a reliable operation of the ecological fluid in agricultural tractors are presented. The designed filtration system ensures a clean fluid during its operation in the tractor. The filtration device can be simply used for different types of tractors because it is connected to the implement hydraulic circuit. It can be made from the filter housing and filter element, which are available in most farms. Based on the measurements, we can conclude that the designed filtration system is suitable for cleaning ecological fluids used in tractors. The manufacturing of the filtration system is simple and affordable. Table 2 shows the progress of fluid contamination up to the limit level after completing 900 engine hours. Table 3 shows a reduction in iron up to 30% after filtering. A positive filtration effect was shown during the cleanliness level measurement, too. This was reflected in a decrease in the cleanliness level for particles larger than 14 μm in two categories.

Monitoring of oil contamination is the main parameter for filtering or change of oils in tractor hydraulic and gear system. In actual practice the high quality oils with very good physical and chemical properties are used in tractors. Therefore the oil contamination is the main indicator for filtering. The producers of oil state the limits for contamination according to oil and tractor type.

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