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RESEARCH

Filtration Systems Design for Universal Oils in Agricultural Tractors

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A B S T R A C T

Three filtration systems using the tractor hydraulic circuit were proposed and verified during the tractors operation. Using the tractor–implement hydraulic system and filter body with accessories the universally useful filtration systems were designed. The designed filtration systems are the second stage of universal oil filtration whereas the first stage is the standard tractor filter. The decrease in the content of iron reached the values 25.53 %, 32.95 % and 41.55 % and the average decrease in oil contamination characterized by average value of decrease in content of iron, copper and silicium reached values 24.3 %, 24.7 % and 35.53 % in dependence on the filtration system and an oil contamination level. The decrease in contamination level verified the ability of designed filtration systems for agricultural tractors.

1. INTRODUCTION

The paper is aimed at the design of three filtration systems for universal tractor oils used in tractors. Universal tractor oil is a multipurpose oil for the lubrication of the transmission, rear axle, differential, wet brakes, and hydraulic system fed by the common oil reservoir.

The cleanliness of oils in lubrication systems is an important prerequisite for maintaining the operating conditions of machines and equipment [1]. Oil contamination is the most common and serious source of machine failure.

Currently, the possibility of compensation of an increasing number of lubricants by ecological equivalent comes to the fore [2]. The oil contamination is very important factor affecting the application of biodegradable oils for hydraulic and transmission systems of tractors because it accelerates the process of oil ageing. [3] and [4] present the monitoring of oil contamination and another oil properties by the reason of biodegradable universal oil application in tractors.

The tests indicated that 52 % of the total losses are caused by passive resistance and friction in the transmission together with the power absorbed by the hydraulic circuit in the neutral position, 40 % by oil splashes in the transmission, 4 % by the brakes, and 4 % by the final reducers and corresponding sun wheels [5]. Universal oils lubricate all the parts of the hydraulic and transmission system and eliminate the losses of energy. On the other hand, contaminated and degraded oils cannot effectively work because physical and chemical properties affect the oil film creation. Oil contamination negatively influences the oil properties, mainly additive depletion and accelerates the wear of all lubricated parts.

The tractor universal oils can be mainly contaminated in three ways. The wear process is the first way how wear particles pollute the oil. During the tractor operation, all the parts of transmission and hydraulic system produce metal particles, generally. Operating the tractor in accordance with the operating instructions without overloads, the normal wear process should provide a scheduled durability life. The tractor is often operated in dusty, moist or else polluted ambient air, and so this is the second way of oil contamination. Tractor manufacturers are still making effort to protect the tractors from environmental influence, and so it contaminates the oil only minimally. The third way contaminates the oil through the tractor–implement hydraulic circuit, connecting the implement (trailers plough, etc.) with the tractor. Every unknown implement contains an unknown oil type with unknown contamination level. It can be concluded that tractors have to be connected only with the own implement with the same oil as in the tractor.

The elimination of oil contamination is aim of many researches, for example [6] and [7]. Contribution [8] presents that the functionality of oils suffers when contaminated with particles. Filtration can play a key role in ensuring that hydraulic and lubricating systems are running effectively.

Many research works are aimed at the extension of oil change interval using filtration, for example [9]. At present, continuation or change of the oil is decided, based on the manufacturer's recommendation and experience in the plant [10]. The suggested oil change period is conservative and results in a non-efficient usage of oil. [11] and [12] confirm this fact presenting the results of hydraulic oil analysis, which mention exceeded contamination limits, but physical and chemical properties, namely kinematic viscosity at 40 °C, total acid number and water content was situated within the required tolerance during all the time of operation. The additional filtration system can eliminate the oil contamination to protect the machine against excessive wear and provides the efficient usage of oil.

There are two solutions to improve the oil cleanliness level, namely increasing the filtration capacity by tractor manufacturer, or using the additional filtration system.

This work is aimed at propose and design of three filtration systems as the second stage of oil filtration, which can improve the efficiency of a standard tractor filtration (the first stage of oil filtration).

2. MATERIALS AND METHODS

2.1 Design of filtration systems for universal tractor transmission oils

Universal tractor transmission oils have the task of providing the function of transmission and hydraulic systems. The only one oil is operated as a lubricant in the transmission system and as a hydraulic fluid in the hydraulic system. Therefore, the oil can be cleaned using the hydraulic system which pumps it during the tractor engine operation. To increase the oil cleanliness level, we have proposed three locations of oil filters in the hydraulic system of the tractor (Fig. 1).

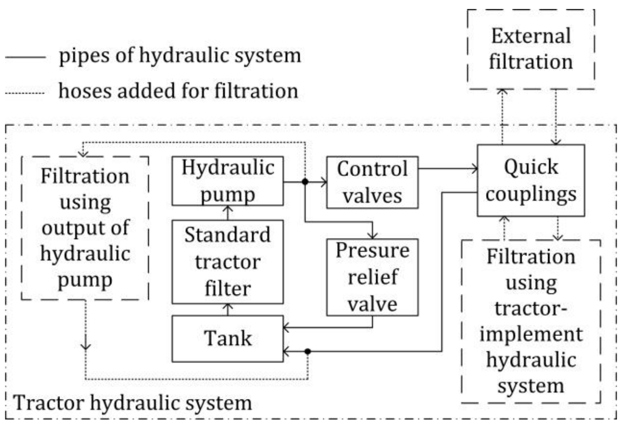

Fig. 1. Design of the three possibilities of universal tractor transmission oil filtration.

The first one (external filtration) uses a portable filtration device placed near the tractor. This filtration system does not continuously work during the tractor common operation but the oil cleaning is performed during the service break. Houses and quick couplers connect the external filtration with the tractor–implement hydraulic system. The next one named as a filtration using the output of hydraulic pump, takes the oil from the output of hydraulic pump and returns it to the tank after cleaning. This system continuously cleans the oil, because the hydraulic pump works steady during the tractor operation. The whole filtration system is mounted to the tractor. The last one is also mounted to the tractor and works continuously during the tractor operation but takes the oil from the implement hydraulic system. Therefore, it is named as the filtration using the tractor–implement hydraulic system.

2.2 Evaluation of oils properties

The main aim of this research was the design of different filtration systems suitable for agricultural tractors to improve the cleanliness level. The oil contamination was evaluated according to the concentration of chemical elements namely Fe, Cu, Si, Al, Pb, Sn and Cr. The contents of these chemical elements in oil samples were analysed by ICP spectrometry according to standard [13,14].

The interpretation of used oils analysis is very complex, because the individual analyses are interdependent. That is the reason why it is necessary to know the entire oil analysis, and not bring conclusions based on individual analysis results [15,16]. Therefore, besides the evaluation of oil cleanliness, base physical properties were evaluated, namely:

- kinematic viscosities at 40 °C and 100 °C [17],
- viscosity index [18],
- water content [19].

The oil properties were evaluated on the basis of oil samples analyses. These were done in the accredited laboratory Wearcheck (Hungary).

The oil contamination, in general terms, affects the physical and chemical properties. Eliminating the oil contamination, the oil properties can be improved due to the oil regeneration. Therefore, the base oil properties were monitored before and after the oil filtration.

2.3 Evaluation of oil filtration quality

The oil contamination and quality of oil filtration were evaluated according to the concentration of chemical elements representing the wear particles and pollution from the environment (Fe, Cu, Si, Al, Pb, Sn and Cr).

Calculating a decrease in the content of chemical elements which represent the oil contamination Δ_E [%], the quality of oil filtration was evaluated:

$$\Delta_E = \frac{E_{CO} - E_{FO}}{E_{CO}}.100 \qquad (1)$$

where: E_{CO} – content of chemical elements in contaminated oil [mg/kg], E_{FO} – content of chemical elements in filtered oil [mg/kg].

The filter element is the main part of every filtration system, made of different materials and requires correct flow rate and pressure gradient by reason of right and reliable function during the machine operation. A lagrer filter element in size is suitable for higher flow rates and allows filtering the oil fill in shorter time. On the other hand, it is more expensive and higher dimensions complicate its placement in the tractor.

The oil circulation number o [1/s] indicates how often the entire filling of oil in a centralised lubrication system's reservoir is circulated in a unit of time [20] and calculated according to the formula:

$$o = \frac{Q_f}{V} \qquad (2)$$

where: Q_f – flow rate through filtration system [dm^3/s], V – volume of universal oil in tractor [dm^3].

Using this parameter, it can be stated how many times the oil flowed through the filter element during the tractor operation with some of the proposed filtration systems. The count of oil circulation through the filtration system c can be calculated according to the formula:

$$c = o t_o \qquad (3)$$

where: o – oil circulation number [1/s], t_o – tractor operation [s].

Oil analysis consists of determination of physical and-chemical properties, contamination and wear debris analysis (WDA) [21]. The aim of this work is the detection and characterization of friction particles during the lifetime of two different universal tractor transmission oils samples.

Average decrease in oil contamination is the parameter which statistically tests the possibility of improvement the oil physical properties due to the elimination of particle contamination. This parameter (Δ_{EA} [%]) is calculated as arithmetical average of decrease in three chemical elements (Fe, Cu, Si) which most pollute the oils:

$$\Delta_{EA} = \frac{\Delta_{EFe} + \Delta_{ECu} + \Delta_{ESi}}{3} \qquad (4)$$

where: Δ_{EFe} - decrease in the content of Fe [%], Δ_{ECu} - decrease in the content of Cu [%], Δ_{ESi} - decrease in the content of Si [%].

Average decrease in oil contamination is calculated for each design of filtration system.

2.4 Oil sampling procedure and error analysis

The oil samples were taken from the inlet of designed filtration systems to state the contaminations of all oil fill in tractor. The errors of contamination evaluation can occur from the reasons of the homogeneity of oil fill. To eliminate this measurement error the oils were sampled during the tractor operation after the heating at operation temperature. The oil fill is homogenized immediately after this procedure because it flows through the transmission system which intensively mixed oil fill. Oil sampling were realised by the minimess test point with dust cap again the contamination from environment. It was allowed at least 200 ml of fluid to flow off. Only then bring the sample bottle into position to collect liquid, after the initial drain-off. We used the standard sampling bottles with 150 ml volume from accredited laboratory Wearcheck. The accuracy of parameters analysed from oil samples is stated in standards of the test methods.

Taking the oil samples without the designed filtration system before its application and after the tractor operation with the filtration system, functions were tested and verified. Using this sampling methodology and equation (1) the designs were evaluated.

2.5 Characteristics of oils used for filtration in tractors

Universal tractor transmission oils are designed for hydraulic and transmission systems of agricultural tractors. These fluids provide lubrication functions in the gear box and the transmission of energy in the hydraulic system of the tractor. Besides the energy transfer, universal oils must lubricate, dissipate heat, and they must be compatible with sealing materials and metal components of the system. The universal tractor transmission oils used in observed tractors are Shell Donax 5W30 [22] and Mol Farm Utto Synt [23]. In one of the tractors, the PP 90 oil type [24] was used.

3. RESULTS AND DISCUSSION

3.2 External filtration

The external filtration uses the tractor–implement hydraulic circuit (Fig. 2).

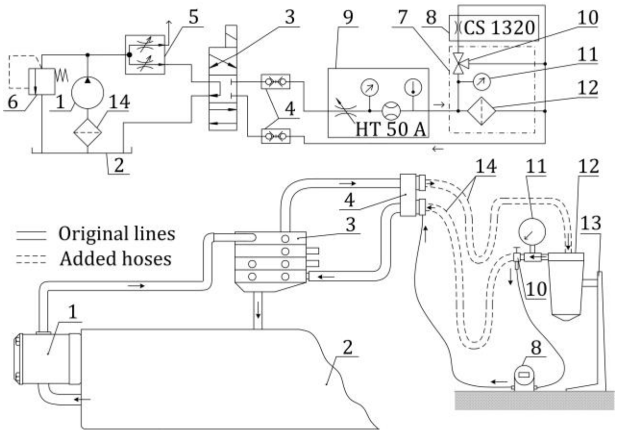

Fig. 2. Hydraulic scheme and draft external filtration: 1 – hydraulic pump, 2 – oil tank, 3 – control valves block, 4 – quick couplers, 5 – priority valve, 6 – relief pressure valve, 7 – external filtration, 8 – contamination sensor (CS 1320), 9 – measuring device (HT 50A), 10 – three way valve, 11 – pressure gauge, 12 – filter body with filter element (FS 02 type), 13 – support stand, 14 – standard filter.

The base parts of this filtration system (7) are a filter body (12) with a filter element. The paper filter element H 1169/2 type (Mann+Hummel, Germany) with 10 micron of nominal micron rating was used. Installing the filter body of FS

02 type (Kovolis Hedvikov, a. s., Czech Republic) with fittings, three way valve (10) and pressure gauge (11) on the support stand (13), the filtration system was designed. This type of the filter body requires a low-pressure (up to 0.2 MPa) during the filtration. Using a measuring device (9) HT 50 A (XPS Corporation, USA), a maximum value of the flow rate (0.2 dm^3 s^{-1}) was set to limit a maximum pressure. A flow control valve of the measuring device allows the hydraulic heating of oil fill before filtration. This measuring device was used also by [25,26] for the measurement of the universal oil flow rate through tractor–implement hydraulic system and a hydraulic heat of the tractor oil fill before the measurement.

Zetor Forterra 114 41 tractor was used to test the external filtration. Using a contamination sensor (8) CS 1320 (Hydac Ltd., Germany), a cleanliness level according to standard [27] was monitored during the test of external filtration. The three way valve passes only small volume of the oil through the contamination sensor to evaluate filtration efficiency. Phillips and Staniewski [28] also used the cleanliness code [27] to quantify the presence of fine particulate in hydraulic fluid. There are a lot of systems for measurement of cleanliness level. Rusnák et al. [29] successfully used the same type of contamination sensor to state the cleanliness level of universal oil for agricultural tractors.

Considering the oil flow (0.2 dm^3/s) through the external filtration and the volume of oil fill (56 dm^3), the oil circulation number o = 0.0035 1/s was calculated according to Eq. (2). Using Eq. (3), the count of oil circulation through the filtration system c = 2 was calculated during approximately 10 min of oil filtration. One filtering of the whole oil fill (in our case 56 dm^3) took about 5 min. After the second oil circulation through external filtration, the cleanliness level (measured by a contamination sensor CS 1320) stayed on the same level. Felix et al. [30] achieved similar results from hydraulic oil filtration using the 10 μm filter during a field test of a 22 t excavator. After oil heating, initial ISO cleanliness code (24/23/12) was measured. In between the second and third filter periods, the ISO cleanliness code dropped down to the level 24/23/10. The count of largest contamination particles decreased during the filtration of oil in this way. These particles are most dangerous for the hydraulic and transmission oil in tractor. Decrease in oil contamination was also verified by measurement of chemical element concentration represented contamination according to ICP spectrometry (Fig. 3).

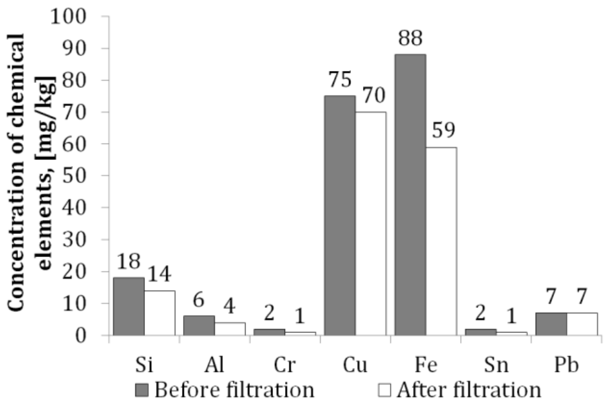

Fig. 3. Concentration of chemical elements before and after the external filtration test.

Lee et al. [31] also cleaned the universal tractor transmission oil using external filtration equipment. The gears pump in the external filtration equipment intakes the fluid through the drain port at the bottom of the oil tank and discharges to the cleansing filter for flushing. The oil passing through the cleansing filter re-circulates into the oil tank. A diagnostic sampling valve was installed near to the drain port of oil tank, and a contamination sensor was used to measure the particle concentration in sample fluid. In contrast with this method, we used the oil flow from the tractor–implement hydraulic system without the need of external pump to make the design of external filtration simpler.

Table 1. Properties of the new oil (Mol Farm Utto Synt), before and after external filtration test.

Parameter	Unit	New oil	Before filtration	After filtration
Total tractor operation	Running hour	0	900	950
Time of oil filtration		0	50	
Kinematic viscosity at 40 °C	mm^2/s	58	54	54
Kinematic viscosity at 100 °C	mm^2/s	10.22	8.8	8.7
Viscosity index	-	165	141	138
Water content	ppm	N*	N*	N*

* Non-measurable value

Using the Eq. (1) and parameters shown in Fig. 4, the oil contamination after filtration was evaluated. The decrease in chemical elements content representing contamination reached the values 32.95 % (Fe), 33.33 % (Si), and 6.66 (Cu). The content of Pb stayed at the same level after filtration. Al, Sn and Cr represent an inessential content of contamination.

The design of external filtration system was applied for the Zetor Forterra 114 41 type with oil Mol Farm Utto Synt type (Table 1). In case of kinematic viscosity at 40 °C the change reached the value only 6.8 % and didn't exceed the limit value. The oil properties exceed the limits value (10 %) in kinematic viscosity 100 °C (13.89 %). The limit was exceeding also in case of concentration of chemical elements represented the oil contamination (Fig. 3).

3.3 Filtration using tractor-implement hydraulic system

The design of filtration system using the tractor–implement hydraulic system is shown in Fig. 5. The filter body (8) type FT-B68 (Filtration technology s.r.o, Czech Republic) and filter element FT-V68 type (Filtration technology, Czech Republic) with 1 micron of nominal micron rating use the oil from the tractor–implement hydraulic system by means of hoses (13) and the quick couplers (7 and 10). Using this filtration system, the tractor–implement hydraulic system can be standardly used for tractor implement because T-fittings with quick couplers do not block it. The filter body is equipped with the filter element with 1 μm filtration capacity and allows absorbing 0.5 dm^3 of water, in contrast to standard tractor filter (8). Maximum oil flow through the filer body is 1.5 dm^3/min and therefore the tractor operator has to set the right value of oil flow after the tractor start. The maximum oil pressure is 30 MPa is higher than maximum pressure in tractor–implement hydraulic system of standard tractors. Using this filtration system, the operation of tractor implements is not affected because the tractor maximum pressure is not reduced and oil flow rate is decreased only minimally. The flow control valve (15) is a part of filter body and protects the filtration system against the high pressure (up 30 MPa) due to high value of flow rate. Therefore this filtration system is suitable only for the tractors with variable displacement hydraulic pump which allows setting the correct value of oil flow rate.

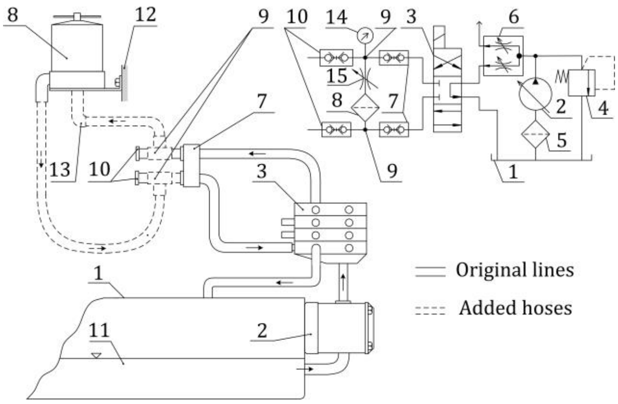

Fig. 4. Hydraulic scheme and draft filtration using the tractor–implement hydraulic system: 1 – oil tank, 2 – tractor variable displacement pump, 3 – control valves block, 4 – relief pressure valve, 5 – standard filter, 6 – priority valve, 7 – tractor quick couplers, 8 – filter body with filter element (FT-B68 type), 9 – T-fitting, 10 – added quick couples, 11 – oil, 12 – console, 13 – hoses, 14 – pressure gauge, 15 – throttle valve.

The filtration device was designed for John Deere 8100 tractor with Shell Donax 5W30 oil. This tractor has a variable displacement hydraulic pump. Therefore, it allows mounting the filtration device to the external hydraulic circuit. This hydraulic pump allows setting the minimal flow rate (0.5 dm^3/min) through the filter system. Using this value and the value 118 dm^3 of universal oil volume in the tractor, the oil circulation number o = 0.0007 1/s was calculated according to Eq. (2). The count of oil circulation through the filtration system c = 37.8 was calculated according to Eq. (3) during 150 running hours of tractor operation with oil filtration.

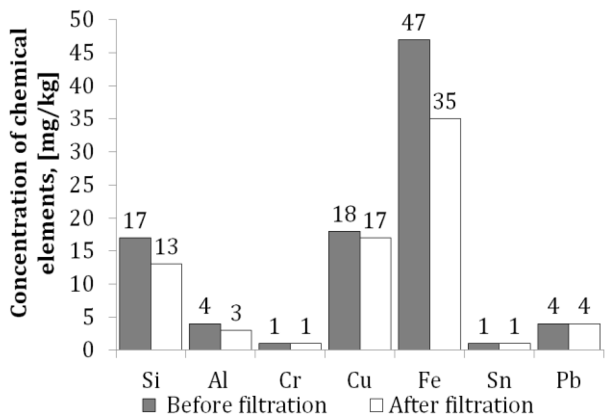

Fig. 5. Concentration of chemical elements before and after filtration using the tractor–implement hydraulic system.

The decrease in the chemical elements content (Fig. 6) representing contamination was calculated according to Eq. (1) and reached the values 25.53 % (Fe), 25 % (Al), 23.53 % (Si), and 5.55 % (Cu). The content of Cr, Sn and Pb stayed at the same level after filtration.

Table 2. Properties of new oil (Shell Donax 5W30), before and after filtration using the output of hydraulic pump.

Parameter	Unit	New oil	Before filtration	After filtration
Total tractor operation	Running hour	0	1900	2050
Time of oil filtration	Running hour	0	150	
Kinematic viscosity at 40 °C	mm²/s	38	41	40
Kinematic viscosity at 100 °C	mm²/s	7.1	6.8	6.8
Viscosity index	-	151	123	127
Water content	ppm	N*	N*	N*

* Non-measurable value

The filtration system was applied in tractor John Deere 8100 tractor with a Shell Donax 5W30 universal oil type. The contamination concentration (Fig. 5) and the physical properties (Table 2) hint as excellent technical condition of oil after 1,900 running hours (shortly before prescribed oil change after 2,000 running hours). Tractors operated in this way can work during the long technical life without an abnormal wear process and risk of catastrophic failure. Concretely, this tractor is operating almost 13,000 running hours without problems mentioned above.

Kosiba et al. [32] evaluated the oil properties and oil contamination of a Shell Spirax S4 universal oil in the hydraulic and transmission system of a John Deere 5720 tractor. This tractor is also equipped with automatic transmission and it is very sensitive to oil contamination. Therefore, the tractor owner pays high attention to oil cleanliness. During the tractor operation, the content of iron (49.63 mg/kg), copper (20.47 mg/kg) and aluminium (3.41 mg/kg) reached the values similar to a John Deere 8100 tractor.

In case of this tractor (John Deere 8100), a difference in kinematic viscosity at 40 °C reached the value 7.3 % and at 100 °C the value 4.2 %. Both differences did not exceed the limit value 10 %.

3.4 Filtration using the output of hydraulic pump

This filtration system (Fig. 6) was used in the new type of tractor Zetor Forterra 124 41.

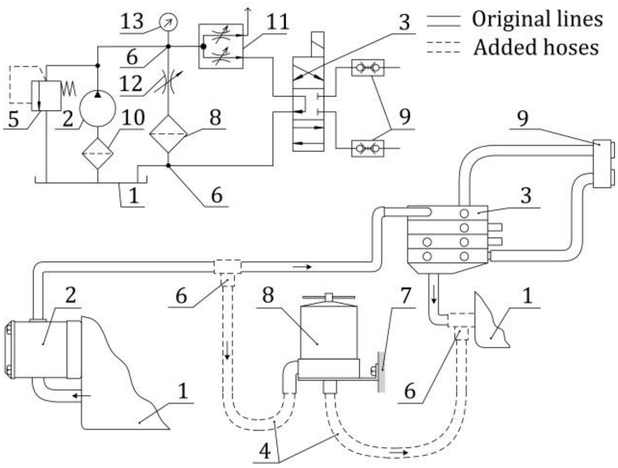

Fig. 6. Hydraulic scheme and draft filtration using the output of hydraulic pump: 1 – tank, 2 – tractor hydraulic pump, 3 – control valve block, 4 – hoses, 5 – pressure relief valve, 6 – T-fitting, 7 – console, 8 – filter body with filter element, 9 – quick couplers, 10 – standard filter, 11 – priority valve, 12 – throttle valve, 13 – pressure gauge.

The fittings of hydraulic lines were replaced by T-fittings (6) which allows dividing the oil flow between original hydraulic line and hoses (4) to the filter body (8) FT-B68 (Filtration technology s.r.o, Czech Republic) and filter element FT-V68 type (Filtration technology, Czech Republic) with 1 micron of nominal micron rating. The hoses allow a flexible connection of the filtration system to the tractor hydraulic circuit. The hydraulic pump (2) works immediately after tractor engine start. The universal oil is pumped from the hydraulic pump (2) to the filter (8) and filtered after tractor engine start. The filtered oil returns to the oil tank (1) through one of the T-fitting (6) and return line of hydraulic circuit. The filter body with filter element was installed on the left tractor frame using a console (7) and considering the space for rotation of driving wheels of tractor. Therefore, a tractor operator can visually check the technical condition of filtration system when he gets on a tractor cabin. Using a throttle valve (12) and pressure gauge (13) the maximum flow rate (0.5 dm³/min) through the filter body was set.

The oil circulation number o = 0.0089 1/s was calculated according to Eq. (2) using the oil fill volume (56 dm^3) and the flow rate (0.5 dm^3/min). The count of oil circulation through the filtration system c = 107 was calculated according to Eq. (3) during 201 running hours of tractor operation with oil filtration.

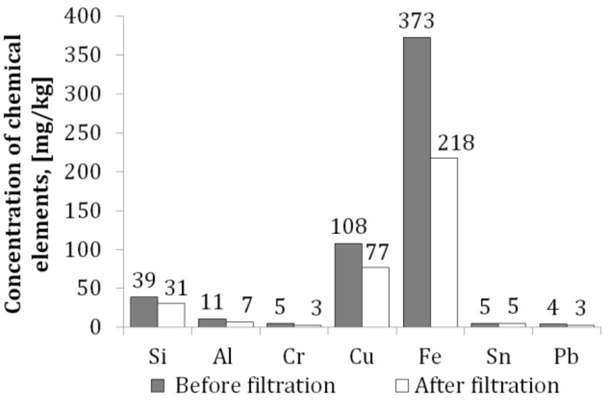

Fig. 7. Concentration of chemical elements before and after filtration using the output of hydraulic pump.

During the tractor operation with filtration using the output of hydraulic pump, the decrease in the chemical elements content (Fig. 8) representing contamination reached the values 41.55 % (Fe), 36.36 % (Al), 28.7 % (Cu) and 20.51 % (Si). The content of Cr, Sn and Pb reached an inessential content of contamination.

Table 3. Properties of new oil (PP 90), before and after filtration using the output of hydraulic pump.

Parameter	Unit	New oil	Before filtration	After filtration
Total tractor operation	Running hour	0	1889	2100
Time of oil filtration		0	201	
Kinematic viscosity at 40 °C	mm^2/s	172	124	123
Kinematic viscosity at 100 °C	mm^2/s	15.6	12.5	12.7
Viscosity index	-	92	91	95
Water content	ppm	N*	N*	N*

* Non-measurable value

A Zetor Forterra 124 41 tractor with a PP 90 oil was used for the design of filtration using the output of hydraulic pump. The oil was strongly contaminated which an extreme content of iron (373 mg/kg) and copper (108 mg/kg) as demonstrated in Fig. 7. Such contaminated oil is not able to work correctly in the tractor for a long time. In this tractor, the low–quality oil was used instead of required universal oil type. [33] observed the same type of oil (PP 90) in Zetor 121 45 tractor with the same transmission and hydraulic system. In this tractor, kinematic viscosity as well as the oil contamination did not exceed the limits. This is a verification of the fact that the right tractor operation mode significantly influences the cleanliness level and quality of the oil. This state was caused by using different and unknown equipment types and origin (trailers, ploughs, etc.) with the old and degraded oils of unknown types which are mixed with the tractor oil fill, resulting in a strong oil contamination.

The difference in kinematic viscosity at 40 °C reached the value 27.9 % and at 100 °C the value 19.8 % in case of this tractor (Table 3). Therefore the kinematic viscosities of oil in the tractor operated this way exceed the limit value 10 %.

3.5 Design of filtration systems for tractors

The three filtration systems namely external filtration, filtration using the tractor–implement hydraulic system and filtration using the output of hydraulic pump, were proposed. The function of designs was verified during the agricultural tractors operation. The filtration systems were designed as the second stage of filtration in the tractor. The tractor manufacturer standardly mounts the filters of first stage filtration. These have a filter ability of 15 micron to 20 micron depending on the tractor type in contrast to higher filter ability of proposed filtration systems. Fig. 9 shows the three filtration systems during the test under tractors operation.

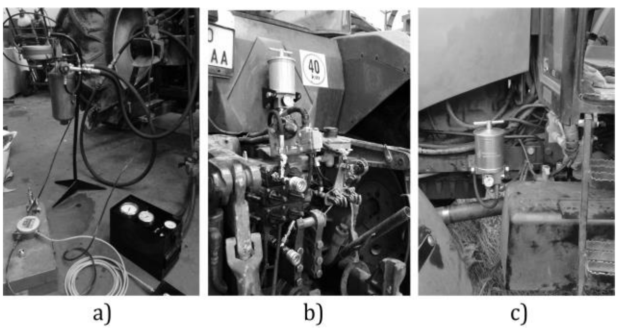

Fig. 8. Three filtration system types: a)external filtration, b) filtration using the tractor–implement hydraulic system, c) filtration using the output of hydraulic pump.

An important measure appears external purification in addition to operating filtration. This method has higher order in terms of separation ability in comparison to the capability of operational filtration [34]. Presenting the results of our research the standard operating filtration used in tractors can be improved using one of the filtration systems proposed in this paper. The hydraulic, transmission or engine oil filtration of machines is complicated and expensive in many cases, compared with the filtration systems designed for tractors. Using the tractor–implement hydraulic system and simple placement of filter body the universally useful filtration systems were designed.

The authors [35] tested a fine hydraulic filter for aircraft hydraulic systems and describe the development and design of a 10 micron hydraulic filter operating at a low pressure with a flow of 40 dm^3/min. In case of the agricultural tractor presented in our work, the three designs of filtration systems are presented to improve the cleanliness level of universal oil using the fine filters. The first of them (the external filtration) uses the 10 micron filter element, the second one (filtration using the tractor–implement hydraulic system) and third one (filtration using the output of hydraulic pump) use the 1 micron filter element.

The external filtration is the system cleaning the tractor oils discontinuously because it is an external device connected to the tractor only during the downtime. The oil is not filtered continuously during the tractor operation. The advantage is the universally use for each tractor type because don't require the oil flow rate setting by tractor hydraulic system. The throttle valve limits the maximum flow rate and also pressure thru this system. The external filtration is very simply solution to improve the cleanliness level of universal tractor oil.

The filtration using the output of hydraulic pump cleans the oil continuously during the tractor operation because it is placed in tractor hydraulic system. The tractor operator doesn't have to pay any attention to the filtration which starts immediately after the tractor start. The main disadvantage is the disassembly of tractor hydraulic system to connect the filtration system to the output of the hydraulic pump.

Filtration using the tractor–implement hydraulic system combines the advantages of systems mentioned above. It is simply connected to the tractor through quick couplings and works continuously during the tractor operation. The disadvantage is the need for tractor hydraulic pump with flow rate regulation to limit the maximum value through filtration system. This feature is only relative disadvantage because it can be predicted that all tractors will be equipped with this possibility in the near future. The relative disadvantage is also the start of filtration by the tractor operator who has to activate the oil flow through tractor implement hydraulic system.

The problem of all designed filtration systems is the filter element saturation in case of extreme oil contamination. The designed filtration systems are suitable for all tractors, but the higher level of oil contamination causes worse oil cleaning efficiency. [28] confirm the fact that changing the existing filters to a smaller pore size and/or higher filtration efficiency is not usually an option as very small particles blind filters more rapidly, requiring their more frequent replacement. In contrast to the fact mentioned above, the designed filtration systems are the second stage of oil filtration. The first stage of oil filtration is standard tractor oil filters which protect the fine filters of the second stage.

The oil filter system of agricultural tractors can be improved according to the following steps: to provide as much filter capacity as economically possible; to increase the filter flow rate; to isolate the pumps from the sources of contaminants [36]. The improvement of filtration system was the main goal of our research, too. The designed filtration systems improved the filtration capacity, but only with minimal tractor hydraulic system modification. This is one of the advantages of designed filtration systems, namely the improvement of oil cleanliness, universal usage for various tractor types, and a need for minimal tractor modification.

3.6 Physical properties of oils in tractors during the filtration

Oil analyses consist of determination of physical and properties, contamination and wear debris analysis (WDA), [37]. The aim of their work is the detection and characterization of friction particles during the lifetime of two different universal tractor transmission oils samples. Eissa et al. [38] also evaluated the viscosity degradation of oil in agricultural machines.

The contamination affects the physical properties of oils. All three oils show the change in their properties during the operation in tractors. The average decrease in contamination (equation 4) reached values 24.3 % for the external filtration, 24.7 % for the filtration using the tractor–implement hydraulic system and 35.53 % for the filtration using the output of hydraulic pump. The only negligible or no changes in oil physical properties after oil filtration were observed (Table 1, 2 and 3). It can be stated that achieved decrease in particle contamination does not influence the physical oil properties.

The results of Hnilicová et al. [11] show that water content considerably affects the most of oil properties. In case of all three tractors, the non-measurable value of water content (Table 1, 2 and 3) is typical for most tractors because the transmission and hydraulic system is well protected against the water from the environment, and liquefied water from ambient air represents only a negligible volume regarding the high volume oil fill.

4. CONCLUSION

The paper presents the design of three filtration systems, namely external filtration, filtration using the tractor–implement hydraulic system, and filtration using the output of hydraulic pump. The function of all designs was verified during the operation in agricultural tractors. During the operation of designed filtration systems the decrease in the content of chemical elements which represent the oil contamination was observed. Therefore, the designed filtration systems were tested to verify a function of the designs.

The reached value of contamination elimination expressed by average decrease in contamination didn't affect the physical properties. This fact was tested with oils in three tractors using the designed filtration systems.

Operating the tractor in accordance with operating service instructions and using one of the filtration systems, the universal tractor transmission oil can reach the high cleanliness level which may help to improve the tractor durability. The high cleanliness level is one of the base conditions for application of biodegradable universal oils in agricultural tractors. The future research will be aimed at prolongation of oil change interval to use the oil fill more effectively, reduce the oil costs and protect the environment.

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