DOI: 10.2478/ata-2020-0008

Acta Technologica Agriculturae 1
Nitra, Slovaca Universitas Agriculturae Nitriae, 2020, pp. 46–52

MONITORING OF SELECTED PHYSICAL AND CHEMICAL PARAMETERS OF TEST OIL IN THE WET DISC BRAKE SYSTEM

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Paper presented is focused on the operating measurements of a tractor wet disc brake system. Operating measurements were evaluated after tractor's operation at 500 Mth on the 3rd, 4th and 5th gear. Reference fluid and ecological fluid were tested during operation. In addition, work results include the evaluation of the fluid samples taken during the operational tests to monitor the tractor braking performance with wet disc brakes. Fluid samples were also tested in order to determine the changes in their physico-chemical properties. Chemical analysis was performed for both oil samples by means of X-ray fluorescence analysis according to the DIN 51829 and DIN 51399-2. Observed physical properties of the tested oils – density, viscosity, acid number, water content – were within the appropriate ranges after the end of test. Further analysis was focused on an amount of abrasive metals, contaminants, additives, and other important elements. On the basis of analyses conducted, it can be concluded that majority of elements preserved their original level showed at the 0 reference hour sample. In terms of the abrasion metals, an increase in their presence was not found. Furthermore, analysis of the physical properties of tested fluids did not prove their negative impact on the tractor wet disc brake system. Results of the operating measurements suggest that neither the applied conference fluid nor the ecological fluid showed negative effect on the minimum braking value. The minimum braking deceleration was implemented in accordance with the Law no. 106/2018.

Keywords: agricultural tractor; deceleration; ecological oil; physical analysis, chemical analysis

Agricultural technology has a negative impact on all elements of the environment (Kučera et al., 2016). The ever-increasing number of mobile transport devices causes air pollution and soil and water contamination with pollutants that burden the environment. It was reported that more than 60% of all lubricants end up in soil and water (Majdan et al., 2013). Together with oil and lubricant manufacturers, producers of mobile transport devices develop special products that are environmentally friendly. Application of suitable ecological oils significantly reduces the damages to the environment, sewer network and communications in case of oil leakage (Janoško et al., 2014; 2010).

Environmental protection has been topical for several years, and it becomes a preferred issue in the established trend of economic development (Majdan et al., 2018; Tóth et al., 2014; Kosiba et al., 2013). According to Janoško et al. (2016) and Čedík et al. (2018), ecological technologies and corresponding technique will become an essential part of everyday life. In addition to acceleration, there is deceleration – braking with specific type of braking system – during the movement of mobile energetic devices. Kamiński and Czaban (2012) stated that an efficient vehicle breaking system is necessary for road safety and in regards to road safety, the braking system of agricultural vehicles has to meet several requirements, including the required braking performance.

One type of brake systems that use oil fillings is called wet disc brake. Friction elements and applied oil fillings are important parts of wet disc brakes (Jablonický et al., 2019). According to Mang et al. (2010), friction is a passive resistance with the opposite direction of action as the relative movement of the friction surfaces. Merely the oil filling in disc wet brake influences the durability of friction elements, as well as the heat dissipation and factors associated with brake efficiency. As it was reported by Tkáč et al. (2014), in practice, mineral oils, synthetic fluids and ecological fluids are the most used for the purposes of gear lubrication and energy transfer. According to Hujo (2017), Hujo et al. (2015), Tulík (2013), Dostál et al. (2019), Hlaváč et al. (2019), the viscosity, viscosity index, stability, oxidation, compressibility and shear stability are key physical properties of fluid in terms of lubrication and energy transfer. The viscosity may decrease or increase during the oil utilization. Helebrant et al. (2001) reported that an increase in viscosity may be caused mainly by oxidation of products or oil contamination. On the contrary, its decrease is mainly caused by mechanical and thermal degradation of the additives. In relation to viscosity, Stopka (2018) pointed out that low viscosity in oils provides a thin lubricating film, resulting in limited lubrication conditions. This leads to metal-to-metal contact and damage of the system components. When two moving metal surfaces get into contact due to insufficient lubrication, excessive wear can occur due to cold

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welding and thus damage of the components. Aim of this paper was to provide the operating measurement of the wet braking system of tractor Zetor Super 5321. Furthermore, a reference oil sample and ecological oil were also tested. The results were compared in accordance with the established methodological procedure. Subsequently, the braking effect of the tractor's wet disc brakes was evaluated, and the physical properties of the oil fillings used were tested. Testing of these oils was to demonstrate whether it is possible to fully replace the reference oil sample with ecological oil and what impact the wet brakes have on the tractor in terms of the degradation processes in the tested oils.

Material and methods

Characteristics of the reference fluid

The reference fluid was mineral oil with additives for increasing of the load-carrying of lubricating film. Basic parameters of the reference fluid are shown in Table 1. It guarantees good lubrication properties, high resistance to oxidation and high load-carrying capacity. The reference fluid is intended for lubrication of mechanical transmissions in vehicles and drive axles requiring properties like SAE 80W – 90 with performance level API GL. It is intended for lubrication of vehicles working under demanding operational conditions and suitable for lubrication of mechanical gearboxes and axle drives of vehicles and trucks, construction machines, agricultural machinery, and other gear applications.

Table 1 Basic parameters of the reference fluid

Properties	Units	Values
Density at 40 °C	$kg \cdot m^{-3}$	878
Kinematic viscosity at 40 °C	$mm^2 \cdot s^{-1}$	146
Kinematic viscosity at 100 °C	$mm^2 \cdot s^{-1}$	15
Viscosity index	–	103
Freezing point	°C	-27

Characteristics of the ecological fluid

Ecological fluid was ecological universal synthetic tractor oil. Basic parameters of the ecological fluid are shown in Table 2. It is intended for manual gearboxes, axle drives transmission and gear power take-off shafts, steering gears, hydraulic systems of tractors and their equipment, wet brakes, clutches and hydrodynamic gears.

Table 2 Basic parameters of the ecological fluid*

Properties	Units	Values
Density at 40 °C	$kg \cdot m^{-3}$	899
Kinematic viscosity at 40 °C	$mm^2 \cdot s^{-1}$	80
Kinematic viscosity at 100 °C	$mm^2 \cdot s^{-1}$	15
Viscosity index	–	202
Freezing point	°C	-48

* The physico-chemical analysis was carried out in accredited laboratory of Klüber Lubrication

Methodology of service brake measurement

The service brake was controlled according to the Methodological Instruction of the Slovak Republic Act. No 106/2018, which states the inspection operations related to the vehicle braking system. The measurement purpose was to determine the maximum deceleration of the tractor's oil brakes. Under the prescribed conditions, the tractor-type vehicle must be capable of achieving the minimum braking effect prescribed by the brake deceleration (z_{min}). Evaluation of the set of measured values on the basis of the service brake measurement on the tractor Zetor 5321 was performed by means of mathematical and statistical analysis and software STATISTICA version 12. Mathematical and statistical data for oils fillings included:

- determination of the number of required experiment repetitions;
- extreme value test;
- conformity test of the sample with constant;
- conformity test of the sample – Pearson χ^2 test;
- determination of hypotheses to assess the impact of tested oils on the system of wet disc brakes.

Values of braking deceleration were monitored by XL-meter. The XL-meter measures with accuracy of ±1%. The expanded uncertainty for XL-meter was determined for expansion coefficient $k = 2$ with 95% probability. Statistical methods were considered with a significance level $\alpha = 0.05$.

For a comprehensive assessment of the test oil and for the purpose of assessing the effect of ecological oil on the service brake efficiency, the measurements were performed after operation at 500 Mth with three gears engaged.

Therefore, the value of deceleration was monitored during sequential shifting of the 3rd, 4th and 5th gears in the Zetor Super 5321 tractor. As a brake oil filling, the reference oil filling was used, which was replaced by ecological fluid on the service interval.

On the basis of reference measurements of the braking effect of the service brake with the original oil filling, it was possible to make comparisons with data obtained from ecological oil filling measurements.

Considering the 3rd and 4th gears, the tractor did not exceed 25 $km \cdot h^{-1}$ and thus the deceleration results were compared with the minimum deceleration $z_{min} = 23\%$.

By shifting to the 5th gear, according to the manufacturer, Zetor Super 5321 achieves a maximum speed of 30 $km \cdot h^{-1}$; therefore, the deceleration results were compared with a minimum deceleration of $z_{min} = 28\%$.

Sampling of the tested hydraulic fluid was performed in accordance with the standard STN 65 6207. After the operational test, the physical properties and chemical analyses of the tested oils were evaluated. The evaluation focused on changes in the amount of water content, total acid number, density and kinematic viscosity after operation at 0, 250 and 500 Mth. Oil viscosity and density measurements were performed by means of the Stabinger viscometer "Anton Paar" STN EN 16896. The total acid number (TAN) is used to determine the quantity of acidic components in the oil sample. Specification of changes in TAN was performed according to the ASTM D644 A. The water content in oils was measured according to Karl Fischer titration (KF). Monitoring of chemical elements in the tested oils was performed by means of X-ray fluorescence analysis according to DIN 51829 and DIN 51399-2. The physico-chemical analysis was carried out at accredited laboratory of Klüber Lubrication by means of test devices that are regularly calibrated and have the required measurement accuracy.

Results and discussion

Values of minimum braking deceleration using reference fluid

On the basis of achieved results, it can be stated that the minimum values of deceleration at 500 Mth given by the legislation were exceed by 2.70% at the 3rd gear and by 10% at the 4th gear. With the 5th gear engaged, the tractor exceeds the deceleration value determined by the legislation by 6.50%. The average results of three consecutive measurements at each gear after 500 Mth are shown in Table 3.

Values of minimum deceleration using ecological fluid

On the basis of obtained results shown in Table 4, it can be stated that, in contrast to deceleration values specified by legislation, the minimum deceleration values after 500 Mth were exceed by 9.60% at the 3rd gear and by 9.10% at the 4th gear. Considering the 5th gear, the tractor exceeded the minimum deceleration value by 1.35%. The average results of three consecutive measurements at each gear after 500 Mth are shown in Table 4.

Values of braking deceleration were measured at 0; 250; and 500 Mth; however, paper presented takes into account only braking deceleration values at 500 Mth, because the oil change interval of tractor Zetor 5321 is 500 Mth.

In relation to the physico-chemical analyses of reference and ecological oil, oils samples were taken at 0; 250; and 500 Mth in order to determine trends and potential oil degradation.

Average braking deceleration was calculated on the basis of EHK Regulation no. 13 as follows:

$$MFDD = \frac{v_b^2 - v_e^2}{25.92(s_e - s_b)} \quad \text{m·s}^{-2} \qquad (1)$$

where:

v_o – initial vehicle speed, km·h^{-1}
v_b – vehicle speed at 0.8 v_0, km·h^{-1}
v_e – vehicle speed at 0.1 v_0, km·h^{-1}
s_b – distance travelled between v_0 and v_b, m
s_e – distance travelled between v_0 and v_e, m

Evaluation and analysis of physical properties of tested oils – changes in density at 40 °C and 100 °C

Fig. 1 shows the course of the density of tested oils at 40 °C depending on the tractor hours worked; Fig. 3 shows the course of the density of tested oils at 100 °C depending on the tractor hours worked.

Evaluation and analysis of physical properties of tested oils – kinematic viscosity change

The values of kinematic viscosity (Figs. 2 and 4) are translated by linear function. For the reference sample, linear function of kinematic viscosity at 40 °C can be calculated using Eq. 2 and at 100 °C using Eq. 3:

$$v_{40} = -0.0237t + 145.28 \quad \text{mm}^2\text{·s}^{-1} \qquad (2)$$

$$v_{100} = -0.0045t + 15.154 \quad \text{mm}^2\text{·s}^{-1} \qquad (3)$$

where:

t – number of tractor hours worked, Mth

Table 3 Measured values of the braking deceleration using reference

	3rd gear	4th gear	5th gear	Units
Braking path, s_0	3.59	5.12	11.26	m
Initial speed, v_0	12.11	19.52	29.94	km·h^{-1}
Braking time, T_{br}	1.75	1.81	3.30	s
Braking deceleration, *MFDD*	2.52	3.24	3.39	m·s^{-2}
Deceleration, z	25.70	33.00	34.50	%

* *MFDD* – average values of braking deceleration

Table 4 Measured values of the braking deceleration using ecological oil

	3rd gear	4th gear	5th gear	Units
Braking path, s_0	2.50	6.67	18.10	m
Initial speed, v_0	12.47	19.96	29.97	km·h^{-1}
Braking time, T_{br}	1.30	2.10	3.26	s
Braking deceleration, *MFDD*	3.20	3.15	2.88	m·s^{-2}
Deceleration, z	32.60	32.10	29.35	%

* *MFDD* – average values of braking deceleration

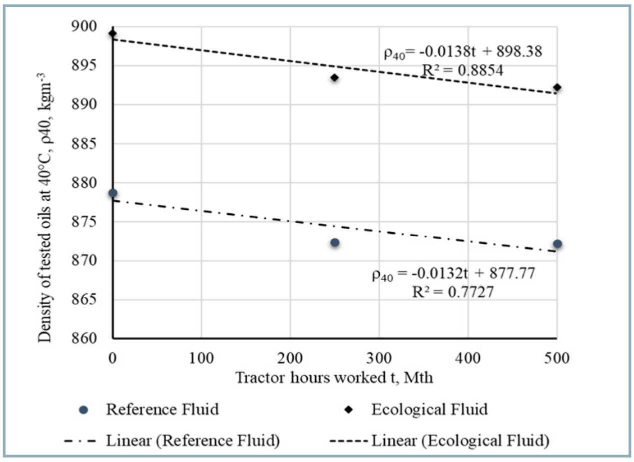

Fig. 1 Density course of tested fluids at 40 °C depending on the number of tractor hours worked

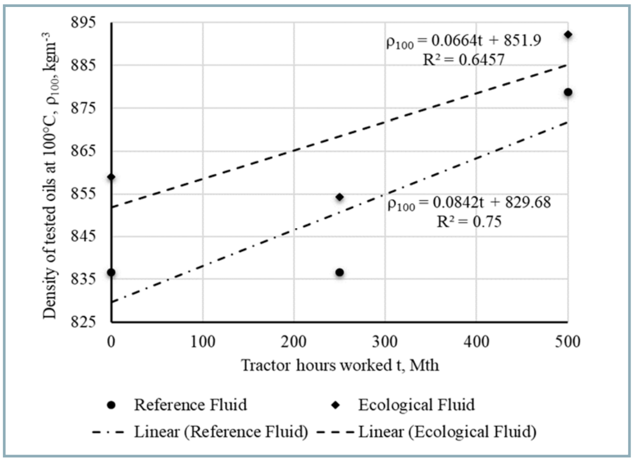

Fig. 3 Density course of tested fluids at 100 °C depending on the number of tractor hours worked

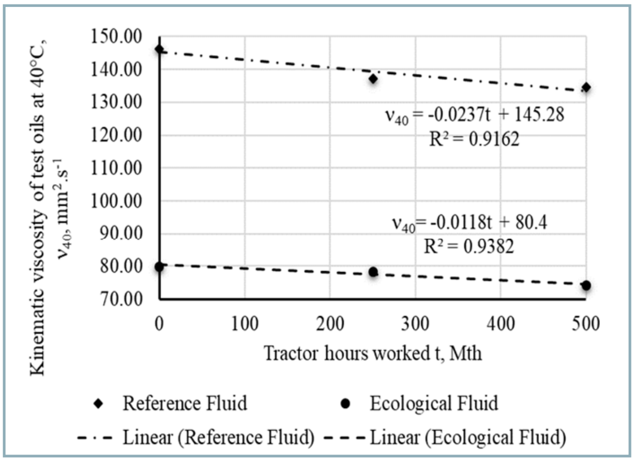

Fig. 2 Kinematic viscosity course of tested fluids at 40 °C depending on the number of tractor hours worked

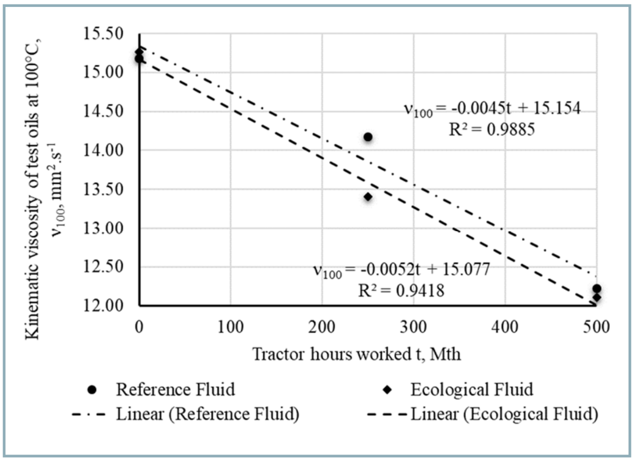

Fig. 4 Kinematic viscosity course of tested fluids at 100 °C depending on the number of tractor hours worked

For the ecological sample, linear function of kinematic viscosity at 40 °C can be calculated by means of Eq. 4 and at 100 °C by means of Eq. 5:

$$v_{40} = -0.0118t + 80.4 \quad mm^2 \cdot s^{-1} \qquad (4)$$

$$v_{100} = -0052t + 15.077 \quad mm^2 \cdot s^{-1} \qquad (5):$$

where:
t – number of tractor hours worked, Mth

The course of viscosity at 100 °C is due to the activation of specific elements, which are contained in the organic oil, caused by increased temperature.

Evaluation and analysis of physical properties of tested oils – acid number change

Fig. 5 shows the dependence of the acid number of tested oils on the number of tractor hours worked. The values of acid number are translated by linear function. Linear function of acid number for the reference sample can be calculated by equation Eq. 6, and by Eq. 7 for the ecological fluid:

$$tan = -0.0004t + 0.36 \quad mm^2 \cdot s^{-1} \qquad (6)$$

$$tan = -0.0002t + 0.5667 \quad mm^2 \cdot s^{-1} \qquad (7)$$

where:
t – number of tractor hours worked, Mth

For the purpose of observation of changes in acid number, the samples were collected with weight ranging from 0.35 g to 0.55 g for both oils, with weighing accuracy of 0.10 g. The values correspond to the acid number range from 0.05 to <1.0 mg·KOH·g^{-1}. Both oils showed results within the tolerance given by legislation a thus it can be concluded that no degradation process occurred after 500 Mth operation.

Evaluation and analysis of physical properties of tested oils – change in water content

The water content values (Fig. 6) are translated by linear function, which can be calculated by Eq. 8 for the reference sample, and by Eq. 9 for the ecological sample:

$$S_{H_2O} = -2 \times 10^{-6}t + 0.0038 \quad \% \qquad (8)$$

$$S_{H_2O} = -2 \times 10^{-6}t + 0.0212 \quad \% \qquad (9)$$

where:
t – number of tractor hours worked, Mth

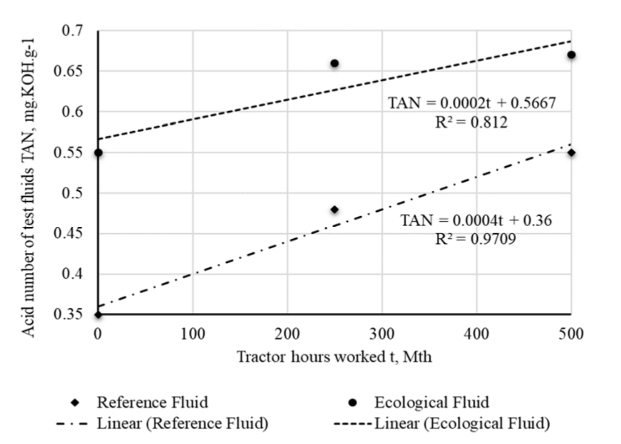

Fig. 5 Acid number course of tested fluids depending on the number of tractor hours worked

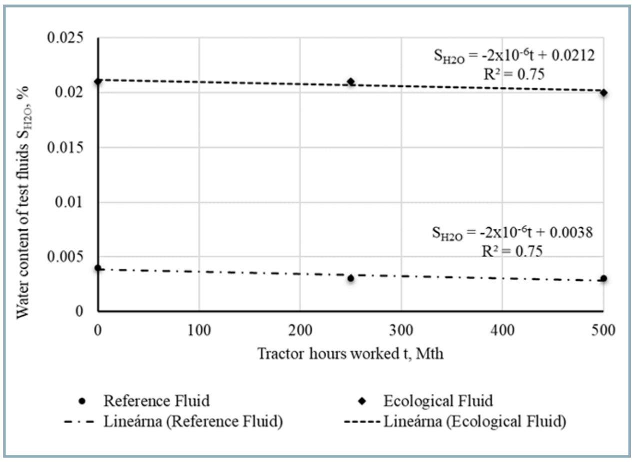

Fig. 6 Water content course of tested fluids depending on the number of tractor hours worked

Fig. 6 shows dependence of the changes in water content in tested oils on the number of engine hours worked. On the basis of laboratory analysis of tested oil, it is possible to conclude that the upper limit of water content in oils was not exceeded. The water content coefficient for both oils tested is R^2 = 0.75. The maximum permissible water content is 0.1% in hydraulic oils and 0.3% in gear oils.

The sampling and evaluation of oil samples were carried out by an employee from an accredited laboratory of Klüber Lubrication. Samples were taken from the system of wet

Table 5 X-ray fluorescence analysis (Oilquant.) – analysis of basic particles for reference and ecological oils

	Chemical element	Symbol	Units	Sampling interval					
				reference oil			ecological oil		
				0 h	250 h	500 h	0 h	250 h	500 h
Wear metals	aluminium	Al	mg·kg^{-1}	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
	molybdenum*	Mo	mg·kg^{-1}	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
	tin	Sn	mg·kg^{-1}	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
	titan	Ti	mg·kg^{-1}	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
	nickel	Ni	mg·kg^{-1}	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
	chrome	Cr	mg·kg^{-1}	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
	cooper	Cu	mg·kg^{-1}	<10.0	<10.0	<10.0	<10.0	10	10
	iron	Fe	mg·kg^{-1}	<10.0	<10.0	<10.0	<10.0	<10.0	10
	lead	Pb	mg·kg^{-1}	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
	zinc*	Zn	mg·kg^{-1}	<10.0	<10.0	<10.0	22	<10.0	<10.0
Contaminants	silicon*	Si	mg·kg^{-1}	<10.0	<10.0	<10.0	62	48	52
	sodium	Na	mg·kg^{-1}	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0
	potassium	K	mg·kg^{-1}	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
Additives	barium	Ba	mg·kg^{-1}	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
	magnesium	Mg	mg·kg^{-1}	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
	phosphorus	P	mg·kg^{-1}	129	226	253	143	187	198
	zircon	Zr	mg·kg^{-1}	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
	calcium	Ca	mg·kg^{-1}	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
Others important elements	manganese	Mn	mg·kg^{-1}	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
	chlorine	Cl	mg·kg^{-1}	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0
	sulphur	S	mg·kg^{-1}	14,460	18,170	18,336	825	4,190	4,230

* Element that can serve also as an additive

disc brakes of tractor Zetor 5321 after specified number of tractor hours worked. Sampling was performed only once in accordance with the methodological procedure of STN 65 6207. The laboratory performed three consecutive measurements of the physico-chemical properties of tested oils, on the basis of which the arithmetic means were calculated. Evaluated samples were translated by linear function with an appropriate coefficient R^2, which is shown in Figs. 1–6. On the basis of the coefficient of determination R^2, it would be possible to state that the linear functions are not suitably selected and if the individual measurement points were translated by polynomial function, the coefficient of determination would reach the value R^2 = 1.00. Due to the scarcity of data, utilization of a polynomial function of the first degree would by physically inaccurate. The polynomial would pass through all points with the determination coefficient R^2 = 1.00, which might seem like a suitable function; however, the linear function has a greater informative value in this case.

Both oils showed only minor changes in their physical properties. The connection of points would not be appropriate, because there would be no trend of increasing or decreasing in observed physical and chemical properties of tested oils after oil change interval.

Evaluation of chemical analysis of tested oils in wet disc brake system

In addition to the monitoring of physical properties, an X-ray fluorescence analysis was performed. During operation, mechanical wear occurs in the tractor's hydraulic system and thus the abrasive particles are produced. Their production is a natural effect, which is unavoidable under practical conditions. A certain small amount of wear particles can also be found in a new oil, since additives may contain these in this case. However, if the particle size increases significantly, it may indicate an issue or malfunction of any part of the hydraulic system or – as in this case – wet brake system. The X-ray fluorescence analysis (Oilquant.) according to the DIN 51829 and DIN 51399-2 was aimed at the concentration determination of important chemical elements in the reference and ecological oils (Table 5).

The samples collected in operational tests were also subjected to X-ray fluorescence analysis. The analysis was focused on testing of reference oil and ecological oil in terms of the content of abrasive metals, contamination, additives and others important elements (Table 5). On the basis of performed analysis, it is possible to conclude that the majority of elements remained at original level of the reference sample (0 tractor hours worked). Considering the content of abrasive metals, increase in their occurrence was not observed. In terms of contaminants, only silicon was activated as additive, and in terms of additives, only a negligible increase in phosphorus was observed. Sulphur was a significant element that was activated, which also serves as protection against wear and abrasion, as well as a source of base oil.

Conclusion

Operational measurements of the wet disc brake system in Zetor Super 5321 were determined.

Two types of oil fillings were tested – a reference oil sample and an ecological oil.

Results of the operational measurements evidence that neither the reference fluid nor the ecological fluid had negative impact on the minimum braking value. Test results in form of graphical dependencies described the changes in physical properties of tested oils. The courses of the individual curves were translated by linear functions with specification of the determination coefficient. Values of the determination coefficient and calculated mean error of the correlation coefficient sr confirmed the reliability of the correlation coefficient, which is a purity measure of tested oils. The correlation coefficient – which characterizes the degree of contamination of the tested oils in this case – confirms the results of analyses in terms of the physical oil properties. At the end of test, both oils showed only minor changes in their physical properties; they did not show any corrosion and negative impacts on the wet brake system of Zetor Super 5321. This was confirmed by the chemical analysis of tested oils according to the DIN 51829 and DIN 51399-2. Furthermore, oil samples were also subjected to X-ray fluorescence analysis, which was carried out at an accredited laboratory Klüber Lubrication. The analysis was aimed at testing of both oils in terms of content determination of abrasive metals, contaminants, additives and other important elements. On the basis of performed analysis, it can be concluded that majority of the elements remained at the original level of the reference 0 hour sample. Considering the abrasive metals, no increase in their values was not observed. In terms of contamination, only silicon was activated as additive. In regards to additives, only the increase in phosphorus in a negligible amount was observed. Considering the important elements, only sulphur was activated; it serves as a protection against wear and abrasion, as well as a source for the base of ecological oil. Experiment conducted confirmed that the ecological oil shows comparable properties to reference oil. Both oils showed only minor changes in their physical properties after completion of operational and laboratory tests. They did not cause corrosion and had no negative impact on the wet brakes system used in tractor Zetor 5321. The results of operational tests and subsequent physico-chemical analysis of samples may serve as a background material for design and development of friction materials used in wet disc brakes system and oil fillings for this type of brakes system. Tested ecological oil is a suitable substitute for conventionally made oils, especially when tractor works in environmentally sensitive areas. The issue of practical measurement of the wet disc brakes system in tractors with application of ecological oil are new and no authors have dealt with it yet. In terms of approving the technical condition of braking systems, merely the braking deceleration is evaluated according to Law no. 106/2018 and the impact of applied oils on properties, such as friction materials, contamination of oil fillings and their influence on values of braking deceleration, are not taken into account. From this point of view, the results can be considered original. The research was focused on potential negative effects of used ecological oil on the wet disc brakes system. Considering the ecological oil application, attention was focused on safety in terms of the minimum braking deceleration and degradation of friction materials, which was monitored by physico-chemical analyses.

Acknowledgment

This work was supported by AgroBioTech Research Centre built in accordance with the project "Building the AgroBioTech Research Centre" ITMS 26220220180.

This work was supported by the project VEGA 1/0155/18 "Applied Research of the Use of Ecological Energy Carriers in Agricultural, Forestry and Transport Technology".

References

ASTM D644. 2015. Standard test method for acid number of petroleum products by potentiometric titration. Hach Company/ Hach Lange GmbH.

ČEDÍK, J. – PEXA, M. – PETERKA, B. – HOLUBEK, M. – MADER, D. – PRAŽAN, R. 2018. Effect of biobutanol-sunflower oil-diesel fuel blends on combustion characteristics of compression ignition engine. In Acta Technologica Agriculturae, vol. 21, no. 4, pp. 130–135.

DIN 51399-2. 2010. Testing of lubricants – Determination of elements content of additives, wear and other contaminations. Part 2: Wavelength dispersive X-ray fluorescence spectrometry (XRF).

DIN 51829. 2010. Petroleum products – Determination of additive and wear elements in greases – Analysis by wavelength dispersive X-ray fluorescence spectrometry.

DOSTÁL, P. – ROZLIVKA, J. – KUMBÁR, V. 2019. Operational degradation of engine oil in agricultural technology. In Acta Technologica Agriculturae, vol. 21, no. 1, pp. 17–21.

EHK Regulation No 13 of the Economic Commission for Europe of the United Nations (UN/ECE). 2015. Uniform provisions concerning the approval of vehicles of categories M, N and O with regard to braking, [2016/194], 2015.

HELEBRANT, F. – ZIEGLER, J. – MARASOVÁ, D. 2001. Technical Diagnostic and Reliability I. Tribodiagnostic. Ostrava : VŠB – Technical University of Ostrava. (In Czech: Diagnostika a spolehlivost I. Tribodiagnostika)

HLAVÁČ, P. – BOŽIKOVÁ, M. – PETROVIĆ, A. 2019. Selected physical properties assessment of sunflower and olive oils. In. Acta Technologica Agriculturae, vol. 21, no. 3, pp. 86–91.

HUJO, Ľ. – KANGALOV, P. G. – KOSIBA, J. 2015. Laboratory test devices for evaluating the lifetime of tractor hydraulic components: proceedings, methods and applications. Ruse : Angel Kanchev University of Ruse, 69 pp. (scientific monograph)

HUJO, Ľ. 2017. Design of Laboratory Test Device for Testing of Hydrostatic Transducers and Hydraulic Fluids Used in Mobile Energy Devices. Nitra : Slovak University of Agriculture in Nitra, 158 pp. (In Slovak: Návrh laboratórneho zariadenia pre skúšanie hydrostatických prevodníkov a hydraulických kvapalín využívaných v mobilních energetických prostriedkoch)

JABLONICKÝ, J. – OPÁLENÝ, P. – UHRINOVÁ, D. – TULÍK, J. – SAVIN, L. 2019. Influence of ecological fluid on the wet disc brake system of the tractor. In 7th International Conferencie on Trends in Agricultural Engineering 2019, Prague, pp. 218–224.

JANOŠKO, I. – ČERNECKÝ, J. – BRODNIANSKA, Z. – HUJO, Ľ. 2016. Environmental Technologies and Engineering. Nitra : Slovak University of Agriculture in Nitra, 306 pp. (In Slovak: Environmentálne technológie a technika)

JANOŠKO, I. – POLONEC, T. – LINDÁK, S. 2014. Performance parameters monitoring of the hydraulic system with bio-oil. In Research in Agricultural Engineering, vol. 60, special issue, pp. 37–43.

JANOŠKO, I. – ŠIMOR, R. – CHRASTINA, J. 2010. The bio-oil testing used in the hydraulic system of the vehicle for waste collection. In Acta Technologica Agriculturae, vol. 13, no. 4, pp. 103–108.

KAMIŃSKI, Z. – CZABAN, J. 2012. Diagnosing of the agricultural tractor braking system within approval tests. In Eksploatacja i Niezawodnosc – Maintenance and Reliability, vol. 14, no. 4, pp. 319–326.

KOSIBA, J. – TKÁČ, Z. – HUJO, Ľ. – STANČÍK, B. – ŠTULAJTER, I. 2013. The operation of agricultural tractor with universal ecological oil. In Research in Agricultural Engineering, vol. 59, special issue, pp. 27–33.

KUČERA, M. – ALEŠ, Z. – PEXA, M. 2016. Detection and characterization of wear particles of universal tractor oil using a particles size analyser. In Agronomy Research, vol. 14, no. 4, pp. 1351–1360.

Law No. 106/2018. Law on the operation of vehicles in road traffic and on amendments to certain Acts.

MAJDAN, R. – OLEJÁR, M. – ABRAHÁM, R. – ŠAREA, V. – UHRINOVÁ, D. – JÁNOŠOVÁ, M. – NOSIAN, J. 2018. Pressure source analysis of a test bench for biodegradable hydraulic oils. In Tribology in Industry, vol. 40, no. 2, pp. 183–194.

MAJDAN, R. – TKÁČ, Z. – KANGALOV, P. G. 2013. Research of Ecological Oil-Based Fluids Properties and New Test Methods for Lubrication Oils. Ruse : Angel Kanchev University of Ruse, 98 pp. (scientific monograph)

MANG, T. – BOBZIN, K. – BARTELS, T. 2010. Industrial Tribology: Tribosystems, Friction, Wear and Surface Engineering, Lubrication. Wiley, 672 pp. ISBN: 978-3-527-32057-8.

STN 65 6207. 1986. Hydraulic oils and liquids. Sampling for determination of mechanic impurities.

STN EN 16896. 2017. Petroleum products and related products – Determination of kinematic viscosity – Method by Stabinger type viscosimeter.

STOPKA, J. 2018. Lubrications and environment. In Tribotechnika, pp. 46–49. (In Slovak: Mazivá a životné prostredie)

TKÁČ, Z. – MAJDAN, R. – KOSIBA, J. 2014. Research of Properties of Ecological Fluids and New Testing Method of Lubricating Oils. Nitra : Slovak University of Agriculture in Nitra., 94 pp. (In Slovak: Výskum vlastností ekologických kvapalín a nových testovacích metód mazacích olejov)

TÓTH, F. – RUSNÁK, J. – KADNÁR, M. – VÁLIKOVÁ, V. 2014. Study of tribological properties of chosen types of environmentally friendly oils in combined friction conditions. In Journal of Central European Agriculture, vol. 15, no. 1, pp. 185–192.

TULÍK, J. 2013. Analysis of hydraulic fluids properties used in hydraulic systems of transport and handling technics. Nitra : Slovak University of Agriculture in Nitra. (In Slovak: Analýza vlastností hydraulických kvapalín používaných v hydraulických systémech dopravnej a manipulačnej techniky) (PhD thesis)