INFLUENCE OF ECOLOGICAL FLUID ON THE WET DISC BRAKE SYSTEM OF THE TRACTOR

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Abstract
The article is focused on the operating measurements of the wet disc brake system of the tractor. Operating measurements were evaluated after tractor's operation of 500 Eh on the 3rd, 4th and 5th gear. The reference fluid and the ecological fluid were tested during operation. In addition, the results of the work include the evaluation of the fluid samples taken from the operational tests to monitor the tractor's braking performance with wet disc brakes. Fluid samples were also tested for changes in their physical properties. Results of the operating measurements evidence that applied reference fluid neither the ecological fluid had negative effect on the minimum braking performance. Also, the physical properties analysis of the tested fluids did not prove their negative impact on the tractor wet disc brake system.

Key words: *agricultural machinery; deceleration; biodegradable oil; physical analysis.*

INTRODUCTION
Agricultural technology has a negative impact on all elements of the environment (*Kučera et al, 2016, Vitázek et al. 2018*). The constant increasing of vehicles number causes air pollution and soil and water contamination by ecologically harmful substances. It was reported that over 60% of all lubricants end up in soil and water (*Majdan et al, 2013*). Environmental protection is an actual topic already for several years, and it becomes a preferred problem in the established trend of economic development (*Tóth et al, 2014; Majdan et al, 2018*). Therefore, the producers of mobile energy machinery together with the oil and lubricants manufacturers develop special products that save the environment (*Vitázek et al., 2018*). Application of suitable biodegradable oils markedly reduces the environmental, sewerage and pathway damage by oil leakage into the environment (*Janoško et al., 2014; Vitázek et al., 2018; Janoško et al. 2010*). Reported by *Tkáč et al. (2014)*, vegetable oils are capable to contribute to the goal of energy independence and security since they are a renewable resource. The amount of biodegradable oils in the market is quite low. There is a catch-up to make a stronger pressure for using biodegradable oils as fillings of hydraulic circuits and gearboxes (*Hujo et al. 2015; Kosiba et al. 2013*). Green technologies and machinery will become an essential part of everyday life *(Janoško et al., 2016*).
In addition to acceleration, the movement of the mobile energy machinery also results to deceleration, uses the braking system. Study (*Kamiński & Czaban, 2012*) states that effective braking system of the vehicle is essential for safety during the transportation. Regards to the road safety, the braking systems of agricultural vehicles must meet several requirements, including the braking performance. The one type of braking system which uses an oil charge is wet disc brake. Friction elements and applied oil fillings are important parts of the wet disc brakes. Reported by *Mang (2010)*, friction is a passive resistance with opposite direction of action, such as relative motion of the friction surfaces. Especially, the oil filling in the wet disc brakes can affect durability of friction elements, heat dissipation and associated braking performance. Reported by *Tkáč et al. (2014)*, mineral oils, synthetic fluids and ecological fluids are the most widespread in praxis to lubricate transmissions. Authors of the research Study (*Hujo, 2017*) and Study (*Tulík, 2013*) report as the main physical properties of lubricating and energy transfer fluids – viscosity, viscosity index, stability, oxidation, compressibility and shear stability. Viscosity may decrease of increase during the oil utilization. Reported by *Helebrant et al. (2001)*, the increase of viscosity may be caused by oxidation products or impurities in the oil. On the contrary, its decrease may be caused by mechanical and thermal degradation of its additives. *Stopka (2017)* states, that oils with low viscosity index provide the thin thickness of lubricating film resulting

in lubrication boundary conditions. That leads to metal to metal contact and the damage of system components. If two moving metal surfaces contact each other due to insufficient lubrication, excessive wear may occur as a result of so-called cold welding.
Aim of this article was to provide the operational measurements in Zetor Super 5321 tractor's wet disc brake system. The oil reference sample and biodegradable oil sample were tested. The results were evaluated in accordance with established methodology. Subsequently, the braking performance of the tractor's wet disc brake was evaluated, and the physical properties of the used fillings were determined. Testing of these oils should demonstrate whether the reference oil sample can be fully replaced with biodegradable oil and find out the extent to which the wet disc brakes affects the degradation processes in tested oils.

MATERIALS AND METHODS

Characteristics of the reference fluid

As the reference fluid, it was used the oil containing additives to increase the loading capacity of the lubricating film. Basic parameters of the reference fluid are shown in Tab. 1. It is a mineral oil that always guarantees good lubricating properties, high oxidation resistance and high loading capacity. The reference fluid is designed to lubricate the mechanical transmissions of vehicles and drive axles if required oils SAE 80W – 90 with API GL – 4 performance level. The oil can be used for lubrication of mechanical transmissions and axle drives of cars and trucks, construction and agricultural machinery and other transmission applications.

Tab. 1 Basic parameters of the reference fluid

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

Characteristics of the ecological fluid

Ecologic universal synthetic tractor oil was used as biodegradable oil. Basic parameters of the ecological fluid are shown in Tab. 2. This oil is assigned for manual gearboxes, axle drives, crankshaft transmissions, steering and gearing transmission, hydraulic systems of tractors and their auxiliary units, for wet brakes, clutches and hydrodynamic transmissions.

Tab. 2 Basic parameters of the ecological fluid

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

Service brake measurement methodology

The service brake was measured according to the Methodological Guideline of SR No. 71/2011 that specify control sequence relating to the vehicles braking system. The purpose of the measurement was to determine the maximum braking performance values of the tractor's oil brakes. Under the prescribed conditions, the vehicle shall be capable to achieve prescribed minimal braking performance values of the service brake expressed by deceleration (z_{min}). For comprehensive assessment of the service brake and to assess the effect of biodegradable oil on the service brake, the measurements were executed after 500 Eh of the machine's operation and three gears engaged. Therefore, tractor was monitored for deceleration values with gradual engagement of 3rd, 4th and 5th gear. The tractor uses the reference fluid as an oil fill. The reference fluid had been replaced by ecological fluid at service interval. Based on the

measurements of service brake deceleration with reference fluid, it was possible to compare these data with those obtained with the measurements with ecological fluid. At 3rd and 4th gear, the tractor did not exceed the rate 25 km. h^{-1}, so the deceleration values were compared with minimal value of deceleration z_{min} = 23%. At 5th gear, the tractor achieves maximal rate 30 km. h^{-1}, so the deceleration values were compared with minimal value of deceleration z_{min} = 28%.
The methodical sampling procedure of tested hydraulic fluid was regulated by the standard STN 65 6207 (Hydraulic oils and liquids). After the operational tests, the physical properties analysis of tested oils was executed. The evaluation process was focused on the changes of water content, acidity number, density and dynamic viscosity after 500 Eh of tractor's operation. The viscosity and density measurements were performed by Stabinger viscometer "Anton Paar" method by the standard STN EN 16896 – kinematic viscosity test, petroleum and related products. Total acid number (TAN) is used to test the number of acidic components in the oil sample. Methodical sampling evaluation procedure on the change of TAN was executed by the standard ASTM D 644 A. The measurement of the water content in the oil was performed by the Karl Fischer (KF) titration method.

RESULTS AND DISCUSSION

Deceleration is defined as the ratio between the total braking force F to the axle (axles) of the vehicles and causal static total mass forces Gv (vehicle mass). The deceleration corresponds to the braking deceleration and gravitational acceleration ratio. Reported by *Rybianský et al. (2009)*, if the prescribed deceleration is reached or exceeded, the deceleration value is enough.

Minimal deceleration values with reference fluid

Based on the achieved results, minimal deceleration values given by legislation were exceeded by 2.70% (3rd gear), by 10.00% (4th gear) and by 6.50% (5th gear). The average values from three consecutive measurements at 3rd, 4th and 5th gear at 500 Eh are shown in Tab. 3.

Tab. 3 Deceleration values with reference fluid

	3rd gear	4th gear	5th gear	
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	%

Minimal deceleration values with ecological fluid

Based on the achieved results, minimal deceleration values given by legislation were exceeded by 9.60% (3rd gear), by 9.10% (4th gear) and by 1,35% (5th gear). The average values from three consecutive measurements at 3rd, 4th and 5th gear at 500 Eh are shown in Tab. 4.

Tab. 4 Deceleration values with ecological fluid

	3rd gear	4th gear	5th gear	
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	%

Evaluation and physical analysis of the tested oils – change of dynamic viscosity

Dynamic viscosity values are defined by linear function. The linear function of dynamic viscosity at 40°C for reference sample can be calculated by equation (1)

$$\eta_{40} = -0.0226t + 127.53 \qquad \text{mPa. S} \qquad (1)$$

where *t* is time in engine hours (Eh).

The linear function of dynamic viscosity at 40°C for ecological fluid can be calculated by equation (2)

$$\eta_{40} = -0.0116t + 72.232 \quad \text{mPa. s} \quad (2)$$

Presented in Fig. 1, the course of dynamic viscosity at 40°C depending on the hours of operation is shown. It is possible to observe the decrease of dynamic viscosity values depending on the hours of operation. Reported by *Paar (2019*), brake liquids must fulfil specifications mainly at -40 °C and +100 °C. Most producers state values at + 40 °C and give the viscosity index. There are three main types of brake fluids which are classified by their different chemical base as polyglycolether/borate ester, silicone oil and mineral oil. This is the reason why they do not mix with each other. Reported by *Wójcik (2019),* it was noted that used brake fluid was characterized by lower viscosity and higher density. The viscosity stays constant in the whole range of a shear rate. Additionally, the decrease of viscosity with the increase of temperature was also observed. By *Čorňák & Skolil (2008),* the change of brake fluid viscosity is affected not only by temperature but also by water content.

Evaluation and physical analysis of the tested oils – change of density at 40°C

Density is expressed as a ratio of mass to a given volume. For liquids, temperature is an important factor that can affect a liquids density. In general, as liquid temperature increases, density decreases. Presented in Fig. 2, the course of density at 40°C depending on the hours of operation is shown. It is possible to observe the higher density values of ecological fluid compared to reference fluid. Study *(Koshizuka et al., 2018)* states that fluid density is important for fluid simulations because mass conservation is expressed by the fluid density and the pressure is calculated by fluid density.

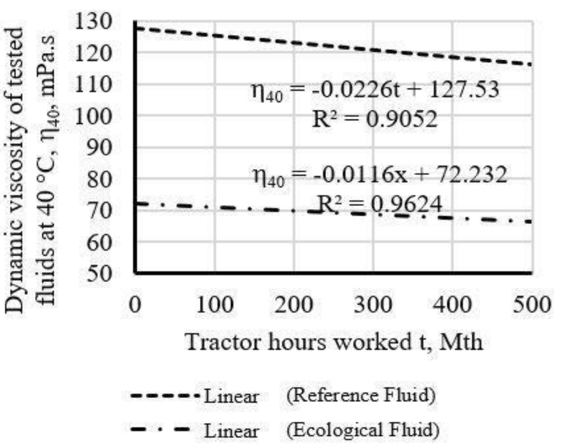

Fig. 1 Course of dynamic viscosity at 40°C depending on the hours of operation

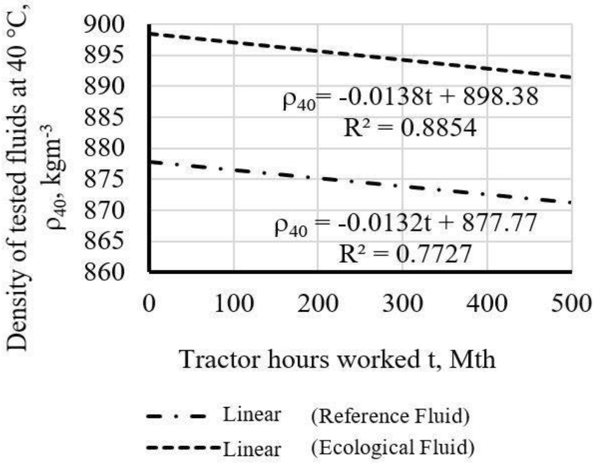

Fig. 2 Course of density at 40°C depending on the hours of operation

Evaluation and physical analysis of the tested oils – change of TAN

Acid Number or Total Acid Number (TAN) is used to test the quantity of acidic components in an oil sample. Presented in Fig. 3, the change of TAN depending on the hours of operation is shown. It is possible to observe the higher TAN values depending on the hours of operation. By *Mantech (2016),* acid number results are used as a guide in the quality control of lubricating oils. The rate of change of the acid number is more important than its absolute value. A rapid increase can be caused by many factors, including excessive degradation due to hotspots from dirty oil ways, top-up with different oil, or a change in fuel sulphur content. More commonly, a steady increase in acid number may be caused by oxidation over time or temperature effects. High operating temperatures can generate increasing levels of weak organic acids. Oils with a high acid number will form undesirable gums and lacquers on metal surfaces. High acid numbers are also associated with increased viscosity of pumping losses and system corrosion – especially in the presence of water.

Evaluation and physical analysis of the tested oils – change of water content

Water content values are defined by linear function. The linear function of water content for reference sample can be calculated by equation (3)

$$S_{H2O} = -2E - 06t + 0.0038 \quad \% \quad (3)$$

where *t* is time in engine hours (Eh).

The linear function of water content for ecological fluid can be calculated by equation (4)

$$S_{H2O} = -2E - 06t + 0.0212 \qquad \% \qquad (4)$$

Reported by *Giani (2018)*, brake fluid is an essential part of a vehicle's hydraulic braking system. Above the critical moisture content, the force applied to the brake pedal is not be transferred to the rest of the system, and the brake system fails. Presented in Fig. 4, the course of water content change depending on the hours of operation is shown. It is possible to observe, that the course of line is almost linear.

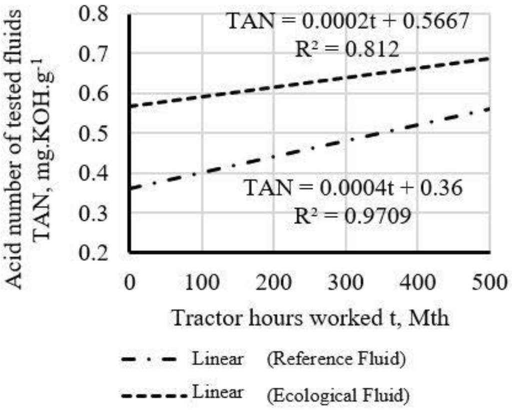

Fig. 3 The change of TAN depending on the hours of operation

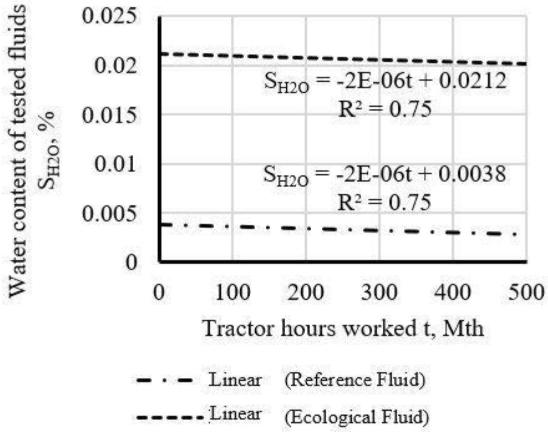

Fig. 4 The water content change depending on the hours of operation

Based on the laboratory analysis of the tested oils, the above – mentioned limits of water content had not been exceeded. The coefficient of water content determination for both tested oils is $R^2 = 0.75$. Maximal permissible value for hydraulic oils is 0.1% and for gear oil 0.3%. The results presented in this paper cannot be compared with already published studies, as it is an innovative research. The comparison of the influence of the oils (mineral and synthetic) on the wet discs brake system and deceleration had not been published yet. Wet braking system measurement methodology used in this contribution was developed during measurement based on the Methodological Guideline of SR No. 71/2011.

CONCLUSIONS

Operating measurements in Zetor Super 5321 wet disc brake system were determined. Two types of the oil fluids were tested – reference oil sample and biodegradable oil. Results of the operating measurements evidence that applied reference fluid neither the ecological fluid had negative effect on the minimum braking performance. Physical properties changes of the tested oils are included in the results as graphical dependencies. The course of individual curves was defined by linear functions to determine the coefficient of determination. The values of determination coefficient and consistent counted mean error of correlation coefficient σ_r certified the reliability of the correlation coefficient which establishes the cleanness degree of the tested oils. The correlation coefficient confirms the results of physical analysis of the tested oils. Both of oils show only minor changes of their physical properties after completion of operating measurements. They do not cause corrosion and any negative impact on the tractor wet disc brake system had not been found.

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