LABORATORY RESEARCH OF TRANSMISSION – HYDRAULIC FLUID

Ľubomír HUJO[1], Štefan ČORŇÁK[2], Zdenko TKÁČ[1], Michaela JÁNOŠOVÁ[3]

[1]Department of Transport and Handling, Faculty of Engineering, SUA in Nitra, Slovakia
[2]Department of Combat and Special Vehicles, Faculty of Military Technology, University of Defence in Brno, Czech Republic
[3]Nemak Slovakia s. r. o., Žiar and Hronom, Slovakia

Abstract
The article is focused on the laboratory research of the qualitative properties of transmission – hydraulic fluid type MOL Farm NH Ultra and its impact on the technical and operational characteristics of the hydraulic pump type QHD 17. Laboratory testing device allowed to simulate the variable testing conditions of the real conditions under which the hydraulic system of agricultural wheel tractor operates. The flow properties of the hydraulic pump with tested hydraulic fluid at precisely defined intervals were monitored during testing. Based on the measured data, the flow properties of the MOL Farm NH Ultra were evaluated by mathematical – statistical analysis.

Key words: *hydraulic pump; hydraulic system; hydraulic pump flow.*

INTRODUCTION
There are high requirements of hydraulic fluids that serve as energy carriers in hydraulic systems. Their producers must consider their demands for quality improvement and simultaneously reducing the burdening of environment (*Rusnák et al., 2009; Vitázek et al., 2018*). The quality of the transmission – hydraulic fluid is an important indicator of the proper operation of the hydraulic system and it has a major influence on the individual components operation of the hydraulic circuit (*Janoško et al., 2016; Kučera et al., 2016*). Reported by *Hujo (2016, 2017),* accelerated fluid testing is used to optimize the testing time, simulating the operational loading under laboratory conditions. After the testing completion, the physical – chemical properties analysis is done. Impact of the tested fluid on the technical characteristics of the hydraulic pump focusing on the changes of the flow characteristics is also monitored. The basic precondition for proper operation and efficient care about hydraulic fluids is the suitably chosen method of the fluid testing with monitoring of the contamination level of the fluid (*Helebrant, 2001; Janoško et al., 2014*). The aim of study was the research of qualitative properties of transmission-hydraulic fluid and its impact on technical state of hydraulic tractor pump. The fluid properties were monitored by the bulk density, kinematic viscosity and pour point. The technical state of hydraulic pump was evaluated by the flow and decrease of flow efficiency.

MATERIALS AND METHODS
Laboratory testing of transmission – hydraulic fluid was realized based on the method below:

- provision of the physical – chemical analysis of the reference fluid sample,
- verification testing of the hydraulic circuit with operating pressures simulation by electro – hydraulic proportional valve,
- the first measurement was realized after 125 Eh and the values of the flow, pressure and temperature sensors were recorded at hydraulic pump speed 500, 750, 1000, 1250, 1500, 1750, 2000, 2250, 2500 and 2750 min $^{-1}$,
- after recording the data mentioned above, before the next measurement, it is necessary to take the sample of the tested hydraulic fluid, further sampling of the fluid will be carried out after 250, 375 and 500 Eh,
- next, the samples of the fluid had been physically and chemically analysed.

To simulate the operational loading of the gear pump used in the tractor's hydraulic system by applying the tested hydraulic fluid, the laboratory testing device was designed. The device allows to realize laboratory testing based on the signals monitored during testing (*Hujo et al., 2015; Majdan et al., 2013*). Signal progress whereby simulated real operational conditions during testing is presented in Fig. 1.

The signal is provided by electro – hydraulic proportional valve connected to hydraulic circuit (*Tkáč et al., 2014 and 2014; Kosiba et al., 2013*).
The methodical sampling procedure of tested hydraulic fluid was regulated by the standard STN 65 6207 (Hydraulic oils and fluids. Sampling to determine the content of mechanical impurities). In order to access the suitability of hydraulic fluid testing in hydraulic circuit of agricultural, forestry, and handling machinery, it is necessary to know the input parameters of the system in which the hydraulic fluid will be tested. It means to know the technical parameters of the hydraulic pump that is connected to the hydraulic circuit during testing. The technical parameters of the hydraulic pump are shown in Tab. 1.

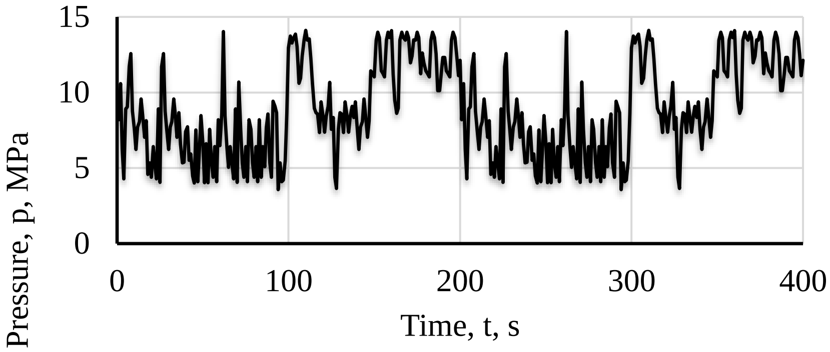

Fig. 1 Pressure signal progress to simulate the operational loading

As tested fluid, it was used the transmission – hydraulic oil type MOL Farm NH Ultra. Its characteristics featured by producers are shown in Tab. 2. This tractor's oil was specially developed for the Case New Holland Group machinery producers. Versatile, long – life oil is aimed on power – shift gearboxes, differentials, wet brakes and high-performance agricultural machinery hydraulic systems.

Tab. 1 Parameters of the hydraulic pump type QHD 17

Parameters		Marking	Unit	Value
Real geometric volume		V_g	dm^3	$17.24.10^{-3}$
Speed	rated	n_n	min^{-1}	1500
	minimal	n_{min}	min^{-1}	350
	maximal	n_{max}	min^{-1}	3200
Input pressure	minimal	p_{1min}	MPa	-0.03
	maximal	p_{1max}	MPa	0.05
Output pressure	max. state	p_{2n}	MPa	29
	maximal	p_{2max}	MPa	31
	peaked	p_3	MPa	32
Rated output flow (min.) at n_n and p_{2n}		Q_n	$dm^3.min^{-1}$	23.2
Maximal flow at n_{max} and p_{2max}		Q_{max}	$dm^3.min^{-1}$	54.3
Input power – rated (max.) at n_n and p_{2n}		P_n	kW	14.8
Maximal rated power at n_{max} and p_{2max}		P_{max}	kW	33.6
Mass		m	kg	10.9

Tab. 2 Characteristics of the transmission – hydraulic fluid type MOL Farm NH Ultra

Characteristics	Unit	Values
Bulk density at 15 ºC	$kg.m^{-3}$	875
Kinematic viscosity at 40 ºC	$mm^2.s^{-1}$	64.2
Kinematic viscosity at 100 ºC	$mm^2.s^{-1}$	10.9
Viscosity index	-	162
Freezing point	ºC	-36
Flash point in open crucible	ºC	210

RESULTS AND DISCUSSION

Presented in Fig. 2, the course of **bulk density** changes at 40 ºC of tested fluid depending on the hours of operation is shown. The tested oil sample shows the highest bulk density at 0 Eh, as it can be seen from the graphical course. Subsequently, after the others sampling at precisely defined intervals, a negligible decrease of the bulk density was recorded. It might be caused by filtration of the impurities. The measured value of the bulk density of the tested transmission – hydraulic fluid before the testing was 860.70 $kg.m^{-3}$. The measured value is defined by linear function with coefficient of determination R = 0.7449. Based on this value, it could be concluded that linear function is not appropriately chosen, but the use of the fourth-degree polynomial function would be physically inaccurate due to insufficient data. Although, the polynomial would go through the all points with determination coefficient $R^2 = 1$ but in this case, the linear function has higher equity of redemption.

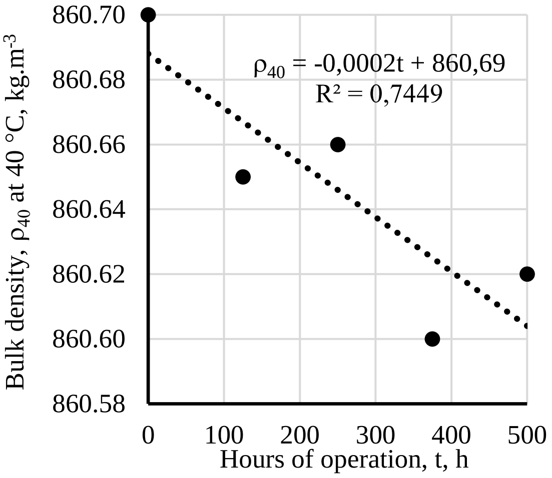

Fig. 2 Course of bulk density at 40 °C depending on the hours of operation

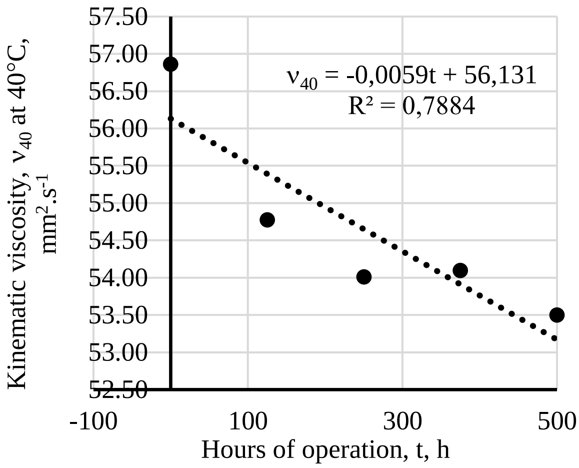

Fig. 3 Course of kinematic viscosity at 40 °C depending on the hours of operation

Kinematic viscosity is one of the basic parameters used to assess the quality of hydraulic oil. Viscosity may increase or decrease during its utilization in hydraulic circuit. Reported by *Helebrant et al. (2001)* the increase of viscosity may be cause by oxidative products or impurities in the oil. The decrease of viscosity is caused by mechanical and thermal degradation of additional additives. Kinematic viscosity values at 40 °C and 100 °C are shown in Fig. 3 and Fig. 4. The values are defined by linear function. The linear function of kinematic viscosity at 40°C can be calculated by equation (1)

$$\nu_{40} = -0{,}0059t + 56{,}131 \quad mm^2.s^{-1} \quad (1)$$

where t is time in engine hours (Eh). Determination coefficient of the kinematic viscosity $R^2 = 0.7884$ at 40 ° C, so it can be state that the type of function is suitably selected. Through the linear function for kinematic viscosity given by equation (1) it is possible to calculate the values for any number of operational hours with hydraulic oil MOL Farm NH Ultra with accuracy of 78.84%. *Asaff et al., (2014)* compared the properties based on DIN 51562-1:1999. At the kinematic viscosity, the authors noted similar changes from 2 to 10%, they recorded similar conclusion that the kinematic viscosity did not achieve a higher change from the initial state by more than 20%.

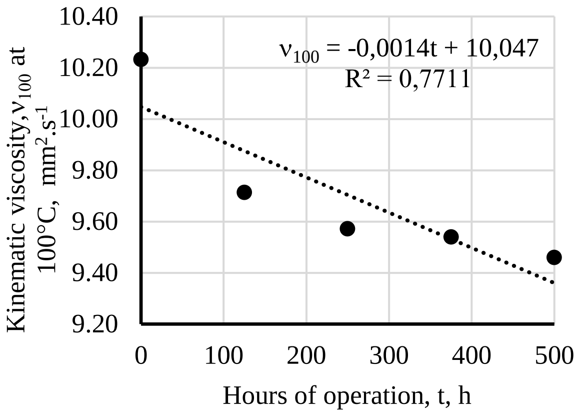

Fig. 4 Course of kinematic viscosity at 100 °C depending on the hours of operation

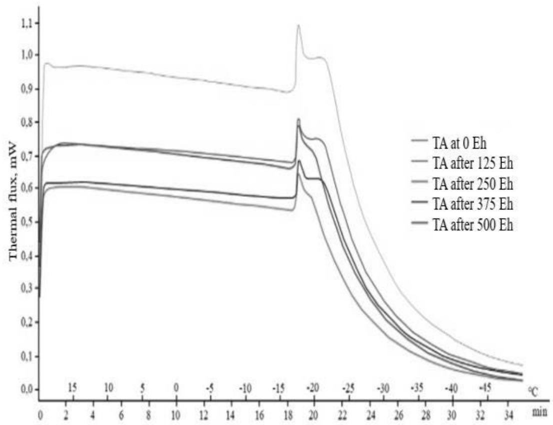

Fig. 5 Thermal analysis (TA) of the hydraulic fluid sample MOL Farm NH Ultra

Testing of the hydraulic fluid sample MOL Farm NH Ultra was also focused on monitoring of the **pour point**. An exothermic peak was recorded at -17.42 °C in the freezing process of the reference sample after 0 Eh. This point is defined as freezing point and the temperature is almost the same as a melting point whereby this temperature depends on the purity of the sample. Since the oil is an amorphous mass, the pour point is performed not only at one point but at the temperature range from -16.99 °C to -18.94 °C. An exothermic peak was recorded at -17.51 °C in the freezing process of the reference sample after 125 Eh. In this case, the recorded temperature range was noted from - 17.02 °C to – 25.29 °C. An exothermic peak was recorded at -17.50 °C in the freezing process of the reference sample after 250 Eh. In this case, the recorded temperature range was noted from - 17.01 °C to – 19.63 °C.

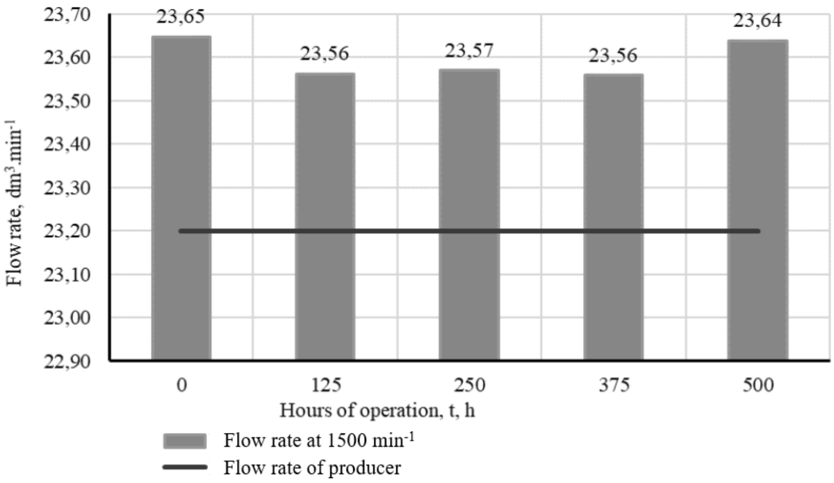

Fig. 6 Flow rate for nominal hydraulic pump speed 1500 min^{-1}

An exothermic peak was recorded at -17.48 °C in the freezing process of the reference sample after 375 Eh. In this case, the recorded temperature range was noted from - 17.05 °C to – 19.45 °C. An exothermic peak was recorded at -17.53 °C in the freezing process of the reference sample after 500 Eh. Autors *Kosiba et al., (2017)*, reached similar course of pour point in their research of degradation process of hydraulic fluids. In this case, the recorded temperature range was noted from - 17.07 °C to – 19.45 °C. Thermal analysis of tested fluid is shown in Fig. 5. The producer of the fluid Mol Farm NH Ultra presents as freezing point the value - 36 °C (*MOL Farm NH Ultra, 2016)*. Repeated measurements demonstrated the change of tested fluid properties by an average value of exothermic peak -17.49 °C. The hydraulic pump **flow** was measured according to the methodological procedure and the values were used to determine the average flow rates depending on the operational hours for speed from 500 min^{-1} to 2750 min^{-1}. For nominal hydraulic pump speed 1500 min^{-1}, the processing of measured data is shown in Fig. 6. Stated speed is indicated by producer as rated parameters of the hydraulic pump. From the dependence mentioned above, it can be state that the physical – chemical characteristics of the tested hydraulic fluid MOL Farm NH Ultra does not affect flow characteristics of QHD 17 hydraulic pump neither elements of transmission – hydraulic system. The value of the average flow rate depending on operational hours is about 1.7% higher. The same conclusions of hydraulic fluids research under laboratory conditions were reached by authors *Halenár et al., (2018), Tkáč et al., (2017), Tulík, et al., (2013) and Kosiba et al., (2013)*. The maximal decrease of the **flow efficiency** was 0.34% after 375 Eh but after 500 Eh, the decrease of the flow efficiency was 0.03% compared to the reference value at 0 Eh. The graphical dependency of the flow efficiency at 1500 min^{-1} is shown in Fig. 7. In accordance with ISO 15380: 2011, it is possible to confirm that the tested fluid does not affect the flow characteristics of QHD 17 hydraulic pump because the flow efficiency decrease did not exceed the value of 20%. Presented in Fig. 8, the course of flow efficiency decrease depending on the hours of operation is shown. Flow efficiency course correspond to the measurement results of *Yoshida and Inaguma (2014)* where the authors concluded that a given flow efficiency is due to the fluid remaining in the gaps while increasing the centrifugal force acting on the liquid as the speed increases.

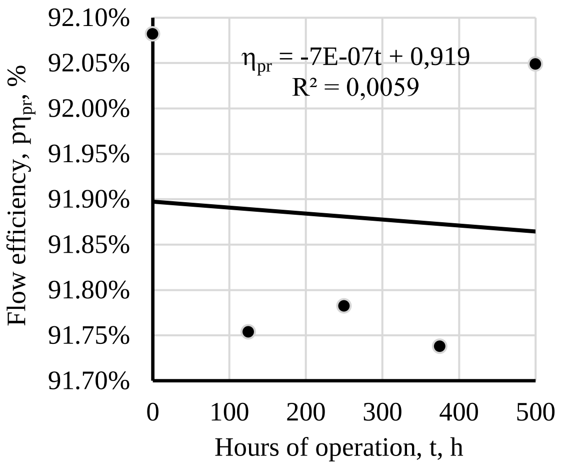

Fig. 7 Flow efficiency for nominal hydraulic pump speed 1500 min^{-1}

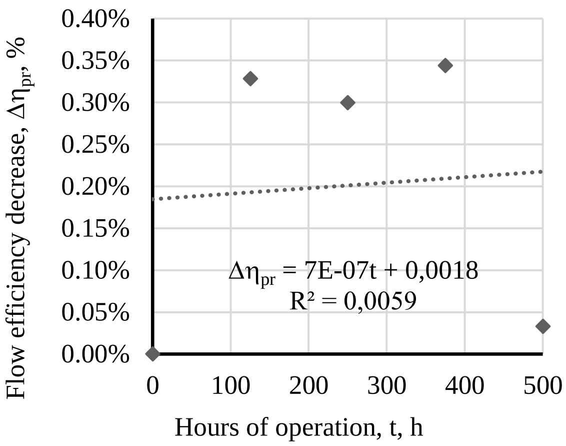

Fig. 8 Flow efficiency decrease for nominal hydraulic pump speed 1500 min^{-1}

CONCLUSIONS

Laboratory testing was focused on qualitative assessment of the transmission - hydraulic fluid MOL Farm NH Ultra, intended for utilization in transmission – hydraulic system of mobile energetic machinery and examine for its impact on QHD 17 hydraulic pump technical and operational characteristics. The laboratory testing device allowed to simulate variable testing condition to simulate the real agricultural wheel tractor operational condition. The flow properties of the hydraulic pump with tested hydraulic fluid at precisely defined intervals were monitored during testing. Based on the measured data, the flow properties were evaluated by mathematical – statistical analysis. Tested transmission – hydraulic fluid MOL Farm NH Ultra was evaluated based on its physical properties from the samples taken at defined intervals. Monitored physical properties of tested hydraulic fluid as bulk density and kinematic viscosity were within the appropriate tolerances after testing. The values of freezing point did not correspond to the data of the hydraulic fluid producer. Based on the results of the MOL Farm NH Ultra transmission – hydraulic fluid testing and its influence on the hydraulic system, it can be stated that hydraulic fluid is able to operate in tractor's hydraulic fluid system without any negative impact on hydraulic pump flow characteristics.

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Corresponding author:
doc. Ing. Ľubomír Hujo, PhD., Department of Transport and Handling, Faculty of Engineering, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, Nitra, 949 01, Slovak Republic, phone: +421 37 641 4530, e-mail: lubomir.hujo@uniag.sk