Evaluation of tractor biodegradable hydraulic fluids on the basis of hydraulic pump wear

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Abstract

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Two types of biodegradable hydraulic fluids (HEES and HEPR) with the mineral oil-based hydraulic fluid (HV) were compared. The tests were performed using a test bench. During the tests with a tractor hydraulic pump, the fluids were loaded by a cyclic pressure load. The tests of fluids were evaluated on the basis of wear of the pump. Evaluation parameters were the flow characteristics of the pump and the cleanliness level of tested fluids. The temperature of the fluid under which the test was performed was measured in real operating conditions of the Zetor Forterra 11441 tractor. It is possible to state upon the test results that the mineral oil-based fluid was classified in the first place, the biodegradable fluid of the HEPR type in the second place, and the biodegradable fluid of the HEES type received the last position.

Keywords: test bench; cleanliness level; flow efficiency; agricultural tractor; fluid temperature

Mineral oil-based hydraulic fluids are excellent lubricants and have served the fluid power industry well for many years (Totten et al. 1997). There is a pressure within the fluid power industry to convert to hydraulic fluids that are more biodegradable than mineral oils, such as vegetable oil-based hydraulic fluids.

Richard and Tessmann (1996) stated that the life and reliability of hydraulic system components are dependent upon the characteristics of the fluid circulating in the system. There is no doubt that the hydraulic component which suffers the most when wrong fluid is used in the system is the pump. There are three different types of hydraulic pumps widely used today – vane, gear and piston pumps. Each of these pumps has its own needs and requirements relative to the hydraulic fluid used in the system. In addition, the pump of a particular manufacturer may possess different requirements than the same type of pump from other manufacturers.

Vegetable oil basestocks can be used to produce acceptable lubricants if they have the proper fatty acid composition and additives. They still display some disadvantages when compared with regular mineral basestocks. Furthermore, the environmental benefits and relative low costs of vegetable basestocks are, at present, a solid argument to promote their use (Garcés et al. 2011).

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This paper deals with the test of new biodegradable fluids using the test bench.

MATERIAL AND METHODS

Test bench. Basic tribological tests are normally far away from the working conditions of the critical elements, but normally give an idea of the general wear and friction properties of materials and lubricants (Mendoza et al. 2011).

Toogood (1981) conducted tests using gear pumps in cyclic load conditions. We designed the test bench so that the course of the test correspond with Standard STN 11 9287 "Gear Pumps and Motors" in which the dynamic load of gear pumps and motors is performed under cyclic pressure load. Design of test bench was published by Tkáč et al. (2008). Therefore, the tests were done under cyclic pressure load from zero up to the nominal pressure with frequency from 0.5 to 1.25 Hz. The test duration was one million cycles.

The cyclic pressure load is achieved through the slide valve with a closed centre which is operated electro-hydraulically. When this valve is in its central position, the fluid passes through the sequence valve. When it is in the left extreme position, the fluid passes directly into the tank. In this way, pressure load conditions at the outlet of the tested hydraulic pump are changed in a cyclical manner. The test bench was designed according to works published by Jobbágy et al. (2003), Kučera et al. (2005), Mihalčová and Hakim (2008, 2009), and Tkáč et al. (2010).

Fig. 1 shows the cyclic pressure load measured on the test bench after its design and construction.

Test evaluation. The tests were evaluated according to the technical condition of the gear pump which was tested with various fluids. Therefore, a better technical condition of the gear pump after completion of the test means better fluid properties.

Richard and Tessmann (1996) presented that in a gear pump the bearings are seldom a problem from a fluid qualification standpoint. The interface between the slide plates and the slide of gear is by far the most prone to wear. In addition, the wear of gear pump will result in a reduction in volumetric efficiency.

When the gear pump is operated, a change in the performance of the pump can be readily measured by the output flow.

Therefore, we evaluated the technical conditions of the hydraulic pump during tests with various fluids according to the loss of flow efficiency (Eq. 1; Majdan et al. 2011)

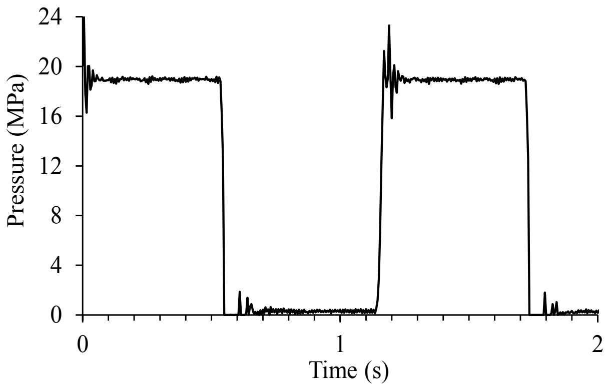

Fig. 1. Cyclic pressure load (Tkáč et al. 2008)

$$\Delta\eta_{pr} = \frac{\eta_{pr0} - \eta_{prm}}{\eta_{pr0}} \times 100 \ (\%) \quad (1)$$

where:

$\Delta\eta_{pr}$ – loss of flow efficiency (%)

η_{pr0} – flow efficiency at 0 cycles (start of the test)

η_{prm} – flow efficiency after 10^6 cycles (end of the test)

Then, the flow efficiency is expressed by Eq. (2):

$$\eta_{pr} = \frac{Q_2}{V_G \times n} \times 100 \ (\%) \quad (2)$$

where:

Q_2 – output flow rate (l/min)

V_G – geometric volume of the hydraulic pump (l)

n – rated rotation speed of the hydraulic pump (min^{-1})

During the measurement of flow characteristics, the hydraulic pump was driven by a three-phase asynchronous motor (F 180 L 0449 T; MEZ, Frenštát pod Radhoštěm, Czech Republic) which is not able to provide a constant rotation speed during the measurement. Therefore, the actual rotation speed was measured by a speed counter (WL 18–2P132; SickAG, Waldkirch, Germany). Flow rates calculated on rated rotation speed 1,500 min^{-1} were used for drawing the flow characteristics. With respect to the fact that volume losses remain practically unchanged within a small range of rotation speed (1,500 ± 75 min^{-1}), the flow efficiency η_{pr} is constant, too. Therefore, it is possible to write the equation introduced by Varchola (2003):

$$\eta_{pr1} = \eta_{pr2} \Rightarrow \frac{Q_1}{V_G \times n_1} = \frac{Q_2}{V_G \times n_2}$$

after modification:

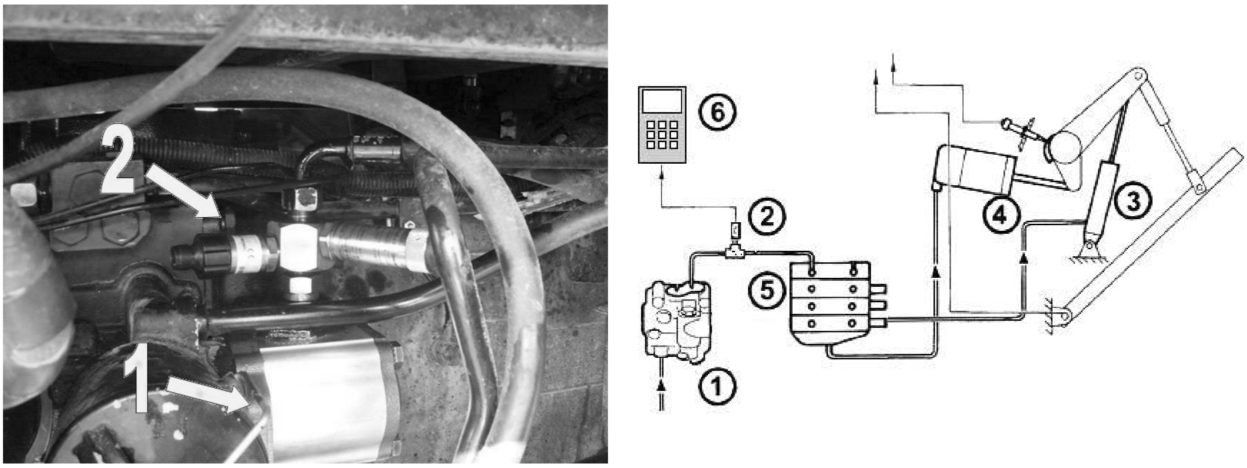

Fig. 2. Hydraulic system of the Zetor Forterra tractor
1 – tractor hydraulic pump; 2 – temperature sensor; 3, 4 – hydraulic cylinders; 5 – flow control valve; 6 – digital recording device HMG 2020

$$\frac{Q_1}{n_1} = \frac{Q_2}{n_2} \Rightarrow Q_2 = Q_1 \frac{n_2}{n_1} \qquad (3)$$

where:

η_{pr1} – flow efficiency during the measurement of flow rate
η_{pr2} – flow efficiency at required rotation speed n_2
Q_1 – flow rate measured at rotation speed n_1 (l)
Q_2 – flow rate at required rotation speed n_2 (l/min)
V_G – geometric volume of the hydraulic pump (l)
n_1 – measured rotation speed (min^{-1})
n_2 – required rotation speed (min^{-1})

The measurement repetition of flow rate values can be stated on the basis of the calculation per formula as follows (Rataj 2003):

$$n = \frac{V_k^2 \times t_\beta^2}{\delta^2} \qquad (4)$$

where:

V_k – variation coefficient
t_β – critical value estimated on the basis of probability
δ – maximum admissible error

The measurement repetition was calculated per formula (4) on the ground of variation coefficient V_k = 22.3%. The calculation was based on maximal choices mistake δ = 4 % and on critical value t_β = 1.282 which was stated on the basis of likelihood 90%. This value is adequate for experiments connected to machine construction (Rataj 2003). The calculated value n = 43 expresses the count of measurement repetition.

Fluid temperature during the test. The temperature of the hydraulic fluid was measured in operating conditions of the Zetor Forterra 1441 agricultural tractor (Zetor tractors a.s., Brno, Czech Republic). This temperature was used in the hydraulic circuit of the test bench. It was the way how to use the real operating conditions on the test bench.

Fig. 2 shows the hydraulic system of the Zetor Forterra tractor together with the system for temperature measurement. The temperature sensor was placed in the outlet pipe of the hydraulic pump. This is the place where the maximum temperature occurred due to high pressure of the fluid.

While the tractor was operated (Fig. 3), the temperature was recorded by digital recording device HMG 2020 (Hydac GmbH, Sulzbach, Germany).

The fluid temperature was measured in the agricultural tractor while working with a plough type

Fig. 3. Fluid temperature measurement under operating conditions

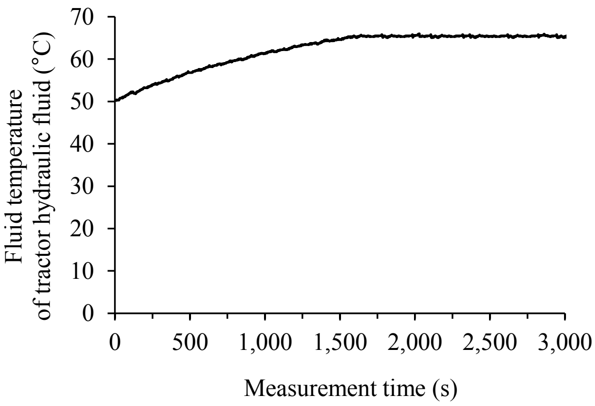

Fig. 4. Results of fluid temperature measurement in the tractor hydraulic system

5-PHN 30 (Agrostroj, Velešín, Czech Republic. Temperature was measured during the ploughing because this operation most loads the hydraulic and transmission system. The measured temperatures are shown in Fig. 4. The fluid temperature reached the maximum value of 65°C. We decided to use this maximum measured value on the test bench. Therefore, the hydraulic fluids were tested under operation temperature.

Hydraulic pump. The hydraulic fluids were tested with the gear pump of type UD 25 (Jihostroj Aero Technology and Hydraulics, Velešín, Czech Republic). The pump is equipped with the hydraulic balancing of axial clearance which is done by sealing in the end face bearings. The hydraulic pump of type UD 25 is used in the Zetor Forterra tractors. Technical parameters are shown in Table 1.

Tested hydraulic fluids. Tests were performed with three hydraulic fluids (HV). The first one to be tested was a mineral oil-based fluid of type HV according to VDMA 24 568 (1994). We tested the mineral oil-based fluid MOL Farm NH Ultra (Slovnaft a.s., Bratislava, Slovak Republic) which is conventionally used in the newest Zetor tractors. A rapeseed oil-based biodegradable fluid of type HETG according to VDMA 24 568 was tested as the second one. This fluid is made of the rapeseed oil and special additives. The last one to be tested was a synthetic oil-based biodegradable fluid of type HEPR according to VDMA 24 568 made of poly-alpha-olefins. At present, this type of fluid is developed. All the fluids have the same area of application (all of them are designed to tractor hydraulic systems) but they were made of different base fluids (crude oil, vegetable oil and synthetic oil) and additives. The tested biodegradable fluids were designed to use in tractors in the future after their tests. All fluids meet the specification SAE 80W, API GL4 for being used in tractors. Three types of fluids (HETG, HEPR and HV) were tested with three hydraulic pumps of the same type (UD 25).

Table 1. The technical parameters of tractor hydraulic pump UD 25 (Jihostroj, 2007)

Nominal displacement		cm^3	25
Rotation speed	nominal	min^{-1}	1,500
	maximum		3,200
	minimum		450
Pressure at the inlet port	maximum	MPa	0.05
	minimum		–0.03
Pressure at the outlet port	max. continuous	MPa	20
	max. pressure		25
	peak pressure		26
Nominal outlet flow rate		l/min	35.1

RESULTS AND DISCUSSION

The first test was performed with the mineral oil-based fluid of type HV. Fig. 5 shows the flow characteristics of the hydraulic pump measured while the mineral oil was tested. The flow characteristics were measured every 250,000 cycles of pressure load.

The loss of flow efficiency $\Delta\eta_{pr\,\mathrm{HV}}$ = –0.19% was calculated according to Eq. (1) on the ground of flow efficiency at 0 cycles $\eta_{pr0\,\mathrm{HV}}$ = 95.95% and flow efficiency after 10^6 cycles $\eta_{prm\,\mathrm{HV}}$ = 96.13% that were calculated according to Eq. (2). These values were determined from the values of flow rates at hydraulic pump nominal pressure 20 MPa (Table 2). The values of flows were obtained from the measurements of flow characteristics (Fig. 5).

During tests, the cleanliness level of fluids was measured in accordance with Standard ISO 4406 (1999). In Fig. 6, it is possible to see the number of contamination particles in the mineral oil-based fluid of type UTTO. The cleanliness level was evaluated concurrently with the measurement of flow characteristics.

The second test was performed with the rapeseed oil-based fluid of type HETG. Fig. 7 shows the flow characteristics of the hydraulic pump measured during the first biodegradable fluid test.

The loss of flow efficiency $\Delta\eta_{pr\,\mathrm{HEES}}$ = 7.3% was calculated according to Eq. (1) on the ground of

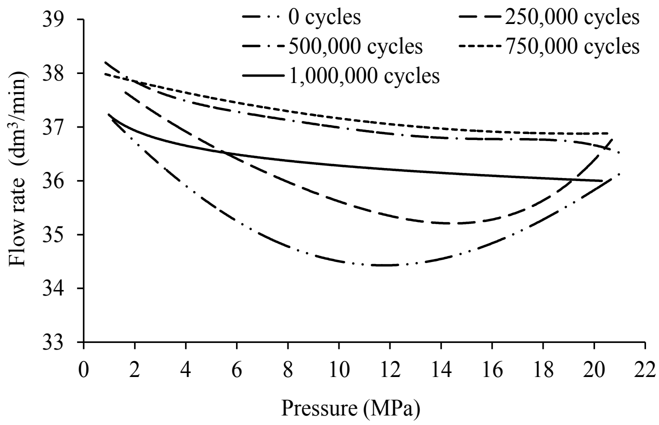

Fig. 5. Flow characteristics of the hydraulic pump of type UD 25 from the test with the mineral oil-based fluid of type HV

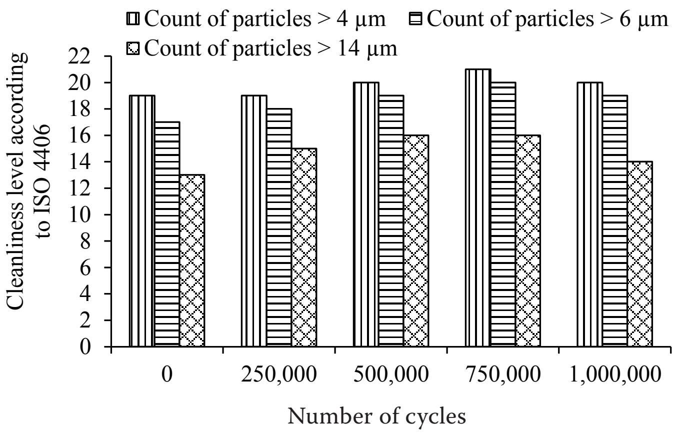

Fig. 6. Cleanliness level of the mineral oil-based fluid of type HV

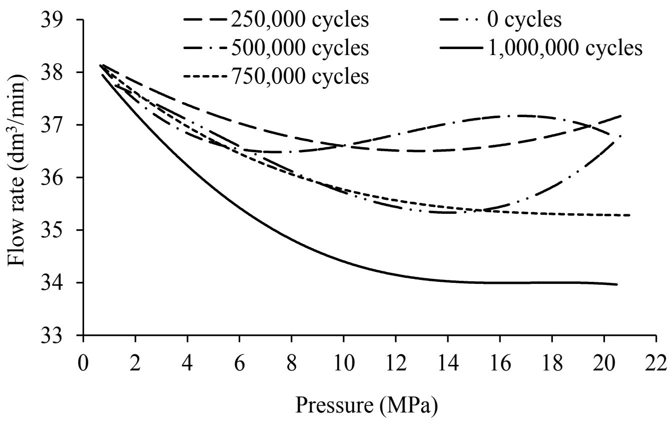

Fig. 7. Flow characteristics of the hydraulic pump of type UD 25 from the test with the rapeseed oil-based biodegradable fluid of type HETG

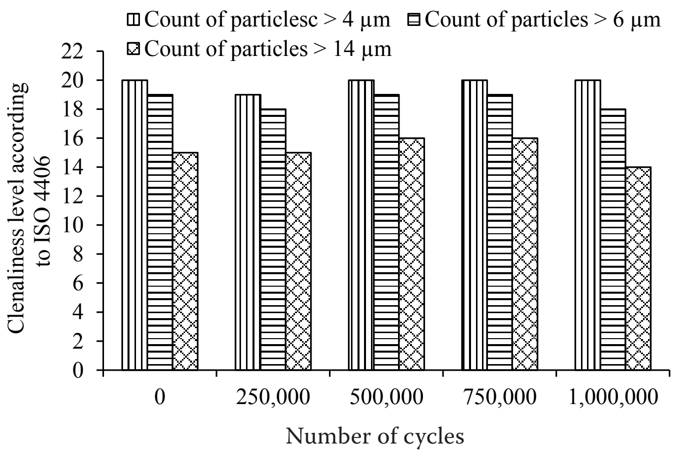

Fig. 8. Cleanliness level of the rapeseed oil-based biodegradable fluid of type HETG

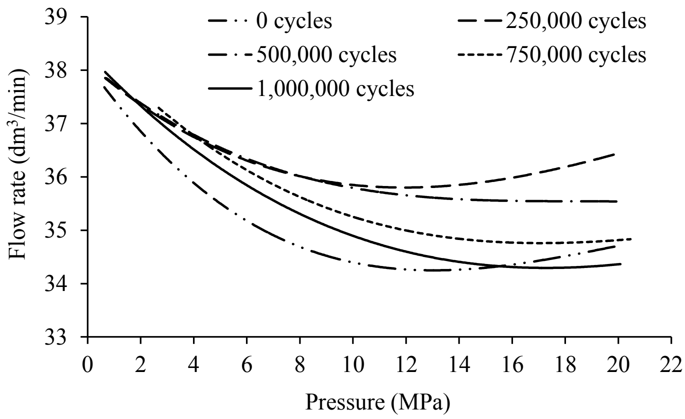

Fig. 9. Flow characteristics of the hydraulic pump of type UD 25 from the test with the synthetic oil-based biodegradable fluid of type HEPR

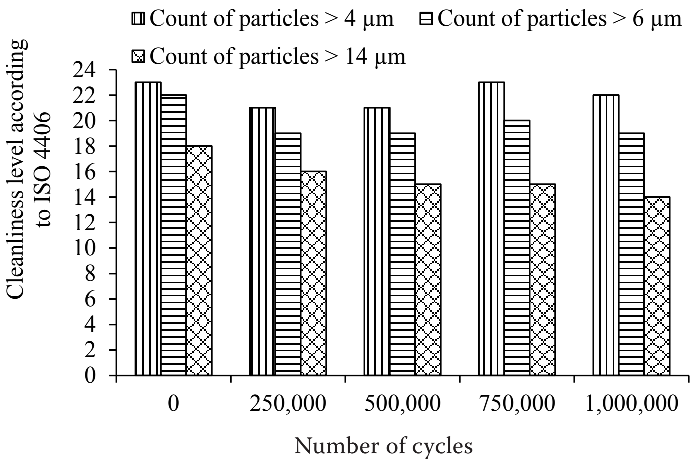

Fig. 10. Cleanliness level of the synthetic oil-based biodegradable fluid of type HEPR

flow efficiency at 0 cycles $\eta_{pr0\ \mathrm{HEES}}$ = 97.5% and flow efficiency after 10^6 cycles $\eta_{prm\ \mathrm{HEES}}$ = 90.4% that were calculated according to Eq. (2). These values were determined from the values of flow rates at hydraulic pump nominal pressure 20 MPa (Table 2). The values of flow rates were obtained from the measurements of flow characteristics (Fig. 7).

Fig. 8 shows the hydraulic pump wear during the test with the biodegradable fluid of type HETG.

The third test was performed with the synthetic oil-based fluid of type HEPR. Fig. 9 shows the flow characteristics of the hydraulic pump measured during the second biodegradable fluid test.

The loss of flow efficiency $\Delta\eta_{pr\ \mathrm{HEPR}}$ = 1.03% was calculated according to Eq. (1) on the ground of flow efficiency at 0 cycles $\eta_{pr0\ \mathrm{HEPR}}$ = 92.5% and flow efficiency after 10^6 cycles $\eta_{prm\ \mathrm{HEPR}}$ = 91.5% that were calculated according to Eq. (2). These values

Table 2. Evaluation of the mineral oil test (HV), the biodegradable fluid test (HETG) and the biodegradable fluid test (HEPR) – rotation speed n = 1,500 min^{-1}

Number of cycles	Mineral oil test (HV)			Biodegradable fluid test (HETG)			Biodegradable fluid test (HEPR)		
	flow rate (l/min)	flow efficiency (%)	loss of flow efficiency (%)	flow rate (l/min)	flow efficiency (%)	loss of flow efficiency (%)	flow rate (l/min)	flow efficiency (%)	loss of flow efficiency (%)
0	35.98	95.95	0	36.55	97.5	0	34.69	92.5	0
250,000	36.46	97.23	–1.3*	37.04	98.8	–1.4*	36.39	97.0	–4.8*
500,000	36.85	98.27	–2.4*	36.63	97.7	–0.2*	35.50	94.6	–2.2*
750,000	36.91	98.43	–2.5*	35.34	94.2	3.2	34.81	92.8	–0.3*
1,000,000	36.05	96.13	–0.19*	33.96	90.4	7.3	34.33	91.5	1.03

*sign minus represents the running-in of the hydraulic pump

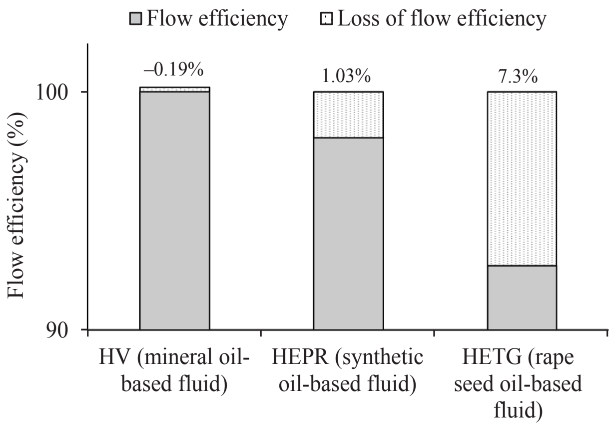

Fig. 11. Evaluation of tests with fluids according to the technical condition of the tractor hydraulic pump

were determined from the values of flow rates at hydraulic pump nominal pressure 20 MPa (Table 2). The values of flow rates were obtained from the measurements of flow characteristics (Fig. 9).

Fig. 10 shows the hydraulic pump wear during the test with the biodegradable fluid of type HEPR.

Various hydraulic fluids can be compared on the basis of tests with the hydraulic pump of type UD 25. The technical condition of the hydraulic pump is expressed by the loss of flow efficiency. A lower wear of the hydraulic pump means better fluid properties. The comparison of three different fluids is shown in Fig. 11.

In case of all tested fluid we can see the increase of flow efficiency due to a running-in of hydraulic pump. During the test the running-up of hydraulic pump hints as excellent lubricating properties of hydraulic fluid. The comparative results were published in the paper of Drabant et al. (2005) where the technical state of gear pump type UN 10L.21 (Jihostroj Aero Technology and Hydraulics, Velešín, Czech Republic) was evaluated after the test of biodegradable fluid Eko Univerzal (Petrochema a.s., Dubová, Slovak Republic). Under the test in the same conditions the running-up finished after 600,000 cycles.

CONCLUSION

We can state on the basis of the results of tests that the mineral oil-based fluid has the best properties, followed by the synthetic oil-based biodegradable fluid, and the rapeseed oil-based biodegradable fluid was classified in the last place (Fig. 11). In the case of mineral oil-based fluid, the hydraulic pump was only running in (Fig. 5). The parameters of the hydraulic pump were better after tests than before them. This state is explained by the loss of flow efficiency $\Delta\eta_{pr\ \mathrm{HV}} = -0.19\%$ and by the minus sign. In the case of synthetic oil-based biodegradable fluid, the flow characteristics increased (Fig. 9) up to 750,000 cycles. The running-in ended at this time. The hydraulic pump wear is expressed by the loss of flow efficiency $\Delta\eta_{pr\ \mathrm{HEPR}} = 1.03\%$. In the case of rapeseed oil-based biodegradable fluid, the flow characteristics raised only up to 500,000 cycles (Fig. 7). The running-in ended at this time. The hydraulic pump wear is expressed by the loss of flow efficiency $\Delta\eta_{pr\ \mathrm{HEES}} = 7.3\%$.

The wear of the hydraulic pump is illustrated by the cleanliness level of the tested fluids. The samples were evaluated in the WearCheck laboratory, Almásfüzitő, Hungary. It can be seen in Figs 6, 8 and 10 that the number of particles during the running-in of the hydraulic pump increases in the same manner as the flow characteristics in Figs 5, 7 and 9. On the other hand, the number of particles starts to decrease when the flow characteristics begin to decrease too. A significant relation between number of particles and wear process of hydraulic pump was found. The explanation for this relation is that the number of particles is larger during the running-in than the operation wear of hydraulic pump.

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