The accelerated laboratory test of biodegradable fluid type "ertto"

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Abstract

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The accelerated laboratory tests can evaluate the properties of new biodegradable fluids under relatively short time. These test results are the ground for the continuity of the tests under operation conditions in machine. The paper presents the test of new biodegradable hydraulic fluid type "Environmentally responsible tractor transmission oil" by designed special test device. The test evaluation was realized by technical state of concrete hydrostatic pump UD 25 which is used in tractors Zetor Forterra. This pump was loaded by cyclic pressure loading during the test with tested fluid. The evaluated parameter was flow efficiency of hydrostatic pump which reached the value 7.3% after the test. The reached value hints a high quality of the tested fluid (the limit value per standard is the flow efficiency decrease – 20%).

Keywords: hydrostatic pump; cyclic pressure loading; testing device; flow characteristics

The hydraulic fluid has to provide various additional functions besides its main function to transmit the pressure energy (Kučera, Rousek 2005). The most common functions result from activities of hydrostatic circuits. These functions relate to the lubrication of the moving components, the rust protection etc. (Mihalčová 2004). The chemical and oxidative stability is coessential as the properties mentioned above because of their influence on economical operation of fluid and all system.

At present, the most perspective production is aimed at the fluids made from the renewable natural resources. The fossil resources for the fluid production are limited and also the environment protection is a very important factor (Wagner et al. 2001). The biodegradable fluids are the solution of both aspects. As was mentioned above, the hydraulic fluids have to meet challenging criteria. Just, the high degree of biodegradation differentiates these biodegradable fluids from fluids made of the crude oil.

The evaluation of properties of newly designed biodegradable fluids is based on various test methods to be progressed. This paper is aimed at the evaluation of a new biodegradable fluid made by the Slovnaft company on the ground of accelerated laboratory test.

MATERIAL AND METHODS

The test description

The fundamental criterion for fluid evaluation in the case of accelerated test is the fluid influence on the durability of concrete type of hydrostatic pump (UD 25). Therefore, the fluid is evaluated on the

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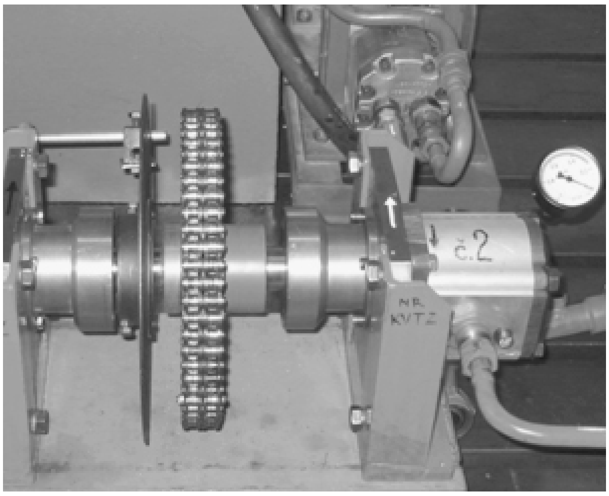

Fig. 1. The hydrostatic pump type UD 25 connected to testing device

ground of technical state of the parts (hydrostatic pump) which is placed in every hydraulic circuits of every machine. The hydrostatic pump is most loaded by fluid under operation conditions. During the test (test takes the time of 10^6 cycles) the hydrostatic pump is loaded by cyclic pressure loading which simulates the hydraulic circuit load under operating conditions. The technical state evaluation of hydrostatic pump according to the flow characteristic and calculation of the flow efficiency are done by fluid evaluation, too. The flow characteristic $Q = f(p)_n$ depends on internal leakages of hydrostatic pump. The new hydrostatic pump has the minimal internal leakages and during the operation it increases. The change of internal leakages affects the change of flow efficiency and flow characteristic. The flow efficiency is calculated on the ground of measured flow under nominal parameters of hydrostatic pump, i.e. pressure of 20 MPa and rotation speed of 1,500 revolutions per min. The maximal flow efficiency decrease is limited by the value of 20% (STN 11 9287).

The flow characteristics were measured during the test (10^6 cycles of pressure loading) in regular intervals every 250,000 cycles. Every measurement was repeated on the ground of the statistical calculations. The characteristics are result of regression analysis done by the MS Excel software.

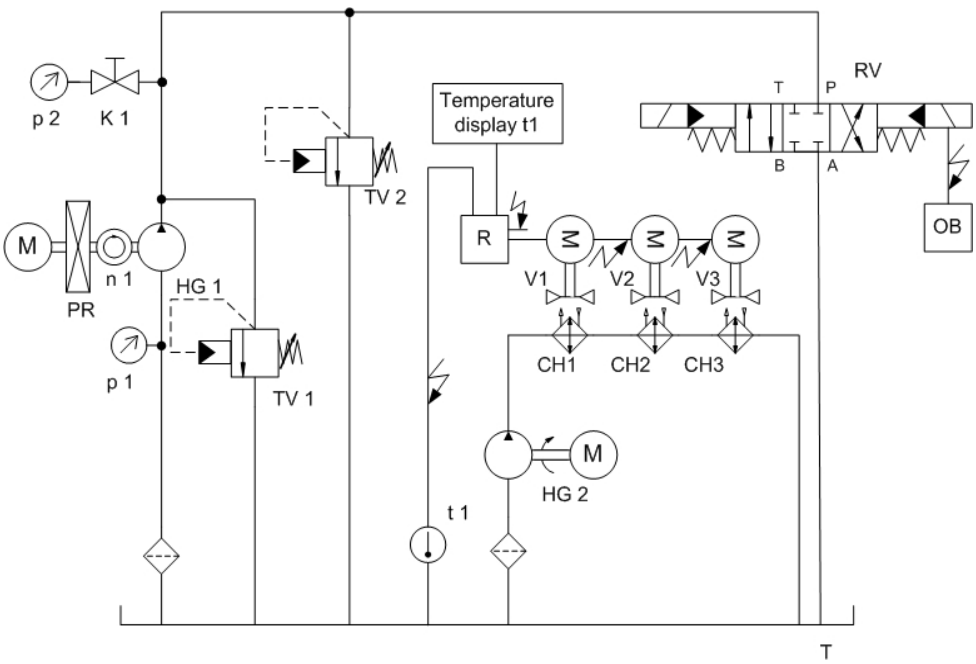

Fig. 2. Testing device for realization of laboratory durability test of hydrostatic pumps (Tkáč et al. 2008): M – electric motor, n 1 – rpm sensor, HG 1 – tested hydrostatic pump, TV 1 – two stage pressure relief valve, TV 2 – two stage sequence valve for adjust nominal pressure in the outlet of hydrostatic pump, p 1 – pressure gauge of pressure in the inlet, p 2 – pressure gauge of pressure in the outlet, K 1 – spherical plug valve, PR – gear box, OB – control block, T – tank, RV – tree-positions, four-port slide valve with closed center which is operated electro-hydraulically, CH 1, CH 2, CH 3 – coolers, V 1, V 2, V 3 – fans, HG 2 –hydrostatic pump for cooler, t 1 – temperature sensor for tank, R – thermostatic regulator which control switching on of cooling fans

The description of hydrostatic pump of UD 25 type

The hydrostatic pump of UD 25 type (Fig. 1) is one-direction hydraulic gear pump made by the Jihostroj Aero Technology and Hydraulics company. This gear pump is equipped with the hydraulic balancing of axial clearance, which is done by sealing in the end face bearings. It is used in smaller and medium agriculture and construction machines. The UD hydrostatic pumps types are used in Zetor tractors and in Tatra commercial vehicles (Jihostroj, Ltd., 2007; Tkáč et al. 2008).

The description of hydraulic fluid type ERTTO

The hydraulic fluid ERTTO (Environmentally responsible tractor transmission oil) is biodegradable tractor oil. The oil is made of natural vegetable oil and special additives. The oil is aimed to use in gearbox and hydraulic circuit of agricultural and construction machines. Primary biodegradation per CEC L-33-A-93 is 90% within 28 days, and by OECD 301 B test method it is 65%. The value of kinematic viscosity under 40°C is 47.89 mm^2/s; viscosity index is 213; pour point is –39°C (Slovnaft, Ltd., 2008).

The test device designed for tests of hydrostatic fluids

The designed test device (Fig. 2 shows the schema) enables to test the hydraulic fluids on the ground of evaluation of technical state of hydrostatic pump which is tested with the fluid. In this case, the load of hydrostatic pump and fluid is realized by cyclic pressure loading under pressure change from p = 0 MPa to nominal pressure p = 20 MPa, frequency f = 1.1 Hz and velocity of pressure increase v = 340 MPa/s. The cyclic pressure loading is technically realized by cyclic change of slide valve position RV. This valve changes its state from central position to left position. The nominal pressure on the outlet of pump is limited by pressure sequence valve TV 2. The test device was designed according to the works published by Drabant et al. (2005) and Petranský et al. (2004).

The test device burdens hydrostatic pump by the cyclic pressure. The characteristic of cyclic pressure loading is shown in Fig. 3 (Radhakrishnan 2003).

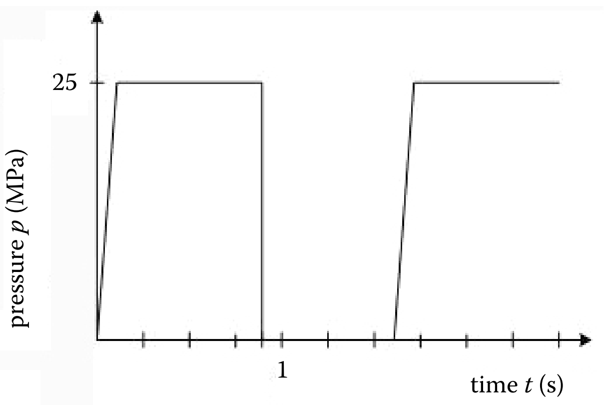

Fig. 3. The characteristic of cyclic pressure loading: p – pressure, t – time (Radhakrishnan 2003)

The device dedicated to flow characteristic measurement

The Fig. 4 shows the schema of designed device dedicated to measurement of flow characteristic. Before every measurement the hydrostatic pump (marked as HG 2), which is used during the test, was dismounted from the test device (Fig. 2) and mounted to device for flow characteristic measurement (Fig. 4). The circuit with the tank T 1 serves for drive of measured hydrostatic pump HG 2. The pressure sensor (s.p.), flow sensor (s.Q.) and temperature sensor (s.t.) are connected to the output of hydrostatic pump which is placed in second circuit with tank T 2. During the measurement the pressure sequence valve adjusts the pressure in range from p = 0 MPa to nominal p_n = 20 MPa. During the continuous pressure change the flow is measured for characteristic $Q = f(p)_n$. All parameters are recorded by digital device HMG 2020.

The count of flow characteristic measurements repetition

The measurement chain is oscillating during the flow characteristic measurement. In consequence, the flow value must be processed from measured values.

The required count of flow values can be stated on the ground of the calculation per equation as follows (Rataj 2003):

$$n = \frac{V_k^2 \times t_\beta^2}{\delta^2} \quad (1)$$

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

The statistical processing of measured values

The arithmetical average was used for calculation of average value from measured values $\bar{x}$:

$$\bar{x} = \frac{1}{N} \times \sum_{i=1}^{n} x_i \quad (2)$$

where:
N – file size
i – signature i of variable value in file
x_i – value of variable in file

Flow conversion by reason of rotation speed change

In the test device the three-phase electromotor was used which cannot provide constant rotation speed during the measurement. Therefore, the actual rotation speed was measured by speedometer. For construction of flow characteristic the flow values after conversion on 1,500 per min were used. Seeing that, the volume losses are constant under less rotation speed change (1,500 ± 75) per min the flow efficiency η_{pr} is constant, too. Therefore, we can write equation (Varchola 1992):

$$\eta_{pr1} = \eta_{pr2}$$

$$\frac{Q_1}{V_G \times n_1} = \frac{Q_2}{V_G \times n_2} \quad \text{after modification:}$$

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

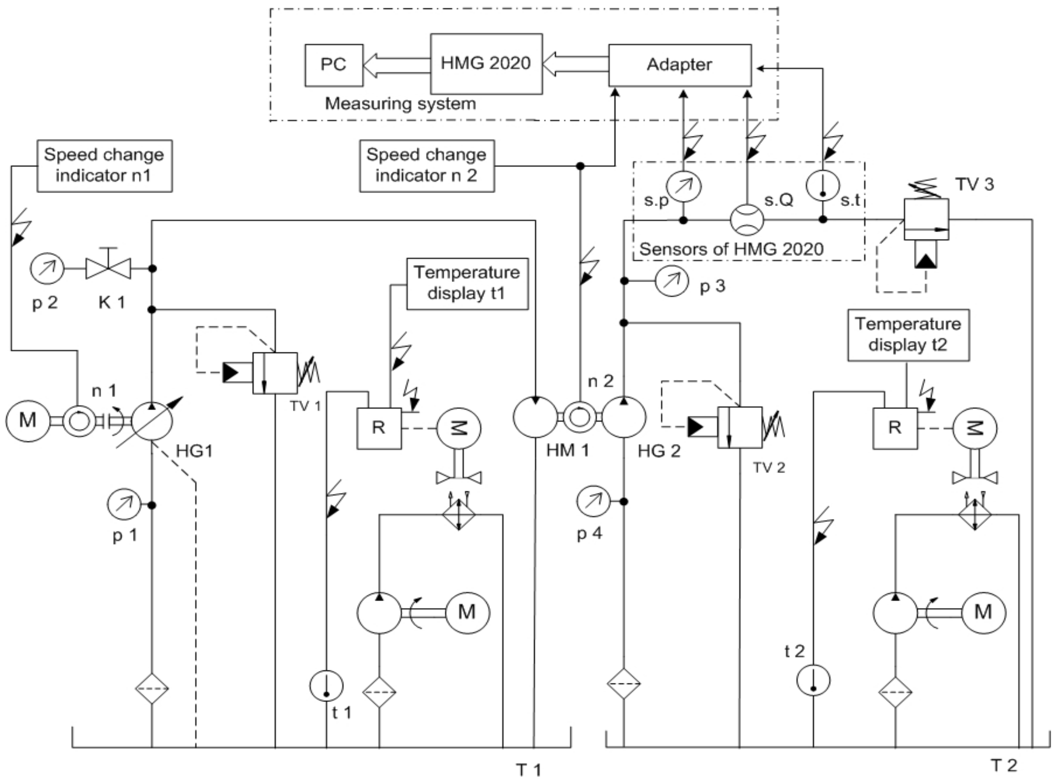

Fig. 4. Testing device for measurement of flow characteristics of hydrostatic pumps (Tkáč et al. 2008): M – electric motor, n 1, n 2 – rpm sensors, HG 1 – variable axial piston pump, TV 1, TV 2 – two stage pressure relief valves, K 1 – spherical plug valve, HM 1 – angled piston motor, HG 2 – tested hydrostatic pump, TV 3 – two stage sequence valve for pressure adjustment, s.p. – pressure sensor, s.Q. – flow rate sensor, s.t. – temperature sensor, R – thermostatic regulators of oil temperature, T 1, T 2 – tanks, p 1, p2, p 3, p 4 – pressure gauges

where:
Q_1 – flow measured at the rotation speed n_1 (dm^3)
Q_2 – flow at required rotation speed n_2 (dm^3/min)
V_G – geometric volume of hydrostatic pump (dm^3/min)
η_{pr1} – flow efficiency during measurement of flow
η_{pr2} – flow efficiency at required rotation speed n_2

The calculation of flow efficiency decrease

The standard STN 11 9287 dictates the way for the evaluation of the test. The fluid must be evaluated per flow efficiency decrease of hydrostatic pump as follows:

$$\Delta\eta_{pr} = \frac{\eta_{pr0} - \eta_{prm}}{\eta_{pr0}} \times 100 \quad (\%) \qquad (4)$$

where:
$\Delta\eta_{pr}$ – the flow efficiency decrease (%)
η_{pr0} – the flow efficiency 0 cycles
η_{prm} – the flow efficiency after 10^6 cycles
Then, the flow efficiency is expressed by equation:

$$\eta_{pr} = \frac{Q_2}{V_G \times n} \times 100 \quad (\%) \qquad (5)$$

where:
Q_2 – conversed flow (dm^3/min)
V_G – geometrical volume of hydrostatic pump (dm^3)
n – nominal rotation speed of hydrostatic pump (1/min)

RESULTS AND DISCUSSION

The required count of measurement repetition

The count of repetition was calculated per Eq. (1) on the ground of variation coefficient V_k = 22.3%. The calculation was based on maximul error allowed 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 repetitions. The measurement system composes of digital record device HMG 2020 and sensors. The system records measured values in time interval 0.05 s. Therefore, the count of values (n = 43), which was calculated per Eq. (1) we obtain from 4 measurements of flow characteristic.

The flow characteristics of hydrostatic pump from the test of fluid type ERTTO

The characteristics (Fig. 5) were obtained by regression analysis and regression model of third degree polynomial type.

Fig. 6 shows the values obtained in the flow measurements. The two most important measurements,

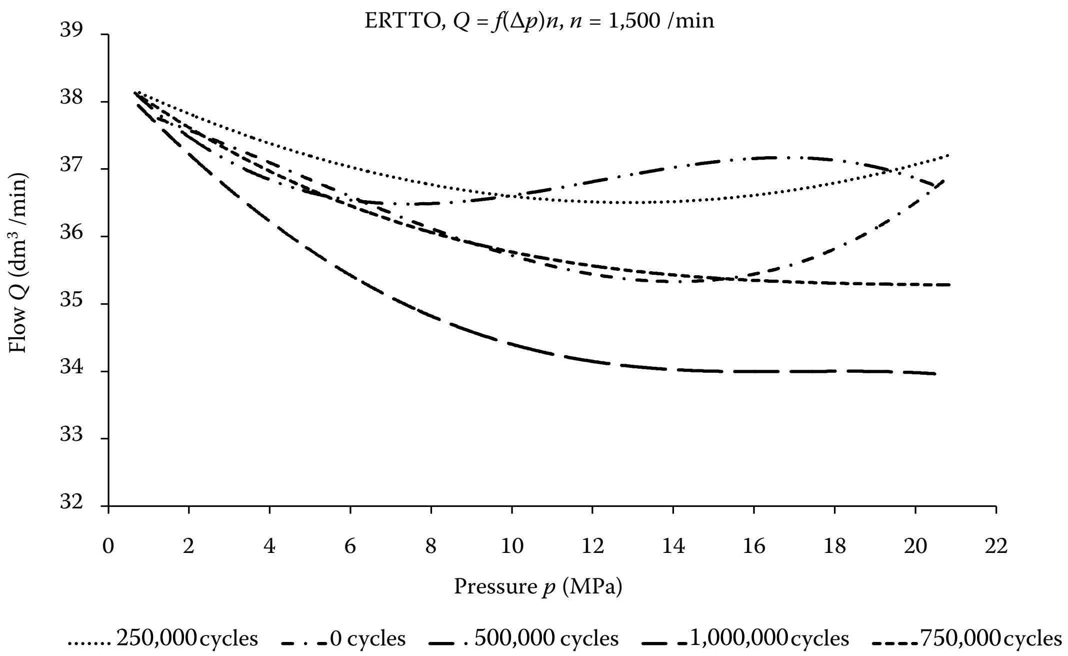

Fig. 5. Flow characteristics from the test of fluid type ERTTO

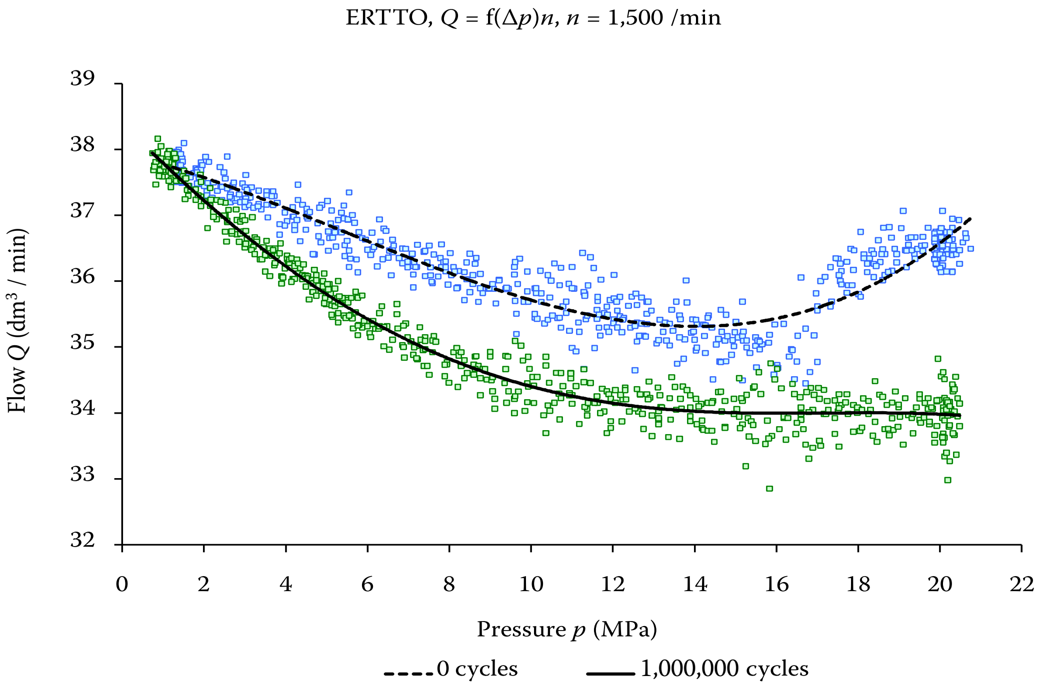

Fig. 6. Measured values for flow characteristics

namely 0 cycles and 10^6 cycles, were selected. The flow characteristics were made with MS Excel by regression analysis with the use of polynomial model of three degree.

The average values of measured flows

The average value under 0 cycles Q_0 = 36.549 dm^3 per min (the start of the test) is arithmetical average of 43 measured flow values (Table 1) and was calculated per Eq. (2).

The average flow value under 10^6 cycles Q_m = 33.958 dm^3/min (the end of the test) is arithmetical average of 43 measured flow values (Table 2) and was calculated per Eq. (2).

The calculation of flow efficiency decrease

The flow efficiency decrease $\Delta\eta_{pr}$ = 7.3% was calculated per Eq. (4) on the ground of flow efficiency under 0 cycles η_{pr0} = 97.4% and flow efficiency after 10^6 cycles η_{prm} = 90.5% calculated per Eq. (5).

Table1. Measured values of flow under pressure 20 MPa – start of the test

No.	Flow Q_0 (dm^3/min)	No.	Flow Q_0 (dm^3/min)	No.	Flow Q_0 (dm^3/min)	No.	Flow Q_0 (dm^3/min)
1	36.13	12	36.40	23	36.58	34	36.72
2	36.19	13	36.40	24	36.59	35	36.72
3	36.23	14	36.46	25	36.59	36	36.74
4	36.25	15	36.46	26	36.62	37	36.74
5	36.26	16	36.47	27	36.63	38	36.74
6	36.26	17	36.48	28	36.64	39	36.75
7	36.34	18	36.52	29	36.65	40	36.80
8	36.34	19	36.52	30	36.65	41	36.81
9	36.39	20	36.54	31	36.66	42	36.74
10	36.39	21	36.54	32	36.71	43	36.94
11	36.39	22	36.54	33	36.72		

Table 2. Measured values of flow under pressure 20 MPa – end of the test

No.	Flow Q_m (dm^3/min)	No.	Flow Q_m (dm^3/min)	No.	Flow Q_m (dm^3/min)	No.	Flow Q_m (dm^3/min)
1	32.98	12	33.78	23	34.05	34	34.17
2	33.26	13	33.80	24	34.05	35	34.17
3	33.34	14	33.81	25	34.06	36	34.18
4	33.39	15	33.82	26	34.06	37	34.18
5	33.55	16	33.86	27	34.08	38	34.19
6	33.55	17	33.88	28	34.08	39	34.22
7	33.62	18	33.92	29	34.10	40	34.22
8	33.62	19	33.93	30	34.15	41	34.51
9	33.63	20	33.96	31	34.15	42	34.55
10	33.66	21	33.96	32	34.16	43	34.61
11	33.68	22	34.03	33	34.16		

CONCLUSION

The biodegradable fluid type ERTTO was tested with special test device using hydrostatic pump type UD 25 of a concrete type of agricultural tractor, Zetor Forterra. The test device was designed in order to test fluid loads in the hydrostatic pump by cyclic pressure loading. The cyclic pressure loading has the form as given in Fig. 3 and it fulfils limit stated in the standard STN 11 9287. On the ground of this standard all the test was evaluated. The flow efficiency decrease reaches the value $\Delta\eta_{pr}$ = 7.3%. The standard reports maximal flow efficiency decrease as 20%. The value of tested fluid is thus greatly below this value. On the ground of the test results we can say that the tested biodegradable fluid is a high quality product.

The comparative results were published in papers of Petranský et al. (1995). The object of his research was gear pump PZ-2-18-KS-2 used in tractors ZTS UR II in that time. In the test according the same standard STN 11 9287 the running-up finished after 600,000 cycles. Drabant et al. (2005) evaluated the technical durability of gear pump type UN 10L.21 used in tractors ZTS UR IV. This test was characterized by flow efficiency decrease $\Delta\eta_{pr}$ = 3.77% after 10^6 cycles.

The test was realized in cooperation with company Slovnaft, Ltd., a member of MOL (Hungary's oil company) group. The petroleum company will use the results in this research in the area of application of new biodegradable hydraulic fluids.

In the near future the last test of this fluid under operation conditions in hydraulic circuit of tractor Zetor Forterra will be carried out.

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