Research of new ecological synthetic oil-based fluid

Výskum vlastností novej ekologickej syntetickej kvapaliny

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Abstract

This paper presents the evaluation of a newly developing synthetic-based hydraulic fluid MOL Farm UTTO Synt, developed by MOL Group, Hungary. The fluid was subjected to a laboratory test by using a gear hydrostatic pump UD 25, which is used in the latest Zetor Fortera tractors. During the test, flow values were statistically evaluated and graphically displayed in the form of flow characteristics and the loss of flow efficiency. On the basis of laboratory test results, it can be concluded that the newly developing fluid meets the specified requirements and it is possible to continue in testing under operating conditions.

Keywords: flow efficiency, hydrostatic pump, synthetic-based hydraulic fluid

Abstrakt

Príspevok je zameraný na hodnotenie novovyvíjanej hydraulickej syntetickej kvapaliny MOL Farm UTTO Synt, vyvíjanej spoločnosťou MOL Group, Maďarsko. Kvapalina bola podrobená laboratórnemu testu za použitia zubového hydrogenerátora UD 25, ktorý sa používa v najnovších traktoroch Zetor Forterra. Počas skúšky boli hodnoty získaných prietokov štatistický spracované a následne graficky vyhodnotené vo forme prietokových charakteristík a poklesu prietokovej účinnosti hydrogenerátora. Na základe výsledkov laboratórnej skúšky je možné konštatovať, že novovývíjaná kvapalina vyhovuje stanoveným požiadavkám a je možné pokračovať v skúškach v prevádzkových podmienkach.

Kľúčové slová: hydrogenerátor, prietoková účinnosť, , syntetická hydraulická kvapalina

Introduction

At present, technical means are at such a high level that there is space for the search and application of innovations that are based on environmental protection.
This has resulted in the development and production of lubricants that originate in renewable natural raw materials, either by reason of limited resources of fossil raw materials but also because of environmental protection (Wagner et al., 2001).

Hydraulic systems are complicated and diverse systems, essentially the same basic actions of which affect the good functioning of machine (Ileninová et al., 2008). The right choice of working medium has also a high impact on a failure-free operation. Momentary, hydraulic systems of mobile machinery are using mainly mineral oils having good properties proven by many years of use (Majdan, 2009). This fact is confirmed also by Jobbágy et al. (2003) and Sloboda et al. (2002).

For environmental reasons, it is important to replace mineral fluids by vegetable fluids or synthetic-based fluids (Tkáč et al., 2010). Understandably, biodegradable fluids have slightly different properties compared with petroleum-based fluids (Rédl et al., 2012). Therefore, we are dealing with the evaluation of properties of a newly developing synthetic-based fluid as a potentially possible substitute for mineral-based fluids.

Materials and Methods

The used ecological fluid is a newly developing ecological fluid, which is made of synthetic fluid based on poly-alpha-olefins. We have chosen this fluid because it has a high chemical stability and miscibility with mineral fluids, which are currently used in tractors in Slovakia. During the test, we used a new ecological fluid MOL Farm UTTO Synt produced by MOL Group, Hungary. This fluid belongs to the group of universal transmission hydraulic fluids designed for tractors. The main specifications of this fluid are listed in Table 1.

Table 1: Specification of synthetic-based hydraulic fluid MOL Farm UTTO Synt

Parameter	**Unit**	**Value**
Kinematic viscosity at 100 °C	mm^2*s^{-1}	10.22
Kinematic viscosity at 40 °C	mm^2*s^{-1}	58.14
Viscosity index *VI*	-	165
Pour point	°C	-42

Majdan et al. (2012) evaluated fluid properties under laboratory conditions on the basis of wear of the sliding pair of a pin and bearing. The test was evaluated on the basis of geometric dimensions and the shape of the pin and bearing. In our case, we performed the laboratory test on the basis of hydrostatic pump technical condition.

The tested synthetic-based fluid was used in a test device that loaded the hydrostatic pump UD 25. The hydrostatic pump belongs to one-way hydrostatic pumps, which are used in the latest Zetor Forterra tractors for a common gear-hydraulic fill. The test device published by Hujo (2012), Kosiba (2012), Majdan (2012) and Tkáč (2008) was designed at the Department of Transport and Handling, Faculty of Engineering, Slovak University of Agriculture in Nitra.

The principle of test device operation is in loading the hydrostatic pump by cyclic pressure load using an electro-hydraulic control valve, which is connected to the output of the hydrostatic pump. A change in the control valve position will change the direction of fluid flow, which then flows through the pressure relief valve into the tank or directly into the tank with fluid. These directional changes of flow result in pressure changes at the hydrostatic pump output. The hydrostatic pump is loaded with cyclic pressure load for the duration of 10^6 cycles, at rated parameters (Tkáč, 2010).

During the fluid test, flow values are recorded in specified intervals at rated parameters (pressure – 20 MPa, operating speed – 1,500 min^{-1}), using a digital recording unit HMG 2020 (Figure 1). After statistical evaluation of flow values, there is calculated the loss of flow efficiency, the limit value of which is 20 %.

Figure 1: Digital recording unit HMG 2020

Statistical method for evaluation of results from the laboratory test of the hydrostatic pump

Arithmetic average – in statistics and mathematics, it is the formula for such a mean value, which is calculated from all statistical units of population. We have a sequence of real numbers $x_1,\ldots, x_N$. The arithmetic average (mean arithmetic value) of this series of numbers is defined as:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (1)$$

where

n – population size

x_i – individual values of population

Variance – the most used measure of variability is variance, which is equal to the average square of deviation from the average. The higher the variance, the more are data deviating from the average:

$$s^2 = \frac{1}{n}\sum_{i=1}^{n} \left(x_i - \bar{x}\right)^2 \qquad (2)$$

where:

n – population size

x_i – individual values of population

$\bar{x}$ – arithmetic average of population

Standard deviation *σ* is defined as a positive square root of variance. Standard deviation is calculated if we have a complete set of possible states of the process (system). In probability theory and in statistics, standard deviation or mean square deviation is a measure of statistical dispersion. Simply said, it refers to how widely the values in a set are distributed (Hill, Lewicky, 2006).

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad (3)$$

where:

n – population size

x_i – individual values of population

$\bar{x}$ – arithmetic average of population

Variation coefficient *k* is a relative measure of variability. It is used for comparing the variability between datasets with different averages. It is calculated as standard deviation divided by arithmetic average.

$$k = \frac{s}{\bar{x}} \qquad (4)$$

where:

$\bar{x}$ – arithmetic average of population

s – standard deviation

Normal distribution $N(\bar{x}, \sigma^2)$

We say that a continuous random variable *x* has normal (Gaussian) distribution with parameters $\bar{x}$, σ^2 if density is:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}}.e^{-\frac{(\bar{x}-\alpha)^2}{2\sigma^2}} \quad \text{for} \quad x \in R_1, \alpha \in (-\infty, \infty), \sigma > 0 \qquad (5)$$

where:

e – base of natural logarithm

σ – standard deviation

$\bar{x}$ – arithmetic average of population

If a variable *x* has normal distribution with parameters $\bar{x}$, σ^2, then after transformation:

$$Z_i = \frac{x_i - \bar{x}}{\sigma} \qquad (6)$$

where:

σ – standard deviation

x_i – individual values of population

$\bar{x}$ – arithmetic average of population

z_i – variable with normal distribution

The variable has normal distribution with mean value zero and variation 1 (then standard deviation is also 1). This distribution is called as standardized normal distribution (Hill, Lewicky, 2006).

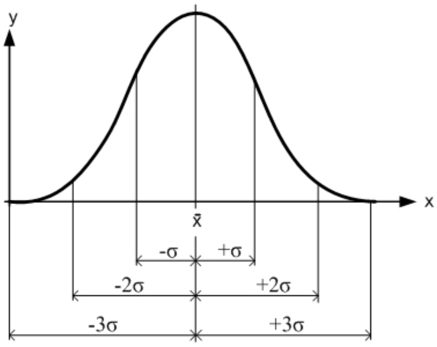

Figure 2: Normal distribution

1. When selecting a value from the range –1σ, +1σ, the probability of standard normal distribution is 68.27 %;

2. When selecting a value from the range –2σ, +2σ, the probability of standard normal distribution is 95.46 %;

3. When selecting a value from the range –3 σ, +3σ, the probability of standard normal distribution is 99.73 % (Figure 2).

When using a larger range, it is less likely that the process will run incorrectly, including the case when measured values are outside of control limits, and they are caused by random deviations. The use of a wider range makes it difficult to identify changes in the process that are non-random and must be determined (Figure 2).

Formulas for calculation of parameters characterizing the technical condition of the hydrostatic pump

The hydraulic fluid is evaluated based on the technical condition of the hydrostatic pump, i.e. based on the loss of flow efficiency. The loss of flow efficiency is defined by percentages:

$$\Delta\eta_{pr} = \frac{\eta_{pr0} - \eta_{prm}}{\eta_{pr0}} \cdot 100, \% \qquad (7)$$

where:

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

η_{pr0} – flow efficiency at 0 cycles

η_{prm} – flow efficiency after 10^6 cycles

The calculation is based on consideration that the measured flow is equal to the flow calculated from theoretical flow and flow efficiency (Petranský et al., 2004):

$$Q = Q_t . \eta_{pr} = V_G . n . \eta_{pr}, \ dm^3 * min^{-1} \qquad (8)$$

where:

η_{pr} – flow efficiency, %

Q – measured flow, dm^3*min^{-1}

Q_t – theoretical flow, dm^3*min^{-1}

V_G – geometrical volume, dm^3

n – speed of hydrostatic pump, min^{-1}

Flow efficiency is then given by:

$$\eta_{pr} = \frac{Q}{V_G.n} .100 \text{, \%} \quad (9)$$

where:

V_G – geometrical volume, dm^3

n – speed of hydrostatic pump, min^{-1}

Q – measured flow, dm^3*min^{-1}

Results and Discussion

The values of flow were statistically evaluated. From values of this sample, we have calculated the arithmetic average according to Equation (1), standard deviation (3) and variation coefficient (2). Then, sample values were converted to a standardized (normalized) form on the basis of Equation (6). The values of the sample of flows and their standardized values are shown in Tables 2, 3. Based on the selection of interval -1σ and +1σ, there were chosen 68.27 % of flow values. Then, flow efficiency (9) and the loss of flow efficiency (7) were calculated from this sample of flow values.

Table 2: Statistical flow values of the new hydrostatic pump UD 25

N	Q dm^3*min^{-1}	SF	N	Q dm^3*min^{-1}	SF
1	34.77	2.28	36	***34.01***	***-0.14***
2	34.83	2.05	37	***34.41***	***-0.14***
3	34.74	2.05	38	***35.06***	***-0.14***
4	35.13	2.05	39	***34.57***	***-0.14***
5	34.93	2.05	40	***34.72***	***-0.14***
6	34.41	1.70	41	***34.65***	***-0.14***
7	34.55	1.70	42	***34.98***	***-0.14***
8	35.00	1.35	43	***34.99***	***-0.49***
9	34.93	1.12	44	***34.71***	***-0.49***
10	34.73	1.12	45	***34.48***	***-0.49***
11	***34.34***	***0.78***	46	***34.40***	***-0.49***
12	***34.48***	***0.78***	47	***34.55***	***-0.49***
13	***34.72***	***0.78***	48	***35.57***	***-0.49***
14	***34.42***	***0.78***	49	***35.06***	***-0.72***
15	***34.61***	***0.78***	50	***34.78***	***-0.72***
16	***34.68***	***0.92***	51	***35.24***	***-0.72***
17	***34.67***	***0.92***	52	***34.73***	***-0.72***
18	***34.58***	***0.92***	53	***35.13***	***-0.72***
19	***34.67***	***0.92***	54	***33.95***	***-0.72***
20	***35.06***	***0.93***	55	34.62	-1.07
21	***34.48***	***0.92***	56	34.80	-1.07
22	***34.67***	***0.92***	57	34.55	-1.07
23	***35.44***	***0.94***	58	34.48	-1.07
24	***34.03***	***0.91***	59	34.66	-1.07
25	***35.00***	***0.93***	60	34.71	-1.41
26	***34.55***	***0.92***	61	34.29	-1.41
27	***35.43***	***0.94***	62	34.48	-1.41
28	***34.04***	***0.91***	63	34.35	-1.41
29	***34.41***	***0.92***	64	34.87	-1.41
30	***34.78***	***0.93***	65	34.81	-1.41
31	***34.62***	***0.20***	66	34.73	-1.41
32	***34.61***	***0.20***	67	34.23	-1.41
33	***34.47***	***0.20***	68	34.59	-1.41
34	***34.55***	***0.20***	69	34.15	-1.41
35	***35.06***	***-0.14***			

Table 3: Statistical flow values of the hydrostatic pump UD 25 (end of test)

N	Q dm^3*min^{-1}	SF	N	Q dm^3*min^{-1}	SF
1	34.94	1.93	36	***33.70***	***0.03***
2	34.18	1.93	37	***34.24***	***0.03***
3	34.25	1.78	38	***34.53***	***0.03***
4	33.83	1.56	39	***34.28***	***0.03***
5	34.29	1.34	40	***34.33***	***-0.19***
6	34.10	1.34	41	***34.28***	***-0.19***
7	34.22	1.20	42	***34.00***	***-0.19***
8	34.22	1.20	43	***34.41***	***-0.19***
9	34.05	1.20	44	***34.50***	***-0.41***
10	34.25	1.20	45	***33.84***	***-0.41***
11	34.55	1.20	46	***34.39***	***-0.41***
12	***33.84***	***0.98***	47	***34.88***	***-0.41***
13	***34.32***	***0.98***	48	***34.48***	***-0.55***
14	***34.65***	***0.98***	49	***33.93***	***-0.55***
15	***34.41***	***0.98***	50	***34.17***	***-0.55***
16	***33.78***	***0.76***	51	***33.78***	***-0.55***
17	***34.70***	***0.76***	52	***33.53***	***-0.77***
18	***34.18***	***0.76***	53	***34.72***	***-0.77***
19	***34.54***	***0.76***	54	***33.82***	***-0.77***
20	***34.51***	***0.61***	55	***34.25***	***-0.77***
21	***34.20***	***0.61***	56	***35.14***	***-0.92***
22	***34.73***	***0.61***	57	***34.35***	***-0.92***
23	***34.36***	***0.61***	58	33.80	-1.14
24	***34.01***	***0.39***	59	34.32	-1.14
25	***34.45***	***0.39***	60	34.45	-1.36
26	***34.28***	***0.39***	61	34.41	-1.36
27	***34.75***	***0.18***	62	34.30	-1.36
28	***34.65***	***0.18***	63	34.00	-1.36
29	***34.74***	***0.18***	64	34.55	-1.50
30	***34.04***	***0.18***	65	34.20	-1.50
31	***34.53***	***0.18***	66	33.41	-1.94
32	***34.99***	***0.18***	67	34.91	-1.94
33	***34.68***	***0.18***	68	34.26	-1.94
34	***34.43***	***0.18***	69	34.42	-1.94
35	***33.88***	***0.03***			

Selected values of the sample were graphically evaluated in the form of flow characteristics of the new hydrostatic pump before and after the test (Figure. 3).

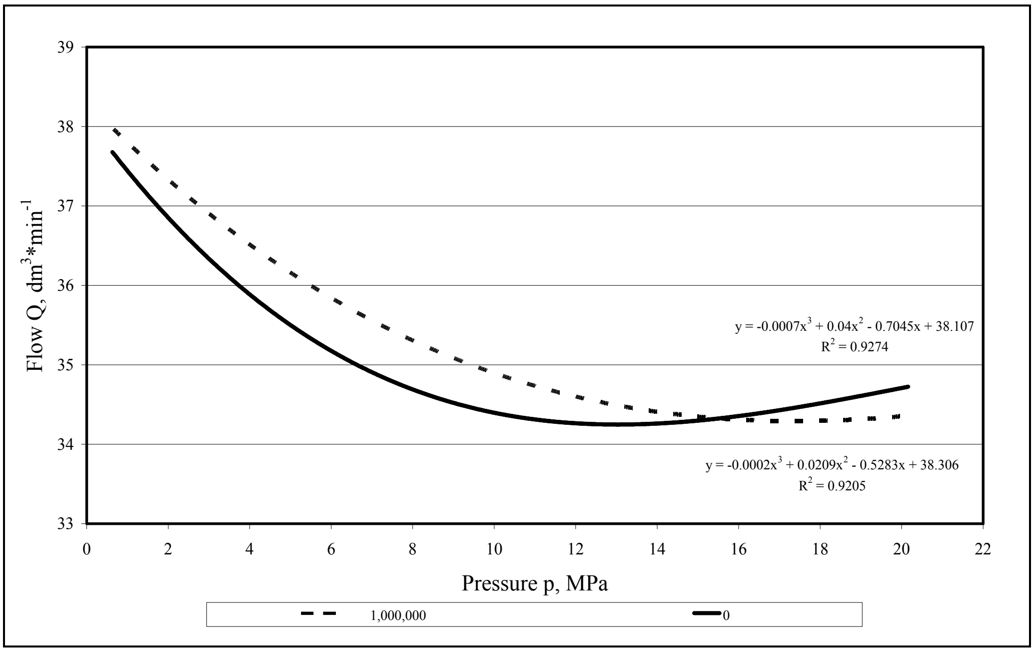

Figure 3: Flow characteristic of hydrostatic pump UD 25

In the graph, we compared the flow characteristics of the new hydrostatic pump before and after the test. The flow characteristics indicate that the hydrostatic pump after the test showed wear due to the loss of flow.

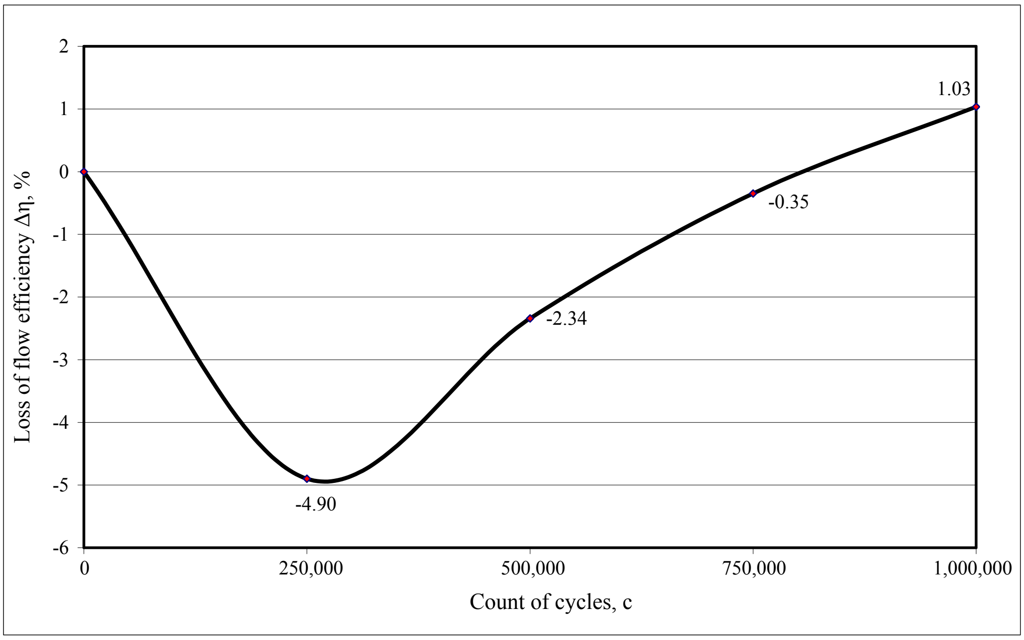

Figure 4: Loss of flow efficiency

From the course of the loss of flow efficiency of the hydrostatic pump that worked with the newly developing synthetic-based fluid MOL Farm UTTO Synt, evaluated every 250,000 cycles, it can be seen that up to 250,000 cycles, the hydrostatic pump improved its operating parameters. There was a negative loss of flow (-4.90 %). The running-up of the hydrostatic pump continued up to about 750,000 cycles. From this moment, there was observed the operational wear of the hydrostatic pump, and at the end of test, there was found a 1.03 % loss of flow efficiency.

Conclusions

This paper is aimed at the evaluation of properties of the newly developing synthetic-based fluid MOL Farm UTTO Synt, which was subjected to the life test of the hydrostatic pump UD 25 performed in the laboratory of the Department of Transport and Handling, Faculty of Engineering, Slovak University of Agriculture in Nitra. The evaluation of this fluid was based on the statistical evaluation of measured values, where the values of the sample were transformed into a standardized form (standard normal distribution). On the basis of statistical analysis, flow values were prepared in a graphic form. From the result of the loss of flow efficiency, it is likely that up to about 750,000 cycles, the hydrostatic pump showed better operating properties than at the beginning of the test (negative value of the loss of flow efficiency). It was therefore the process of hydrostatic pump running-up. After completion of the test, we found a 1.03 % loss of flow efficiency, indicating the beginning of operating wear. The loss of flow efficiency did not exceed the limit value (20 %), and the hydrostatic pump UD 25 has very good operating properties with synthetic-based fluid. On the basis of this fact, it is possible to continue with fluid test under operating conditions without further risk.

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