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Some rheological properties of new and used mineral lubricant and biolubricant for tractors

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Abstract. It is important to know physical characteristics of lubricating oils to ensure the highest reliability for operation of device. The use of ecological lubricants depends on their characteristics; the most important are density and viscosity, protection against wear and tear, corrosion resistance etc. The objective of this work was to find changes of the rheological properties of the synthetic oil and bio lubricant. We compared two different oils in our measurements. One sample was synthetic oil and the other was mineral oil (bio lubricant). Both oils are universal oils for tractors. Further, comparison of new and used sample after million cycles was performed. The density and the dynamic viscosity show strong exponentially decreasing dependence. With the increasing temperature, values of the both properties, decreased. It can be also observed that used samples have lower viscosity and density. The results presented in this article can be important when putting ecological lubricants into operation.

Key words: dynamic viscosity, density, ecological oil ertto, fluidity, kinematic viscosity, mineral oil ultra.

INTRODUCTION

Environmentally friendly hydraulic fluids have specific characteristics determined by their readily biodegradable. The main conditions required for biodegradable lubricants imply that they must be readily biodegradable and they cannot have toxic effect on organisms in the environment where they have penetrated. The biggest risk arises when the hydraulic fluid gets into surface waters and ground waters (Rusnák et al., 2009). One of the ways to reduce the adverse effects on the ecosystem caused by the use of lubricants is to replace petroleum base oil with biodegradable products. The aim of the article is to compare rheological characteristics (density and viscosity) of mineral oil with ecological oil. We compared new samples with samples after accelerated test of million cycles of pressure stress.

‘Majdan & Tkáč (2008) dealt with comparison of ecological fluid Ertto and mineral oil Ultra, too.’ They studied flow characteristics and stated that ecological fluid does not have negative impact on lifetime of pump. ‘Majdan et al. (2016) did research on a universally useful filtration system for increasing the cleanliness level of biodegradable oils.' 'Bell (1993) states that the oil must remain fluid under all conditions to perform its functions, ideally maintaining the right physical properties to perform them efficiently'. The viscosity of the oil plays a predominant role. High viscosity oils would be favored simply to prevent wear. Many other publications, e.g. Guo et al. (2007), Mang & Dresel (2007) and Albertson et al. (2008) have suggested that density and dynamic viscosity show high temperature dependence while measuring, particularly when increasing the temperature, the value of density and dynamic viscosity decreased.' 'Sejkorová et al. (2017) presented measurement of dependence of viscosity on wear and tear (mileage) in their article, while presenting graphical dependencies of decreasing value of viscosity with the increasing wear and tear.' 'Nedić et al. (2009) observed the value of viscosity up to prescribed interval of substitution in their article.' 'Some other parameters, which define operating instructions of ecological oils were studied in Tóth et al. (2014).' 'According to Sejkorová et al. (2017) one of the reasons for decreasing viscosity could be intrusion of impurities from circulatory system into oil.' The low viscosity of oil means too thin film, which could lead to bigger wear and tear of device. It means that lower viscosity causes bigger wear and tear. 'Tkáč et al. (2017) consider oils as a media that helps to obtain information on processes and changes in the systems they lubricate.'

MATERIAL AND METHODS

We compared two different oils in our measurements. One sample was synthetic oil and the other was biolubricant. Both oils are universal oils for tractors. They are used for greasing of transmissions, hydraulic circuits and wet brakes of agricultural and construction machinery. Mol Traktol Ertto (Environmentally Responsible Tractor Transmission Oil) is an ecological oil which is biodegradable according to CEC L-33-A-93 (28 days) almost 91%.

Production of oil is based on the basis of vegetable oil with addition of special types of additives. Oil is especially suitable for machines working near water sources or the forest environment. Thanks to high rate of biodegradability, oil MOL Traktol NH Ultra can be categorized as mineral oil of type HV. It reaches almost 45% of biodegradability according to CEC L-33-A-93 (28 days).

Test was realized on a special test device according to the standard STN 11 9287 on Department of Transport and Handling, SUA in Nitra. Hydraulic pump was loaded with pressure changing cyclically from 0.1 MPa to the nominal pressure of the hydraulic pump 20 MPa during the test. Mainly these pressure impacts burdens hydraulic system of tractor the most. That is one of the main reasons of choosing this type of straining in laboratory conditions (Tkáč et al., 2010; Majdan et al., 2011; Tkáč et al., 2014).

The measurement of density was carried out on densimeter Mettler Toledo DM40. The principle of measurement of density is based on electromagnetic induced oscillation of U–shaped glass tube. Dynamic viscosity was measured on viscometer DV2T fy Brookfield. The both measuring devices are part of the Agrobiotech Research Center in Nitra, Slovakia. The principle of measurement is based on measurement of torque of spindle rotating in the sample at constant speed.

Dynamic viscosity derived from Newton's law is characterized by a relationship:

$$\tau = \eta \; grad \; v \qquad (1)$$

where $grad \; v = \frac{dv}{dh}$ – the size of velocity gradient (s^{-1}); τ – shear stress (Pa); η – dynamic viscosity (Pa s).

The basic unit of dynamic viscosity is Pa s. More commonly, a thousand times smaller unit mPa s is used (Krempaský, 1982; Ruban & Gajjar, 2014).

The temperature effect on viscosity can be described by an Arrhenius type equation:

$$\eta = \eta_0 e^{-\frac{E_A}{RT}} \qquad (2)$$

where η – dynamic viscosity (Pa s); η_o – the reference value of dynamic viscosity (Pa s); E_A – activation energy ($J \; mol^{-1}$); R – gas constant ($8.314472 \; J \; K^{-1} \; mol^{-1}$); T – thermodynamic temperature (K).

Many authors (Munson et al., 1994; Hlaváč et al., 2016) explain, that the temperature dependence of viscosity can also be explained by cohesive forces between molecules. With increasing temperature, these cohesive forces between molecules decrease and flow becomes freer. As a result, viscosity of liquids decreases with increasing temperature. The fluidity of liquids in liquid state can be explained by relatively weak forces of mutual activity of molecules and their high movability. The fluidity of different liquids is different and it equals to reciprocal of dynamic viscosity, with basic unit $Pa^{-1} \; s^{-1}$.

$$\varphi = \frac{1}{\eta} \qquad (3)$$

Kinematic viscosity can be defined as quotient of dynamic viscosity and density of liquids if they are measured at the same temperature:

$$v = \frac{\eta}{\rho} \qquad (4)$$

where η is dynamic viscosty in Pa s and ρ is density in kg m^{-3}. The basic unit of kinematic viscosity is $m^2 \; s^{-1}$, but smaller unit $mm^2 \; s^{-1}$ is usually used.

The fluidity is ability of matters to flow. Parts of liquid matters can move easily towards one another, because the particles are not bounded in fixed positions. The measure of fluidity is expressed by viscosity. It is defined as reciprocal of dynamic viscosity Eq. (3).

RESULTS AND DISCUSSION

The density measurements were made in interval from 20 °C to 90 °C. From the measured data, we created graphical dependencies of the density from temperature for all samples.

On Fig. 1 it is clear that the new sample and the cyclically worn sample have very similar density values. Decrease in density of both samples is evident. After this comparison, we can conclude that the process of wear of the hydraulic pump occurred, resulting in the lowest density values in used Ertto sample.

Fig. 2 shows that the samples have similar density values. For the sample of one million cycles, the smaller density values were measured - a new sample at 40 °C had a density of 875.5 kg m^{-3} and the sample after one million cycles reached a density of 874.2 kg m^{-3}. The decline is also seen in graphical dependence, but the differences are not significant. It is also noticeable that bigger differences occurred in sample Ultra in higher temperatures.

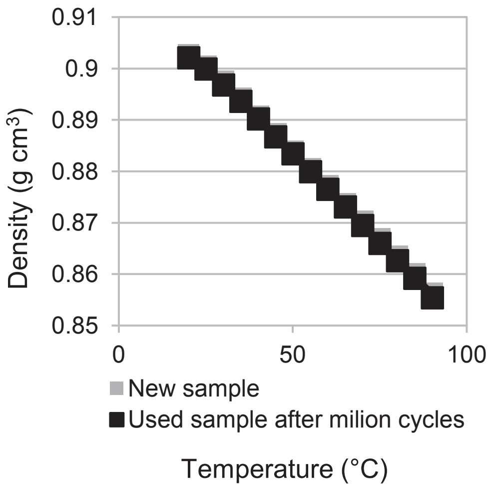

Figure 1. Temperature dependencies of density for samples Ertto.

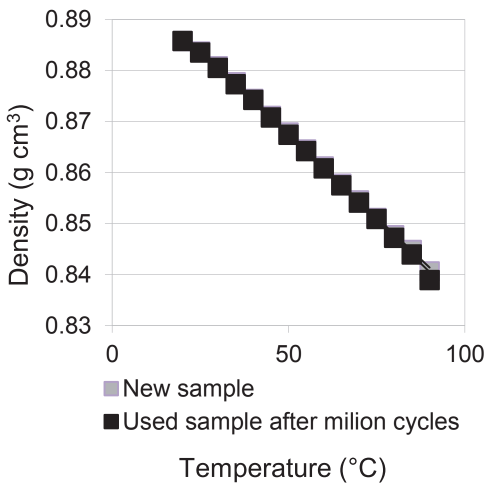

Figure 2. Temperature dependencies of density for samples Ultra.

In the Table 1, we place exponential regression equations and coefficient of determination R^2. As it can be seen from the dependencies for all samples, the development is characterized by the curve very well. The determination coefficients for all the samples are very high, which also confirms strong exponentially decreasing dependence.

Table 1. The overview of exponential regression equations and coefficients of determination of dependence of density (ρ) on temperature (t) for sample Ertto

	Ertto (Eco)		Ultra (Mineral)	
	New Sample	Used sample after million cycles	New Sample	Used sample after million cycles
Regression equation	$\rho = 0.918e^{-0,0008t}$	$\rho = 0.917e^{-0,0008t}$	$\rho = 0.901e^{-0,0008t}$	$\rho = 0.901e^{-0,0008t}$
Determination coefficient R^2	0.999	0.9988	0.9986	0.9977

From the point of view of physical interpretation, the exponential dependence of the Arrhenius type is better suited. 'Nešťák (2016) measured the density of ecological lubricants, while the sample he used Mogus Hees 46 had a density of 906.5 kg m^{-3} at 20 °C and at a temperature of 90 °C the density was reduced to 859.9 kg m^{-3}'. The coefficient of determination directly reached 1. To compare our ecological liquid Ertto, which at 20 °C had a density of 902.7 kg m^{-3} and after reaching 90 °C the density dropped to 856.3 kg m^{-3}. Our sample has a determination coefficient of 0.999. Decrease has been almost linear in some parts of the graphical dependency. When comparing with the values given by the manufacturer, small differences were found, which may be due to measurement inaccuracy, aging, or sample storage.

The viscosity measurements were made in interval from 20 °C to 90 °C. The data of viscosity at temperature of 95 °C and 100 °C were calculated from regression equation. From the data, we created graphical dependencies of the dynamic viscosity on temperature for all samples.

Temperature dependencies of dynamic viscosity for both samples Ertto are shown in Figs 3, 4. It is possible to observe that dynamic viscosity of samples is decreasing exponentially with increasing temperature, what was expected and what corresponds with conclusions reported in literature (Trávníček et al., 2013; Hlaváč et al., 2014; Vozárová et al., 2015). We also noticed a difference between new and the used sample. The sample, which has been used already for one million cycles, has lower viscosity in all temperature range. Further, differences between viscosities at lower temperatures are greater and also more spread. Which means that it is not enough to measure this physical property just at one temperature. Wider range is necessary to know better the sample behavior.

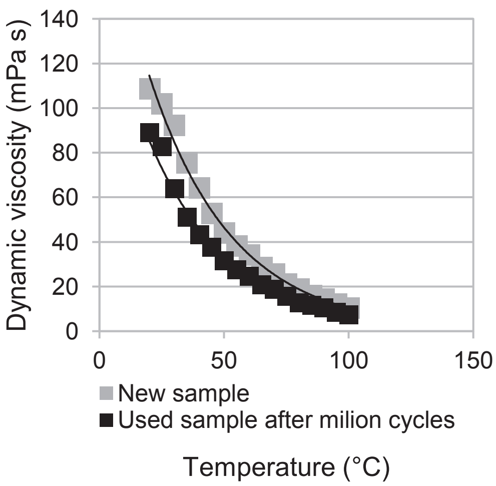

Figure 3. Temperature dependencies of dynamic viscosity for samples Ertto.

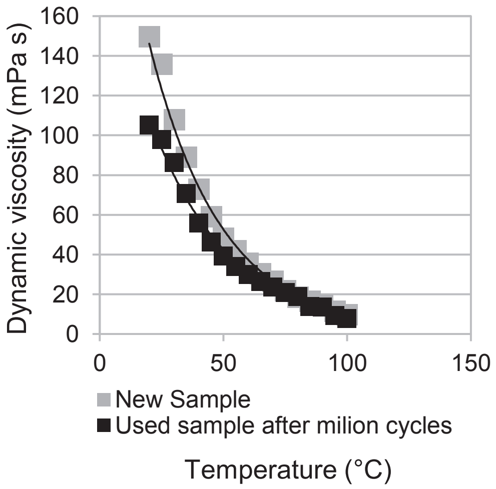

Figure 4. Temperature dependencies of dynamic viscosity for samples Ultra.

When it comes to comparison between mineral oil - Ultra and biological one - Ertto, we also noticed differences. First characteristic is viscosity at lower temperatures. Where, in case of sample Ultra, we can observe much higher viscosity than particular one of sample Ertto. But with the increase of temperature, the values of those two samples, are much more similar. And observing Figs 3, 4, we can conclude that difference between new sample Ultra and used sample Ultra are much bigger, than new and used sample Ertto.

The coefficients of regression equations and coefficients of determination are summarised in the Table 2. The determination coefficients for all the samples are very high, which also confirms strong exponentially decreasing dependence. The progress can be described by a decreasing exponential function, which is in accordance with Arrhenius equation.

Table 2. Overview of exponential regression equations and coefficients of determination of dependence of dynamic viscosity (η) on temperature (t) for the sample Ertto and Ultra

	Ertto		Ultra	
	New Sample	Used sample after million cycles	New Sample	Used sample after million cycles
Regression equation	$\eta = 211.0e^{-0.03t}$	$\eta = 159.8e^{-0.03t}$	$\eta = 291.9e^{-0.03t}$	$\eta = 214.4e^{-0.03t}$
Determination coefficient R^2	0.996	0.994	0.995	0.996

The comparison of mineral oil and ecological one is shown in the Table 3. Bigger difference between the new sample and the sample after accelerated test was in ecological fluid.

Table 3. The comparison of dynamic viscosity of ecological and mineral oil at temperature of 100 °C

	Mineral Oil Ultra	Ecological fluid Ertto
New Sample	9.74 mPa s	10.5 mPa s
Used sample after 10^6 cycles	7.9 mPa s	7.2 mPa s

As the literature mostly report kinematic viscosity at 40 °C, thus we calculated it according to the Eq. (4), namely the measured dynamic viscosity divided by the measured density. Graphical dependences of the kinematic viscosity on temperature were created for all samples. We can observe from Fig. 5 and Fig. 6 that the kinematic viscosity of samples is decreasing with increasing temperature.

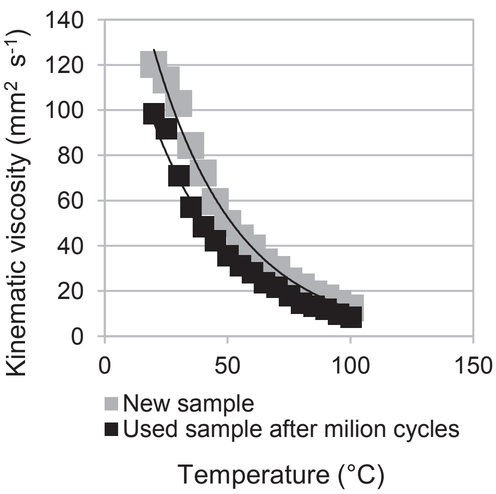

Figure 5. Temperature dependencies of kinematic viscosity for samples Ertto.

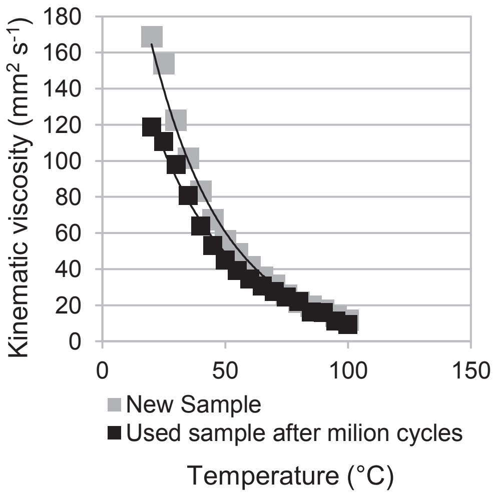

Figure 6. Temperature dependencies of kinematic viscosity for samples Ultra.

It seems that the values of the kinematic viscosities decreased in cyclically worn Ertto sample. It is also observed that the differences are bigger at lower temperatures. For comparison, we can see that kinematic viscosity of new Ertto at 40 °C has 64.2 mm^2 s^{-1} and cyclically worn sample has 43.33 mm^2 s^{-1}. As an indicator of viscosity change we indicate viscosity index (VI). Oils with high viscosity index (> 130) cause less wear. New Ertto sample has VI of 152.849, and the worn one has 128.084. As it is known, the greater the VI, the smaller the change in fluid viscosity. Thus, a lower VI in the used sample, could be assumed.

We can see from graphical dependencies that new sample of Ultra had higher viscosity than the sample after accelerated test. In Fig. 6 is shown that the figure of viscosity changed at low temperatures in a rather wide range. When increasing the temperature, the figure of viscosity for each sample differs in a smaller range. For better understanding, we state for the Ultra new sample at 40 °C 83.332 $mm^2 s^{-1}$ and for the 1 million cycles sample 63.829 $mm^2 s^{-1}$. We can conclude that difference between new and worn Ertto sample is bigger than of Ultra ones. It is also confirmed by VI. New Ultra sample as VI of 132.604, and worn one has 129.625. The higher VI, the smaller is the difference between high viscosity and lower viscosity of oil.

The fluidity of compared samples Ertto and Ultra is shown on Figs 7, 8.

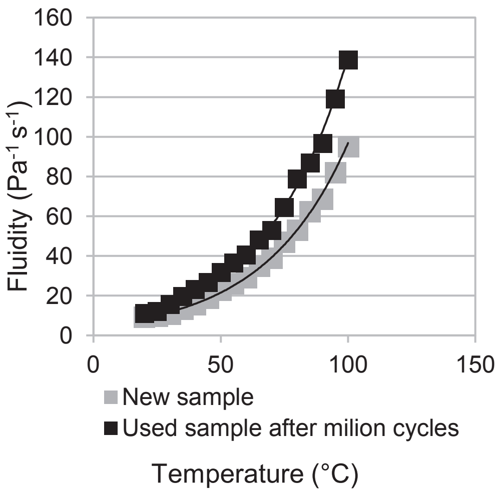

Figure 7. Temperature dependencies of fluidity for samples Ertto.

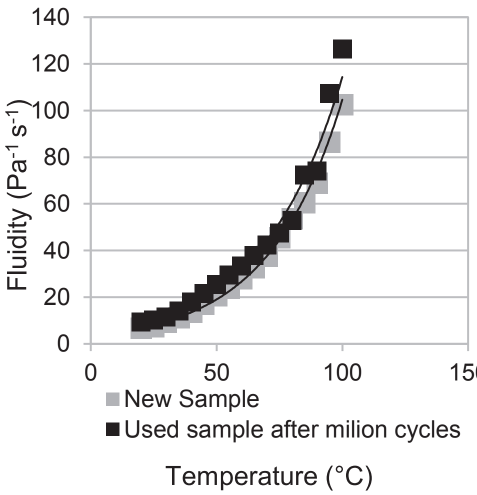

Figure 8. Temperature dependencies of fluidity for samples Ultra.

Differences can be observed from the Fig. 7 at the beginning and at the end of temperature range. Namely, at 20 °C Ertto new sample has fluidity of 9.208 $Pa^{-1} s^{-1}$ and used one has 11.24 $Pa^{-1} s^{-1}$. But at higher temperatures differences are bigger. When we compare fluidity at 100 °C of new and used sample, we got 95.238 $Pa^{-1} s^{-1}$, 138.84 $Pa^{-1} s^{-1}$, respectively. So the total difference between samples at 20 °C is 2.032 $Pa^{-1} s^{-1}$ and at 100 °C is 43.602 $Pa^{-1} s^{-1}$.

Contrary to the previous sample, differences between new and used Ultra sample are not so great. Measured value at 20 °C of the Ultra new sample is 6.68 $Pa^{-1} s^{-1}$ and of used one is 9.5057 $Pa^{-1} s^{-1}$. Fluidity at 100 °C of the Ultra new sample is 102.631 $Pa^{-1} s^{-1}$ and of used one is 126.458 $Pa^{-1} s^{-1}$.

We can see from graphical dependencies (Figs 7, 8) that, when heating the compared samples, their fluidity increases. As the samples after a million cycles of accelerated test had lower viscosity in comparison with the new samples, the fluidity of these samples was higher.

CONCLUSION

The results presented in this article can be important when putting ecological lubricants into operation. The use of ecological lubricants depends on their characteristics; the most important are density and viscosity, protection against wear and tear, corrosion resistance etc. It is important to know physical characteristics of lubricating oils to ensure the highest reliability for operation of device. Knowledge of the density and viscosity behaviour of an engine oil as a function of its temperature has a big importance, especially when considering running efficiency and performance of combustion engines. The objective of this work was to find changes of the rheological profile of the mineral oil and bio lubricant. The density and the dynamic viscosity show the significant temperature dependence. With the increasing temperature, the density and the dynamic viscosity decreased. Temperature dependencies of samples of dynamic viscosity had an exponential decreasing shape, which is in accordance with Arrhenius equation.

We have compared ecological oil and mineral oil in our work. At the same time, we have compared new sample with the sample after accelerated test according to the standard STN 11 9287. In both cases (Ertto and Ultra) changes in the color were not measured, only based on the visual, it can be stated that the used sample is darker. Ecological oil Ertto reached higher density than a mineral oil, but the difference between the new sample and the sample after accelerated test was little in both cases. Dependence of viscosity on temperature confirmed decreasing exponential function, while mineral oil had higher value of viscosity. The samples after accelerated test had lower dynamic and also kinematic viscosity than new samples. For fluidity applies that samples after test reached higher values than new samples. Ecological oils in comparison with mineral oils have higher fluidity.

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