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RESEARCH

Tribological Properties of Biodegradable Universal Tractor Transmission Oil

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A B S T R A C T

The annual consumption of lubricants in the world is around 40 million tons out of which less than 40 % are collected and properly processed meaning regeneration, re-refining and controlled incineration while the rest is disposed without control thus contaminating soil, water and atmosphere. It's one of the reasons that the last twenty years the environmentally friendly lubricants are more and more used. For the production of environmentally friendly lubricants are mostly used vegetable oil. In the field of the application of environmentally friendly lubricants attention should be given to the technical requirements including protection from the wear, corrosion protection, high load carrying properties and fulfilment of all the requirements imposed by the producer of the mechanical system.

This paper presents development and testing of the biodegradable universal tractor transmission oil (UTTO) based on the vegetable oils. Tribological properties of the oils based on rapes oil, sunflower and soya, after corresponding testing, compared with the features of the commercially available mineral universal tractor transmission oil.

1. INTRODUCTION

These One of the biggest world's problem is how to preserve the planet from the ever-growing pollution. The big part of the environment pollution can be attributed to the lubes. The annual consumption of lubricants in the world is around 40 million tons out of which more than 60 % finishes in the environment with no control. In most cases lubes are of mineral origin, toxic and not readily degradable [1]. However it is encouraging fact that their interest for the ecologically acceptable lubes is increases every year, especially in the fields where the application of mineral oils can cause the damage to the environment such as oil losses in motor saws, agricultural, foresters and civil engineering machinery, railroads and tramway crosses, outboard motors, oils in civil engineering, wire ropes and chains, and in the other fields of application where the total amount of lubes remains finally in the environment.

Up to date research in this field shows that the vegetable oils can substitute some of mineral oils just because it's good lubricity and biodegradability. Even more, vegerable oils are renewable source i.e. renewable natural resource. Research in the field of application of biodegradable oils indicate that vegetable oils have certain advantages over mineral oils such as nontoxicity, biodegradability, good lubricity, high flash point, high VI and low evaporation but also some disadvantages such as poor oxidation stability, poor fluidity under low temperatures and poor hydrolytic stability [2-4].

Agricultural machinery is the first choice for using biodegradable lube because the machinery is used directly in the environment where the lubes can easily come in contact with soil, water and plants. Tractors as well as other agricultural machinery usually work in highly specific conditions including extremely high or low temperatures, in different position and slopes, under the influence of thick dust and exposed to different chemical agents (plant protection agents, mineral fertilizers) and often work many hours under full load. This often extreme work of the agricultural machinery requires high quality of lubes [5].

The universal tractor transmission oil (UTTO) is highly functional oil used in the agricultural machinery such as tractors, combines etc. The main functions of the UTTO oils are:

- lubrication of gearbox, rear axle and gears,
- power transfer and hydraulic system lubrication,
- providing adequate cooling and friction wet brakes.

Biodegradability and nontoxicity are very important properties of vegetable oils but the most important properties are those that have to fulfil the requirements of reologic and working characteristics as defined by the specifications and standards of the producers of technical systems [6-8].

2. CHARACTERISTICS OF VEGETABLE OILS

The main constituents of vegetable oil (typically more unsaturated) and animal fats (typically more saturated) are triglyceride. A triglyceride (TG, triglycerol, TAG,) is an ester derived from one molecule of glycerol and three fatty acids. The three fatty acids are usually differ one of another, in different length of carbon chain and the level of saturation [9-11].

Considering the numbers of common saturated, monounsaturated and polyunsaturated fatty acids, it is evident that produces many different triglycerides.

We tested three types of vegetable oils (soybean, rapeseed and sunflower oil) with the composition presented in Table 1. In all of them fatty acids with a chain length C18 are dominant, but their chemical composition are different - the proportion of saturated, monounsaturated and polyunsaturated acids is different. The presence of polyunsaturated fatty acids (C18:2 and C18:3) was higher in soybean and sunflower oil then in the rapeseed oil. Participation of monounsaturated fatty acid (C18:1) was higher in rapeseed oil.

Different chemical composition has the effect of different physical and chemical properties.

Table 1. Physicochemical properties of vegetable oils used in the experiment.

Physical-chemical characteristics	Unit	Rapeseed oil	Soybean oil	Sunflower oil
Density at 20 ^{0}C	g/cm^3	0,92	0,92	0,92
Kinemati viscosity, 40 ^{0}C	mm^2/s	34,07	32,59	35,6
Kinematic viscosity, 100 ^{0}C	mm^2/s	7,84	7,66	7,75
Index viscosity		213	217	196
Flash point	^{0}C	322	326	328
Pour point	^{0}C	-13	-8	-14
Iodine number	mgKOH /g	118,41	126,2	131,2
Content of fatty acids in	%			
C14:0 (Myristic acid)		0,06	0,05	0,04
C16:0 (Palmitic acid)		6,58	10,24	6,35
C16:1 (Oleopalmitic acid)		0,36	0,15	0,13
C18:0 (Stearic acid)		2,88	5,24	5,35
C18:1 (Oleic acid)		53,10	29,33	27,13
C18:2 (Linoleic Acid)		28,72	47,95	58,53
C18:3 (Alpha linolenic acid)		6,54	5,35	0,16
C20:0 (Arachidonic acid)		0,41	0,52	0,41
C20:1 (Eicosenoic acid)		0,73	0,29	0,20
C22:0 (Behenic acid)		0,28	0,65	1,31
C22:1 (Erucic acid)		0,17		
C24:0 (Lignoceric acid)		0,10	0,20	0,35

In terms of operating temperatures, polyunsaturated fatty acids with a large number of unsaturated (double) bonds polymerize much faster than with monounsaturated or saturated (C16:0 and C18:0) fatty acids. However, saturated fatty acids induce the poor fluidity of vegetable oil at low temperatures. As a compromise between oxidation stability and low temperature properties, monounsaturated acids represent the best solution [12-14].

Kinematic viscosity at 40 ^{0}C of vegetable oils is usually 32 to 36 mm^2/s. The higher kinematic viscosity is achieved by adding a thickener.

Vegetable oils have much **higher viscosity index** (VI> 200) then mineral oils, thus enables reliable operation at higher temperature. This is an advantage for the formulation of lubricants, beeing used in a wider range of temperature.

Flash point of vegetable oils is higher than 300 ^{0}C and is important for the transport and storage due to risk of fire. Vegetable oils have higher values of flash point compared to mineral oils.

Pour point of vegetable oils is extremely poor and it limits their use at low operating temperatures. Vegetable oils tend to form a crystal structure at low temperatures thus causing decrease fluidity. Improving the pour point is achieved by adding additives pour point depressant.

The Iodine number in analytical chemistry, measure of the level of unsaturation of an oil and a fat. Vegetable oils with high iodine number have lower oxidative stability. Iodine value of rapeseed oil was 118.41 mgKOH/g, which indicates better oxidation stability compared to soybean (136 mgKOH/g) and sunflower oil (144 mgKOH/g). Improving oxidation stability is achieved by adding antioxidants.

3. EXPERIMENTAL WORK

3.1 Samples preparation

The tests were performed on four samples of oil, three different UTTO oils based on vegetable oil and one based on mineral oil, shown in Table 2. Three UTTO oils are formulated with different vegetable oils (rapeseed, soybean and sunflower) but the same additives packages designed for the production of biodegradable oils. Tribological properties of these oils were compared with commercial mineral UTTO oil.

Table 2. Tested samples.

Sample	Base oil	Code
Biodegradable UTTO oil	Rapeseed oil (cold-pressed, degummed	**RE**
Biodegradable UTTO oil	Soybean oil (cold-pressed, degummed)	**SO**
Biodegradable UTTO oil	Sunflower (cold-pressed, degummed)	**SU**
Mineral base UTTO oil	Mineral oil (API Group I)	**MN**

3.2 Tests conditions

Tribological tests for all four samples were conducted on tribometer TPD-93, type "block on disc", shown in Fig. 1.

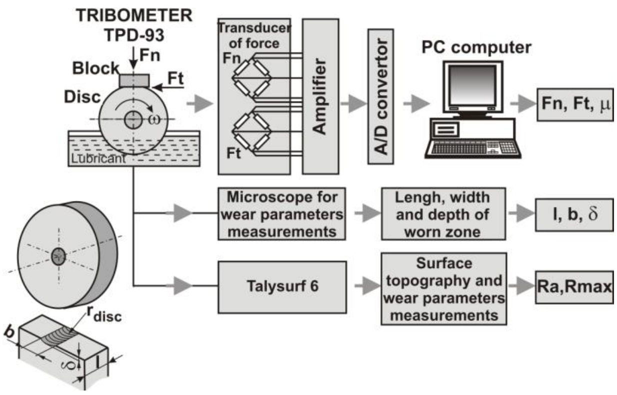

Fig. 1. Measuring system for the determination of wear characteristics.

- Measurement equipment- Tribometer TPD-93 type "block on disc
- Materials of block and disc - annealed alloy steel 16MnCr5 (Č4320) having the hardness of 35 HRC.
- Sliding speed in the contact zone- v = 0.8 m/s.
- Contact duration (duration of the tests of each sample) is T = 60 minutes.
- Normal external loading (Fn) changed during test.
- Type of lubrication: boundary

Fn1 = 30 N t1 = 15 min
Fn2 = 100 N t2 = 15 min
FN3 = 300 N t3 = 30 min

Lubrication is carried out in such a way that the bottom part of disc is immersed in the oil reservoir, so the disc took certain amount of oil, and did boundary lubrication contact. Between the surface of the block and circumferal disc area line contact is established. The special design of the carrier block insures continually full length blocks contact.

The basic indicator of tribological properties of materials is the change of coefficient friction during the contact time. To obtain a clearer picture of changing a coefficient of friction at certain time intervals, the values of the coefficient of friction are recorded every 2 seconds. This gives the information on the dynamics of the process that takes place on the tribometer [15-19].

3.3 Results and analysis of research results

The results obtained during tests contain information about coefficients of friction, the force of friction, width and depth of wear scar, wear shape of contact surface on block, change of the coefficient of friction and temperature during the contact time, topography of block and disc surfaces before and after investigation, wear scar on block and disc, etc.

Continuous recording of the force and coefficient friction is made in order to evaluate the process dynamics of contacts and to process date later.

On the basis of measurements were obtained corresponding histograms. They represent a change in the coefficient of friction measured after a time of contact on the Tribometer depending on the oil samples and the depth of wear scar on block. Data analysis and results obtained made it possible to identify specific tribological phenomena. One is related to the friction shown by the coefficient of friction and wear expressed by width and depth of the scar wear.

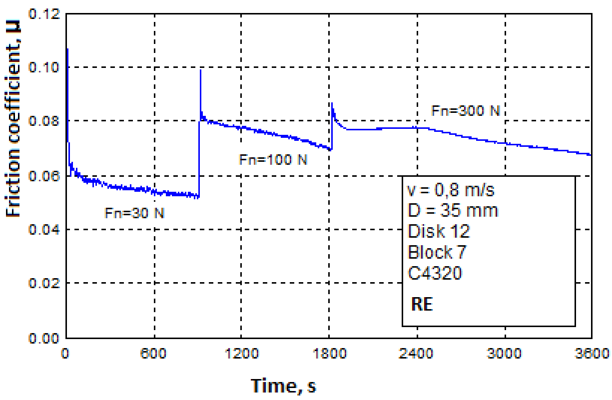

Fig. 2. Change the coefficient of friction in oil samples RE.

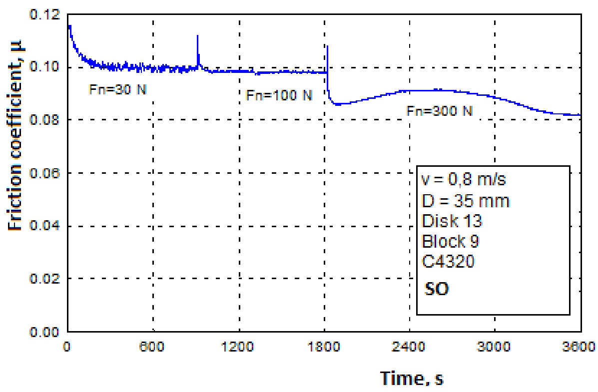

Fig. 3. Change the coefficient of friction in oil samples SO.

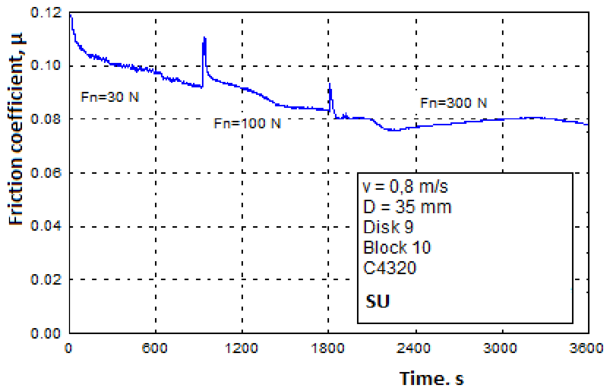

Fig. 4. Change the coefficient of friction in oil samples SU.

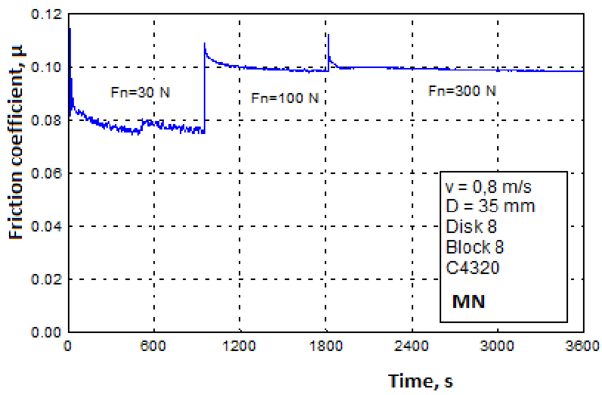

Fig. 5. Change the coefficient of friction in oil samples MN.

Figures 2 to 5 are shown the diagrams represented changes the friction coefficient of the tested oils in function of testing time and variation of loads, and Table 3 shows average values of the coefficient of friction for the test oils, as well as the size of the width and depth of the wear.

The results of measurements of all the testing oils are given in Figs. 2–5. They show that after an initial increase up to a maximum value, the friction coefficient is gradually decreasing in each phase of the load. At a later stage of testing its value stabilizes around a constant value. The time period in which the value of the coefficient of friction has intensive change is 0 to 200 seconds (depending on the type of oil) and is specified as the breaking-in phase. Breaking-in phase characterized by significant changes in the topography of the block and the disc, due to topography differences from the transition of the technological to the exploitation phase. Finally it achieves real geometry of the contact. This means that the surface hardness to "balance" in terms of topography.

The diagrams show that the coefficient of friction of tested samples based on vegetable oils (Figs. 2, 3 and 4) is lower than the one of reference mineral UTTO oil (Fig. 5), especially at higher loads.

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Table 3. Results of measurements of testing samples.

Sample	Friction coefficient μ			Boundary lubrication	
	Fn=30N t=15 min	Fn=100N t=15 min	Fn=300N t=30 min	width of wear scar mm	depth of wear scar mm) (μm)
RE	0,053	0,071	0,077	1,460	15,232
SO	0,098	0,098	0,091	1,513	16,359
SU	0,093	0,084	0,080	1,345	12,926
MN	0,076	0,098	0,099	1,585	17,954

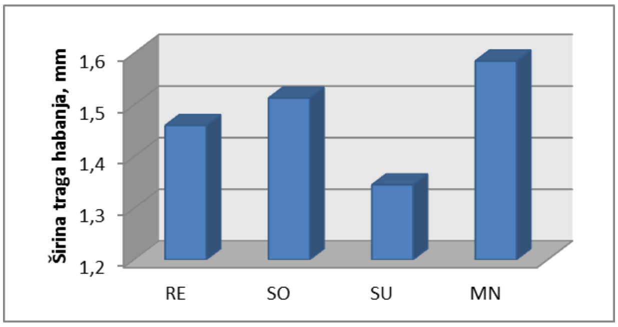

Fig. 6. Measured width of the scar wear on block.

Figure 6 also shows, the diagrams of changes the width of a wear scar on the block for all tested oils. Wear scar on the block is the largest in sample of mineral UTTO oil –Sample MN (1.585 mm), and the lowest in the sample biodegradable UTTO oils based on sunflower oil -Sample SU (1.345 mm). Narrow wear scar in samples RE, MA and SU indicate good lubricity of vegetable oils. It shows excellent antiwear properties of vegetable oils even at maximum load.

Wear scar on the blocks in tribological tests can be seen in the photographs shown in Fig. 7.

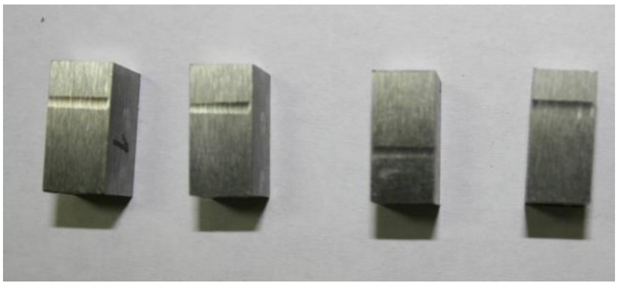

Fig. 7. Wear scar on the blocks in tribological tests.

4. CONCLUSION

From this study it is possible to conclude:

- The use of the tribometer TPD-93, type "block on the disk." Is one of the best ways to determine all-enpassing tribological characteristics.
- Characteristics of vegetable oils can be improved by the addition of suitable additives.
- The coefficient of friction is very dependent on the type of oil. The best results, the lowest value of the coefficient of friction, shows UTTO oil based on rapeseed oil.
- Biodegradable UTTO oils have a coefficient of friction lower than the mineral UTTO oil.
- The presents of triglyceride (esters) in vegetable oils ensures excellent lubricity under different loads. The natural esters of fatty acids of vegetable oils are even used as additives for improving the lubricity.
- The width and wear depth on the block is the highest in samples of mineral UTTO oil. Low levels of track widths of wear in samples RE, MA and SU indicates good lubricating properties of vegetable oils.

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