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TRIBOLOGY TESTING OF BIODEGRADABLE OILS

Abstract

One of the biggest problems today is how to preserve planet from the ever growing pollution and how to preserve natural resources for future generations. The consequences are more and more noticeable through climate changes, pollution of water streams, soil and atmosphere. The big part of the environment pollution is caused by the lubricants. The annual consumption of lubricants in the world is around 40 million tons and more than 60% of it is spread without any control into the environment. The lubricants are mostly of mineral origin, they are toxic and not readily biodegradable. The catastrophe due to the intensive pollution of environment, threatening the planet Earth, draws the public attention and ecological awareness demanding the development of the ecologically acceptable lubricants. The ecologically acceptable lubricants when put into contact with the environment produce minimum of harmful effects. To be ecologically acceptable the lubricant must be biologically degradable and nontoxic. The most important raw material for the formulation of the ecologically acceptable lubricants is plant oils being biodegradable, nontoxic and represent renewable resource.

This paper presents the testing of the biodegradable oil for the lubrication of the chains in chain saws. Physical and chemical properties are tested as well as tribology characteristics on the tribometer "block on disc". Disk material, having the diameter of 35 mm and block having the dimensions 6.3x10x15 mm^3 is the steel 16MnCr5. The testing time on tribometer is 60 minutes with the load of 30, 100 and 300 N and with the sliding velocity of 0.8 m/sec. The results present tribology characteristics of formulated biodegradable oil for the lubrication of chains in chain saws compared with commercially available mineral oil.

1. Introduction

A number of significant and feasible requirements for environmental protection will lead to application of much more severe provisions, legislations and regulations. Two basic parameters mean that saving of non-renewable resources as well as minimizing lubricants' harmful effects on the environment is main tasks of eco-tribology. Eco-tribology primarily means saving basic finite resources of energy and materials and includes special attention paid to environmental protection.

For this reason, biodegradable lubricants extracted from plants are feasible and have potentials for application. Vegetable oils will have priority over mineral oils because they are non-toxic, biodegradable and have less adverse effects to the environment. Vegetable oils are cheaper than synthetic oils and very significant because they are produced from renewable raw materials. In comparison to mineral oils, vegetable oils have the following advantages: better lubricating properties, higher viscosity index, lower evaporation rate including lower consumption, higher resistance to flammability due to higher ignition temperature. In comparison to mineral oils, vegetable oils have the following disadvantages: with lower oxidation stability, they are subject to hydrolysis in the presence of humidity when corrosive acids occur. With significantly poorer flow ability at lower temperatures, they are more apt to foam occurrence and oil filters' plugging. They have adverse effects to sealing elastomers and shorter storage and usage life. The above stated disadvantages restrict possible application of these oils. Therefore, they usually apply for producing oils for chain saw oils, steel ropes, mould release oils, railway axles, metalworking oils, two-stroke engines, as well as hydraulic and universal oils for tractors.

Global annual consumption of biodegradable lubricants amounts to approximately 400,000 tons, which is about 1% of the total consumption of lubricants. Consumption of biodegradable oils increased by 10% annually in the last 10 years, as presented in Figure 1. In comparison to mineral oils, vegetable oils' portion in global consumption is small. However, state authorities and various institutions have been supportive lately in order to reduce differential price and equalize prices of vegetable oils and mineral oils.

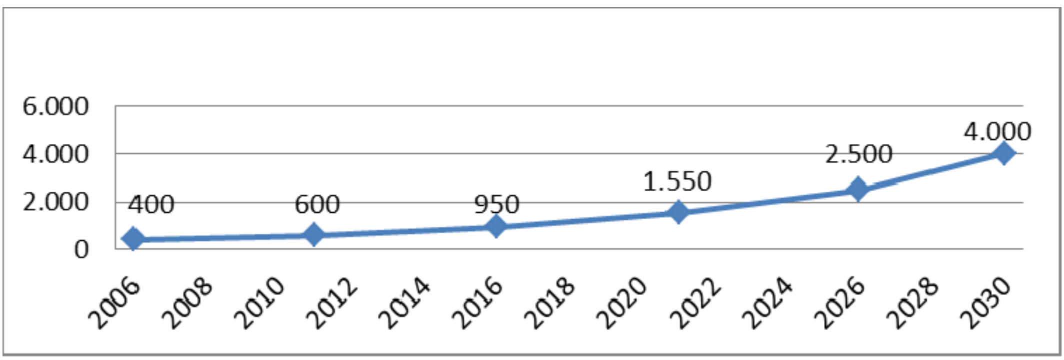

Figure 1: Consumption of biodegradable oils (in 000 t) worldwide and assessment of consumption by 2030

2. Experimental part

2.1 Preparation of oil samples

For the purpose of testing, oil for chain saw oils is extracted from the rapeseed oil. The rapeseed oil is purchased from the "Victoria oil" a.d. Šid manufacturer. It is produced by pressing and extracting the seed and specially degumming raw oil. The composition of fatty acids contained in the rapeseed oil tested is presented in Table 1, whereas physical and chemical characteristics are presented in Table 3.

The following additives are used for chain saw oil which is extracted from the rapeseed oil: antioxidant, pour point depressant, EP additive, polar additive and antifoaming agent. Additives for the oil tested are purchased from the Lubrizol Company. Characteristics of the biodegradable oil produced are compared to the characteristics of mineral commercial oil for chain saw oil. This mineral oil is used as the reference oil, produced by Lubricants' Department of the NIS-Gaspromneft. Three different oil samples have been tested and specified under codes presented in Table 2.

Table 1: Composition of specific fatty acids [%]

Fatty Acid	Rapeseed Oil
C14:0 (Myristic Acid)	0.06
C16:0 (Palmitic Acid)	6.58
C16:1 (Oleopalmitic Acid)	0.36
C18:0 (Stearic Acid)	2.88
C18:1 (Oleic Acid)	53.10
C18:2 (Linoleic Acid)	28.72
C18:3 (Linolenic Acid)	6.54
C20:0 (Arachidic Acid)	0.41
C20:1 (Eicosenoic Acid)	0.73
C22:0 (Behenic Acid)	0.28
C24:0 (Lignoceric Acid)	0.10

Table 2: Codes of tested oils

Tested Oils	Codes of Oils
Rapeseed oil	RE
Biodegradable chain saw oil	BT
Mineral chain saw oil (reference oil)	MT

2.2 Results of tests and discussion

Laboratory analyses of the oils tested are presented in Table 3. The results of oil samples tested are compared to the results of the reference mineral chain saw oil. Vegetable-based oils have a significantly higher viscosity index (VI > 200) as compared to mineral oils, which allows their usage in a wide range of temperatures. Vegetable oils have greater flash point values as compared to mineral oils.

Table 3: Physical and chemical characteristics of oils tested

Physical and Chemical Characteristics	UOM	Methods	RE	BT	MT
Kinematic viscosity at 40 °C	mm²/s	ASTM D 445	42.35	69.89	90.56
Viscosity index		ASTM D2270	218	227	95
Flash point	°C	ASTM D 92	254	260	220
Pour point	°C	ASTM D 97	-8	-21	-26
Oxidation stability, RBOT	min	ASTM D2272	13	60	149
Wearing (1 h; 75 ºC; 40 kg and 1200 r/min)	mm	ASTM D 4172	0.39	0.38	0.40
4-ball EP test: until seizure occurs	N	ASTM D 2783	1372.8	1569.0	980.6

Oxidation stability of oil samples is assessed by applying the method of ASTM D2272 (RBOT). Oxidation stability of vegetable oils is very low. Additive bond for the rapeseed oil lasts for 13 minutes maximum. Oxidation stability of vegetable oils is improved by dosing antioxidant additive in order to reach the value required.

Vegetable oils' flow ability at low temperatures is extremely low, which limits their application at low operating temperatures. In order to improve low-temperature characteristics, pour point depressant (PPD) additive is dosed to the vegetable oil. The function of pour point depressant additive is to prevent triglyceride molecules' crystallization at low temperatures as well as their grouping. Figure 2 shows pour point depressant additive which reduces the pour point from -8 ^{o}C to -21 ^{o}C.

Resistance to wearing and high pressures is checked by the four ball test. Table 3 shows that oil for lubricating chain saw, which is extracted from the rapeseed oil, have greater values than the mineral oil, as well as significantly greater potentials for resistance to wearing, extreme pressures and impact loads. Laboratory tests of resistance to extreme pressures (4-ball EP test) show that vegetable oils without EP additive have even better results than mineral oils with additives, as presented in Figure 2.

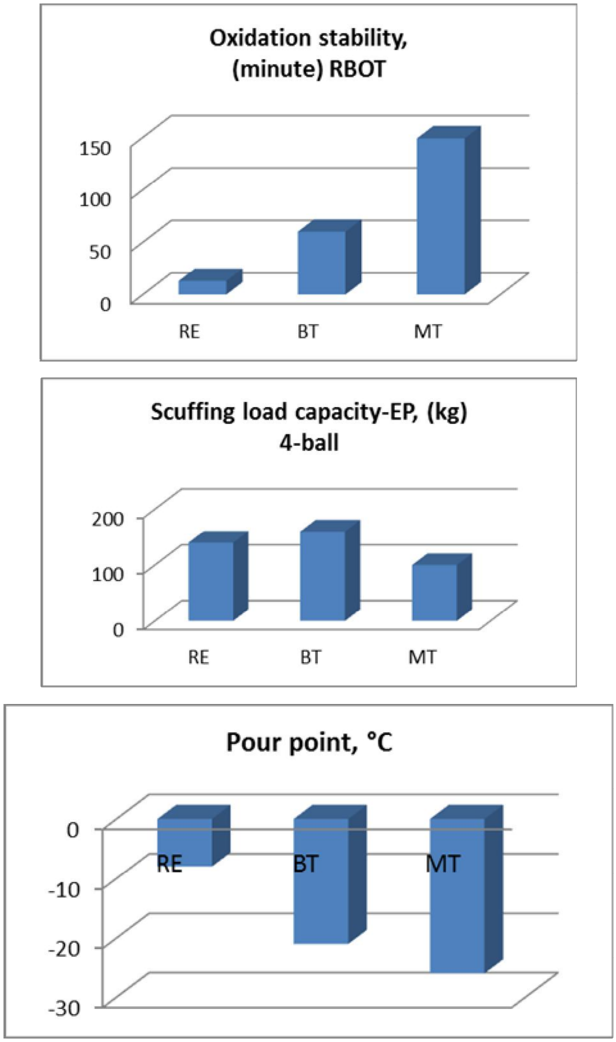

Figure 2: Physical and Chemical Characteristics of Oils Tested

2.3 Testing by tribology instrument

Tribology characteristics of oil tested, as presented herein, have been determined in the Laboratory for Tribology of the Mechanical Engineering Faculty in Kragujevac. The experiment includes measuring of friction force, friction coefficient and wearing parameter, as presented in Figure 3.

Prior to testing, conditions of testing have been defined, more precisely, contact pairs' materials, normal load, sliding speed, lubrication method, contact geometry and test period:

- Material 16MnCr5 (Č4320) in a raw material form (soft flame)
- Disk with 35 mm diameter
- Block with 6.3 mm x 10 mm x 15 mm dimensions
- Sliding speed v = 0.8 m/s
- Load 30, 100, 300 N
- Test period duration: t = 60 min
  (30 N: 15 min; 100 N: 15 min; 300 N: 30 min)

Prior to testing, parameters of disks and blocks topography should be measured in order to check the level of roughness. If roughness of some element significantly differs from roughness of other elements, such an element will be ground again or eliminated from testing. Oil samples are subject to tribology tests of the block on disk type. Lubrication is conducted as follows: a lower part of the disk goes through the lubrication oil tank. In this way, the disk catches a certain oil quantity and conducts limit lubrication of the contacts. A line contact is conducted between the block surface and great disk surface. Special construction of the block support provides total block fitting at any moment along the entire contacts length.

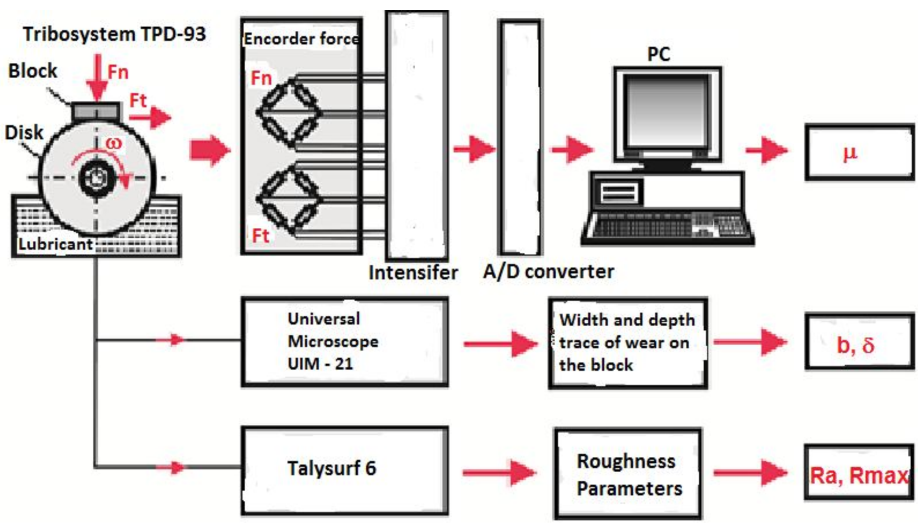

Figure 3: Sequence of tribology test results

The results of tribology tests of oils are presented in Table 4, whereas Figure 5 shows diagrams of changing friction coefficient of oils sampled in the function of test periods and load change.

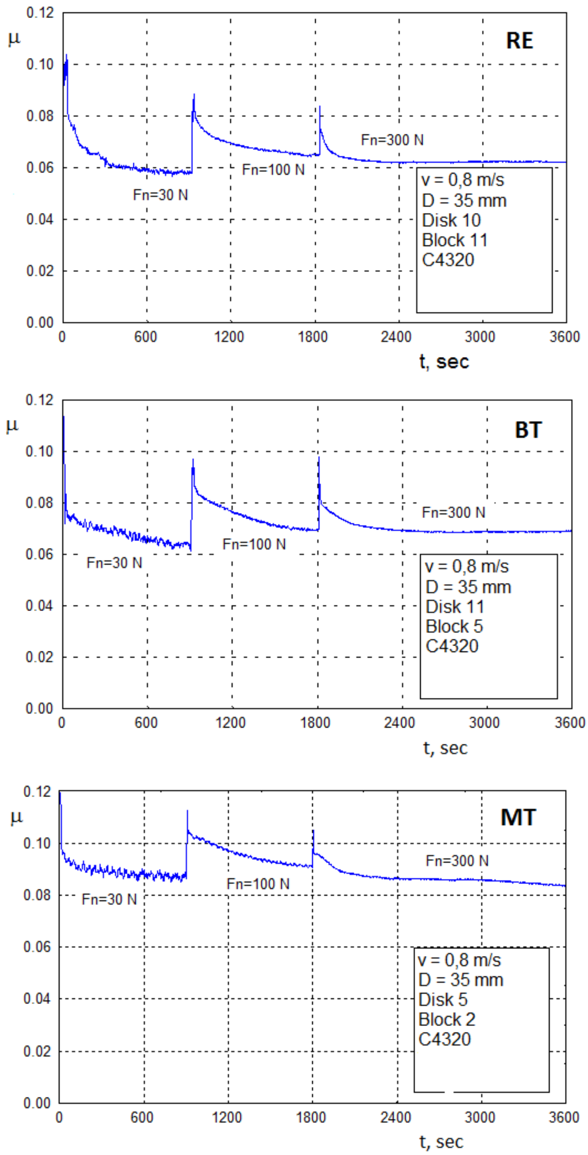

Figure 5: Change of friction coefficient in the function of test periods and load change

The results of measuring friction coefficient at the tribology instrument, as presented in Figure 5, show that, after initial increase to the maximum value, friction coefficient gradually decreases in each load stage, so that in the next test stages its value can stabilize and remain at a constant value. The time period in which the friction coefficient value significantly changes is approximately 60 seconds. It is marked as a trial stage. The trial stage is characterized by a significant change in topography of block and disk surfaces due to transfer of technological topography into exploitation topography and reaching real geometry of contacts, and/or the surfaces tend to be equalized in terms of topography.

Even if there are no additives in vegetable oils, such oils have lower friction coefficient than the friction coefficient of the mineral oil with additives. This proves an assumption that vegetable oils, due to the present of triglyceride, have excellent lubrication characteristics in all load stages.

Diagrams presented in Figure 5 show lower friction coefficients as compared to the reference mineral chain saw oil, especially when greater loads are concerned.

Table 4: Results of tribology tests of oils

Samples	Friction Coefficient (μ)			Boundary Lubrication	
	F_n = 30 N t = 15 min	F_n = 100 N t = 15 min	F_n = 300 N t = 30 min	Width of wearing traces at the block (mm)	Depth of wearing traces at the block (μm)
RE	0.058	0.065	0.062	1.217	8.7145
BT	0.063	0.069	0.069	1.175	6.1135
MT	0.086	0.091	0.086	1.311	12.3588

Figure 6 presents the diagram of change of the width of wearing traces at the block after testing oils sampled. Low value of the width of BT sample's wearing traces indicates good lubrication characteristics, and/or shows that triglyceride structure is efficient enough to prevent wearing during the maximum loads. Block wearing traces during tribology tests can be seen in photographs shown in Figure 7.

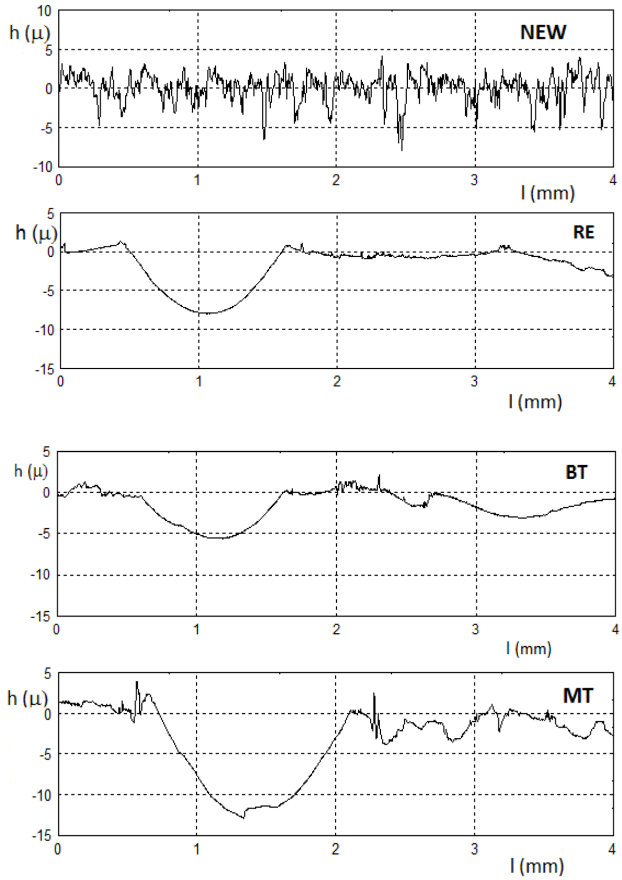

Figure 6: Topography of block surface

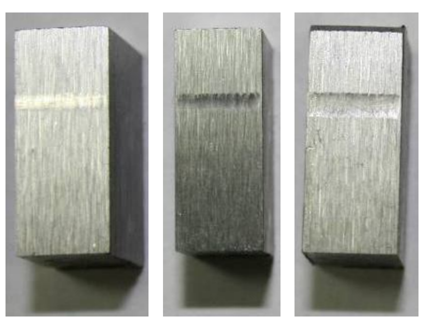

Figure 7: Wearing traces of blocks during tribology tests

3. Conclusion

Pursuant to the results of testing oil samples it may be concluded that almost all tested characteristics of the biodegradable chain saw oil reach satisfactory characteristics of or even better characteristics than the mineral oil. The exception includes oxidation stability and low-temperature characteristics. Characteristics of the vegetable oil are improved by dosing appropriate additives which are specially intended for vegetable base oils. Oxidation stability of vegetable oils without additives is very low and can be improved by dosing antioxidant additive which has increased oxidation stability from 13 to 60 minutes by applying the method of ASTM D2272 (RBOT). Vegetable oils flow ability at low temperatures is extremely low, which limits their application. In order to improve low-temperature characteristics, pour point depressant additive is dosed to the vegetable oil in order to reduce the pour point from -8 ^{o}C to -21 ^{o}C. The results of measuring friction coefficient by the tribology instrument show that vegetable oils without additives have lower friction coefficient than the friction coefficient of the mineral oil with additives. This proves an assumption that vegetable oils, due to the present of triglyceride, have excellent lubrication characteristics in all load stages.

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