# PERFORMANCE INVESTIGATION OF CHAIN SAW LUBRICANTS BASED ON NEW SUNFLOWER OIL (NSO)

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## 1 INTRODUCTION

Vegetable oils and animal fats have been used as lubricants for a very long period of time through the history of mankind. However, since the start of the industrial revolution and introducing of lubricants produced from mineral oil, vegetable oils and animal fats became unattractive and were left by the wayside. Attention on vegetable oils was refocused only during wartime and oil shortage situations. The mineral oils still dominate the market, but the uses of them have become more and more questioned. The growing environmental and health and safety awareness has caused a rapidly growing interest for vegetable oils as base for lubricants. For example, although rapeseed originally began its career as an agricultural crop used for producing lubricants, until the 1970s vegetable oil was not again considered as an environmentally acceptable alternative for lubricant production, and has been effectively sold on the market from the early 1990s [1].

Vegetable oils belong to the group of bio based products. Bio based products are commercial or industrial products (other than food or feed) that are composed in whole, or in significant part, of biological products or renewable agricultural materials or forestry materials [2]. Vegetable oil base lubricants are regarded as environmentally acceptable (EA) lubricants. The lubrication industry uses a variety of terms to address “environmental” lubricants. A few of these terms, all preceded by the term “environmentally” are: “acceptable”, “aware”, “benign”, “friendly”, “harmless”, “safe”, “sensitive” and “suitable” [3]. Manufacturers and end users agree that for a lubricant to be classified as an EA type it should be biodegradable and nontoxic.

Thanks to advancements in biotechnology, lubricants obtained from oilseeds are being used, over the past twenty years, in the sensitivity environment, as a substitution for mineral oils. These vegetable oils are drawing attention also as biodegradable alternatives for synthetic esters because they are less expensive and are available from renewable resources. Vegetable oils are readily biodegradable (72 – 80 % of tested oils carbon is converted to $CO_2$ in 28 days), while the mineral oils generally exhibit a very slow biodegradation (42 – 48 %). The synthetic esters exhibit biodegradation rates, varying from relatively low up

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to approximately the same level as for vegetable oils (55 – 84 %) [4]. The prices are variable but the approximate relative costs of base fluids, compared to the refined mineral oil, are: vegetable oils: 1.5 – 2 and synthetic esters: 4 – 12 [5, 6]. Both vegetable oil based lubricants (biolubricants) and synthetic ester based lubricants are manufactured in much smaller quantities when compared to mineral oil based lubricants, resulting in higher production costs and thus retail price.

Generally, the advantages of using vegetable oils as a base for EA lubricants are: non-toxicity, biodegradability, resource renewability, good lubricity and high viscosity index. However, vegetable oils have some of the following disadvantages: oxidative instability, poor low temperature properties and poor hydrolytic stability.

Frost and Sullivan studies of the market in Europe showed that in 1999 some 100,000 tones, or 2 % of the market were biolubricants [7] and that, since 2000, the market for biolubricants has experienced a restricted growth in volumes with an estimated total European volume of 127,000 tonnes in 2006 [6]. Biolubricants market is dominated by independent suppliers and there are around 70 – 80 independent manufacturers supporting 80 % of the biolubricants market.

In this paper laboratory investigations of physical and chemical properties, friction and wear characteristics of the chain saw lubricant, based on domestic New Sunflower Oil (NSO), are presented and compared with standard mineral oil based lubricant used for the same purpose. At the first stage the main issue was to solve the selection of base oil and additives regarding their compatibility, mutual solubility and stability. In the second stage the additive influence on oxidation stability improvements were investigated and finally tribological properties were tested.

## 2 VEGETABLE CHAIN SAW LUBRICANTS

Vegetable chain saw lubricants (like all the other biolubricants) can be produced from a wide variety of oilseeds with appropriate characteristics and mainly from: rapeseed, soybean and sunflower. Undesirable characteristics of vegetable oils could be improved through the selective plant breeding or genetic modification, but vegetable oils, like mineral oils, can not meet most lubricant requirements without adequate functional additives.

Lubricants derived from vegetable sources have been used in many applications, particularly in areas where they can come into contact with water, food or people. Among these applications the chain saw lubricant demands are very often. Good lubricity of the biolubricants provides that the lubricant adheres to the chain better and longer, resulting in lubricant savings. Chain saw lubricants are termed “total loss lubricants” because the parts they lubricate are exposed to the environment, and the lubricant can be flung off onto the ground, plants or water. That is why the major issues at chain saw lubricants, beside technical performance demands, are biodegradability and nontoxicity.

Generally the two most significant opportunities for all biolubricants are:

- In applications where there is a high probability of accidental exposure of the lubricants to sensitive environments: “high-risk lubricants” for example hydraulic equipment in forests and by water;
- “Total loss lubricants” – where, by the design of the equipment or application the lubricant ends up almost entirely in the environment.

Research of the areas and volumes in which biolubricants were used, for 1999, shows that the most significant market, after hydraulic oils, is chain saw oils with over 29 % of share (*Table 1*).

| Lubricants marked as “biolubricants” | Market volume in 1999 [tons] |
|---|---|
| Hydraulic oils | 51,000 |
| Chain saw lubricants | 29,000 |
| Concrete release agents | 10,650 |
| Metalworking fluids | 4,000 |
| Two-stroke engine oils | 2,000 |
| Greases | 1,700 |
| Gear oils | 1,000 |

*Table 1: European (EU-15) market volumes for biolubricants in 1999 [8]*

# 3 PROPERTIES OF SELECTED VEGETABLE OIL

## 3.1 Base Oil Characteristics

Selection of vegetable oil was made on the basis of the domestic vegetable oils market analysis and the information and research trends in the world. Some adjustments of the vegetable oils characteristics with the lubricants application demands were also made. It was concluded that only a few domestic vegetable oils could be used as a base for biolubricants. For the further investigation domestic New Sunflower Oil (NSO) was chosen, which physical and chemical characteristics are presented in *Table 2*. Test methods used for the determination of these characteristics were standard ones.

Domestic NSO was produced through the selective plant breeding. The approximate relative cost of this base oil, compared to the refined mineral oil, is: 1.3 – 1.5.

| Characteristic | Test method | Value |
|---|---|---|
| Density at 15 ºC [kg/m$^3$] | ISO 3675 | 917 |
| Viscosity [mm$^2$/s]<br>at 40 ºC<br>at 100 ºC | ISO 3104 | <br>38.5<br>8.48 |
| Viscosity index | ISO 2909 | 206 |
| Flesh point [°C] | ISO 2719 | 255 |
| Pour point [°C] | ISO 3016 | – 18 |
| Neutralization number [mgKOH/g] | ISO 6619 | 0.35 |
| Corrosiveness to copper | ISO 2160 | 1a |
| Carbon residue [%] | ISO 6615 | 0.26 |
| Ash [%] | ISO 6245 | 0.01 |
| Trace amounts of sediment [%] | ASTM D 2273 | 0.0 |
| Moisture and volatile matter content [%] | ISO 662 | 0.03 |
| Foaming characteristics [ml]<br>at 24 °C<br>at 93 °C<br>at 24 after 93 °C | ISO 6247 | <br>0/0<br>0/0<br>0/0 |
| Iodine value [g/100g] | ISO 3961 | 97 |
| Saponification value [mgKOH/g] | ISO 3657 | 190 |
| Refractive index | ISO 5661 | 1.465 |

*Table 2: Physical and chemical characteristics of selected vegetable oil*

## 3.2 Oxidation Stability

One of the very important properties of lubricating oils is their oxidation stability. Oils with low values of oxidation stability will oxidize even more rapidly in the presence of water and at elevated temperatures. When oil oxidizes it will undergo a complex chemical reaction that will produce acid and sludge. Sludge may settle in critical areas of the equipment and interfere with the lubrication and cooling functions of the fluid. The oxidized oil will also corrode the equipment.

To improve the oxidation stability of vegetable oil products a research on formulating a proper mixture of base oil with a suitable additive package must be done. For mineral oil formulations small amounts of antioxidants (0.1 – 0.2 %) are effective. Vegetable oils, however, may require large amounts (1 – 5 %) of antioxidants to prevent oxidative destruction [5].

Suitable antioxidant was chosen, in the amount of 3 %, and mixed with the base oil. Oxidative stability was investigated for both samples (base oil and base oil with 3 % of antioxidant) according to the ISO 4263 standard. The results of the test are presented in *Fig. 1*.

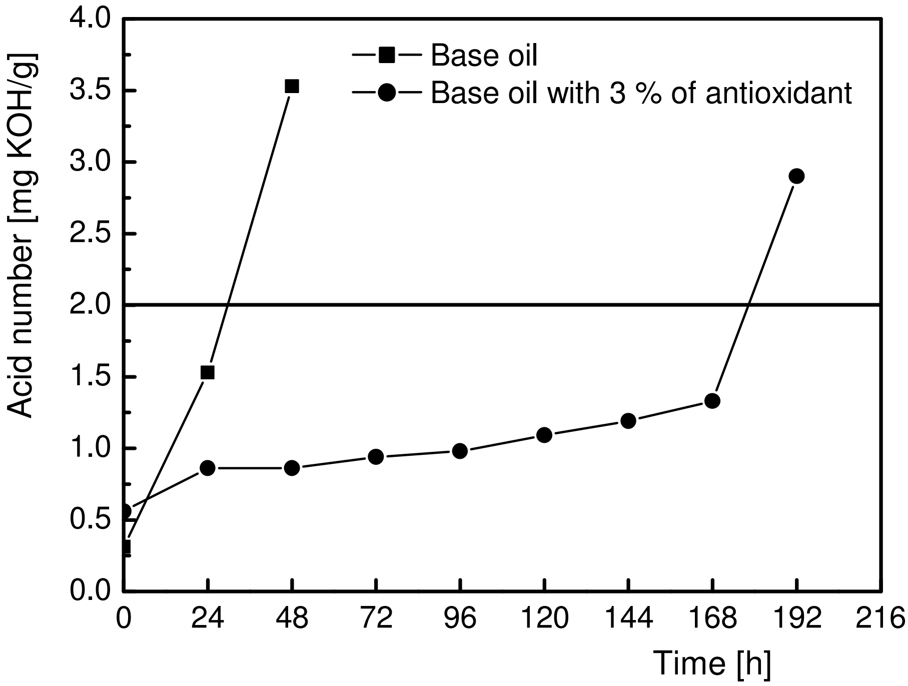



*Figure 1: Oxidation stability of the tested samples*

The results of the test show that oxidation stability of the base oil with additive (178 h) was significantly improved compared with the base oil (30 h), and that this formulation could be used for the further investigation.

# 4 FRICTION AND WEAR STUDIES

## 4.1 Physical and Chemical Characteristics of Finished Biolubricant

In order to improve other characteristics of the finished biolubricant (beside oxidation stability) suitable additives as thickeners and PPD were added. Base oil is mixed with these additives to provide the resulting final product with physical, chemical and tribological characteristics required for successful application.

This finished biolubricant (ref. as lubricant A) was compared with a product from market – a commercial product based on mineral oil (ref. as lubricant B). Physical and chemical characteristics of both tested chain saw lubricants are presented in *Table 3*.

| Characteristic | Lubricant A | Lubricant B |
|---|---|---|
| Density at 15 ºC [kg/m$^3$] | 917 | 881 |
| Viscosity [mm$^2$/s]<br>at 40 ºC<br>at 100 ºC | <br>47.6<br>10.5 | <br>99.60<br>11.20 |
| Viscosity index | 218 | 98 |
| Flesh point [°C] | 245 | 248 |
| Pour point [°C] | – 20 | – 25 |
| Neutralization number [mgKOH/g] | 0.63 | 0.47 |
| Corrosiveness to copper | 1b | 1a |
| Ash [%] | 0.035 | 0.16 |
| Foaming characteristics [ml]<br>at 24 °C<br>at 93 °C<br>at 24 after 93 °C | <br>120/0<br>120/0<br>70/0 | <br>0/0<br>20/0<br>0/0 |

*Table 3: Physical and chemical characteristics of tested chain saw lubricants*

## 4.2 Test Method and Conditions

Friction and wear tests of both chain saw lubricants were carried out on the block-on-ring tribometer under lubricated sliding conditions, in ambient air at room temperature ($\approx$ 27 °C). Blocks dimensions were: 5.9 mm $\times$ 12 mm $\times$ 16 mm. Material of blocks was gray cast iron (220 HB) with the following chemical composition: Fe-C(3.1) - Si(1.9) - Mn(0.9) - S(0.047) - P(0.009) - Cr(0.11) - Ni(0.05), wt.%. Rings having 45.31 mm outer diameter and 10 mm thickness were made of unalloyed steels for hardening and tempering (DIN Ck 60, 46 – 48 HRC) with the following chemical composition: Fe - C(0.58) - Mn(0.74) - P(0.04) - S(0.038), wt.% and standard heat treatment. Lubrication was provided by revolving of the ring which was dipped into oil container. Surface roughness of blocks and rings was $R_a$ = 0.1 – 0.3 μm.

Before and after testing, both the block and ring were degreased and cleaned with benzene. Wear scars on blocks were measured in accordance with ASTM test method G 77 – 98, with accuracy of 0.05 mm, after each test to calculate the volume loss, while the rings were weighed with accuracy of $10^{-3}$ g before and after each test to calculate the mass loss. The values of oil and ambient temperature, friction coefficient, normal and friction force were monitored during the test and through data acquisition system stored in the PC. Tests were carried out at selected test conditions: sliding speed of 1 m/s, sliding distance of 3600 m and normal load of 250 N. For each lubricant, in order to achieve a higher confidence level in evaluating test results, four duplicate runs were performed and the results were averaged.

## 4.3 Results and Discussion

Friction and wear investigations were just an initial one, with preliminary results and some more experiments have to be done to completely understand tribological behaviour of these chain saw lubricants. An improvement of physical and chemical characteristics of the vegetable base oil is also possible.

Obtained average values of the friction and wear testing are presented in *Table 4*. The results indicate good repeatability of the test. The coefficient of variation ($V_r$) was calculated as a standard deviation divided by the average value.

| Obtained average value | Lubricant A | Lubricant B | $V_r$ (lub. A) [%] | $V_r$ (lub. B) [%] |
|---|---|---|---|---|
| Final dynamic coefficient of friction | 0.053 | 0.074 | 5.8 | 5.7 |
| Block scar volume [$mm^3$] | 0.0267 | 0.0228 | 12.7 | 4.2 |
| Lubricant temperature rise [ºC ] | 19.1 | 21.4 | 5.7 | 9.3 |

* Average rings weight losses were not greater than 1 mg

*Table 4: Obtained average values from the friction and wear testing**

The values of final dynamic coefficient of friction indicate boundary lubrication condition for both lubricants. Lubricant A shows lower value of friction coefficient than lubricant B, but slightly higher wear. Attended values of friction coefficient and oil temperature during the testing were presented in the form of diagram form (*Fig. 2*). It could be clearly noticed that there are different shapes of friction coefficient curves for two lubricants. Lubricant A, as a biolubricant with good lubricity, shows descending tendency of friction coefficient from the beginning of the test (*Fig. 2a*).

Obtained block wear scar was of very good shape with weakly pronounced jagged scar edges (cross hair was run through a visual average of the jagged edges during measuring) (*Fig. 3*). Wear test results showed that, for the investigated conditions, lubricant A approves higher wear of both bodies in contact than lubricant B. This could be explained with the fact that tested biolubricant (lubricant A) did not contain antiwear additive. Average rings weight losses did not exceed 1 mg, and ring scar volume was reported as “too small to accurately measure”.

Lubricant temperature was rising during the tests, since it was not controlled, but after initial running-in period it become stabile and had the value of 46.1 °C and 48.4 °C, for lubricant A and B, respectively (*Fig. 3*). Consequently the lubricants temperature rose during the testing, was also lower for lubricant A than for lubricant B.

*Figure 2: Attended values of friction coefficient and oil temperature for: (a) lubricant A and (b) lubricant B*

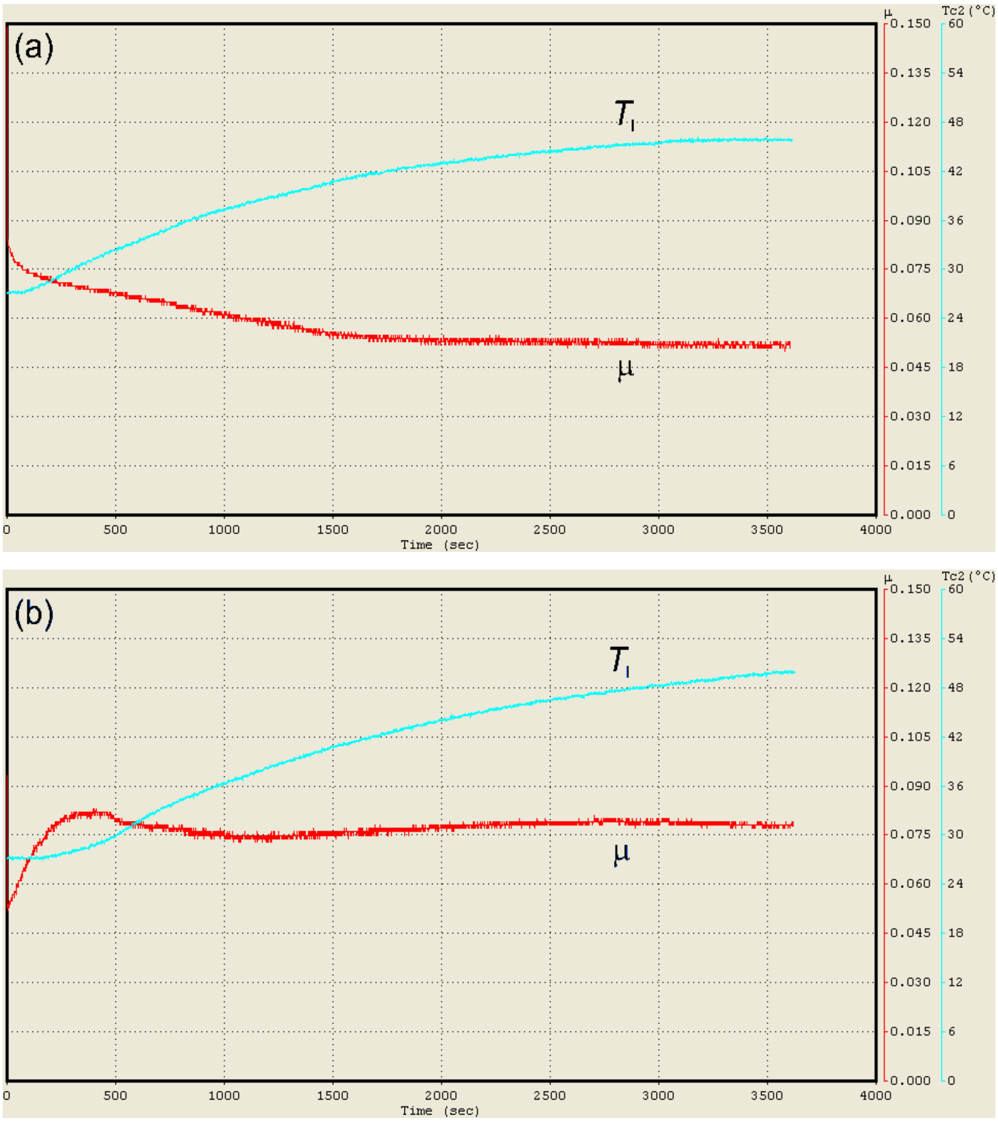
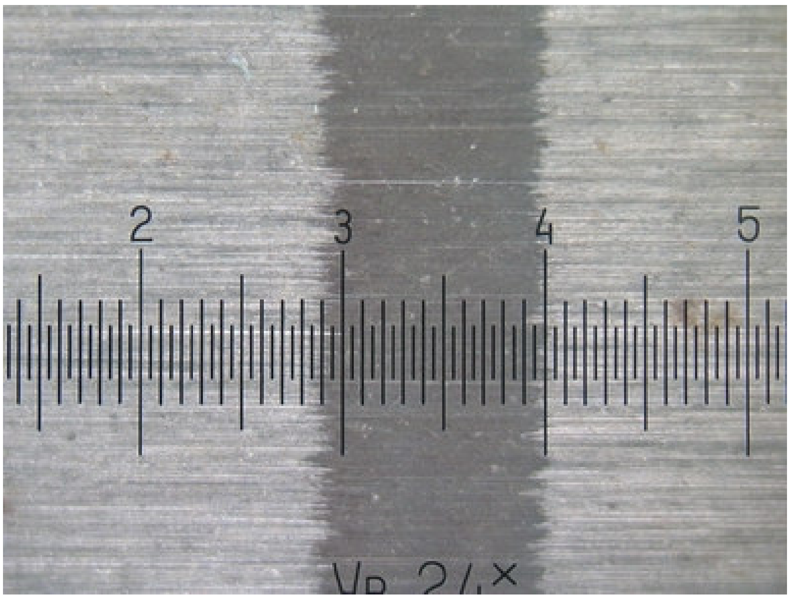



*Figure 3: Example of block wear scar*



# 5 CONCLUSIONS

Application of environmentally acceptable lubricants has increased during the last twenty years, in order to save a sensitive ecosystem, and among them use of biolubricants is becoming evident.

Vegetable oils obtained through selective plant breeding, like domestic New Sunflower Oil, could be appropriate base oil for lubricants.

The friction and wear results show that properly formulated biolubricant is comparable with mineral base lubricant and it could be an adequate substitution as a lubricant for chain saws.

# 6 LITERATURE

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