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THE INFLUENCE OF DEGUMMING PROCESS ON TRIBOLOGICAL BEHAVIOUR OF SOYBEAN OIL

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Abstract: This paper presents experimental results for pointing out the tribological behavior of two soybean oils (crude and degummed) in comparison to the transmission oil T90, with the help of tests on a four-ball machine. The following parameters were analysed: the friction coefficient, the average wear scar diameter (WSD) and the flash temperature parameter (FTP). The balls have a diameter of 12.7 mm with a high accuracy (± 0.0005 mm) and high quality of the surface ($Ra = 0.02...0.03$ μm), are made of rolling bearing steel. The test parameters are: load 100 N, 200 N and 300 N, sliding speed 0.461 m/s, 0.576 m/s and 0.691 m/s, test time being 60 minutes. The friction coefficient was higher for the two vegetable grades, especially with load of 100 N and for the crude soybean oil, but its values kept in the range of 0.025...0.095 for these vegetable oils suggest a mixed or boundary regime that could be practically accepted. The WSD was lower for these two vegetable oils under lower loads: at 100 N, WSD was in the range of 0.217...0.233 mm for the crude soybean oil, 0.240...0.289 mm and at 200 N, this parameter is higher, 0.250...0.280, except for the highest speed, for which WSD increases at 0.4 mm for the degummed soybean oil. For 300 N, WSD was higher than 0.4 mm for all tested oils. Flash temperature parameter (FTP) was better for the two grades of soybean oil, its values exceeding $1200 \text{ N/mm}^{1.4}$ for these oils, at tests with 200 N. Under higher load (300 N), this parameter is kept within the range $800...1000 \text{ N/mm}^{1.4}$, for all tested oils. The conclusion is that, for all tested speeds and loads of 100...200 N, the soybean oils (crude and degummed) have a better tribological behaviour.

Keywords: four ball test, Flash Temperature Parameter (FTP), soybean oil, degummed, friction coefficient, wear scar diameter.

1. INTRODUCTION

Industrial use of soybean oil has increased and researchers are interested in enlarging its applications, including those for lubrication [1-3].

Vegetable oils have potential to be used as base stock for lubricants when blended with proper additives [4,5] or/and with a test-confirmed evaluation for the actual regime. The long fatty acid chains and presence of polar groups in vegetable oil structures make them capable to be used as lubricants in mixed or boundary regimes [6,7].

Specialists are interested in testing vegetal oils on four ball machine in order to compare them with mineral and synthetic oils [8-10]. The wear scar diameters of epoxidized soybean oil and high-oleic soybean oil are affected by additivation (ZDDP), temperature, speed, load and interactions with the contacting surfaces [11]. Zhao et al. [12] investigated the tribological behaviour of two types of polymerized oils with high viscosities, synthesized by nitrogen plasma polymerization of soybean oil. The load-carrying capacities of polymerized oils reached 940.8 N and 1049 N,

respectively, higher than that of conventional soybean oil (646.8 N). For the tests performed on four ball tribotester, for different oil temperatures (55 ... 125 °C) and ASTM conditions (load 392 N, speed of 1200 rpm and tests during 60 minutes) for jatropha, engine and hydraulic oils as base lubricant, the coefficient of friction and wear scar diameter increase with the increase of the oil temperature. FTP decreases with the increase in oil temperature. Jatropha oil has higher anti friction and anti-wear ability than engine oil and hydraulic oil and the highest value for FTP was for jatropha oil [13]. Four ball test are also reliable for evaluating changes of tribological characteristics in case of contaminated, oxidated or aged oils [14].

The advantages of the soybean oil would be: even if the dynamic viscosity is lower than some commonly used lubricants, its viscosity is less dependent on temperature [15-17], thus, its viscosity index is bigger and their pressure coefficient for viscosity has intermediate values (10 – 20 GPa⁻¹) [18], low evaporation loss, a better lubricity (the oil behaviour in boundary regime makes the wear scar diameter smaller, even if the value of the friction coefficient is higher as compared to other oils), the flash point is higher, offering safer transportation and exploitation and, also, the costs are acceptable for obtaining the oil and the maintenance of the system it is introduced [15,19,20].

This paper presents experimental results for pointing out the influence of the degumming process of the soybean oil.

2. TESTED SOYBEAN OILS AND METHODOLOGY OF INVESTIGATION LUBRICATING CAPABILITY

The two grades of soybean oils (crude – Table 2 and degummed) were tested on a four-ball machine and there were analysed the following parameters: the friction coefficient, the average wear scar diameter (WSD) and the flash temperature parameter (FTP). The degumming process of this soybean oil is done at Prutul SA Galati and prevent oil to form gum deposit and to ferment [21].

Table 1. Chemical composition in fat acids of the crude soybean oil (wt. %)

Fat acid	Symbol	Concentration
Miristic	C14:0	0.11
Palmitic	C16:0	12.70
Palmitoleic	C16:1	0.13
Heptadecanoic	C17:0	0.05
Heptadecenoic	C17:1	0.06
Stearic	C18:0	5.40
Oleic	C18:1	21.60
Linoleic	C18:2	52.40
Linolenic	C18:3	5.70
Arahidic	C20:0	0.25
Eicosenoic	C20:1	0.20
Behenic	C22:0	0.50
Erucic	C22:1	0.16
Lignoceric	C24:0	0.20

Table 2. Chemical composition (wt. %)

Material	C	Cr	Mn	Si	S	P
Steel grade EN31	1.0	1.3	0.5	0.35	0.05	0.05

Figure 1 presents the four-ball machine (in the “Lubritest” Laboratory of “Dunărea de Jos” University of Galati, the design allowing for a maximum load of 6000 N, in agreement with the standard SR EN ISO 20623:2004 Petroleum and related products. Determination of the extreme-pressure and anti-wear properties of fluids. Four ball method [22]. The main elements are: electric motor (1), machine body (2), loading system (3), electric panel for tuning and monitoring (4), support (5).

The balls have a diameter of 12.7 mm with a high accuracy (± 0.0005 mm) and high surface quality ($Ra = 0.02...0.03$ μm), were delivered by SKF. The test parameters are: load 100 N, 200 N and 300 N, sliding speed 0.461 m/s (1200 rpm), 0.576 m/s (1500 rpm) and 0.691 m/s (1800 rpm), test duration of 60 minutes. The test balls are lime polished, made of chrome alloyed steel (Table 2), with 64 – 66 HRC hardness, conforming to requirements of ISO 683-17:2014 Heat-treated steels, alloy steels and free-cutting steels. Part 17. Ball and roller bearing steels, type 1.

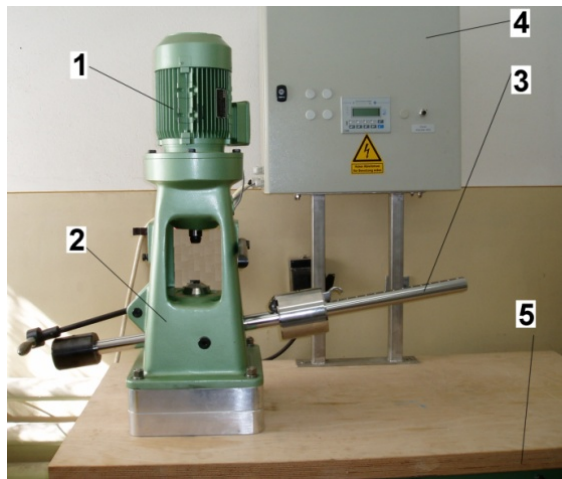


Figure 1. The four ball machine

3. RESULTS

This study included the following parameters: the wear scars diameters (a value of WSD was obtained by averaging two diameters for each ball, one along the sliding and the other – perpendicular to it) on the three fixed balls, the friction coefficient and the flash temperature parameter.

Four ball machine is more intense used for characterizing lubricants as comparisons are easy to make and it is also convenient to point out difference in ranking lubricants, for improving additivation and limiting carrying capacities [5,6,23].

Rico [24] obtained a very sharp increase of WSD, from 0.46 mm to 2.85 mm, when passing from $W = 126$ kgf to 160 kgf for a mineral oil on a four ball tribotester. Jayadasa et al. [25] determined a WSD of 0.54 mm for coconut oil used as lubricant in a four ball tribotester, at 1236 N, higher than the rapeseed oil.

In this study, the smallest values for the WSD was obtained for the crude soybean oil, followed by the degummed soybean oil and the transmission oil T90 (Fig. 2).

Comparing the values obtained for all three tested oils, the two vegetable oils produced lower values of WSD for low load (100 N and 200 N). For the load of 300 N, WSD are all above 0.4, for all tested oils. The crude soybean oil produced a WSD less sensitive to the speed for lower loads of 100 N and 200 N, same behavior was noted for the transmission oil T90 for $W = 200$ N and even for $W = 300$ N.

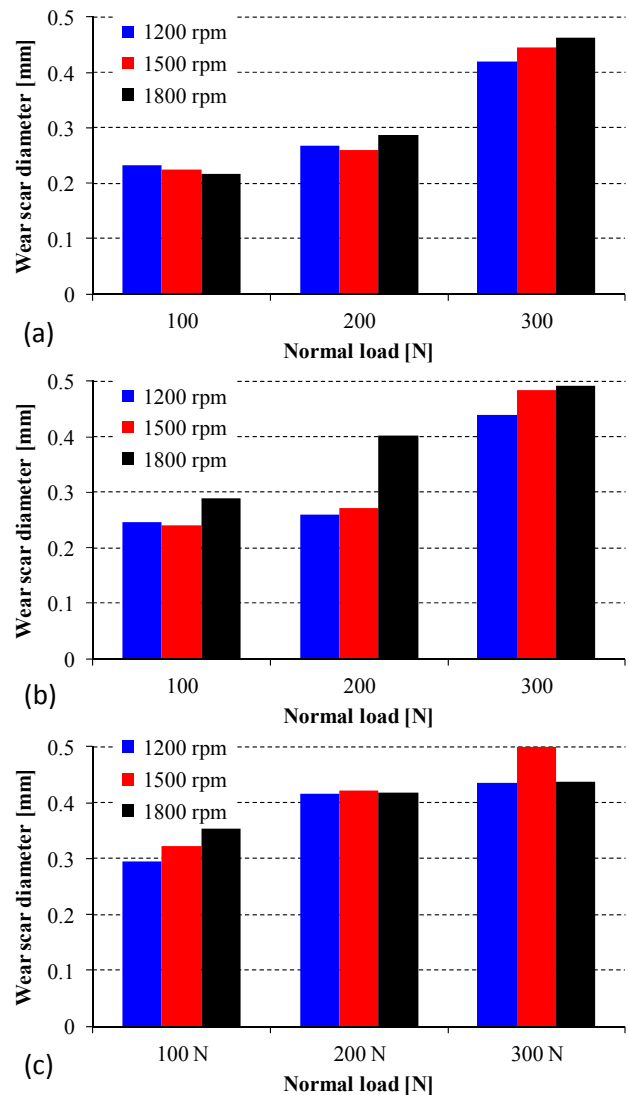


Figure 2. Values of wear scar diameter as a function of load and speed: (a) crude soybean oil, (b) degummed soybean oil and (c) transmission oil T90

Tests done on the four ball machine pointed out low values of friction coefficient as prove of a very thin lubricant film, at least for the test parameters (normal load 100...300 N and sliding speed, 0.461 m/s, 0.576 and 0.691 m/s) and acceptable values of WSDs (Fig. 3).

FTP (Flash Temperature Parameter) is used for ranking the lubrication capability of oils under high load that develop high temperatures in contact, but also for fluids involved in forming and cutting tools. FTP of a fluid is the lowest temperature that it can vaporize to form an ignitable mixture in air [26].

Higher FTP is a positive point of lubricant oils because they do not evaporate if temperature is low and their film thickness is still enough to reduce the heat flux generated by friction. In other words, low friction and

temperature will exist even in a mixed or boundary regime. Analyzing all three parameters here presented, one may conclude that a combination of (low friction coefficient, low WSD and high FTP) offers a highly reliable lubricant in contact. But this capability could be “transferred” to actual systems with prudence, as laboratory conditions (especially those for four ball tests) are well controlled.

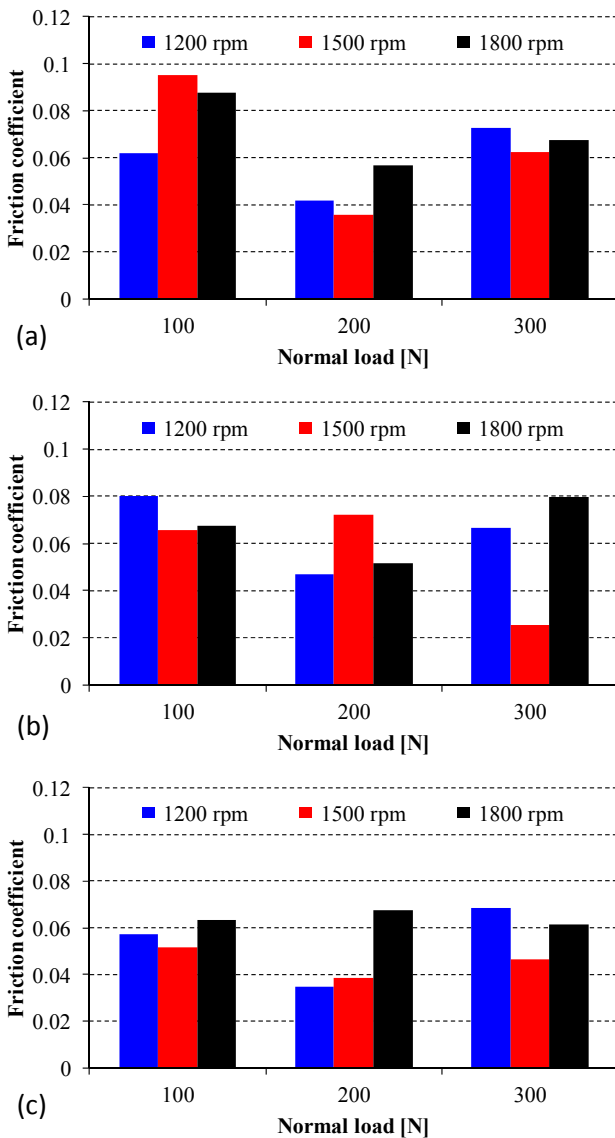


Figure 3. Values of friction coefficient as a function of load and speed: (a) crude soybean oil, (b) degummed soybean oil and (c) transmission oil T90

The “flash-temperature” concept is a means of accounting for the local maxima of frictional heat flux. Several factors influence the surface temperature: rubbing time, speed, load, temperature of lubricant and environment and the configurations characterizing the friction couple, including

size, shape, texture quality, their physical and mechanical properties [27].

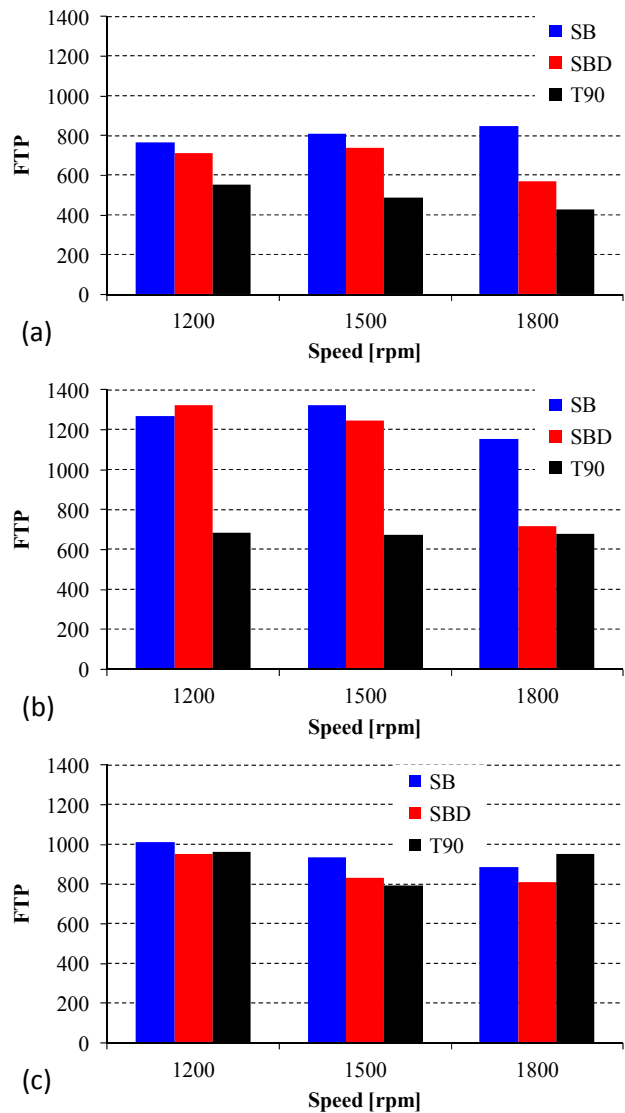


Figure 4. FTP for the tested oils, for different rotational speeds and load: (a) 100 N, (b) 200 N and (c) 300 N

This single number (FTP) expresses the critical flash temperature above which a given lubricant will fail under given conditions [28]. According to Equation (1), there exist an inverse proportionality between FTP and wear scar diameter, under constant load:

$$FTP = \frac{W}{d^{1.4}} \quad (1)$$

where W is the load on the machine axle, in N, and d is the WSD in mm; thus, the unit of FTP being $N/mm^{1.4}$ in this paper.

A higher value of FTP number means the lubricant stability in a particular condition of exploitation. The lower values causes

breakdown of lubricant film, hence WSD increases. Masjuki et al. [23] proposed a mathematical model, including speed and test duration, but the equation (1) is more used to express the lubricating contact capability, this will be used in this paper for evaluating the three tested oils.

In this study, at lower load ($W = 100$ N and $W = 200$ N), the highest values were obtained for the crude soybean oil; for the degummed soybean oil the values were just a little bit lower, but for all tests (Fig. 4). Under load $W = 100$ N, the difference in this parameter could be acceptable for actual applications, one may notice that the increase of the load to $W = 200$ N differentiate the transmission oil to the vegetable oils. Only under the highest tested speed, FTP of the degummed soybean oil is slightly higher than that of the transmission oil, suggesting that low loads and high speed could be a solution for using this grade of soybean oil.

Under $W = 300$ N, the difference in values of FTP is lower and all are kept above 800 N/mm^{1.4}, the values being only with 20 % over 800 , indifferently of speed.

For these soybean oils, larger values than 1000 N/mm^{1.4} were obtained for the intermediate value of load ($W = 200$ N), especially for speeds of 1200 and 1500 rpm.

The transmission oil has a more pronounced tendency of increase the FTP with load and less with speed. This difference in the behavior of these two categories of oils (mineral and vegetable) points out the necessity of testing the lubricating capabilities and not estimating by general tendency of a lubricant class.

4. CONCLUSIONS

Both grades of soybean oil had exhibited a good behaviour as lubricant, for smaller ranges of speed and load, as compared to the transmission oil T90.

Values for friction coefficient were higher for the two vegetable grades, especially with load of 100 N and for the crude soybean oil, meaning the regime is either a mixed or a

boundary one. The WSD was lower for these two vegetable oils under loads of 100 N and 200 N. For a load of 300 N, WSD was higher than 0.4 mm for all tested oils. Flash temperature parameter (FTP) was better for the soybean oils, its values exceeding 1200 N/mm^{1.4} for these oils under 200 N. For $W = 100...200$ N, FTP for the transmission oil was in the range $550...680$ N/mm^{1.4}. Under higher load ($W = 300$ N), this parameter is kept within the range $1000...1200$ for all tested oils, only for speeds of 0.461 m/s (1200 rpm) and 0.576 m/s (1500 rpm).

A synthesis conclusion is that these two vegetable oils could be used in mild regimes (load and speed), and the degumming process does not affect in a significant manner the tribological behaviour of the soybean oil, at least for the tested conditions. Of course, tests have to continue on how these oils keep the lubricating capabilities in time. The test duration of 60 minutes is far to be the duration of an actual application. But the results obtained for the soybean oils are promising as they have not been additivated, yet.

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