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On the tribological performance of vegetal lubricants: experimental investigation on Jatropha Curcas L. oil

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Abstract

The limited resources of petroleum-based lubricants and increased environmental contamination, that they produce, lead to increased demand for bio-lubricants. Due to several factors such as biodegradability, good lubricating properties and low production costs, the plant oils represent a good alternative as reference to replace the petroleum-based oils. Obviously, the need to ensure the use of vegetable oils as a source of food makes non-edible vegetable oils a formidable source for plant oil lubricants. Thus, the toxicity of Jatropha Curcas L. oil makes it a very attractive and alternative lubricant source. Therefore, the aim of this work is to investigate on tribological performance of Jatropha Curcas L. oil in the lubricating contact pair AISI 52100 steel sliding against X210Cr12 steel. The experimental tests were carried out using ball-on-flat reciprocatory tribometer for several frequencies and with normal load of 12N. The Jatropha Curcas L. oil was analyzed for its chemical and physical properties such as viscosity, density and flash point. The results were interpreted on the basis of the evolution of the friction coefficient. The evolution of the friction coefficient was monitored for 40 min in all tests. The results show that the friction coefficient decreases with the increase of the frequency, and the final value stays in the range of 0.04-0.122.

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Keywords: Jatropha Curcas L., natural-based oil, tribological performance, AISI52100 steel, X210Cr12 steel.

1. Introduction

The quick exhaustion of fossil reserves, the rise in prices of products made from petroleum and the high levels of environmental pollutants lead to explore alternative and no contaminant lubricants [1]. Unfortunately, due to their low biodegradability and high toxicity, the mineral oils are not a viable alternative. The lubricants do not create many problems with respect to a set of other products released into the environment, although it a large portion of lubricants, during or after their use, can pollute the environment [2]. Several advantages and properties are offered by the use of vegetable oils: biodegradability [3, 4], low production costs [5], good lubricating properties, low toxicity, high viscosity and high flash points [6]. The plant oils are employed in various industrial applications as for the automotive lubricants. In this case the lubricants are derived from rapeseed, and soy oils that are finding good use in European countries [7].

Jatropha Curcas L. is a perennial shrub, poisonous, with a maximum height of approximately 5 m, which belongs to the Euphorbiaceae family. Areas where Jatropha Curcas L. grows are subtropical and tropical regions in Africa, Central and South America and South Asia as well. Seeds of Jatropha Curcas L. plants are pressed and the obtained oil is used in many industrial

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branches from health services to a production of biodiesel [8, 9]. Conditions for pressing of seeds and an optimization of the pressing process are described by many authors [8]. Being Oil Jatropha Curcas L. a cheap natural-based lubricant, it is important to assess its characteristics to extend the application conditions. Experimental investigation describes important oil characteristics as viscosity, density and flash point. The authors performed tests, to know its chemical and physical properties, according to the standard ASTM D445 - Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity).

Therefore, the aim of this work is to investigate on tribological performance of Jatropha Curcas L. oil in the lubricating contact pair AISI E52100 steel sliding against X210Cr12 steel. The test was carried out using a ball-on-flat reciprocatory tribometer for several frequencies and with normal load of 12N. The results were interpreted on the basis of the evolution of the friction coefficient.

2. Methods

Jatropha Curcas L. seeds from Indonesia were pressed by Labor Tech MP Test 5.050 machine, and the pressure of 5 kN was applied. Deformation speed corresponded to 10 mm·min^{-1}. According to the standard ASTM D445 the density, viscosity and flash point of the Oil Jatropha Curcas L. were investigated. All tests were performed in the ETSIDI laboratory of chemical engineering of the Polytechnic University of Madrid. For the density a pycnometer of 10 ml was used and the result was obtained at a temperature of 15ºC. For the viscosity, the temperature was of 40ºC under ASTM D445-65 recommendation and Afora Cannon-Fenske viscometer (Series 300) was employed (**Figure 1**).

Figure 1: Afora Cannon-Fenske viscometer (Series 300)

For the flash point a Flash Point Tester was used, according to Pensky-Martens ASTN D93 IP 34 Semi-Automatic DIN 51758. The flash point measures the tendency of the sample to form an ignitable mixture with air. The sample is heated slowly (5ºC/min) and at constant speed with continuous stirring. At regular intervals a small flame in the glass has been introduced by stopping, simultaneously, the agitation. The flash point is defined as the lowest temperature at which ignition of the vapor above the sample occurs. The test was performed at an atmospheric pressure of 703 mmHg. For this reason, according to the standard ASTM D445, this result should be corrected, using the formula reported below, at a pressure of 760 mmHg.

$$T = T_{obs}(^{\circ}C) + 0.333 \times [760 - P_{obs}] \quad (1)$$

Friction tests were carried out using a ball-on-flat testing apparatus on a TR-BIO 282 Reciprocatory Friction Monitor (Ducom Instruments, Bangalore, India), following a consolidate procedure [10,11]. In **Figure 2** the schematic apparatus is represented. An AISI E52100 steel pin – circular section, 6 mm diameter – was hold in contact against a flat specimen of X210Cr12 steel.

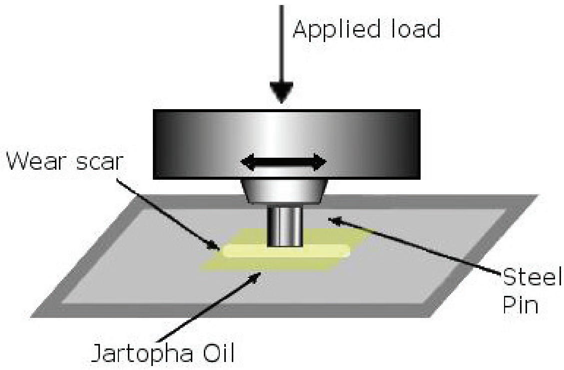


Figure 2: Schematic representation of the friction test apparatus

To gain lubricated contact between the two surfaces, few drops of Jartopha Curcas oil were released at the interface [12]. The reciprocating movement is imposed by the instrument to the pin holder by a stepper motor, which swings a portion of the complete round back and forth. The spinning motion is therefore converted to a linear movement by a rocker arm. The friction force is constantly acquired by a load cell, and the evolution of the friction coefficient during the test is recorded.

To obtain different sliding velocities the tests were performed varying the oscillation frequency, while all others parameters were kept constant. Thus, the normal load was set to 12 N, the stroke to 8 mm and the test time to 40 min. Sliding frequency was equal to 2, 5, 8 and 20 Hz. Every test was realized at room temperature, in laboratory air at controlled levels of relative humidity. To better understand the influence of the oscillation frequency on the friction coefficient, a lubrication parameter was evaluated, using the following formula:

$$\sigma = \frac{f\,s\,\eta}{L} , \quad (2)$$

where f is the oscillation frequency (Hz), s the stroke (m), η the viscosity (cSt) and L the normal load (N).

3. Results

All test for density, viscosity and flash point have been repeated three times. The results and corrected results are reported in the **Table1**.

Table1: Physicochemical properties of Jatropha Curcas L. oil.

Properties	**Jatropha Curcas L. oil**
Density at 15ºC (g/ml)	0.9169
Kinematic viscosity at 40ºC (cSt)	36.605
Flash point at 760 mmHg (ºC)	263±0.5

In **Figure 3** the coefficient of friction (μ) evolution during the tests is shown. This plot is obtained directly by the instrument acquisition software, which operates an averaging on the friction values acquired during 10 s of consequently time intervals.

This image shows the influence of the relative velocity – in term of oscillation frequency – to the coefficient of friction. A lower μ mean value is obtained as the frequency rises.

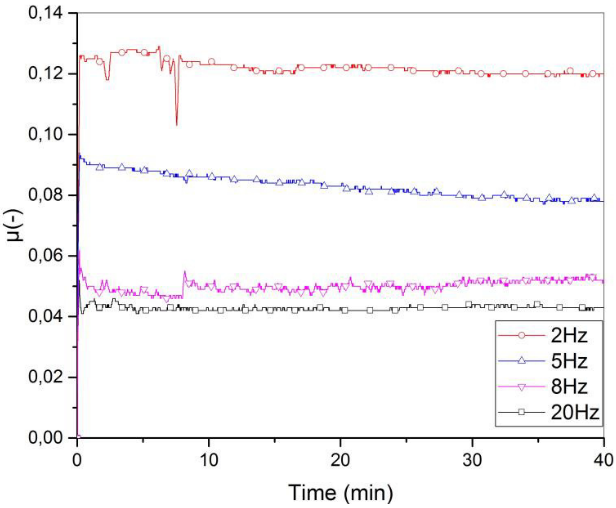


Figure 3: Evolution of the friction coefficient during the test time

In **Table 2** those values are quickly reported: mean μ were obtained excluding the first 10 min of tests, to avoid transient phase influence [13,14].

Table2: Mean μ values after 10 min of the test for several frequencies.

Sliding frequency (Hz)	Mean μ (-)
2	0.121±0.005
5	0.083±0.004
8	0.050±0.002
20	0.043±0.001

Furthermore, it was obtained the curve of the friction coefficient as function of the lubrication parameter (using equation 2), **Figure 4**. The diagram gives a qualitative information on the lubrication regime achieved. As the mean velocity rises the lubrication switches from boundary to mixed regime.

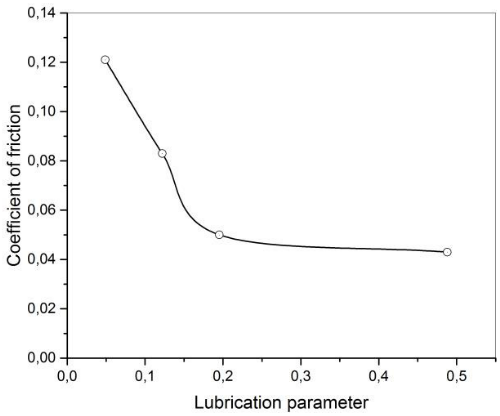
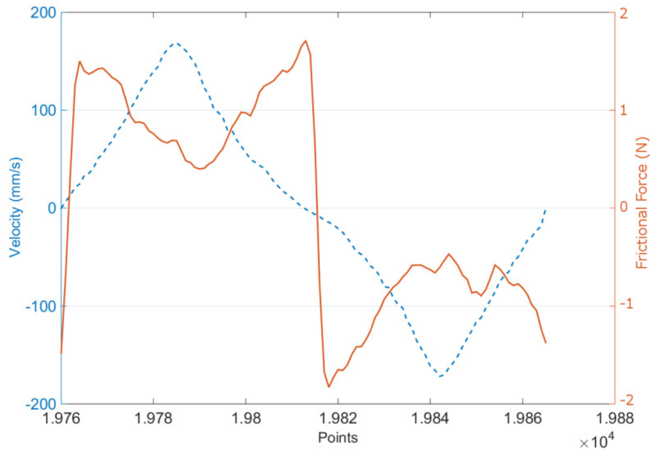


Figure 4: Evolution of the coefficient of friction as function of the lubrication parameter.

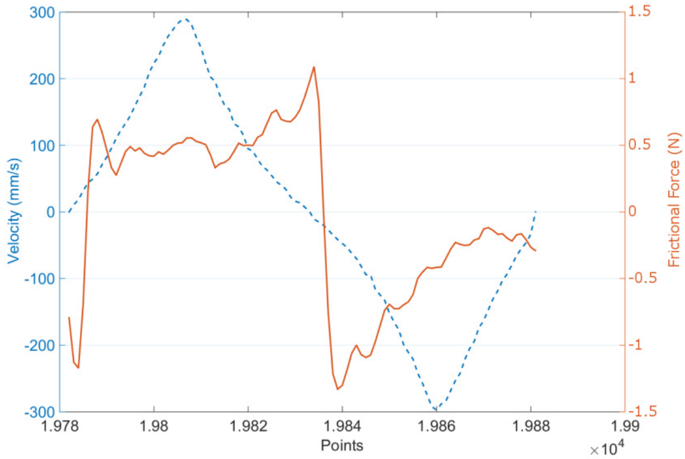
In **Figure 5**, it is reported the evolution of the frictional force and the pin velocity as function of the points acquired (i.e. the time passing). These plots are limited to a single complete cycle, which is a way back and forth of the pin, extracted during the stationary phase of the test.

When the pin inverts its motion the velocity is zero, in this moment the frictional force approach to zero but rapidly increases, as the pin starts to move again, to its highest values. This corresponds to the static frictional phase [15, 16]. The velocity increase to its highest value in the middle of the stroke, during this period the frictional force reaches its lowest points.

a)



b)



c)

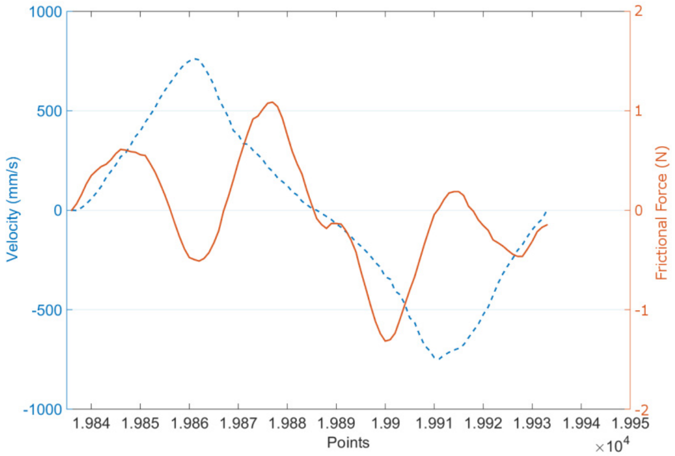


Figure 5: Evolution of the pin velocity and the frictional force *vs.* aquired points. a) 5Hz; b) 8Hz; c) 20Hz. 2Hz is omitted in the interest of brevity.

In the first graph (a), it is represented the evolution obtained by 5 Hz oscillation. The velocity peak is equal to 172 mm/s – absolute value –, during the second phase of oscillation. Maximum force is equal to 1.98 N, whereas 0.40 N is the lowest force recorded during dynamic friction. In the second graph (b) the oscillation is 8 Hz, the highest velocity is 297 mm/s, whereas maximum and minimum – during dynamic phase – forces are 1.33 N and 0.12 N. The third graph (c) regards the test with 20 Hz of oscillation, where the highest velocity and force are 762 mm/s and 1.1 N, respectively. In this case, the force recorded during the sliding phase, when the lubrication could be hydrodynamic, more than reducing itself reaches negative values. Probably, this occurs due to the fluid inertia forces that at high values of the test frequency are much larger, and with more apparent effect, compared to the low frequencies tested. The explanation of this phenomenon requires a further analytical study on the lubrication phenomena [17, 18, 19, 20], involving the inertia components influence in the Reynolds equation. The plot relative to 2 Hz of oscillation is omitted, in the interest of brevity, because it exhibited very nearly the same behavior of the 5 Hz case.

4. Conclusions

In this work the tribological performance of Jatropha Curcas L. oil in the lubricating contact pair AISI E52100 steel sliding against X210Cr12 steel was investigate. The physicochemical properties of the Oil Jatropha Curcas L. (density, viscosity and flash point) were investigated. Tests were conducted by using a reciprocating pin on flat tribometer varying the oscillation frequency (to 2, 5, 8 and 20 Hz). The normal load was set to 12 N, the stroke to 8 mm and the test time to 40 min. Following conclusions can be deduced from the experiment results:

- the oil exhibited good physicochemical properties and could be favorably used as lubricant feedstock in industrial application;
- the final value of the friction coefficient in all tests stays in the range of 0.04-0.122, besides the first 10 min of transient, the deviation was slightly present;
- from the obtained results it can be observed that the friction coefficient, for the tribological pair under study, decreases with the increase of the average speed of the pin;
- from a qualitative analysis of the reached lubrication regime it is apparent that the lubrication switches from boundary to mixed regime when the mean velocity rise;
- due to the fluid inertia forces, that at high values of the test frequency are much larger and with more apparent effect compared to the low frequencies tested, the force recorded during the sliding phase (in the case of the test with 20 Hz of oscillation) more than reducing itself reaches negative values. This phenomenon requires a further study that involves the inertia components influence in the Reynolds equation;
- the oil, interposed between the contact pair – AISI E52100 steel vs. X210Cr12 steel –, partially separates the sliding surfaces as the oscillation velocity rises.

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