Effect of Nano SiO$_2$ as an Additive in Cotton Seed Oil

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Abstract: Vegetable oil can be a deserving candidate as an eco-friendly lubricant because of its properties like biodegradability, non-toxicity, excellent lubricity, Viscosity Index and low volatility. But they have some unsatisfactory tribological properties. The lubricant used in this investigation is cottonseed oil, focused on the issues related to environmental pollution, toxicity and its cost. Even though cottonseed oil lubricant is one of the best choices for lubrication purpose, however the properties are slightly lesser than mineral oil. To improve the lubricant properties, nano Silicon dioxide additive is added in different concentrations. Four ball Tribotester is used for conducting anti-wear test according to ASTM standard D 4172. This paper describes the effect of Silicon dioxide nano additives on tribological properties of refined cottonseed oil. The refined cottonseed oil with 2 % of Silicon dioxide as additive shows good results which are very close to 20W50 oil.

Keywords: Vegetable oil, Wear Scar Diameter, Cottonseed oil, Silicon dioxide, 20W50, ASTM D 4172.

1. Introduction

Now days market demands for lubricants are increased environmental compatibility, reduced emissions with greater safety, and superior performance. Proper lubrication between the moving parts is very much essential for the effective and efficient working of an automobile at various operating conditions. Because of proper lubricant, the parts can slide smoothly over mating surfaces. This decreases loss of energy and also reduces wear and friction which has very importance in engines and drives. From last many years mineral oils have been used in engine as a lubricant. Now, the depletion of reserves of mineral oil and giving importance to the environment against pollution have changed the interest of researchers towards making of eco-friendly lubricants as a substitutes for mineral oils in industrial applications and also in engines [6]. Replacing petroleum base oils with biodegradable oils is one of the ways to reduce the adverse effects on the ecosystem caused by the use of lubricants. Vegetable oil based lubricants are having the most important properties such as high lubricity, high load carrying capacity, high flash point, high viscosity index, low toxicity, low emission into the environment as compared to synthetic and mineral oils [1,2,3]. However, the tribological properties of vegetable oil are poor and can be improved by adding suitable additives or by performing some chemical reactions [7, 8]. India has a great potential of producing edible and non-edible vegetable oil seeds. These oil seeds can be used as a most prospective source for producing vegetable oil based lubricants [3]. This experimentation will try to check the possibility of the replacement of mineral oil based lubricants with cottonseed oil based lubricants.

2. Vegetable Oils as Alternative Lubricants

Tribology is the branch of science which deals with study of interacting surfaces which are having relative motion between them. This brings all major disciplines together involving mainly wear, friction and lubrication between the matting surfaces. So the study of different parameters like friction, wear, and lubrication related to tribology became an important aspect of the research. The lubrication
process of reducing friction and wear between moving or sliding surfaces, by the inserting lubricants in between them is called lubrication [2]. The purposes of lubrication are to reduce friction, wear and heat between contacting surfaces. It is also required to reduce oxidation, prevention from rust and reduce energy consumption [1, 2].

2.1 Advantages and Disadvantages of Vegetable Oils

Vegetable oils have several advantages and also some limitations when considered for automobile, industrial and machinery lubrication because of their good inherent qualities. Table 1 summarizes the some of the advantages and disadvantages of vegetable oils as compared to mineral oils [1, 2, 3].

| Advantages                                      | Disadvantages                              |
|------------------------------------------------|--------------------------------------------|
| Fast biodegradation                            | Poor Oxidation Stability                   |
| Less toxic                                     | Limitations in Operating Temperature       |
| Renewable and clean                            | Unpleasant smell                           |
| High VI                                        | High pour point                            |
| Low volatility                                 |                                            |
| Higher lubricity                               |                                            |
| Higher flash points                            |                                            |
| Good boundary lubrication                      |                                            |
| Reduced engine emissions                       |                                            |
| Disposal at minimal expense                    |                                            |

2.2 Properties of Vegetable Oils

Vegetable based lubricating oils have many useful physio-chemical properties which are listed in Table 2 [5].

| Properties Vegetable oils | Kinematic Viscosity (at 40°C) cSt | Pour point (°C) | Cloud point (°C) | Flash point (°C) | Density (kg/l) |
|---------------------------|-----------------------------------|-----------------|------------------|-----------------|----------------|
| Corn oil                  | 34.9                              | -40.0           | -1.1             | 277             | 0.9095         |
| Linseed oil               | 22.2                              | -15.0           | 1.7              | 241             | 0.9236         |
| Peanut oil                | 39.6                              | -6.7            | 12.8             | 271             | 0.9026         |
| Rapeseed oil              | 37.0                              | -31.7           | -3.9             | 246             | 0.9115         |
| Soya bean oil             | 32.6                              | -12.2           | -3.9             | 254             | 0.9138         |
| Sunflower oil             | 33.9                              | -15.0           | 7.2              | 274             | 0.9161         |
| Palm oil                  | 39.6                              | -                 | 31.0             | 267             | 0.9180         |
| Cotton seed oil           | 33.5                              | -15.0           | 1.7              | 234             | 0.9148         |

3. Experimentation

3.1 Selection of Oil and nano additive
Cottonseed oil, in India, is available on large scale, mainly in Gujarat and Maharashtra state. Moreover, the cost of cottonseed oil is very less as compared to others. Silicon dioxide is used as a nano additive and added with different concentrations in the refined cotton seed oil. The specifications obtained from supplier for Silicon dioxide are Purity: 99.5% APS: 15-20 nm and Density: 2.4 g/cm³. The present work is an attempt to touch the potential of refined cottonseed oil as an alternative lubricant compared to mineral oils. Generally, SAE multi-grade oil i.e. SAE 20W50 is used as a lubricant in multi-cylinder...
engine to have proper lubrication. Table 3 shows the properties of SAE 20W50 and refined cotton seed oil. These properties of RCSO are tested at CHEMTECH Laboratories, Pune and of SAE 20W50 oil is taken from manufacturers catalogue.

Table 3: Properties of lubricating oil

| Lubricant→ | SAE 20W50 oil | RCSO | Test Method       |
|------------|---------------|------|-------------------|
| Specific gravity | 0.8954        | 0.9040 | ASTM D 4052 2016 |
| Kinematic Viscosity (40°C) cSt | 174.8         | 32.78   | ASTM D 7042 2016 |
| Kinematic Viscosity (100°C) cSt | 19.1         | 15.80  | ASTM D 7042 2016 |
| Viscosity index | 124          | 181.67  | ASTM D 2270 2016 |
| Flash point (°C) | 229          | 290-292 | ASTM D 92 2016 b |
| Fire Point (°C) | --            | 304-306 | ASTM D 92 2016 b |
| Pour point (°C) | -30          | -20     | ASTM D 97 2017 b |

3.2 Sample Preparation

Silicon Dioxide as anti-wear additive is added at 1%, 1.5% and 2% wt. concentrations in refined cotton seed oil (RCSO) to prepare the test samples. The sample is prepared of 30 ml by volume. The weight of the nano additive is measured on a digital weighing machine. The magnetic stirrer with hot plate is used for dispersion of additive in the oil. The dispersion process with the help of magnetic stirrer improves the dispersion stability. The sample calculation is described below. All other sample calculations are also done in the same way.

3.3 Sample calculation for RCSO + 1% SiO₂

Volume of Sample  = 30 ml
Volume of RCSO    = 30 ml
Weight of RCSO    = Volume × Density
                  = 30 × 0.9060 gm/ml
                  = 27.18 gm
Weight of SiO₂    = 27.18 × 1/100
                  = 0.2718 gm
Volume of SiO₂    = weight / density
                  = 0.2718 gm / 2.4
                  = 0.1133 ml
Actual volume of  = 30 – 0.1133
RCSO             = 29.8867 ml

3.4 Tribological Testing on Four Ball Tribotester

The wear preventive characteristics of lubricant were tested as per ASTM D 4172 standard. The four-ball tribotester TR-30L-1AS, manufactured by DUCOM, Bangalore, India is used to evaluate wear preventive characteristics of oil. The tribotester uses four balls where three balls are kept at the bottom and one on top. The bottom three balls are fastened firmly in a ball pot which is containing the lubricating oil under test. The top ball is rotated at the desired speed, while the bottom three balls are pressed against it. The lubricant under test is characterized by measuring the wear scar formed on the
surface of balls. This wear scar is measured using an image acquisition system [10]. The Four-ball tribotester is shown in Fig. 1 and the testing conditions as per ASTM D 4172 are as shown in Table 4.

| Parameters | Condition |
|------------|-----------|
| Load       | 392 ± 2 N |
| Temperature| 75 ± 2 °C |
| Speed      | 1200 ± 60 rpm |
| Time       | 60 ± 1 min |

Table 4: Wear Test Conditions

Testing balls are made of chrome alloy steel (AISI standard E-52100), with a diameter of 12.7 mm and a roughness value of $Ra = 0.035$ mm. Acetone is used as a cleaning fluid, which is nontoxic and avoiding transfer of test oil from one test to the next. It is also not contributing in wear or anti-wear of the test lubricant.

4. Results and Discussion

The results obtained from Four-Ball Tribotester for wear tests of testing samples with and without additives are discussed further.

4.1 Friction and Wear Behavior

The wear characteristics (Wear Scar Diameter) of lubricating oil were measured using the image acquisition system. The average values of the wear scar diameters and coefficients of friction for all samples of SAE 20W50 oil and refined cottonseed oil are as shown in Table 5.

Table 5: Average values of coefficient of friction and wear scar diameter for test oils.

| Sample Oil                        | Average WSD (µm) | Coefficient of Friction |
|-----------------------------------|------------------|-------------------------|
| SAE 20W50 oil                     | 530              | 0.08839                 |
| Cottonseed oil (CSO)              | 866              | 0.07720                 |
| Refined cottonseed oil (RCSO)     | 696              | 0.09259                 |
| RCSO+1% Silicon Dioxide           | 624.33           | 0.09822                 |
| RCSO+1.5% Silicon Dioxide         | 565.66           | 0.08870                 |
| RCSO+2% Silicon Dioxide           | 558              | 0.08947                 |
Figure 2: (a) WSD and (b) COF for different samples

Figure 3: Scar images for SAE 20W50 Oil

Figure 4: Scar images for Refined CSO

Figure 5: Scar images for RCSO + 2% wt. SiO₂
From the results shown in the table 5, Figure 2, 3, 4 and 5, it is observed that coefficient of friction for pure cottonseed oil is less than that of the coefficient of friction of SAE 20W50 oil, but the scar diameter is higher. But wear scar diameter and coefficient of friction of refined cottonseed oil is larger than SAE 20W50 oil. This increase in wear scar diameter is because of the continuous removal of metallic soap film. This film is formed because of the reaction of the oil with the metallic surface during relative motion. This metallic film is continuously reforming by further chemical reactions. The shear strength of the metallic soaps is low, so as a result, the coefficient of friction for vegetable oil is also low. From the Table 5, further it is observed that the wear scar diameters for 1%, 1.5%, and 2% silicon dioxide additive wear scar diameter is lesser than refined cottonseed oil. The wear scar diameter of RCSO is decreasing with increasing the concentration of SiO$_2$ additive. The 2% SiO$_2$ with refined cotton seed oil shows the lowest value of wear scar diameter. This is because SiO$_2$ forms a reactive film layer that prevents direct contact between metal surfaces. The protecting layer may act as a cushion between the metal and it prevents the formation of corrosion wear on metal surfaces. The coefficient of friction remains almost same for RCSO + 2% SiO$_2$ as like 20W50 oil. Figure 6 shows the graph between Frictional Torque and time. It shows that it remains almost constant when SiO$_2$ added in refined cotton seed oil.
5. Conclusions

India is one of the largest countries in production of oilseeds in the world with its rich agro-ecological diversity. So, India can grab this opportunity to expand the market share of lubricants based on vegetable oil. Vegetable oil-based lubricants are biodegradable and biodegradability is one of the major required properties of lubricant in case of automobile applications. From anti-wear test carried out on Four-Ball Tribotester, the wear scar diameter of refined cottonseed oil is more; it can be improved by adding anti-wear additives like Silicon Dioxide. The WSD of RCSO+2% SiO2 is lower and very close to 20W50. At the same time there is no much difference in the COF. It can be concluded that the cottonseed oil can become an alternative for mineral oil by adding some additives.

Acknowledgement

The author thanks BCUD, Savitribai Phule Pune University, Pune for providing financial assistance under Research Promotion Scheme.

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