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TRIBOLOGICAL ANALYSIS OF MUSTARD AND COCONUT OIL AS ENVIRONMENT FRIENDLY LUBRICANT

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Abstract- *Tribological analysis of lubricating oil shows the feasibility and applicability of any lubricating oil. The properties of lubricating oils can be measured using deferent tribological test. On the other hand, Environment friendly lubricant is the key demand in 21st century for the issue of global climate change. Vegetable based lubricant is one of the environment friendly lubricants. Mustard and coconut oil are most common vegetable oil in subcontinent including Bangladesh. These are renewable and easily accessible from any region. This study investigated the aspect of these vegetable oils as lubricant. Several tribological experiments as like viscosity and density measurement, 4-ball wear test, friction test, high pressure rheological test, etc. of pure mustard and coconut oil were done and compared with a conventional mineral oil. Friction and wear behavior of the mustard and coconut oil expresses their boundary lubrication properties. Density and viscosity of mustard and coconut oil are acceptable for the application as lubricant. Oiliness of the oils is good enough compared with mineral oil. Results also found that these vegetable oils have high viscosity index, good lubricity, better boundary lubrication property and environment friendly, but low temperature fluidity is not good enough. This study also investigated the high pressure behavior and their phase diagrams are drawn. Results concluded that mustard and coconut oil could be used as base oil for environment friendly lubricant.*

Keywords: Tribology, Vegetable oil, Density, Viscosity, Friction, Wear

1. INTRODUCTION

It is well known that mechanical systems often employ lubricants, the majority of which are petroleum based, to decrease component friction and surfaces wear. Increased concerns about environmental damage caused by mineral oil based lubricants, has created a growing worldwide trend of promoting vegetable oil as base oil for automobile lubricants. Bartz [1] explained in details about the effect of lubricant application on global environment. Now a days, due to rising of petroleum based oil prices, the diminishing supplies of natural resources, global climate change and increased environmental sensitivity, various alternatives to petroleum based lubricants are currently being explored. Such alternatives include synthetic lubricants and vegetable based lubricants. Synthetic lubricant is much expensive than vegetable oils. The popularity of vegetable oil as lubricant increases day by day. Vegetable oils exhibit positive production trends and show good potential for a variety of industrial applications. The worldwide production of oilseed is increasing day by day, but at present it is costly compared to petroleum based oils. Economic losses are justified when considering the life cycle advantages of vegetable based lubricants [2]. From both production and life cycle standpoints, the future seems optimistic for vegetable oils as a viable replacement for petroleum based lubricants. There are many researches [3-5] on vegetable oils, especially on rapeseed oil, soybean oil, sunflower oil and palm oil. Castor oil is widely applied vegetable oil as lubricant. Among the vegetable oils, mustard and coconut oils are widely used in subcontinents. Usually people in subcontinent like Bangladesh used mustard oil for cooking purpose and coconut oil for hair oil. This study investigated the probability of mustard and coconut oil as lubricant. Jayadas et al. [6] modified coconut oil with various additives and used as base oil for industrial lubricants. Several tribological experiments as like viscosity and density measurement, 4-ball wear test, friction test, high pressure rheological test, etc. of pure mustard and coconut oil were done and compared with a conventional mineral oil. Friction and wear behavior of the mustard and coconut oil expresses their boundary lubrication properties. Density and viscosity of mustard and coconut oil are acceptable for the application as lubricant. Oiliness of the oils is good enough compared with mineral oil. Results also found that these vegetable oils have high viscosity index, good lubricity, better boundary lubrication property and environment friendly, but low temperature fluidity is not good enough. Mustard and coconut oil can be used as lubricant in subcontinent as like Bangladesh, also anywhere in the world.

2. EXPERIMENTAL

2.1 Physical Properties of the sample oils

Physical properties (density and kinematic viscosity) of mustard and coconut oil are given in Table 1. Properties of a mineral oil P150N is also given for comparison. Viscosity index of both mustard and coconut oil is higher than the mineral oil P150N. From the chemical structure, it has found that the coconut oil has the higher content of saturated fatty acid and mustard oil has little bit different chemical composition of higher carbon series [7]

Table 1: Physical properties of tested oils

Oil name	Density ρ (g/cm^3)	Kinematic Viscosity ν (mm^2/s)		Viscosity Index (VI)
	15°C	40°C	100°C	
Mustard oil	0.9180	44.1	9.4	205
Coconut oil	0.9260	27.6	5.9	165
Mineral oil (P150N)	0.8663	28.6	5.1	105

2.2 Measurement of boundary lubricant property

Friction and wear properties of the sample oil were measured as the boundary lubricant property. 4-ball wear test and Soda type pendulum test were done to measure the frictional and wear property of mustard and coconut oil. Experimental set up and procedure is same as Ohno et al. [8] used in their research.

In 4-ball wear test, bearing steel balls of 19.05 mm in diameter and 5.7 nm in mean surface roughness were used. All experiments were conducted at load 1.39 kN and at upper rotating ball speed 60 rpm, corresponding to a sliding speed of 0.035m/s. Duration for each experiment was 1 h, and thus total sliding distance was 124.6 m. Load of each pair was 564 N, corresponding mean Hertzian pressure = 2.6 GPa, and Hertzian diameter d_H = 0.521 mm. Friction was measured by means of a torsion bar to which the bottom of the oil container was clamped. Experiments were carried out at room temperature. After an hour, released the load and removed the fixed balls from the ball holder and rotating ball from the rotor shaft. The four balls were clean using ultrasonic cleaner. Then photograph of the wear scar was taken using a microscope at 10X zooms. Wear scar diameter of each fixed ball was calculated from the photograph.

Soda pendulum test machine is fixed on a column of steel with the T-pattern pendulum in the center. The pendulum is supported on four bearing steel balls by a roller pin. It is the device which measures the frictional coefficient from the degree of decline in the free swing of the pendulum. Steel ball diameter was 4.75 mm and roller pin diameter is 3.0 mm with hardness number 60-66. Other parts are base stand with a leveler, weight, roller pin holder, V-ring and oil container. Prior to each test, all these parts were carefully cleaned by immersion in an ultrasonic cleaner, rinsed out in hexane and dried in hot air. The base stand has a curvature like scale from where pendulum reading was taken for calculation. Experiment has started from setting the pendulum at 0.5 by pushing a lever and let the device swing freely till it stopped at 0 of curvature like scale. The number of pendulum swings and the scale reading of each swing were taken for calculation. This reading was different for different oils and thus gave different frictional coefficients. The experiment was repeated twenty times with the same conditions for same sample oil. The coefficient of the static friction μ was calculated from the readings. These have good lubricity and low coefficient of friction has been found.

2.3 High pressure rheological test

There are many researches on vegetable oil but high pressure rheological study of vegetable oils is not enough. Mia et. al (2010) presented high pressure tribological behavior of several vegetable oils as lubricant. They found that pressure viscosity coefficient of vegetable oils showed lower values compared with mineral oil and due to low pressure viscosity coefficient these can be used in elastohydrodynamic lubrication. In this research pressure viscosity coefficient of mustard and coconut oil is examined and compared with a mineral oil. Pressure viscosity coefficient of the sample oils was calculated from the high pressure viscosity measurement. Measurement is same as Ohno et al. (2001) used in their study. A high-pressure falling ball viscometer is used to determine high-pressure viscosity up to 0.4 GPa and at temperature from 20 to 60 °C in the range of viscosity $\eta<10^3$ Pas, where η is the absolute viscosity. The basic principle is that a solid body having higher density than the liquid to be tested slowly falls through a liquid filled tube. The density difference and the gap between the falling body and the tube wall determine the viscosity of the falling body. Pressure-viscosity relation at different temperature is shown in Fig.1. Pressure-viscosity coefficient α was found from the slope of the curve. Again, solidification pressure corresponding to a temperature was found from the high pressure density measurement. Phase diagram of the sample oils was drawn using the experimental results.

3. RESULTS AND DISCUSSION

Mustard and coconut oils showed high viscosity index, which is an essential property of lubricating oil. The viscosity at 100 °C is very close to meeting SAE30 grade requirements and at 40°C is in between the ISO32 and ISO46 viscosity grades. Causes of higher viscosity index compare to mineral oil can be explain by the fact that hydrogen bonding becomes less substantial with increasing temperature.

High pressure rheological behavior of mustard and coconut oil has been investigated. The effect of viscosities continued on the high pressure behavior of the oils. The pressure-viscosity relation of mustard oil at different temperature has shown in Fig.1.

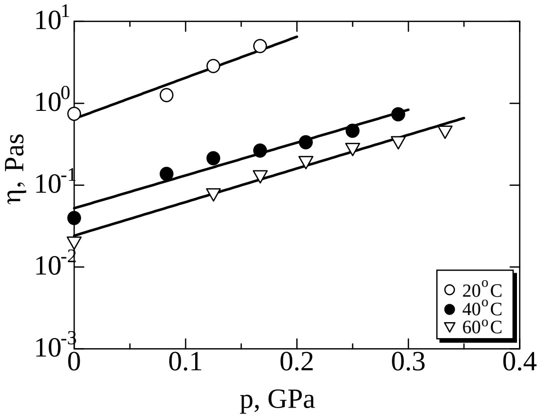

Fig. 1 Pressure-viscosity-temperature relation of Mustard oil

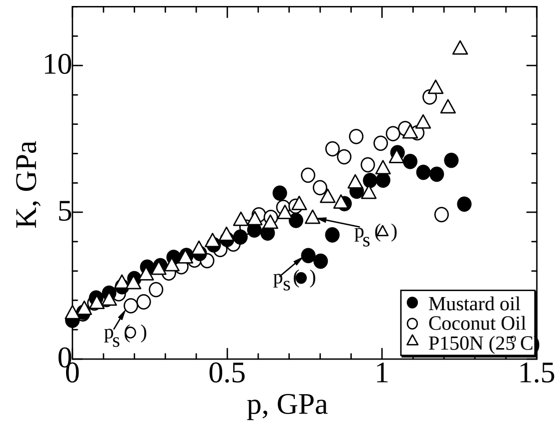

Fig. 2 Pressure-bulk modulus relation for identifying the solidification point.

Table 2: Experimental results of tested oils

Oil name	Pressure viscosity coefficient α, GPa^{-1}	Wear scar area A, mm^2	Friction coefficient μ
	40°C		
Mustard oil	9.46	0.2945	0.0921
Coconut oil	13.09	0.5081	0.0880
Mineral oil (P150N)	12.65	0.3126	0.1330

Pressure-viscosity coefficient of the oil has found using the Barus's [9] pressure-viscosity relation. Pressure viscosity coefficient of coconut oil is almost same as P150N oil but it is lower in case of mustard oil. Pressure viscosity coefficient α at 40°C is shown in Table 2.

Again solidification of the sample oil was observed from the density pressure relation. Tangent bulk modulus can found by differentiating the density-pressure curve and viscoelastic solid transition point can be obvious from the abrupt change of bulk modulus with respect to pressure as shown in Fig. 2. Solidification point of mustard and coconut oil at 40°C temperature has found as 0.762 GPa and 0.189 GPa correspondingly, whereas solidification point of P150N oil at 25°C temperature has found as 0.78 GPa. The solidification temperature at atmospheric pressure of Mustard oil, coconut oil and P150N oil has found as -26°C, 7°C and -36°C respectively.

Solidification temperature at atmospheric pressure of the oils have found by lowering the temperature using the liquid nitrogen. The samples started to solidify at the above temperature at atmospheric pressure. Finally phase diagram of the sample oils is drawn using all solidification temperature and pressure. The phase diagram of mustard oil and coconut oil comparing a mineral oil is shown in Fig. 3. Phase behavior is almost same as like P150N, though temperature level is different only.

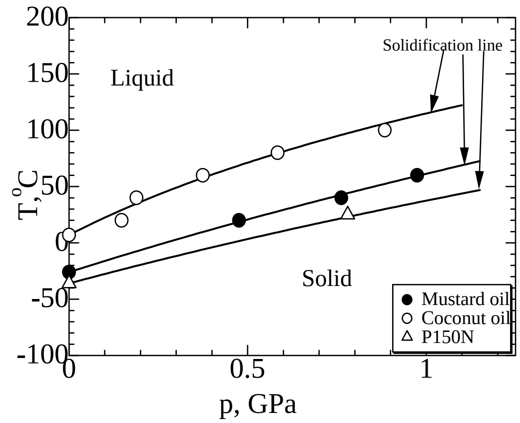

Fig. 3 Phase diagram of mustard and coconut oil

Experimental results on friction and wear scar area have also given in Table 2. This frictional and wear behavior of lubricating oil indicates their boundary lubrication properties. High wear scar area has found for coconut oil due to its low pressure resistance capacity but lubricity of coconut oil is good enough and it showed lowest coefficient of friction.

4. CONCLUSION

Mustard and coconut oils are biodegradable vegetable oil, available in all over Bangladesh. From the study, we have found the mustard and coconut oils have good lubricant property. For the global climate issue to reduce carbon emission, mustard oil and coconut oil can be used as lubricant for friendly environment. Their boundary lubrication property is good enough though low temperature fluidity of coconut oil is not good, but it can use by adding some additives. These vegetable oils can also be used in moderate high pressure application can be replace the mineral oil as like P150N oil to meet the global warming crisis.

5. ACKOWLEDGEMENT

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7. NOMENCLATURE

Symbol	Meaning	Unit
T	Temperature	(°C)
p	Pressure	(GPa)
ρ	Density	(g/cm^3)
η	Absolute viscosity	Pa·s
ν	Kinematic viscosity	mm^2/s
α	Pressure-viscosity coefficient	GPa^{-1}
μ	Friction coefficient	
A	Wear scar area	mm^2