CHAPTER IV

RESULTS AND DISCUSSIONS

Viscosities, lubricities, flash points and corrosion of 4 vegetable oils, a synthetic ester and their mixtures with paraffinic oil have been measured. Then, empirical expressions for viscosity, wear and flash point with respect to the mass fraction of vegetable oil have been developed as well.

4.1 Viscosity Property

Viscosity of vegetable oils, synthetic ester and petroleum oil at 40°C and 100°C , as well as viscosity indices, have been measured and are summarized in Table 4.1

Table 4.1 Kinematic viscosity of vegetable oils, synthetic ester and petroleum oil

Oils	Viscosity@ 40°C (cSt)	Viscosity@ 100°C (cSt)	Viscosity index	Density (g/ml)
Palm	40.72	8.334	186.48	0.900
Rice bran	40.62	8.286	185.26	0.902
Soybean	38.62	7.894	181.81	0.898
Coconut	32.47	5.962	130.43	0.886
Synthetic Ester	34	5.210	74.10	0.884
Petroleum oil	24	5.082	140.87	0.880

The viscosities of all vegetable oils at both temperatures are quite higher than that of petroleum oil. The viscosity indices except coconut oil, also become higher than the petroleum oil. In comparison with the synthetic ester, all vegetable oils have higher viscosity than that of the synthetic one. In particular, the viscosity indices of vegetable oils are about twice or higher than that of the synthetic ester. Since the prime function of neat cutting oil is lubricating the metal work, in this point of view, the coconut oil can be an alternative additive for neat cutting fluids due to both viscosity and viscosity indexes being close to that of the synthetic one.

In comparison among vegetable oils themselves, the results have suggested that the viscosity of coconut oil is the lowest one due to the lowest average chain length of fatty acids carbon 12-13 carbon. While other vegetable oils have the average chain length of fatty acids about 17-18 carbon atoms, the viscosities are slightly different from one another due to the difference in fatty acid composition.

For mixtures between a selected vegetable oil and the petroleum one, the viscosities of such mixtures are in between the original values of the corresponding vegetable oil and the petroleum one. In other words, since the viscosity of all selected vegetable oil is greater than that of the petroleum oil at the same temperature, the viscosity of such mixtures becomes greater than that of the original petroleum oil without vegetable oil, as summarized in Table 4.2

Table 4.2 Kinematic viscosity of mixtures between selected vegetable oils and paraffinic petroleum oil

oil	Viscosity@ 40° C (cSt)				
	0 %	5%	10%	15%	20%
Palm oil	24.00	24.64	25.48	26.36	27.02
Rice bran oil	24.00	24.56	25.41	26.29	26.90
Soybean oil	24.00	24.53	25.20	25.87	26.50
Coconut oil	24.00	24.16	24.61	25.13	26.61

Based on the mixing rule of viscosity for hydrocarbon mixtures, proposed by Kendall and Monroe [18], the expression for binary mixtures can be written as.

$\mu_M = (x\mu_A^{1/3} + (1-x)\mu_0^{1/3})^3$ .... (4-1)

μ_A= viscosity of vegetable oil, μ_0 = viscosity of petroleum oil

x = mass fraction of vegetable oil

The calculated viscosity of those mixtures is different from the measured one within ±1.4%, as summarized in Table 4.3.

With another mixing rule of viscosity for non-hydrocarbon mixtures shown in Technical data manual [18], the correlation for binary mixtures can be expressed as

$$\mu_M = \mu_A^{X}\,\mu_0^{1-X} \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4-2)}$$

The calculated viscosity of the mixtures with the expression (4-2) becomes different from the measured values within ±1.5%, as summarized in Table 4.3.

Table 4.3 The comparison of calculated viscosity of mixtures between selected vegetable oils and parafinic petroleum oil with mixing rule and the measure viscosity

Mixed oil	Density (g/ml)	Viscosity (CP)				
		Experiment $\mu=\rho\nu$	Eq (4-1)	Error(%)	Eq (4-2)	Error(%)
5% Palm oil	0.880	21.68	21.77	0.42	21.71	0.14
10% Palm oil	0.880	22.42	22.42	0.00	22.32	-0.45
15%Palm oil	0.882	23.25	23.10	-0.65	22.94	-1.33
20% Palm oil	0.884	23.89	23.78	-0.46	23.54	-1.47
5% Rice bran oil	0.881	21.64	21.77	0.60	21.71	0.32
10% Rice bran oil	0.882	22.41	22.42	0.04	22.32	-0.40
15% Rice bran oil	0.882	23.19	23.09	-0.43	22.94	-1.08
20% Rice bran oil	0.884	23.78	23.78	0.00	23.58	-0.84
5% Soybean oil	0.880	21.59	21.69	0.23	21.65	0.28
10% Soybean oil	0.881	22.20	22.28	-0.58	22.19	-0.05
15% Soybean oil	0.881	22.79	22.87	-1.38	22.75	-0.18
20% Soybean oil	0.882	23.37	23.47	-1.30	23.32	-0.21
5% Coconut oil	0.880	21.26	21.47	0.99	21.45	0.89
10% Coconut oil	0.880	21.66	21.82	0.74	21.78	0.55
15% Coconut oil	0.880	22.11	22.17	0.27	22.12	0.05
20% Coconut oil	0.878	22.49	22.53	0.18	22.47	-0.09

Since the density of mixtures of vegetable oils and paraffinic oil are close to one another, kinematic viscosity of these mixtures can be estimated directly from the kinematic viscosity of each vegetable oil and paraffinic one with respect to their mass fractions in the mixtures by replacing the viscosity with the corresponding kinematic viscosity, as shown below. The results, obtained by both expression below, and summarized in Table 4.4

$$\nu_M = (x\nu_A^{1/3} + (1-x)\,\nu_0^{1/3})^3 \quad \text{..............................(4-3)}$$

and

$$\nu_M = \nu_A^{x}\,\nu_0^{1-x} \quad \text{... (4-4)}$$

Table 4.4 The comparison of calculated kinematic viscosity of mixtures between selected vegetable oils and paraffinic petroleum oil with mixing rule and the measure viscosity

Mixed oil	Viscosity (Cst)				
	Experiment	Eq (4-1)	Error(%)	Eq (4-2)	Error(%)
5% Palm oil	24.64	24.70	0.24	24.64	0.0
10% Palm oil	25.48	25.41	-0.27	25.30	0.71
15%Palm oil	26.36	26.14	-0.83	25.98	-1.44
20% Palm oil	27.02	26.88	-0.52	26.67	-1.30
5% Rice bran oil	24.56	24.70	0.57	24.64	0.33
10% Rice bran oil	25.41	25.41	0.0	25.30	-0.43
15% Rice bran oil	26.29	26.13	-0.61	25.97	-1.22
20% Rice bran oil	26.90	26.87	-0.11	26.66	-0.89
5% Soybean oil	24.53	24.62	0.37	24.58	0.33
10% Soybean oil	25.20	25.26	0.24	25.17	-0.43
15% Soybean oil	25.87	25.90	0.12	25.78	-1.22
20% Soybean oil	26.50	26.56	0.23	26.40	-0.89
5% Coconut oil	24.16	24.38	0.91	24.37	0.87
10% Coconut oil	24.61	24.77	0.65	24.74	0.53
15% Coconut oil	25.13	25.16	0.12	25.11	-0.08
20% Coconut oil	25.61	25.56	0.19	26.50	-0.43

The estimated kinematic viscosities of the mixtures from equation (4-3) and (4-4) are different from the measured are within ±1% and±1.5% , respectively.

According to the experimental results, the viscosity of a mixture can be increased by adding an oil with high viscosity. In addition to coconut oil, other selected vegetable oils, having higher viscosity than coconut oil, can be used to replace the synthetic ester with proper fraction of each vegetable oil. Furthermore, with a similar fraction of the synthetic ester, palm oil, rice bran oil and soybean oil can improve the viscosity of the mixture more greatly than the synthetic ester does.

In comparison with commercial neat cutting oil, Garia D as shown in Table 2.5, it is recommended for gear shaping, tapping, treading and broaching of high-carbon steels and stainless while Garia T is suggested for drilling, hobbing,gear shaping and broaching of low, medium and high-carbon steels. So the viscosity of mixtures are in between 15-32 cSt [15], can be used for hobbing, tapping and broaching of medium and high-carbon steels.

4.2 Lubricity Property

Lubricity property of a lubricating oil has been measured with 4-ball wear scar diameter. Only lubricities of selected vegetable oils and synthetic ester have been measured, because the equipment was damaged prior further measurement of their mixtures in paraffinic petroleum oil. Coconut oil and the synthetic ester, with lower viscosity than the remained vegetable oils, have resulted higher wear scar diameter than others vegetable oils, as summarized in Table 4.5.

Table 4.5 Wear scar diameter of the selected vegetable oils and synthetic ester

Oils	4 ball wear scar diameter @ 40kg.(mm.)
Palm	0.791
Rice bran	0.689
Soybean	0.877
Coconut	2.008
Synthetic Ester	2.049

Since the film of lubricating oil varies directly with the viscosity of the oil under the source machinery operation, the wear scar diameter alters inversely with the film thickness or the viscosity. Thus the wear scar diameter is inversely proportional to kinematic viscosity of the selected oil, as shown in Figure 4.1

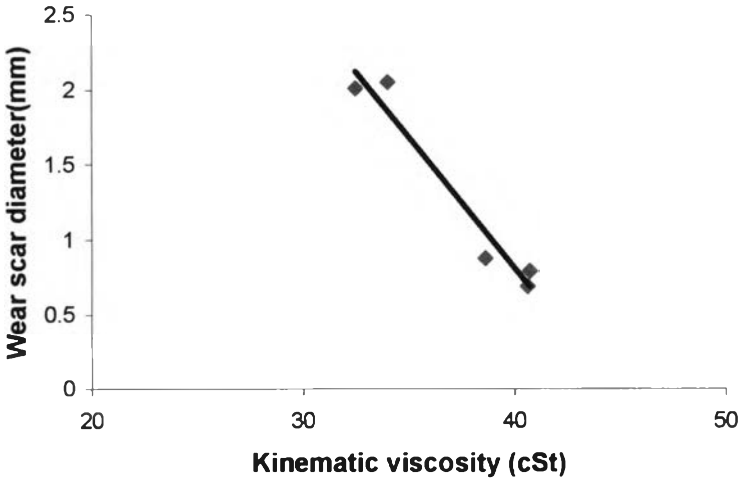

Figure 4.1 Relationship between the wear scar diameter and the kinematic viscosity of selected vegetable oils and synthetic ester

The empirical expression for lubricity of the mixtures for selected vegetable oil become $D = -0.1742\nu+7.7769$ ....(4-5)

D= Wear scar diameter, ν= Kinematic viscosity

Besides replacement of the synthetic ester with coconut oil, other selected vegetable oils tends to be used as lubricity improver for neat cutting oils.

4.3. Flash Point Property

Flash point of selected vegetable oils are differed from that of the paraffinic oil about 5-15 °C , as summarized in Table 4.6.

Table 4.6 Flash point of selected oils, the synthetic ester and the paraffinic oil.

Oils	Flash point (°C)
Palm	210
Rice bran	220
Soybean	210
Coconut	196
Synthetic Ester	210
Petrolium oil	204

In comparison with normal paraffins, the flash point of the petroleum oil, containing a mixture of paraffins mainly, becomes close to that of normal paraffins with 22 carbon atoms [19]. While the flash point of selected vegetable oils, excluding coconut oil, which are mixtures of a large number of glycerides and fatty acids, are comparable with that of a fatty acid with about 20 carbon atoms [19]. The results have suggested that fatty acids in these vegetable oils, containing fatty acids with the average number of carbon atoms about 18 atoms has evaporated and then has been ignited at temperature about 20-30 °C above the flash point of stearic acid, consisting of 18 carbon atoms. Similarly, the flash point of coconut oil, containing mostly lauric acids with 12 carbon atoms, is about 40 °C above the flash point of lauric acid. Since the vapor pressure of fatty acids are much higher than the corresponding simple triglycerides, a relatively large amount of free fatty acid in vegetable oils reduces the flash point of such oils [1]. Therefore, reducing the content of free fatty acids in the oils may increase the flash point of vegetable oils.

For mixtures of a vegetable oil and the paraffinic oil, the flash point of these mixtures have been confined in between both original values and they vary directly with the fraction of the vegetable oil in the mixture, as summarized in Table 4.7. However the change in flash point becomes unproportional to the mass fraction of the vegetable oils in the mixtures, as shown in Figure 4.2

Table 4.7 Flash point of mixtures of the selected vegetable oils and the paraffinic petroleum oil

oil	Flash point (°C)				
	0 %	5%	10%	15%	20%
Palm oil	204	203	205	206	206
Rice bran oil	204	205	207	210	212
Soybean oil	204	205	207	206	207
Coconut oil	204	201	200	200	198

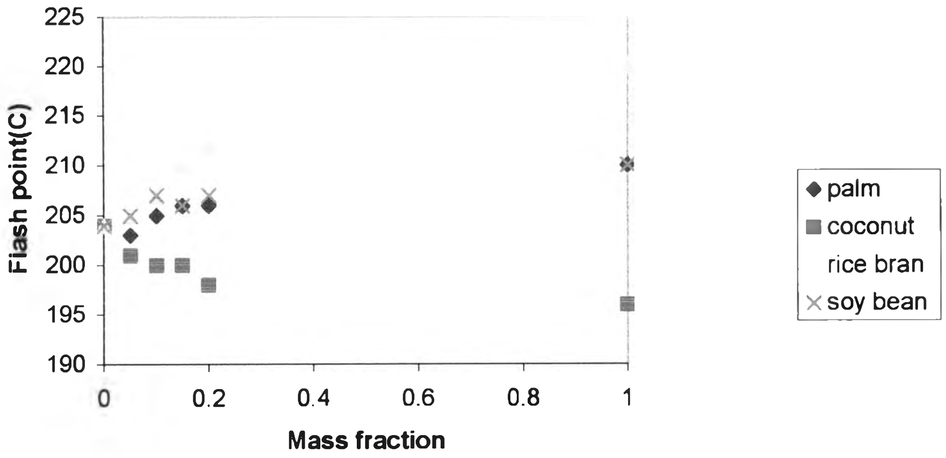

Figure 4.2 Flash point of mixed oil at various % mass fraction of vegetable oils

Linear relationships between flash points and mass fraction of vegetable oil have been investigated in various correlation forms, the square of the Peason product moment correlation coefficients, R^2 are summarized in Table 4.8 (see details in Figures A-1 – A-24)

Table 4.8 R^2 of linear correlations for the mixtures of selected vegetable oils

Linear correlation form	Palm	Rice bran	Soybean	Coconut
FP vs x	0.8988	0.8881	0.8643	0.6520
FP vs 1/x	0.8119	0.7469	0.6602	0.7175
FP vs ln(1/x)	**0.9880**	**0.9887**	**0.8971**	**0.9284**
10000/FP vs x	0.8555	0.8751	0.8604	0.8123
10000/FP vs 1/x	0.8228	0.7621	0.667	0.7175
10000/FP vs ln(1/x)	**0.9871**	**0.9886**	**0.8980**	**0.9284**

The results have suggested that flash point of each vegetable oil mixture becomes quite proportional to the logarithmic of the reciprocal of the vegetable oil mass fraction in the mixture. Alternatively, the correlations between the reciprocal of flash point and the logarithmic of the reciprocal of the main fraction are almost linear, as well. The empirical expressions for flash point of the mixture of selected vegetable oil are

$$FP = b - \ln x^{m} \qquad \text{.......................}(4\text{-}6)$$

$$FP = \frac{10{,}000}{B - \ln x^{M}} \qquad \text{.......................}(4\text{-}7)$$

However, these correlations may not be applied to the mixtures containing a relatively small fraction of vegetable oil. Parameter; b,B, m and M are summarized in Table 4.9

Table 4.9 Correlation constants of equation (4-6) and (4-7)

Oil	m	b	M	B
Palm	-2.2794	210.01	0.5328	45.442
Rice bran	-5.1919	219.94	1.1501	47.662
Soybean	-1.5938	209.81	0.3691	47.61
Coconut	1.7333	195.95	0.4330	51.013

4. Corrosive Property

Corrosion property of all selected vegetable oils and synthetic ester has been tested on copper according to ASTM D130. The results has been revealed as class 1a for all oils as shown in Table 4.10. In other words, theses vegetable oils are the least corrosive fluids. Since, the corrosion property of the petroleum oil is also the same class as the vegetable oils, the mixture of them have the same corrosion property.

Table 4.10 Copper strip corrosion

Oils	Copper strip corrosion (class1-4)
Palm	Class1a
Rice bran	Class1a
Soy bean	Class1a
Coconut	Class1a
Synthetic Ester	Class1a
Petroleum oil	Class1a