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Technical Paper

Properties of Crude Oil from Indigenous Oilseeds in Africa*

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Abstract

Properties of crude oil from four indigenous oilseeds in Africa (Kenya) were determined and their potential use as fuel, lubricants, hydraulic fluids, and brake fluids were evaluated. The oils were extracted chemically and mechanically using petroleum ether and ram press respectively. The properties determined included density which decreased linearly with increase in temperature, kinematic viscosity which decreased exponentially with increase in temperature, viscosity index, calorific value, ash content, flash point, specific heat, thermal conductivity, and pH value. Empirical equations were derived for the change of density and kinematic viscosity with temperature. Methods of extraction had significant effect on the ash content and flash point of the oils. The values obtained were compared to those of diesel and sunflower oil.

[Keywords] indigenous oilseeds, crude oil, extraction method, potential use, oil property

I Introduction

Modern industry is mainly based on petroleum oil which is non-renewable.
However, as early as 1900, vegetable oils were used in engines as fuel.[1),2)] They have also shown high potentials for alternative uses especially as lubricants. Castor oil is one of the few naturally occurring oils that is nearly a pure compound and is a very good lubricant used in racing cars and jet engines .[3)] Thus a high potential for the oil from indigenous oilseeds would promote their commercialization, boost the economy, and improve the environment through afforestation by planting the oilseed trees.

The seeds used in the test were from trees which mainly grow in the semi-arid areas in most parts of Africa. They included; (1) *Calodendrum capense* which is an outstanding deciduous tree attaining a height of 15 m and is common in the Rift Valley and at the coast in Africa. (2) *Croton megalocarpus* which is a tall timber tree reaching 35 m and common in the Rift Valley. (3) *Podocarpus gracilior* which is a large evergreen forest tree reaching a height of 25 m and common in the highlands.[4)] *Pittosporum vindiflorum* which reaches a height of 18 m and is mainly found in the semi arid areas in the Rift Valley. The research was therefore aimed at determining the properties of the crude oils which characterize their use as potential substitutes for petroleum oil.

1. Viscosity Analysis

The weak van der Waals type forces between molecules provide cohesion to a body of liquid and hence resistance to internal displacement and flow. The resistance is termed viscosity. Since liquids expand with tempera-

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ture rise, intermolecular distances increase and the viscosity falls. The quotient of the dynamic viscosity and the density of the oil defines the kinematic viscosity. The relation between kinematic viscosity and temperature is generally given by;[5]

$$\nu = A\exp\left(\frac{\beta}{T+C}\right) \tag{1}$$

The constants A, β, and C are obtained by regressing the experimental data. The viscosity index (VI) expresses the variation in viscosity with change in temperature. An oil with high viscosity index has less change in viscosity when the temperature changes. Therefore, an oil with a high viscosity index is more suitable. Based on the ASTM method D 567, the viscosity index is calculated as follows.

$$VI = \left[\frac{(L-U)}{(L-H)} \times 100\right] \tag{2}$$

where L, H, and U are viscosities of the oils at 311 K that have an arbitrary viscosity index of zero, 100 and unknown respectively. Thus the oils with viscosity L and H are used as reference oils whereas that with viscosity U is the test oil. The three oils have the same viscosity at 372 K. The values for L and H are obtained from the ASTM tables for viscosity index. A high viscosity index of over 90 is desirable when hydraulic oil is subjected to wide variation in temperature.

2. Thermal Diffusivity and Conductivity Analysis

Thermal diffusivity (α) is a derived property suggesting a heating time and thus associated with unsteady state or transient heat flow. The thermal conductivity sets the rate of heat flow through the material by conduction. Based on the Dickerson method,[6] when the rate of change of temperature with time at the outer surface and at the centre is constant and the same, the Fourier's equation for radial temperature gradient is given by ;

$$\frac{B}{\alpha} = \frac{d^2\theta}{dr^2} + \frac{d\theta}{rdr} \tag{3}$$

where B is the rate of change of temperature at the outer surface and at the centre. Integrating equation (3) with respect to r and t gives the following solution.

$$\theta(r, t) = \frac{Br^2}{4\alpha} + \theta_o + Bt \tag{4}$$

If the surface and centre temperatures are $\theta_s = \theta(R,t)$ and $\theta_c = \theta(0, t)$ respectively, then the thermal diffusivity is generally expressed as;.

$$\alpha = \frac{BR^2}{4(\theta_s - \theta_c)} \tag{5}$$

Thus the thermal conductivity λ can be calculated indirectly from the equation below.

$$\lambda = \alpha \rho C_p \tag{6}$$

where ρ is density and C_p is the specific heat of the material.

II Experiment Methodology

Four indigenous oilseeds were used (Figure 1) namely *Calodendrum capense* (CAL), Croton megalocarpus (CRO), *Podocarpus gracilior* (POD), and *Pittosporum vindiflorum* (PIT) commonly known as Cape chestnut, Musime, Podo and Munyamati respectively. Sunflower (SUN) and diesel (DIE) oils were used for comparison in the experiment as Vegetable oil and Petroleum oil (P) respectively. *Podocarpus gracilior* and *Pittosporum vindiflorum* were extracted using chemical method only due to low oil content and hard testa. The rest of the oils were extracted both chemically (C) and mechanically (M) using Soxhlet extractor and Bielenburg ram press respectively. For chemical extraction, petroleum ether was used. The chemical was heated at 323 K in the soxhlet extractor and then condensed above the crushed oilseed sample. Due to its high affinity for oil, the condensed chemical desolved the oil in the sample as it flowed through it. The extracted oil was then dried in an oven at 378 K for 24 hrs to ensure complete removal of the free water, petroleum ether and other volatile substances. For all the tests the experiment was repeated three times and the average values computed.

The density of the oils was determined

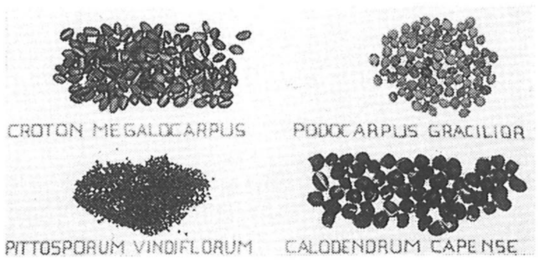

Fig. 1 Indigenous oilseeds

using a density bottle within a temperature range of 283 K to 373 K. The calorific value was determined by use of the IKA-Bomb Calorimeter C400 (Institute of Petroleum-IP 12/73)[7] whereas the kinematic viscosity was determined by a U-tube viscometer (IP 71/75) within a temperature range of 283 K to 373 K . For the ash content, 0.01kg of the oil was weighed in a platinum crucible and heated gently to a point of ignition. The oil was allowed to burn spontaneously until only carbon residue was left. The residue was then mixed with distilled water before being filtered using an ashless filter paper (Cat. No. 1441240). The residue was then burned in a muffle furnace at a temperature of 773 K. The specific heat was determined by a thermal calorimeter whereas the thermal diffusivity was determined by an improvised Dickson apparatus. The oil was placed in a copper cylinder which was then put in an agitated water bath. The water was heated and the variation of temperature with time at the outer surface of the cylinder and at the centre recorded. The temperature difference was noted when the rate of change of temperature with time was constant and the same at the outer surface and at the centre of the cylinder. The thermal conductivity was calculated indirectly from the thermal diffusivity. The flash point was determined by the Closed Cup Pensky-Martens Flash Tester (IP 35/63). The pH value was determined by use of a glass electrode pH meter. The effect of temperature and methods of extraction on some of the oil properties were then analyzed. The obtained results at 298 K are tabulated in Table 1. Where methods of extraction had no significant effect, the average values for the chemically and mechanically extracted oils were used in the graphical analysis.

III Results and Discussion

1. Density

Podocarpus gracilior had the highest density of 943.9 kg/m^3 whereas *Pittosporum vindiflorum* had the lowest value of 913.7 kg/m^3 at 298 K. The density of the oils was not affected by the methods of extraction but decreased linearly with increase in temperature and was well expressed by the equation below. For oil k;

$$\rho_k = A_k T + D_k \tag{7}$$

where ρ_k is density (kg/m^3), T is absolute temperature (K), and D_k (kg/m^3) and A_k (kg/m^{3}K) are oil dependent constants.. The value for A_k was almost the same for all the oils. A constant value of -0.65 was used for all the oils and reulted in a high correlation coefficient (r^2) as shown in Table 2. Thus equation (7) becomes;

$$\rho_k = -0.65\,T + D_k \tag{8}$$

Figure 2 shows the graph for the experimental and calculated values for some of the oils. The lines drawn are for the calculated average values for POD, CAL and DIE. The densities of the oils were within the recommended ranges for diesel engine fuels (750-950) kg/m3, lubricants (800-1005) kg/m^3, hydraulic fluids (800-1500) kg/m^3 and brake fluids (800-1060) kg/m^3.

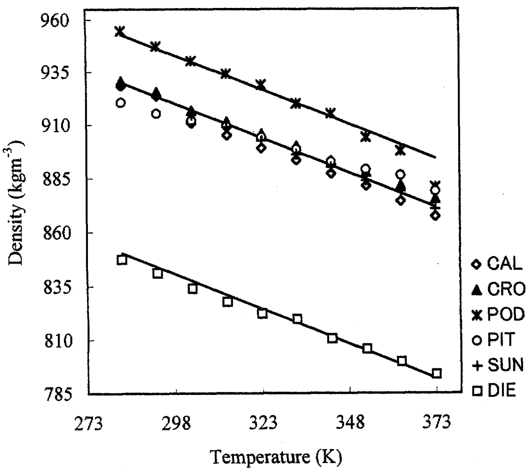

Fig. 2 Variation of density with temperature

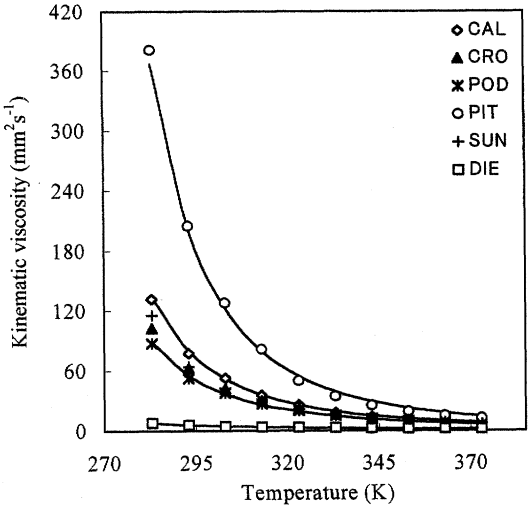

Fig. 3 Variation of kinematic viscosity with temperature

2. Viscosity

The kinematic viscosity of the oils decreased exponentially with increase in temperature (Figure 3). *Podocarpus gracilior* had the lowest value of about 45.1 mm^2/s whereas *Pittosporum vindiflorum* had the highest value of 166.5 mm^2/s at 298 K.

The lines drawn are for the calculated average values for CAL, POD, and DIE respectively. The regression curve for the experimental data was well fitted by equation (9) based on the general exponential equation for viscosity of fluids. For oil k;

$$\nu_k = A_k exp\left(\frac{\beta_k}{T+C_k}\right) \quad (9)$$

where ν_k (mm^2/s) is kinematic viscosity , T (K) is absolute temperature and A_k (mm^2/s), β_k(K), and C_k (K) are oil dependent constants which were high for oils with high kinematic viscosity. For the temperature range used, the values for B_k and C_k were almost the same for all the oils. Constant values of 0.25 and 170 were used respectively and resulted in a high correlation coefficient (r^2) as shown in Table 2. Thus equation (9) becomes;

$$\nu_k = 0.25 exp\left(\frac{\beta_k}{T+170}\right) \quad (10)$$

Methods of extraction showed no significant effect on the viscosity of the oils. The viscosity index of the oils ranged from 136 for PIT to 176 for POD. Thus the rate of change of viscosity with temperature was relatively low for the indigenous vegetable oils. The kinematic viscosities of the oils were outside the recommended range for diesel engine fuel (1.5-5.5) mm^2/s, hydraulic fluids (13-54) mm^2/s, and brake fluids (6-7) mm^2/s but were within the recommended range of 19-3140 mm^2/s for lubricants. The viscosity index of the oils were within the recommended range for lubricants (76-150).

3. Thermal Properties

(1) Calorific Value

For fuels, one of the other important parameters is calorific value since it rates the oil's ability to produce enough energy after combustion to run the engine. For the oils tested, *Podocarpus gracilior* had the highest value of about 41.1 MJ/kg whereas *Pittosporum vindiflorum* had the lowest value of about 39.1 MJ/kg. The values obtained were generally slightly high compared to the calorific value of sunflower oil (39.7 MJ/kg) but slightly low compared with diesel oil (44.4

MJ/kg). However, the values obtained were within the recommended range of 39-46 MJ/kg for diesel engine fuel.[5] Methods of extraction had no significant effect on the calorific value of the oils.

(2) Specific Heat

The oils had generally low specific heat of about 2 kJ/kgK and methods of extraction had no significant effect on it. The values obtained were within the limits for lubricants (1.5-2.0) kJ/kgK and hydraulic fluids (0.8-1.5) kJ/kgK.

(3) Thermal Conductivity

The thermal conductivity of the oils ranged from 1.3 kJ/mhK for *Calodendrum capense* extracted chemically to 5.8 kJ/mhK for *Croton megalocarpus* extracted mechanically. The values obtained were within the recommended range for lubricants and hydraulic fluids. There was no general trend on the effect of methods of extraction on the thermal conductivity of the oils since both the chemically and mechanically extracted oils had low and high values.

(4) Flash Point

The flash point values obtained were high compared with that of diesel especially for the mechanically extracted oils. *Croton megalocarpus* extracted mechanically had the highest value of 520 K whereas *Podocarpus gracilior* had the lowest value of 301 K. The methods of extraction had significant effect on the flash point of the oils (Figure 4). The flash point for the chemically extracted oils were generally within the recommended range of 323-353 K for diesel fuel, 333-573 K for lubricants, and 372-541 K for hydraulic fluids. Only *Croton megalocarpus* extracted chemically had its flash point within the recommended range of 393-463 K for brake fluids. All the mechanically extracted oils had flash points within the recommended range for lubricants.

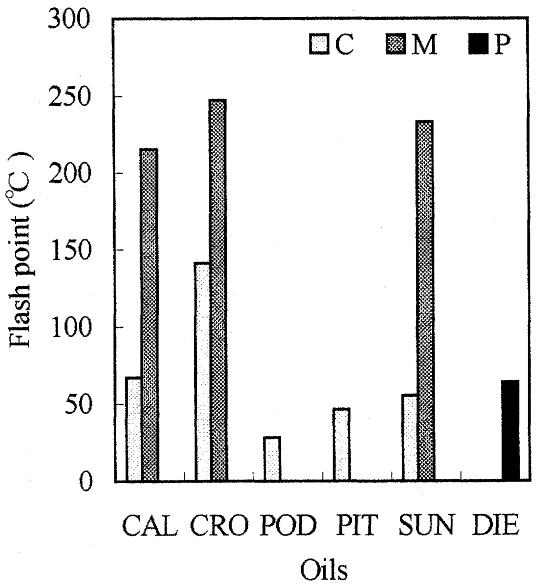

Fig. 4 Effect of methods of extraction on flash point

4. Chemical Properties

(1) Ash Content

The oils showed varied values of ash content which were significantly affected by the methods of extraction. *Calodendrum capense* extracted mechanically had the lowest value of 0.008% compared to 0.42% for *Pit-*

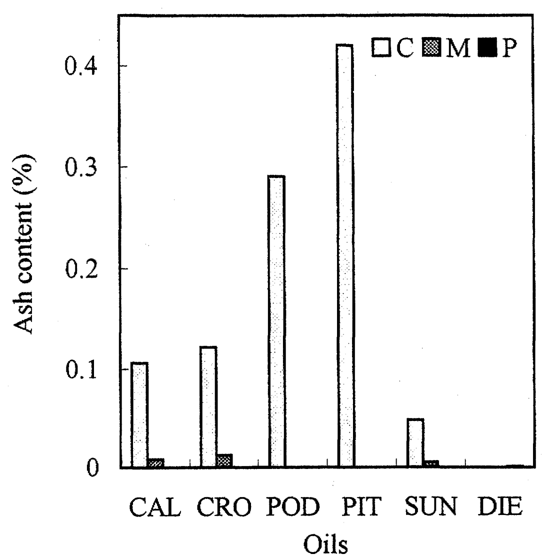

Fig. 5 Effect of methods of extraction on ash content

tosporum vindiflorum. Thus the chemically extracted oils had significantly high values compared to the mechanically extracted oils and diesel (Figure 5). The values for the mechanically extracted oils were within the recommended range of less than 0.05% for diesel engine fuel. However, the ash content for the mechanically and chemically extracted oils were both within the recommended range of 0-6.7 % for lubricants.[8)9)]

(2) pH Value

Since the degree of alkalinity or acidity is critical due to wear and corrosion, the pH value of the oils is an important factor. The oils tested were slightly acidic with pH values of over 5.0. However, *Calodendrum capense* extracted mechanically had a low pH value of about 3.7. Thus the pH values of the oils were generally within the recommended range of 6.5-8 for diesel fuel and 7-12 for hydraulic fluids.

Ⅳ Conclusion

The indigenous vegetable oils showed a high potential for use in various application based on the properties obtained. For use as fuel in diesel engine, the oils had relatively high calorific values and their high viscosity could easily be reduced through increase in temperature. The high flash point for the mechanically extracted oils and high ash content for the chemically extracted oils can be overcome by considering the method of extraction, refining of the oil and through esterification. The oils have also a high potential for use as lubricants for various applications ranging from motor oil to gear oil as recommended by Lansdown. Their potential for use as hydraulic and brake fluids is low based on the determined parameters. Further research on quality and the actual performance test is recommended. The cetane rating, sulphur content, carbon content, smoke point, fatty acid content, and pour point should also be tested.

Table. 1 Properties of oil from indigenous oilseeds

Oils	ρ(kg/m^3)	ν(mm^2/s)	Q(MJ/kg)	AC(%)	FP(K)	pH	C_p(kJ/kgK)	λ(kJ/mhK)	*VI*
CAL. C	916.8	63.2	40.4	0.106	67	6	2.2	1.3	160
CAL. M	917.8	66.9	40	0.008	215	3.7	2.1	6.8	158
CRO.C	920.3	57.5	40.5	0.122	141	5.1	2.4	4.5	165
CRO. M	922.2	46.9	39.9	0.012	247	5.7	2.2	5.8	173
PDO. C	943.9	45.1	41.1	0.29	28	5.7	2.2	2.4	176
PIT. C	910.8	166.5	39.1	0.42	46	5.7	1.5	2.4	136
SUN. C	917.1	51.2	39.5	0.048	55	6.6	2.1	3.2	170
SUN. M	921.2	54.7	39.8	0.005	233	6.4	2.2	1.7	163
DIE	837.6	5.05	44.4	0.001	64	7.4	1.6	6	*

ρ : Density, ν : Kinematic viscosity, Q : Calorific value, AC : Ash content, FP : Flash point, C_p : Specific heat, λ : Thermal conductivity, *VI* : Viscosity Index, * : Outside range

Table. 2 Equations constant and correlation coefficient (r^2)

Oils	D_k(kg/m^3)	r^2 (ρ_kk)	β_kk (K)	r^2 (ν_kk)
CAL.C	1111	0.99	705.1	0.99
CAL.M	1116	0.97	710.5	0.98
CRO.C	1113	0.98	691.9	0.99
CRO.M	1117	0.99	666.6	0.99
POD.C	1138	0.95	661.9	0.99
PIT.C	1106	0.95	827.4	0.97
SUN.C	1110	0.99	680.4	0.99
SUN.M	1117	0.99	686.1	0.99
DIE	1035	0.96	388.5	0.98

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技術論文

アフリカ産植物油の特性*

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要 旨

アフリカ産の植物油をディーゼルエンジンの燃料および潤滑油，油圧ブレーキオイルとして利用する観点から，その燃料特性の測定を行った。植物油は化学的方法と力学的（圧搾）方法により抽出し，ディーゼル油およびヒマワリ油と比較検討した。測定は，植物油の密度，動粘性係数，熱量，灰分，引火点，発火点，熱伝導率およびｐＨを求めた。その結果，植物油の密度は温度に対し直線的に減じ，動粘性係数は温度の減少とともに指数関数的に増加することを明らかにし，これらの関係についての精度の高い実験式が求められた。また，灰分および引火点は搾油方法の影響が大きいことが分かった。

［キーワード］アフリカ産油種子，原油，搾油方法，利用可能性，油性

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コ メ ン ト

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現在ケニアで生産されている４種の植物油の年間生産量と実際の使用目的について1998，97年度分を教えて下さい。

［コメントに対する著者の見解］

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