Physical Properties of Crude Oil from Cape Chestnut (*Caledendrum capense*)

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ABSTRACT

Physical properties of crude oil from cape chestnut (*Caledendrum capense*) were determined. The effects of temperature and methods of extraction on some of the properties were analysed. The density of the oil decreased linearly with increase in temperature from 9316 kg/m^3 at 10°C to 8659 kg/m^3 at 100°C. Methods of extraction had no significant effect on the density of the oil. The viscosity of the oil decreased exponentially with increase in temperature from 134.7 mm^2/s at 10°C to 7.5 mm^2/s at 100°C and was not significantly affected by the methods of extraction. The calorific values of the oil was about 40^4 MJ/kg and its specific heat capacity was less than 2.2 kJ/kg °K whereas thermal conductivity was greater than 1.3 kJ/hr °K m. The ash content of the oils ranged from 0.008% for mechanically extracted oil to 0.106% for chemically extracted oil. The chemically extracted oil had low flash point of 67°C compared to the mechanically extracted oil of 215°C. The chemically extracted oil had a high pH of 6.0 where as the mechanically extracted oil had a lower pH of 3.7. The oil showed a high potential for use as a lubricant and as fuel in diesel engine.

KEY WORDS

Caledendrum capense, oil

1.0 INTRODUCTION

Modern industry is dependent upon petroleum oils. However, with the escalating world population and rocketing industrial development, traditional sources such as non-renewable oils have been under threat. As the supplies of petroleum oils and natural gas approach their economic limits, finding alternative renewable sources of oil is critical. History records that Rudolph Diesel, the inventor of the engine that bears his name, used vegetable oil as fuel in his engines as early as 1900 (Pugh and Court, 1955). Short-term engine tests have so far shown that vegetable oils are promising as an alternative source of fuel (Goodier 1980, Mazed et al 1985, Pryde 1984, Wright 1950, Segal 1985, Worgetter 1989).

The vulnerability of continued reliance on non-renewable energy sources was earlier highlighted by the economic repercussion of the energy and fuel crisis of the 1970's (Hardwood, 1984). Oils like castor are now finding an increasing use in high speed engines as lubricants. Despite the problems presented by vegetable oils when used as a substitute for petroleum oils, their industrial utilization is viable. Poor research and extension infrastructures have greatly contributed to the problem of vegetable oil production. In order to surmount the barriers to increased vegetable oil production, consideration of appropriate methods of extraction and the analysis of their properties becomes paramount in order to promote their diversified use. Indigenous oilseeds (mainly from trees growing naturally) provide a high potential alternative source of oil which can be used both for food and other industrial applications. Some of the indigenous oilseed plants in Kenya grow in the arid and semi-arid areas which constitute over 75% of the total land area of the country. This area which is underutilized at present could thus be put to productive use if products of drought resistant plants like cape chestnut could find use in the industrial sector.

Cape chestnut is an outstanding indigenous deciduous tree, attaining a maximum height of 21 m. It has a shapely, spreading crown, widespread in evergreen and riverine forest in the highlands. The tree is common in the Coast, Central and Rift Valley Provinces at altitudes between 1524-2134 m and has two flowering seasons in February and August. The fruits ripen six months after flowering season. The fruits are round, about 38 mm in diameter, very rough on the outside with coarse woody spines and the seed are black in colour. It is slow-growing but hardy and drought resistant once established, often flowering in 6 to 8 years.

Well focussed research on the properties of oils from indigenous oilseeds will provide scientific information required for their specific utilization. This would also promote afforestation which would in turn reduce soil erosion, desertification and improve soil and water conservation in addition to providing wood for timber and firewood. Thus the objectives of this study were to determine physical properties of crude oil from cape chestnut (*Caledendrum capense*), which can justify its use as a fuel and lubricant, and to evaluate the effect of temperature and methods of extraction on some of the properties.

2.0 METHODOLOGY

The experiment was carried out using standard methods recommended by International Union of Pure and Applied Chemists (IUPAC, 1979), British Standard Institute (BSI), Institute of Petroleum (IP, 1976), American Society of Agricultural Engineers (ASAE) and American Standards of Testing Material(ASTM). However, improvised methods were used to determine specific heat and thermal conductivity. The oilseeds were obtained from the Kenya Forestry Research Institute and were collected from Nyeri District. The experiments were done at an average room temperature of 25°C and relative humidity of 50%.

2.1 Extraction of the oil sample

The test samples were extracted from whole seeds using a ram press for mechanical extraction and a soxhlet extractor for chemical extraction. Mechanical extraction was carried out on whole seeds whereas chemical extraction was done on ground seeds. The oil extracted was dried in an oven at 103 $\pm$ 2°C for at least 1 hr before being filtered through an ashless Whatman filter paper. The required parameters were then determined.

2.2 Determination of Specific Heat Capacity

Improvised thermal calorimeter was used to determine specific heat capacity (C_p) of the oil (Perry 1973, Ward 1952, Clark *et al.* 1946). The thermal calorimeter was calibrated using distilled water having a theoretical specific heat capacity of 4.187 kJ/kg°C. 100 g of the oil sample was accurately weighed and put in the calorimeter of known mass and specific heat capacity. The calorimeter was then placed in the insulated jacket before assembling the whole thermal calorimeter. After equilibrium, the initial temperature of the sample θ_1 was noted. About 200 J of energy was then passed through the sample using a joule meter and the temperature rise noted till a steady state was reached. The final temperature θ_2 was recorded. The change in temperature (θ_2-θ_1=$\Delta\theta$) was calculated and substituted in equation (2.1) to get the specific heat capacity of the sample.

$$C_p = \frac{Q - m_c C_c \Delta\theta}{m_s \Delta 0} \qquad \ldots\ldots\ldots\ldots 2.1$$

Where Q denotes Heat supplied; m_s, Mass of sample; m_c, Mass calorimeter; c_c, Specific heat capacity of the calorimeter

2.3 Determination of Thermal Diffusivity

Dickerson method for determining thermal diffusivity (Mohsenin 1980, Nowrey 1968) was improvised. This was by use of a calorimeter in which thermal probes were positioned at the centre and on the surface. This consisted of a water bath, an electric heater, an electric thermometer probe, high conductivity copper cylinder, and a stirrer. The improvised facilities were calibrated using distilled water of thermal diffusivity 5.877 x 10^{-4} m^2/h. An accurate weight of 100 g of the sample was placed in the coppper cylinder. The cylinder was then placed in a water bath which was heated and agitated and the time - temperature variation recorded until a constant rate of temperature rise was obtained for both inner (θ_c) and outer (θ_s) temperatures. Temperature was monitored using an electrical probe. The inner and outer temperatures were plotted against time and the gradient of the outer temperature line C_T calculated. Thermal diffusivity (α) was calculated using equation 2.2 and the corrected results (standard error of 0.738 was used) replicated. Corrected thermal conductivity (k) was calculated from equation 2.3 using the values of thermal diffusivity, specific heat (C_p) and density (ρ) determined.

$$\alpha = \frac{C_T Z^2}{4(\theta_S - \theta_C)} \quad \text{.............. (2.2)}$$

Where Z stands for Probe position from the cylinder surface

$$k = \alpha \rho C_p \quad \text{...............2.3}$$

3.0 Results and Discussion

3.1 Specific Gravity

Though the specific gravity of the oil was high, it was within the recommended range for fuels (Table 1) used in diesel engines. Thus the problem of atomization, pumping, ignition, and knock would not be critical when the oil is used. Methods of extraction had no significant effect on specific gravity.

Table 1. Determined properties of mechanically and chemically extracted cape chestnut oil and those recommended for fuels

Properties	Recommended Range	Determined Values Chemically Extracted	Mechanically Extracted
Calorific value (MJ/kg)	38 - 46	40.4	40.4
Viscosity (mm^2/s)	1.5 - 5.5	34.2	36.8
Flash point (^{o}C)	49 - 80	67	215
Specific gravity (sg)	0.74 - 0.95	0.92	0.93
Ash content (%)	<0.05	0.106	0.008
pH	6.5 - 8.0	6.0	3.7

The density of the oil decreased linearly with increase in temperature (Table 2) following the relation:-

$$p = M\theta + C \quad \text{..............................3.1}$$

Where p denotes Density; θ, Temperature; M, C are Constants. The values of M and C obtained were -6.1×10^{-4} and 0.93 respectively.

The oil showed relatively higher values of specific gravity which were outside the recommended range for lubricants (Table 3).

Since specific gravity is not critical for the lubricating oil, the high values are not a limitation. However, specific gravity is important when it comes to the volume and weight aspect of the oil.

Table 2. Variation of density (Kg/m^3) with temperature (°C)

	Kinematic Viscosity (mm^2/s)	
Temperature (°C)	Chemically Extracted	Mechanically Extracted
10	9253	9316
20	9216	9258
30	9119	9098
40	9061	9041
50	9000	8983
60	8939	8930
70	8871	8872
80	8820	8808
90	8726	8761
100	8659	8687

The values of "a" and "b" obtained were -4.0 x 10^{-3} and 0.354 respectively. The methods of extraction showed no significant effect on the values obtained.

$$\text{Log} (\log (\gamma + 0.8)] = a \log T + b \quad \text{.......................3.2}$$

Where T denotes AbsoluteTemperature in K; γ, Kinematic viscosity in mm^2/s; a,b are Constants.

3.2 Kinematic Viscosity

The oil had a very high kinematic viscosity which was outside the recommended range as fuels (Table 3). High kinematic viscosity can lead to poor atomization of the oil thus causing poor combustion and related problems. Thus the oil cannot be used directly in a diesel engine. Low kinematic viscosity can be achieved by heating the oil to over 90°C since it decreased with increases in temperature following equation 3.1 (Table 4).

The oil showed lower values of kinematic viscosity at 40°C. However, the values were within the recommended range for various applications as lubricants as shown in Table 5 (Cameroon 1981, Lansdown 1982, Pugh 1970).

Low values can result in excessive wear and leakages whereas very high values can result in excessive power loss. Thus high kinematic viscosity is recommended for high speed, heavy and high temperature systems. For systems requiring varied kinematic viscosity, it can be varied by setting the temperature or through refining. Since crude oil was used, its behaviour under operating conditions cannot be pre-empted.

3.3 Viscosity Index

The rate of change of kinematic viscosity of oils with temperature relates to the viscosity index of oil. This is because viscosity index is a ratio of difference in kinematic viscosities of different oils. High kinematic viscosity and viscosity index are recommended for lubricants used where high temperatures are experienced so as to avoid wide range changes. The oil showed relatively higher viscosity index values, though they were not within the recommended range (Table 2). Oil with high values is important when it is used in systems where changes in temperature are high and kinematic viscosity at the operating temperature is low.

Table 3. Determined properties of mechanically and chemically extracted cape chestnut oil and those recommended for lubricants

Properties	Recommended Ranges	Determined Values	
		Chemically extracted	Mechanically extracted
Kinematic viscosity (mm^2/s)	19 - 3140	34.2	36.8
Viscosity index	76 - 150	160	158
Fire point (°K)	333 - 573	340	488
Specific gravity	0.8 - 0.9	0.92	0.93
Ash content(%)	0.0 - 6.7	0.106	0.008
Specific heat (kJ/kg °K)	1.5 - 2.5	2.2	2.1
Pour point (°K)	213 - 273	*	*
Sulphur content (%)	1.5 - 3.0	*	*

* Not determined

Table 4. Variation of kinematic viscosity (mm^2/s) with temperature (°c)

Temperature (°C)	Chemically Extracted	Mechanically Extracted
10	129.2	134.7
20	76.1	78.4
30	50.2	55.3
40	34.2	36.8
50	24.2	27.2
60	18.1	17.9
70	14.2	13.7
80	11.1	11.9
90	9.1	10.6
100	7.5	7.5

Table 5. Viscosity ranges for various applications of lubricants

Use as Lubricant	Viscosity Range (mm^2/s)
Motor	10 - 50
Turbine	10 - 50
Roller Bearing	10 - 300
Plain Bearing	20 - 1500
High Speed Gears	15 - 100
Hypoid Gears	50 - 600
Worn Gears	200 - 1000
Open Gears	100 - 50,000

3.4 Calorific Value

The calorific value of the oil was relatively low. However, the values obtained were within the recommended range for fuels (Table 1) making it suitable for use in a diesel engine. Methods of extraction showed no significant effect on the calorific value of the oil.

3.5 Ash Content

Unlike the chemical extraction oil, the mechanically extracted oil had low ash content which was within the recommended range for fuels (Table 1). The high ash content for chemically extracted oil could be attributed to the reaction between the oil and the extraction solvent resulting is non-combustible product. Thus mechanical extraction can be used to minimize the problems of engine wear and deposits. The methods of extraction can be used to minimize the problems of engine wear and deposits. The methods of extraction thus showed a significant effect on the ash content of the oil. Refining can be done to remove naturally occuring gums and free fatty acids which most likely contribute to the high ash content. However, ash content is not critical in lubricants as it is in fuels, although high ash content contributes to wear of mating parts since ash content is a measure of the wear reducing capacity of an oil. The value obtained was within the recommended range for lubricants (Table 2).

3.6 Flash Point

The mechanically extracted oil had a higher flash point than that extracted chemically (Table 1). Thus the method of extraction had a significant effect on the flash point of the oil. This could be attributed to the interaction between the oil and the solvent which needs further investigation. High flash point oils are suitable for use as fuel since fire risks are low and they can be handled easily. However, very low flash points can be risky especially if the fuel tank is exposed to a heat source like the sun or when the oil leaks close to the engine. Flash point is a critical property where high temperatures are experience in lubrication systems due to high fire risks high. The values obtained (Table 3) were within the recommended range for its use as a lubricant. Thus the mechanically extracted oil would be more suitable in systems where high temperatures are experienced compared to chemically extracted oil.

3.7 pH Value

The mechanically extracted oil had a very low pH value of 3.7 compared to the chemically extracted oil which had a slightly higher value of 6.0. This was however still below the recommended range for fuels. The low pH value of the oil can result in corrosion of the metallic parts of the fuel system and the engine walls. However, pH value does not affect the performance of the oil in the engine but it gives information on the acidity and basicity of the oil. Methods of extraction showed a significant effect on the pH value of the oil.

3.8 Specific Heat Capacity

The oils showed close values of C_p which were within the recommended range (Table 3) and greater than 2.0 kJ/kg°C. Methods of extraction had no significant effect on the values obtained. Thus the oils are convenient for use as lubricants based on their C_p. High C_p is suitable since heat is released during lubrication and it must be disposed of. Overheating of a lubricant results in the loss of its lubricating qualities thus increasing wear of the mating parts.

4.0 Conclusion and Recommendations

In the analysis of the physical properties of crude oil extracted from cape chestnut, the following conclusions and recommendations were reached:-

For the sample of oil used, it was observed that the methods of extraction had no significant effect on most of the parameters determined. This included density, viscosity, calorific value, specific heat, and refractive index. Most of the values obtained were within the theoretical expectation thus qualifying the experimental methods used. However, methods of extraction were found to have a significant effect on the flash point of the oils. Thus chemically extracted oil is recommended for use as fuel where as the mechanically extracted oil is recommended for use as a lubricant. The variation of density and kinematic viscosity with temperature of the oil was as expected. However, the oil had slightly higher density and viscosity. Although this is a constraint to its use as a fuel in diesel engine due to poor atomization and injection blockage, the constraint can be minimized through formulations with other oils, refining and heating. The high ash content of the chemically extracted oil is a disadvantage to its use as fuel due to the problem of engine desposits and wear, unlike the mechanically extracted oil. Within the operating temperatures of some equipment, the oil would be suitable for use as a motor oil, general purpose house hold oil, hydraulic oil, roller and plain bearing oil and as gear oil. The high viscosity index of the oil makes it more suitable for use as a lubricant, though it has low kinematic viscosity at room temperature.

The use of the indigenous oil cannot be solely based on its properties due to the expected varied characteristics under different operating conditions. With the limited parameters determined, no comprehensive conclusion can be made on the actual suitability of the oil as a fuel and a lubricant. Thus there is need for more intensive research into the properties of the oil. This should include determination of fatty acid content, pour point, sulphur content, smoke point, iodine value, shelf life, carbon content, and the cetane rating. More accurate and standard method should also be sued to determine specific heat and thermal conductivity of the oil. Tests should also be carried out on the refined oil to assess the effect of refining on the propertieis of the oil. There should also be short and long term engine tests on the use of the oil as a fuel and lubricant since this is the only sure way of approving the suitability of the oil. Research should also be done on the economic viability of producing the oilseeds on large scale especially in the semi-arid areas.

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