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Thermo-physical properties of selected oil samples as predictor of marine engines life span

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Abstract: *The break down of hydrodynamic regime of lubricants especially at higher operating temperature promotes direct metal-to-metal contact between surfaces. This often results in wear and tear, overheating and fatigue on the sliding surfaces of engines. This paper determines the actual viscosities of six oil samples (Mobil oil, Abro oil, Con oil, Tonimas oil, Oando oil and Total oil) using their coefficient of viscosities and specific heat capacities obtained in the laboratory. The results indicate that Mobil oil is the most appropriate for oil marine engines; closely followed by Tonimas oil, and Total oil. The results also reveal that Con Oil, Oando Oil and Abro Oil have low viscosities at higher temperatures. This thermo-physical property may render these oils very unstable for marine engines, especially for international voyage.*
Key words: *Hydrodynamic, lubricants, marine engine, viscosity, temperature and overheating.*

I. Introduction

From the Roman era, many liquids including water were used as lubricants for the purpose of reducing friction, heat and wear and tear between mechanical parts in contact with each other. Lubricating potential of fluids is a measure of their viscosities. In a simple form, viscosity is a physical property of a fluid that reflects its tendency to flow. Fluids with high viscosity are considered as being “thick” and low viscosity fluids as being “thin” [1]. It is an important property of vessel oil because changes in viscosity affect the ability of the oil to lubricate and protect the moving parts of an internal combustion engine.

Lubricating oil in automobiles is usually subjected to elevated temperature in the range of 35^{O}C to about 140^{O}C [2]. Heat lowers oil film thickness, makes it less viscous and flow faster [3]. This could further inform the break down of hydrodynamic regime while promoting direct metal-to-metal contact between surfaces, thereby resulting in wear and tear, overheating and fatigue on the sliding surfaces.

Lubricating oils are categorised into two based on their mode of manufacture namely mineral oils (those refined from crude oil or naturally occurring petroleum) and synthetic oils, which are manufactured from polyalphaolefins [4]. Mineral base lubricating oil has the advantage of being produced in a wide range of viscosity, which determines its effectiveness. [1] noted that over 85% of lubricating oil produced worldwide is derived from crude oil and they play vital functional and sensory roles in marine engine including the smooth and easy running of the engine, whih improves the lifespan of the engine. The optimum design of heating and cooling systems for lubricating oil and the lubricating processes require fundamental understanding of the thermo-physical properties of the oil. Two of the important thermo-physical properties are viscosity and specific heat capacity [1].

Some multi-grades engine oil suffer severe viscosity breakdown leading to premature engine failures. Therefore, a good understanding of the thermo-physical properties of oil samples will help dispel the challenge faced due to use of poor quality oil in vessels as well as aid in making a well informed choice of engine oil in the face of other contending engine oils.

The present work determines the actual viscosity and specific heat capacity of six oil samples within a temperature range of 35^{O}C – 70^{O}C and used the results to select the suitable lubricants that could prolong the life span of marine engines.

II. SAE viscosity grading system

The Society of Automotive Engineers (SAE) had established a viscosity grading system for engine oils. According to the SAE viscosity grading system all engine oils are classified into monograde or multigrade [5].
Monograde engine oils are designated by one number (20, 30, 40, 50, etc.). The number indicates a level of the oil viscosity at a particular temperature. The grade numbering is directly proportional to the oil viscosity. Viscosity of engine oils designated with a number only without the letter “W” (SAE 20, SAE 30, etc.) is specified at the temperature 212°F (100°C). According to [5] these engine oils are suitable for use at higher ambient temperatures. Viscosity of engine oils designated with a number followed by the letter “W” (SAE 20W, SAE 30W, etc.) indicating *winter* are specified at 0°F (-18°C). These grades are used at lower ambient temperatures [5].

Viscosity of engine oils may be stabilized by polymeric additives (Viscosity Index Improvers). Viscosity of such engine oils is specified at both high and low temperature called multigrade oils. They are designated by two numbers and the letter "W" (SAE 5W-30, SAE 15W-30, SAE 20W-50, etc.). The first number of the designation specifies the oil viscosity at cold temperature, the second number specifies the oil viscosity at high temperature. For example: SAE 15W-30 oil has a low temperature viscosity similar to that of SAE 15W, but it has a high temperature viscosity similar to that of SAE 30. This gives multigrade oils wide temperature range [6].

2.1 Application of oil to marine engines

Lubricating oil for an engine is stored in the bottom of the crankcase, known as the sump or in a drain tank located beneath the engine. The oil is drawn from the tank through a strainer, one of a pair of pumps, into one of a pair of fine filters. It is then passed through a cooler before entering the engine and being distilled to the various branch pipes. The branch pipe for a particular cylinder may feed the main bearing, for instance. Some of this oil will pass along a drilled passage in the crankcase to the bottom end bearing and then up a drilled passage in the connecting rod to the gudgeon pin or crosshead bearing [7].

Where the engine has oil-cooled pistons, there is always a supply from the lubricating oil system, possibly at a higher pressure produced by booster pumps (e.g. Sulzer RTA engine). A good lubricating oil lubricates pistons without any carbon deposited on the hotter parts of the engine [6]. Some engine mechanisms that need lubrication are piston motion in cylinder, crankshaft rotation in engine bearings, piston pin rotation in the brush of small end of the connecting rod, camshaft rotation in camshaft bearings and Cams sliding over the valves rods.

2.1.1 Velocity gradient

When a fluid is moving through a pipe or a solid object is moving through a fluid, the layer of fluid in contact with the sides of the pipe or the surface of the object tends to be in the same state of motion as the object with which it is in contact. The layer of fluid along the side of the pipe can be said to be at rest, while the layer in contact with the moving object is been carried along at the same velocity as the object. If the difference in velocity between the fluid at the sides of the pipe and that at the centre, or between the moving object and the fluid through which it is moving, is not significant, it means that the fluid is flowing in a continuous smooth layers; that is, the flow is laminar.

The difference in velocity between adjacent layers of the fluid is known as velocity gradient and it is expressed as

$$V_g = v/x \qquad (1)$$

where v is the velocity difference and x is the distance between the layers. To keep one layer of fluid moving at a greater velocity than the adjacent layer, a force F is necessary, resulting in a shearing stress (F_s) given by

$$F_s = F/A \qquad (2)$$

where A is the area of the surface in contact with the layer being moved.

2.2 The coefficient of viscosity

The ratio of the shearing stress to the velocity gradient is a measure of the viscosity of the fluid and is called the coefficient of viscosity η

$$\eta = Fx / Av \qquad (3)$$

The cgs unit for measuring the coefficient of viscosity is the poise. Experiments have shown that the coefficient of viscosity of liquids decreases with increasing temperature, while the coefficient of viscosity of gases increases with increasing temperature. In liquids an increase in temperature is associated with the weakening of bonds between molecules; since these bonds contribute to viscosity, the coefficient is decreased. On the other hand, intermolecular forces in gases are not as important a factor in viscosity as collisions between the molecules, and an increase in temperature increases the number of collisions, thus increasing the coefficient of viscosity. A striking result of the kinetic theory of gases is that the viscosity of a gas is independent of the density of the gas. Viscosity is the principal factor resisting motion in laminar flow [6]. However, when the velocity increases to a point at which the flow becomes turbulent, pressure differences resulting from eddy currents rather than viscosity provide the major resistance to motion. This paper adopts the Stokes formula (4) to determine the coefficient of different oil samples used for lubricating marine engines.

$$\eta = \frac{2ga^2(\rho - \sigma)}{9V_0} \qquad (4)$$

2.3 Determining viscosity index

The viscosity index can be determined based on a single, discrete sample or on a continuous sample stream [4, 5]. A sample is fed into a first pressure drop device where a first pressure drop is measured. A first sample temperature and mass flow are measured at that point. A first density of the sample is determined from a sample mass flow meter so that a first kinematics viscosity can then be determined using the first sample pressure drop, temperature, and density. Then the sample temperature is changed to a second sample temperature and the sample is passed through a second pressure drop device. The second sample temperature, sample density and pressure drop are used to determine a second kinematics viscosity at the second sample temperature. The viscosity index of the sample is determined using the first and second kinematics viscosities.

2.4 Effect of temperature on the viscosity of the fluid

Understanding the effect of temperature on the viscosity of the fluid is very important [14, 20, 21, 23, 24, 25, 26]. As the temperature of the fluid increases, its viscosity decreases. The viscosity is the property of the fluid that resists the flow of the fluids (liquids and gases). In engines, the lubricating oil is usually heated to very high temperatures due to combustion of the fuel [8, 16, 17, 18 19]. Hence, it is vital to distinguish those lubricating oils that will be viscous enough to be able to lubricate the moving parts of the engine at high temperatures.

There are chances that at high temperature the fluid may loose its viscosity, which may render it useless when used in high temperature. In most cases, some of the fluids may even start evaporating at high temperature [9, 15].

Whenever a fluid is to be used for any mechanical application, the operating temperature should be given due consideration [10]. The fluid that can sustain those operating temperatures should only be selected for those applications; otherwise the very purpose of using the fluid will be lost [7, 16].

2.5 Theoretical background of viscosity

When a spherical ball bearing is allowed to fall through a viscous liquid, it experiences a resistive viscous force (F) until it acquires terminal velocity (V_0). The resistive force is given by

$$F = 6\pi V_0 \mu r \qquad (5)$$

where μ is the coefficient of viscosity and r radius of the ball bearing.

The weight (w) of the ball bearing of mass, m under gravity (g) is given by

$$W = (4/3)\pi r^3 g \qquad (6)$$

Since the bearing occupies space, it displaces a volume of liquid which equals its weight. The upthrust (U), which opposes a falling ball bearing, is given by

$$U = (4/3)\pi r^3 \rho g \qquad (7)$$

The growth of this force does not enable the bearing to have a change in velocity anymore (therefore a = 0) and it is said to attain a terminal velocity (V_O) just when the resulting force on it is zero. Hence, the net force on the bearing is

$$6\pi\mu r V_0 - 4/3\pi r^3 (\sigma-\rho)\, g = 0 \qquad (8)$$

where

$$\mu = \frac{2gr^2\rho - \sigma}{9V_0} \qquad (9)$$

$$6\pi\eta r V_o = \underline{4\pi r^3}\, (\rho-\sigma) \qquad (10)$$

$$6\Pi\eta r V_0 = \frac{4r^2 x\rho - \sigma}{36V_0} \qquad (11)$$

$$\eta = \frac{4r^2 x\rho - \sigma}{18V_0} \qquad (12)$$

Therefore:

$$\eta = \frac{2gr^2(\rho-\sigma)}{9v_0} \qquad (13)$$

III. Materials And Methods

The thermo-physical properties of selected oil samples were carried out using the following: beaker, thermometer, retort stand with clamp, viscometer, Bunsen burner, weight balance, micro-screw gauge, spherical ball bearing and oil samples (Mobil Oil, Tonimas Oil, Con Oil, Total Oil, Abro Oil and Oando Oil).

A spherical ball bearing is allowed to descend though the oils and the terminal velocity of the ball in the oil was determined. Then Stoke's law was applied to determine the coefficient of viscosity of the oil samples.

3.1 Specific heat capacity

If a given quantity of heat (Q) is added to a homogenous sample of matter of mass (m) (such as a pure substance or a solution), the quantity of heat needed to raise its temperature is proportional to the mass (m) as well as to the rise in temperature (Δ T). These parameters are related quantitatively by

$$Q = C \times m \times (\Delta T) \quad (15)$$

where c is a constant of proportionality representing specific heat capacity and m is the mass of oil samples. Specific heat capacities provide a convenient way of determining the heat added to, or removed from a material [11, 12, 22, 24].

This work adopted the calorimetory method and the principle of conservation of energy stated as

$$c_1 m_1 t_1 = c_2 m_2 t_2 \quad (16)$$

to determine the specific heat capacities of the six oil samples at the temperature ranging from 35^{O}C to 70^{O}C. The actual viscosity of the oil samples was computed using

$$\mu = A \exp \tfrac{B}{T} \quad (17)$$

Therefore,

$$\text{Log } \mu = \text{Log } A + \underline{B}\,(0.434)\,T \quad (18)$$

The constants A and B in equ 18 were determined.

IV. Results and Discussion

Table 4.1 is the summary of the coefficient of viscosity obtained for the various oil samples at different temperature. Table 4.2 shows the logs of the coefficient of viscosity of oil samples and their temperature inverse. This enabled the computation of the constants in equ 18 and is presented on Table 4.3. The actual viscosity of the oil samples are contained in Table 4.4.

The variation in viscosity of different oil samples with temperature also shows that viscosity is inversely proportional to temperature. This result agrees with [7]. As the heat applied to oil is increased, the lubricating potential falls until the oil completely loses its viscosity. This exposes the engine the risk of over heat and eventually damage.

Oil samples selected for this study presented different peak value of viscosity. The viscosity value of Mobil oil hits the higher peak compared to others, while Abro oil had the lowest viscosity value showing that Mobil oil is more viscous than others. From table 4.10, Mobil oil had the highest viscous value (0.18 kg/m.s) at 35^{O}C. This value drops to 0.09 kg/m.s at 70^{O}C.

Tonimas oil and Total oil had very similar viscosity value at low temperature (0.15 kg/m.s at 35^{o}C). At 70^{O}C, Total oil has a viscosity of 0.07 kg/m.s while the viscosity Tonimas oil is 0.08 kg/m.s. The disparity in their viscosities begins at 45^{o}C and a maximum value of 0.01kg/m.s is obtained. This level of disparity is considered not significant. Therefore, the two oils have similar thermo-physical property.

Oando oil has a viscosity value of 0.11 kg/m.s at 35^{o}C and losses its viscosity rapidly as heat is applied to it. From 55^{o}C-70^{o}C its viscosity falls to 0.06 kg/m.s. Results indicate that Con oil has the same characteristics as Oando oil. However, that Oando oil has a more viscous ability of 0.01 kg/m.s higher than that of Con oil at higher temperatures. The peak specific heat capacity values for the different samples were significantly different. Oil samples present different peak values of specific heat capacity. Abro oil (c=5.047J/g^{O}C) has the highest values of specific heat capacity compared to other oil samples. Other samples have the following values (Mobil oil: 4.658 J/g^{O}C, Tonimas oil: 4.731J/g^{O}C, total oil: 4.762J/g^{O}C, Oando oil: 4.616J/g^{O}C, con oil: 4.743J/g^{O}C). According to [3,2,13] when oil film thickness is low at high temperature, its hydrodynamic regime is broken and direct metal-to-metal contact between surfaces occurs and this may cause wear and tear, overheating and fatigue on the sliding surfaces.

However, those oils with high viscosity at low temperatures could be very useful lubricants in the refrigerator compressors, since the suction side of the compressor operates at low temperature; while high temperature is on the discharge side of the compressor.

Table 4.1: Summary of average coefficient of viscosity at different temperature

Samples	35^{O}C	40^{O}C	45^{O}C	50^{O}C	55^{O}C	60^{O}C	65^{O}C	70^{O}C
Mobil	93.297	72.483	64.517	52.943	26.340	17.394	14.047	11.962
Tonimas	54.397	28.221	22.627	21.038	21.521	18.819	14.492	11.962
Con	59.999	36.916	32.819	19.865	17.507	13.655	11.899	8.447
Total	29.314	23.295	22.159	21.297	17.114	12.727	11.034	7.685
Oando	24.317	23.494	22.259	18.962	14.758	14.365	8.333	6.907
Abro	26.118	23.272	22.401	19.925	18.925	16.735	13.561	8.398

Table 4.2: Log of oil samples and 1/temperature

TK	308	313	318	323	328	333	338	343
1/3 ($x10^{-3}$) k^{-1}	3.25	3.20	3.15	3.10	3.05	3.00	2.95	2.90
Mobil Oil	1.9699	1.8602	1.8097	1.7238	1.4206	1.2404	1.1476	1.0778
Tonimas Oil	1.7356	1.4506	1.3546	1.3230	1.3329	1.2746	1.1611	1.0778
Con Oil	1.7781	1.5672	1.5161	1.2981	1.2432	1.1353	1.0755	0.9267
Total Oil	1.4671	1.3673	1.3456	1.3283	1.2334	1.1047	1.0427	0.8856
Oando Oil	1.3859	1.3710	1.3475	1.2779	1.1690	1.1573	0.9208	0.8393
Abro Oil	1.4169	1.3668	1.3503	1.2994	1.2994	1.2236	1.1323	0.9242

Table: 4.3 Log A exp B/T for all oil samples

Oil Samples	A	B	μ
Mobil	0.06	6.36	0.06 exp 6.36/T
Tonimas	0.00	5.37	0.00 exp 5.37/T
Con	-0.029	3.31	-0.029 exp 3.31/T
Total	-0.14	5.07	-0.14 exp 5.07/T
Oando	-0.2	3.96	-0.2 exp 3.96/T
Abro	0.114	2.21	0.114 exp 2.21/T

Table 4.4: Actual viscosity values of oil samples at various temperatures

Sample	μ	Temperature 35°C 308K	40°C 313K	45°C 318K	50°C 323K	55°C 328K	60°C 333K	65°C 338K	70°C 343K
Mobil	0.06 e6.36/T	0.18	0.16	0.14	0.13	0.12	0.11	0.10	0.09
Tonimas	0 e5.37/T	0.15	0.13	0.12	0.11	0.10	0.09	0.08	0.08
Con	0.03 e3.31/T	0.10	0.08	0.07	0.07	0.06	0.06	0.05	0.05
Total	-0.14 e5.07/T	0.15	0.13	0.11	0.10	0.09	0.09	0.08	0.07
Oando	-0.12 e3.96/T	0.11	0.10	0.09	0.08	0.07	0.07	0.06	0.06
Abro	-0.11 e2.21/T	0.06	0.06	0.05	0.04	0.04	0.04	0.03	0.03

V. Conclusion

The study shows that, not all engine oils are suitable for marine engines. This is because viscosity of some oils is very low at higher temperatures. Thereby, such oil becomes poor lubricant at that temperature. The viscosities oil sample at higher temperature is a good parameter for the selection of appropriate engine oil that can enhance the lifespan of water craft engines (main and auxiliary). The results show that Mobil oil is the most appropriate oil for marine engines; closely followed by Tonimas oil, and Total oil. However, the results reveal that Con Oil, Oando Oil and Abro Oil are not very suitable for marine engines due to their low viscosities at higher temperatures. This can easily result in fuming of the oils at higher temperatures which sacrifice their viscosities. Therefore, Master mariners should note the order of preference of the oil samples and advice the chief engineers accordingly.

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