Density and Thermal Conductivity Changes in Engine Oil During its Life Cycle: An Experimental Study

Sudhir Chitrapady Vishweshwara and Omar Khamis Hamed Al Badi

***Abstract*— Oil is used in internal combustion engines purely for lubrication. The main function is to minimize wear of moving parts. The lubricating oil also helps to clean and prevent corrosion of engine parts. It's further helps in sealing, and cools the moving parts of the engine. The few critical properties of engine oils are: Thermal conductivity, Density and Viscosity, these properties determine the worthy of the oil in its real world applications. Current paper focuses on the experimental analysis on few important Thermo-Physical Properties especially Thermal conductivity and Density of Engine Oils over the period of its use. The purpose is to know how the properties change with time and temperature. For the purpose of study, different vehicles were used and tested in order to study changes in thermal conductivity and density. For the study, three sedan cars and one heavy duty truck was considered for study. The thermal conductivity was measured by using KD2 pro device, Density was measured by using a standard density measuring 25ml standard glassware. From this study it was discovered that, the relationship between temperature and thermal conductivity, Density and viscosity is inversely. Furthermore the thermal conductivity and density inside engine increase by running time. The study included three passenger vehicles and one truck engine oil sample were drawn at the each interval of 1000 kilometer of running starting form new oil till it is being replaced. The testing was carried out at different temperatures so that it reflects temperature conditions inside the engine. The studies indicate an inverse relationship between thermal conductivity of engine oil and the temperature inside the vehicles. Further thermal conductivity decreases with running period.**

***Keywords*— Engine Oil, Density, Thermal Conductivity and Life Cycle**

I. INTRODUCTION

Oil used in internal combustion engines for lubrication and cooling purposes. As known to all, the main function is to minimize wear of moving parts; moreover it helps clean, prevents corrosion, enhances sealing, and cools the moving parts of the engine. Engine oil helps engine cooling the important parts of engine, like piston assembly, head, and valves [1]. Engine oils are generally formulated oils. They consist of mineral, semi- or fully synthetic base oil (base stocks) plus a varying number and amount of additives. The quality of an engine oil depends on the base stock and its properties as well as on the additives (Rinker et al., 1994).

The main requirements for engine oil are defined temperature viscosity properties, protection against wear and corrosion, keeping the engine clean, holding particles like soot or abrasives in suspension, yield strength under compression and many more. Engine oil is available in different SAE grades to suit the climate where it is used and the purpose of the user (Sanderson, 1949).

Three important properties of engine oils, which determine its purpose of fitness, are Thermal conductivity, Viscosity and Density. These three properties are very important for engine oil as it affects the oil's ability to take away from the heat engine. Relationship between the thermal conductivity and the efficiency of the engine is direct, means if thermal conductivity is high the engine efficiency is also high as it minimizes friction loss. The purpose of this study is to see the relationship between thermo physical properties of engine oil and the temperature with the running time of engine.

The engine oil thermal conductivity is of important traits affecting lubricating oil's ability to transfer heat from the engine to the atmosphere. The engine oil of higher thermal conductivity and specific heat are rated as more efficient, and play a vital role while designing effective engine cooling system. Studies carried out by Wrenick et al., [2] reflects that thermal conductivity is a function of temperature Oils and report that oils with a larger thermal conductivity value will transfer heat energy more efficiently. Moreover their studies show the variation of thermal conductivity for various fluids with respect to temperature as depicted in Fig. 1. The figure clearly show as engine oil temperature increases, its thermal conductivity decreases.

Density of engine oils is a function of engine operating temperature. Its known fact that the density of lubricating oil decreases with rise in temperatures. The research work of F. Jian et al., [3] exemplifies this fact and variation of kinematic viscosity and density of oil with respect to temperatures is shown in the Fig. 2.

Engine oil colour is first indicators of engine oil deterioration. When the oil is used in an engine it undergoes a burning experiences due to heat associated with combustion inside the vehicle engines, this will change the characteristics

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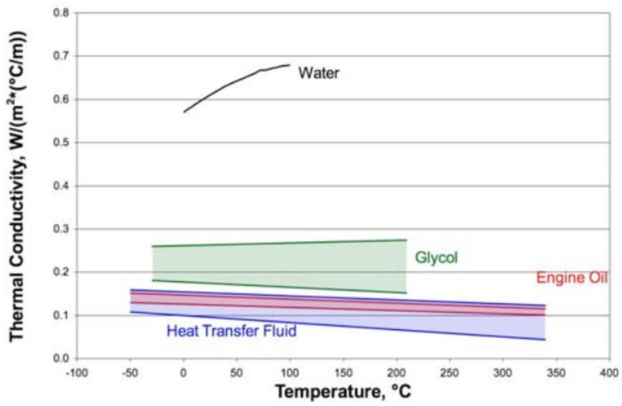

Fig. 1: Thermal Conductivity variation with temperature [2]

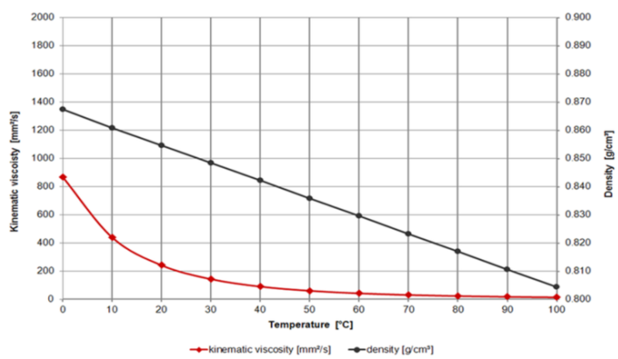

Fig. 2: Viscosity and density variation with temperatures

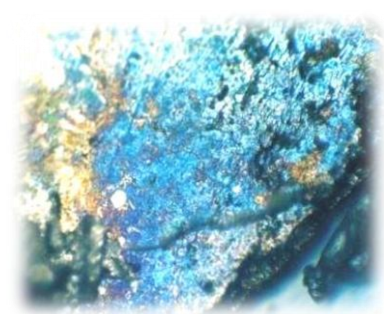

Fig. 3: Oil deposit [4]

of the engine oil such as color, viscosity and density. The oil colour will tend to change drastically during the course of time, as oils tend to accumulate foreign materials [4] which may be partially burnt sulphated ash in the engine oil [5].

The two important thermal physical properties of engine oil, namely thermal conductivity and viscosity has significant effect on engine performance. Hence many researches are underway to increase the heat carrying capacity of the engine oils so as to make the engine more efficient and long life. The research work of Choi and Eastman, (1995) suggest that the lubrication oil properties can be increased through the addition of nanoparticles. Choi and Eastman suggest that, in an engine oils; conduction heat transfer capacity can be increased through nanoparticles. Since better interaction between fluid particles in presence of nanomaterial will aid in transferring engine heat to the atmosphere.

Viscosity is one of the most important in physical properties of engine oil. It is one factor responsible for the formation of lubricating films under both thick and thin film conditions (Van Duren, 2003). Viscosity affects heat generation in bearings, cylinders and gears due to internal fluid friction. It affects the sealing properties of oils and the rate of oil consumption. It determines the ease with which machines can be started at various temperatures, particularly cold temperatures (van Duren, 2003). When heat is applied to fluids, molecules can then slide over each other more easily making the liquid to become less viscous. The effect of temperature on the kinematic viscosity of liquid is described by means of the Arrenhius equation (Azian MN, 2001). Booser (1994) suggest that, engine oil should lubricate and mitigate wear and it should serve as a heat-transfer fluid in engines. For engine cooling system design, oil thermal conductivity and specific heat are important parameters, and are a function of temperature. Oils with a larger thermal conductivity value will transfer heat energy more efficiently. Oils with a larger specific heat value will have a smaller temperature rise for a given amount of heat energy absorption. Thermal conductivity of oil engine is decreasing with increasing of temperature degree.

II. EXPERIMENTAL SET-UP

A. *Thermal Conductivity measurement setup*

To measure thermal conductivity of engine oil samples collected at different time period of running a KD2 pro analytical device and KS-1 sensor is used. KD2 pro (Fig. 4) is a battery operated manual device that measure thermal conductivity of the samples using a unique KS-1 sensor recommended for oil samples by the supplier. The device reads the Thermal Conductivity is W/m K.

Fig. 4: KD2 Pro

B. Scheme of Experiments

In order to measure the car cabin temperature, the car was parked in an open parking space and care was taken such that there was no interference from local shadows during the measurements. A white color, 2007 make, Toyota Corolla of was chosen for this experimental work. There were no medications done on the chosen car, and all the factory settings were retained all throughout the experiments. While experiments were carried out, the car was parked at a chosen parking space and direction for all the days so as to obtain consistency during experiments. In the current research paper the filed experiments for most of the days in the month of May 2013 is discussed and analyzed.

A Constant solar global insolation was assumed during the measurement periods, which was indeed evident as the ambient temperature was considerably similar for all the days of experiments. In order to mitigate the rise in car cabin temperature a standalone ventilation system was developed and fabricated which was driven through solar PV power. In order to facilitate ventilation inside the car, the necessary circuit and controls supplying fresh air in to cabin was developed and installed on to the car. The ventilation system essentially consists of a pair of suction fans and a blower to blow in the fresh air in tandem. In order to drive the suction fan and blower fan in tandem, a timer circuits was designed and developed such that the suction fans was driven for Two and half minute and the blower fan was driven for half minute in a cycle of 3 minutes.

In order to drive these power circuitry elements, commonly available solar PV panel of peak power rating of 10 Watts of dimension of 335 x 235 mm was used. The fan and blower assembly along with circuitry was installed inside the car cabin, such that it mounted on the tray behind the rear seat as shown in the Fig. 2. The necessary air circulation pipes were installed which contributed for air exchange process. However, a great care was taken along with necessary safety precautions such that car cabin is secured and functionality of any part of the car is not compromised.

III. RESULTS AND DISCUSSION

Host of experiments were carried out in order to arrive at a conclusive understanding of temperature rise inside a parked car. The scheme of experiments was so chosen so to meet the objectives framed under the study. In ordered to study the performance of the developed ventilation system, car was parked under the sunlight continuously such that ventilation system was switched on every alternate day during the days of experiments. The ambient air temperature was continuously measured during the experimental hours. The most of experiments were carried out during the summer months in Oman and in this paper the findings are reported for the month of May as the solar global insolation is its peak. From the set experiments conducted, as a sample, two consecutive days are presented in this paper.

Fig. 5, Fig. 6 and Fig. 7 represent the record of front, middle and rear of the car cabin air temperature which was averaged with two thermocouples spreading for 2nd and 3rd of May 2013. On the May 2nd, the car was parked at the desired parking space at 8.00 AM and readings for each hour were recorded from 9.00 to 17.00 hrs. During the experiments car was parked with all windows up and ventilation turned on, contributing for air exchange across the car cabin. While on 3rd May 2013 the same car was parked in the same parking space at 8.00AM and hourly readings were taken as before but with ventilation turned off.

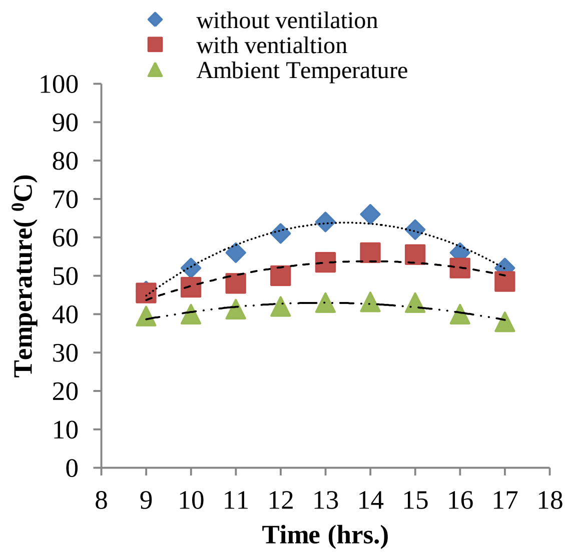

Fig. 5: Temperature measured at the front of car cabin for two consecutive days

Fig. 5 depicts the cabin air temperature time profile at the front end of the car cabin for above said two consecutive days. There were two thermocouples which were mounted in the front end of the car cabin, one at the left side and other one in right side and the average of the two is considered for discussion. It was observed that the cabin air temperature rose sharply for the first four hours of parking.

The maximum of 66 ^{0}C air temperature was recorded at 14 hours when the car was parked without ventilation system, while the two days average ambient temperature at the 14 hours was 43.2^{0}C. Interestingly, when the car was parked with ventilation system the air temperature was 56 ^{0}C at the same time period. Since the car windshield allows large amount of solar radiation to penetrate through it and blocks the reflected ones, this contribute for air temperature rise as the materials such as dashboards and seats present in the front cabin absorb the radiation and release heat to the cabin air.

Fig. 6 represents the temperature time profile, of the cabin air temperature at the middle portion of the car cabin. Since side windows of the car are offers lower area for radiation to enter compared windshields in the front and rear, hence they allow only limited exposure for sunlight and radiation to enter the cabin. There were two thermocouples which were mounted in the middle row of the car cabin, one at the left side and other one in right side and the average of the two is considered for discussion. The temperature rise in the middle row of the car was observed to be lower than the front and back rows with in the car cabin. However the temperature rise cannot be ignored as the cabin temperature was 10^{0}C higher than ambient temperature at 14.00 hrs when car was parked with ventilation systems. However, on the previous day when car was parked under the sun with the ventilation turned on the middle row car cabin air temperature was 20^{0}C higher than the ambient temperature for the same hour. Even though air temperature rise at the middle row of the car is not predominantly due to the direct solar radiation entering through side windows, but it may attributed for the natural convection heat transfer from the front and back side of the car cabin.

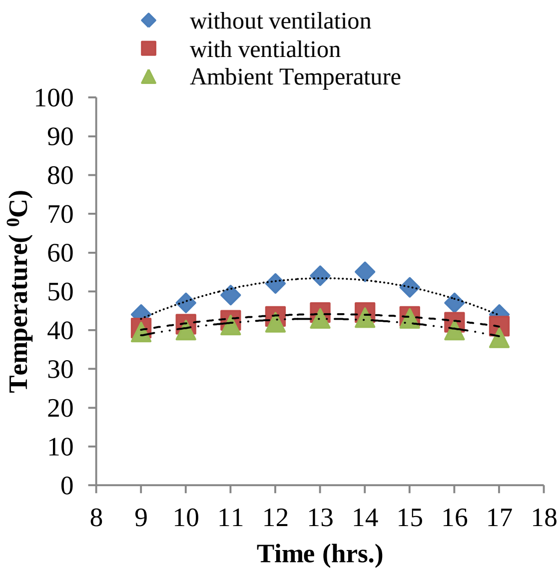

Fig. 6: Temperature measured at the middle of car cabin two consecutive days

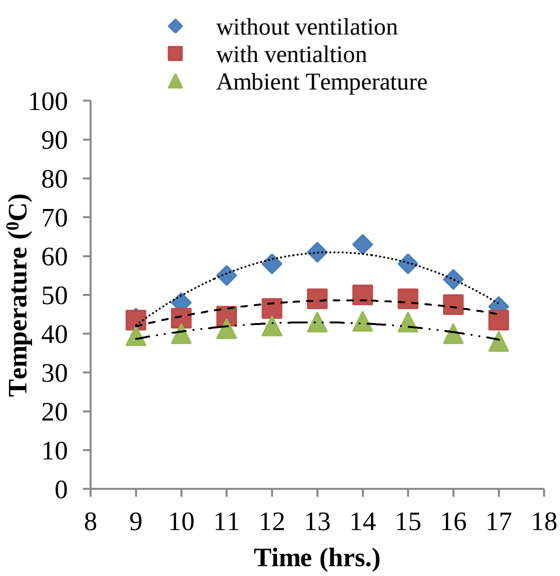

Fig. 7: Temperature measured at the rear of the car cabin two consecutive days

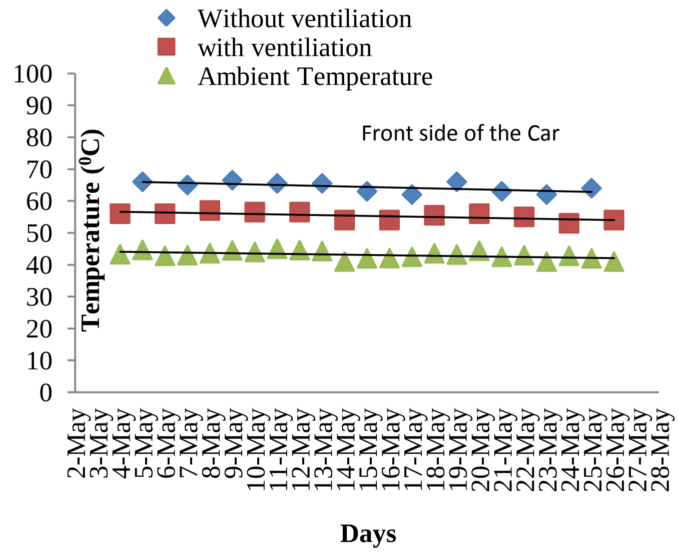

Fig. 8: Temperature measured at the front of car cabin at 14 hrs for consecutive days for the month of May

Fig. Fig. 7 shows the cabin air temperature time profile for the rear end of the car cabin, as explained earlier two thermocouples were used and their average readings are considered for discussion. The aperture area available for radiation to penetrate through the windshield at the rear end of the car is lower than the front side. Hence the solar radiation entering the car rear windshield is relatively lower than the front side, hence contributing lower temperature rise compared to the front. The record of temperature also testify the above statement and the maximum of 63 ^{0}C air temperature was recorded at 14 hours when the car was parked without ventilation system, while the two days average ambient temperature at the 14 hours was 43.2^{0}C. Interestingly, when the car was parked with ventilation system the air temperature was 50^{0}C at the same time period. The high temperature prevailing inside the car parked under the sunlight is definitely unreceptive to the occupants when they arrive to take a drive. Although this intolerable car cabin conditions prevails for a relatively shorter period of time, but it cannot be ignored as it causes a serious health threat for children or pets left inside the car. It was consistently observed for the all the days of experiments maximum cabin air temperature was observed at 14.00 hours of the day. It was indeed observed that for most of the days the lower cabin temperature was recorded when car was parked with ventilation system turned on vis-à-vis to that of without ventilation system.

Fig. 8 depicts the cabin air temperature readings recorded at the front side of the car for 14.00hrs for consecutive days for the month of May 2013. It was seen that, the difference between maximum cabin air temperatures with ventilation and without ventilation systems was very much similar for all the days of the experiments. However it was interesting to note the average difference between car cabin temperature and ambient air temperature was consistently around 12^0C when car was parked with ventilation system turned on. However, the average difference between the temperatures rose to $21.^0$C when the ventilation system was turned off. The ventilation system developed was effective enough to bring an air exchange such that the temperature difference between ambient temperature and cabin air temperature was nearly reduced to nearly just over half compared to the temperature difference without the ventilation.

IV. CONCLUSION

From the above mentioned experimental investigation, it was evident that the solar PV powered ventilation system was successfully performed when tested for its intended application. Thus temperature time profile inside the car parked under the sunlight was studied and ventilation system developed to perform air exchange was successfully tested and the results show that the ventilation system was successful in mitigation of rise in cabin temperature. The results of test show that the rise car cabin temperature with ventilation system was lower compared to that without ventilation system. The peak cabin air temperature difference with reference to ambient air temperature was nearly halved with the aid of developed ventilation system. Besides that, cabin air temperature was found higher at the front end of the car cabin as the car windshield allows the larger quantum of radiation to enter the car cabin. Alas the cabin air temperature was found to be faraway from the region of human thermal comfort and it calls for further study for mitigate the temperature rise. Although the developed ventilation system aid in reducing the cabin air temperature to certain extent, but much such effort is required to bring the temperature rise with in the acceptable level especially meeting the climatic condition of Oman.

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