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Evaluation of Frictional Heat Generated in a Mechanical Contact due to Debris Formation and the Cooling Rates of some Lubricating Oils

Achebe C.H., Nwagu A.I. and Anosike B.N.

Department of Mechanical Engineering，Nnamdi Azikiwe University Awka

Chinobert2k@yahoo.com

Abstract

In this study, a test rig was set up to experimentally evaluate the amount of frictional heat generated in a Mitsubishi main journal bearing and the cooling performance of some lubricating oils. The test rig used in this experiment is a mechanical apparatus that consists of mechanical drive, metal support, bevel gear, a rotating shaft and a bearing attached at its lower end. When the shaft was rotated by the mechanical drive of power 0.75kw, the frictional force in journal bearing helped to convert the mechanical energy of the drive into frictional heat. The amount of heat absorbed from the surface of the journal bearing by the oil cooled the surface. The cooling rate of oil was obtained at each time interval. The vibrational movement of molecules helped to transfer the frictional heat to the lubricant and the calorimeter. This effect caused the temperature of the system to rise and it was measured and recorded. The frictional heat generated in the contact increased linearly with the change in temperature in the mechanical contact which was absorbed

differently in the three lubes, depending on their heat capacity and molecular movement. When there was no debris in the contact, the temperature changed within the range of 1.2-1.8^{0}C at interval of 3minutes in oil ‘B’, 1^{0}C in oil ‘C’ and 0.8-1.2^{0}C in oil ‘A’. When there was sand debris in the contact, the temperature changed within the range of 2-2.5^{0}C at interval of 3minutes in oil ‘B’, 1.5-2^{0}C in oil ‘C’ and 2^{0}C in oil ‘A’. Oil ‘B’ has the best cooling performance based on the three lubricants used.

Key Words: Lubricant, Mechanical contact, Frictional heat, Cooling rate, Debris.

1.INTRODUCTION

Mechanical devices do fail due to the wear of the rubbing surfaces of their bearings and journals. There are lots of wear in mechanical contacts such as galling, abrasive wear, erosive wear and adhesive wear. Galling damages mechanical contact due to the combination of friction and adhesion between the surfaces, followed by the slipping and tearing of crystal structure beneath the surface. These wear processes are accelerated in a mechanical contact when there is an elevation of contact temperature due to the frictional heat generated in it.

Lubricants break down and lose important properties such as viscosity, cooling properties and lubricating properties due to the heat generated in the mechanical contact. Harmful materials are deposited in the contact after the thermal oxidation of the oil. These materials degrade the surface of the contact by reacting with it and the volatile components affect the operator and the environment negatively. The properties and the cooling performance of the lubricants differ when they are used in the same mechanical contact after being subjected to the same environmental and operational conditions. The rate of degradation of oils differs among the oils of the same grade.

A power station provides many examples of wear associated with useful and necessary friction forces (Carter, 1993). In a large coal-fired power station some 10^7kg of coal will have to be moved from the coal stock at ground level to the high-level coal bunkers to maintain the flow of coal to the milling plant and hence to the boiler furnace. Much of this bulk handling is done speedily and efficiently by the use of belt conveyors possibly moving 10^6kg of coal per hour, at speeds of 2 metres per second or greater. Belt drives of various kinds are used throughout the station, and, like the conveyor belt, they depend on friction forces (Carter, 1993).

Friction has ‘stick-slip’ effect at the interaction of two surfaces moving relative to each other. If two metal surfaces are moved relative to each other, one or both surfaces will gradually be eroded. The process of erosion depends on the nature of the surfaces but, in general, tiny fragments (debris) are torn out of the surfaces as the wielded junctions shear at the areas of contact. Lubricant cleanliness refers to the absence of contamination in the lubricating oil. Microscopic particles are the most harmful form of contamination in lubricants. They can irreversibly damage gear and bearing surfaces, shorten the service life of equipment, and cause unexpected breakdown (Moon, 2007). The entry of lubricant borne solid particles into machine element contacts is important, both for prediction of the body abrasive wear, and for an understanding of the behaviour of solid lubricant additives (Dwyer and Heymer, 1996).

Debris is characterized into ferrous and non-ferrous particles in which sand, atmospheric contaminants and eroded particles from the bearing belong (Bose et al, 2011). The wear of the surfaces can theoretically be eliminated by introducing a material weak in shear, known as lubricant between them. If the film of lubricant is deep enough, the surfaces will be sufficiently far apart to prevent the formation of any wielded junctions directly between them. Lubricant helps to reduce forces necessary to make the surfaces slide thereby reducing the energy loss at the bearing points and to cool the sliding surfaces.

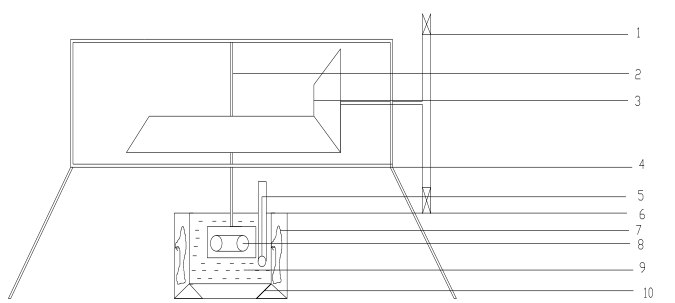
However, a lubricant must also fulfill a considerable number of other requirements if it is to be suitable in actual service, for it must be stable and effective under all normal operating conditions. At the same time, the lubricant itself must have low intermolecular forces so that lubricant molecules will slide readily over one another. A good lubricant should have low viscosity. The physical state of the lubricant must not change such that it must not freeze into solid or evaporate appreciably or entrain gases to form foams (since gas bubbles are non-lubricating and interfere with liquid flow), also, the lubricant must retain it properties. The cooling ability of the oils would be more effective if the lubricant has high heat capacity. For safety reasons, the flash point (the temperature at which the vapour will ignite spontaneously under ideal condition) must be beyond the working temperature range.

A bearing is one of the fundamental elements in machine; even the simplest machine, the lever, must have a bearing or fulcrum (Carter, 1993). All movements in mechanisms and machines require some sort of bearing to locate and guide the moving parts. A machine designer will try to convert as much as possible of the energy put into a machine into useful output work and will therefore attempt to reduce the energy losses that arise through friction at the bearings. Mechanical devices stop working after sometime due to the failures of mechanical contacts when there is insufficient lube supply and rapid degradation of the quality of the lubricating oils. Mechanical failures that occur in mechanical contacts are fatigue, galling, indentation, erosion and fretting. These failures release debris in the contact. Most of the analysis to determine oil film thickness in machine element assumes a clean lubricant. In this research work, the experimental evaluation of heat released in a Mitsubishi main journal bearing due to different nature of debris in it was carried out. Also, the cooling rates of different oils were evaluated experimentally with and without debris in the mechanical contact.

2.MATERIALS AND METHOD

I. Materials

Experiments were carried out to evaluate the amount of frictional heat generated in Mitsubishi main journal bearing of serial number 4G32N24232 due to debris formation. In these experiments, the cooling rates of some lubricating oils (tagged 'A', 'B' and 'C') were also evaluated. To achieve this, the following materials were employed in carrying out this experiment: Lagging Material, high speed lubricants with known specific heat capacity, a stop watch, a calorimeter, and frictional heat evaluation apparatus. A good lagging material does not melt and it does not support combustion (Prakash and Kirti, 2014). The lagging material used in this experiment is cotton wool. The three high speed lubricants which were used in the experiment on June 18, 2016, had prices of a litre of oil 'A', 'B' and 'C' as ₦800, ₦1200 and ₦1000 respectively. The oil grade SAE of the lubricants is 20W-50. This means they can be used at a lower as well as a higher temperature, whereas an SAE of 50 without 20W implies higher temperature applications only. It could be noted that they will have the same viscosity at 212^0F (Udonne, 2011). Having known the specific heat capacity of the lubricant, the amount of heat absorbed by it could be calculated. A lubricant can be "synthetic" or "mineral" oil based on the type of base stock or hydrocarbon backbone that makes up its molecules. All modern lubricants, synthetic or mineral, rely heavily on additives to give many of their performance characteristics. However, since the structure of synthetic base stocks is controlled, additives can be tailor-made for optimum response resulting in improved performance. The primary advantage of appropriate synthetic oil comes from the ability to reduce viscosity, and hence reduce hydrodynamic friction, without running into volatility problems and without comprising high temperature wear performance (Lalit and Navneet, 2012). Physical properties such as the melting and boiling points and the fluidity of the liquid oil depend on the magnitude of the molecular movements. Thus, they are directly related to the mass of the molecule and to the forces between them. Other physical properties depend on the shape of the molecule and on the distribution of charge on its outer surface. These include such properties as surface tension; at the surface, the regular shape and absence of atoms with a highly polarized charge distribution such as chlorine and oxygen, enable the molecule to come very close to any solid surface. Chemical properties also depend very largely on the presence of chemically reactive centers or asymmetry within the molecule. The hydrocarbons obtained from crude oil, being symmetrical and without reactive centres are called paraffin hydrocarbons. The word paraffin means 'little affinity', and these hydrocarbons are notable for their low chemical reactivity (Sander, 2012). The measurement of temperature is based on the principle of zeroth's law in thermodynamics (Gavrilov et al, 2013). A mercury-in-glass thermometer with a range of 0^0C to 360^0C was used. It had a fine narrow bore which improves its sensitivity. A digital weighting machine was used for measuring the masses of the debris (sand and iron fillings), bearing, lubricant and calorimeter, which were employed in the experiment. It was an electronic scale of model SF-400 which was equipped with a high precision strain gauge sensor system LCD display. It had a range of 1g to 7000g and a mode function of gram and ounce. The electronic scale had over-load and low battery indicator. It was powered with two dry cells each of 1.5V. The stop watch of model unicon-1 was used to measure the time. A copper Calorimeter of mass 200g was equally used and the specific heat capacity of copper is 400J/kg K. Mitsubishi Main Journal bearing was the mechanical contact used in this experiment. The bearing and its housing were joined together and immersed in different lubricants during the experiment. The size of the journal bearing was 0.25. The type of engine was Mitsubishi and its model was 4G32N24232. The Electric Motor a mechanical drive was used to rotate the Journal of the bearing. The name of the AC motor was Hawker Siddley. The model number was 5000/99 and its class was F. The required input voltage of the motor was 230Vand that of current was 7.7A. Its alternating source frequency was 50Hz. The power rating of the electric motor was 0.75kw and its speed was 1440rpm. The Frictional Heat and Cooling rate Evaluation Apparatus comprised mechanical drive, weight carrier, bevel gear, a bearing fixed at its lower end and metal framework. The mechanical drive produced mechanical energy (kinetic energy) which was converted into frictional heat. The frictional heat was absorbed by the copper calorimeter, the lubricant and the bearing with its housing. The lagging materials used to cover it served to prevent heat losses. A removable journal bearing was attached at its lower end which was replaced at each time interval during the experiment. This experiment could serve in determining the rate of degradation of different oils.



1. PULLEY 2. ROTATING SHAFT 3. BEVEL GEAR 4. METAL FRAMEWORK 5. THERMOMETER 6. CALORIMETER 7. LAGGING MATERIAL 8. STEEL BEARING 9. LUBRICATING OIL 10. INSULATING SUPPORT

Figure 1: Schematic of the Frictional Heat and Cooling Rate Evaluation Apparatus

II. Debris characterization

Two kinds of debris were used in this experiment. They were: silicon IV oxide debris and iron filings debris. Silicon IV oxide debris consists of sand of fine particles of diameter 0.012mm while iron filings debris consists of iron powder of diameter 0.013mm. Silicon is a crystalline semi-metal or metalloid. One of its forms is shiny, grey and very brittle, that is, it will shatter when struck with a hammer. Its purest form is quartz and other forms are jasper and opal. It is a group four element in the same periodic group as carbon, but chemically behaves distinctly from all of its group counterparts. Silicon shares the bonding versatility of carbon, with its four valence electrons, but is otherwise a relatively inert element. However, under special conditions, silicon can be made to be reactive. Silicon exhibits metalloid properties, that is, it is able to expand its valence shell and is able to be transformed into a semiconductor. This characteristic distinguishes it from its periodic group members (Osei et al, 2011).

Figure 2: Silicon IV oxide (diameter 0.012mm) used in the experiment

Iron is a transition element with all the properties that characterize this particular group. Besides having coloured ions, iron can form complex ions by coordinate bonding. The iron atom can lose two 4s electrons to form iron II compounds, where it has an oxidation state of +2. It can also lose two 4s electrons and 3d electron, i.e. a total of three electrons, to form iron III compounds, where it has an oxidation state of +3. The iron iii ion Fe^{3+} is more stable than the iron ii ion, Fe^{2+}.

Figure 3: Iron particles (diameter 0.013mm) used for the experiment

III. Method

An experimental method was used for the evaluation of the amount of heat generated in the mechanical contact like that of rotating journal bearing. The rotating mechanical element releases the frictional heat energy while trying to overcome the friction in the contact. The calorimeter and its content absorb the heat. The heat absorbed was calculated from the principle of elementary physics. The experiment was performed with three lubricating oils using different nature of debris in the contact. Nine experiments were carried out to evaluate the amount of heat generated in the mechanical contact and the cooling rates of the lubricating oils under different conditions. The first set of experiments was carried out with the lubricants under debris-free condition while the second was done with lubricants containing silicon debris. The third experiment considered the same lubricants containing ferrous materials like iron filings. To evaluate the amount of heat energy released in the lubricated mechanical contact using a clean lubricant. The following apparatus was used; a digital weighing machine, a thermometer, a stop watch, lubricants (oils 'A', 'B' and 'C'), lagging material (cotton wool) etc. The mass of the bearing (M_1) and the mass of the empty calorimeter (M_2) were noted. A known volume of the lubricating oil 'A' (V) is also poured into the calorimeter. The mass of the calorimeter and its content (M_3) is equally taken. The initial temperature (θ_0) of the calorimeter and its content was recorded. The oil and the calorimeter will have the same initial and final temperature according to the zeroth law of thermodynamics. This law is the basic principle of thermometry (Odume, 2011). The temperature of the bearing is approximately mid-way between the temperature of the oil film

(Khurmi and Gupta, 2012). The calorimeter and its content were placed under the frictional heat evaluation apparatus as shown in the figure 1, so that the rotating journal bearing and its housing were completely immersed in the oil ‘A’, that is, electrohydrodynamic lubrication EHL. The motor and the stop watch were started at the same time and the final temperature θ_2, θ_3, θ_4, θ_5, θ_6, were read and recorded at an internal of 3minutes respectively. The quantity of heat energy released cannot be measured with an instrument directly but could be calculated with the elementary formula Q = MCΔθ (Odume, 2011), where M = mass, C = Specific heat capacity of the substance, $\Delta\theta = \theta_2 - \theta_1$ change in temperature. The components that absorb the heat are the journal bearing, the oil and the copper calorimeter. The same procedures were repeated in the second and the third experiments with silicon IV oxide debris and iron filings debris introduced in the mechanical contact respectively. The above procedures were replicated for in oil ‘B’ and in oil ‘C’.

Calculating the quantity of heat, the amount of heat supplied is equal to the amount of heat absorbed by the lubricant, copper calorimeter and the bearing at a particular temperature.

$$Q_T = Q_1 + Q_2 + Q_3 + Q_4 \tag{1}$$

Where: Q_1 = quantity of heat absorbed by the bearing

$$Q_1 = M_1 C_1 (\theta_{i+1} - \theta_i) \tag{2}$$

M_1 = mass of the bearing (g), C_1 = specific heat capacity of steel (bearing), θ_{i+1} = final temperature at the end of each 3min which will be the same for the three materials mentioned above, θ_i = Initial temperature, Q_2 = quantity of heat absorbed by the calorimeter.

$$Q_2 = M_2 C_2 (\theta_{i+1} - \theta_i) \tag{3}$$

M_2 = mass of the copper calorimeter (kg), C_2 = Specific heat capacity of copper calorimeter (J/kg k), M_3 = mass of oil + calorimeter, M_2 = mass of the empty calorimeter, C_3 = specific heat capacity of the lubricating oil = 2.09J/g k.

3.RESULTS, ANALYSIS AND DISCUSSION

I. Heat Evaluation for Debris-Free Conditions in the Three Oils.

The results of the heat generated in a Mitsubishi journal bearing when there was no debris in the contact in the three oils were presented in figure 4. During the experiment, heat energy was generated as the journal rotated on the surface of the bearing.

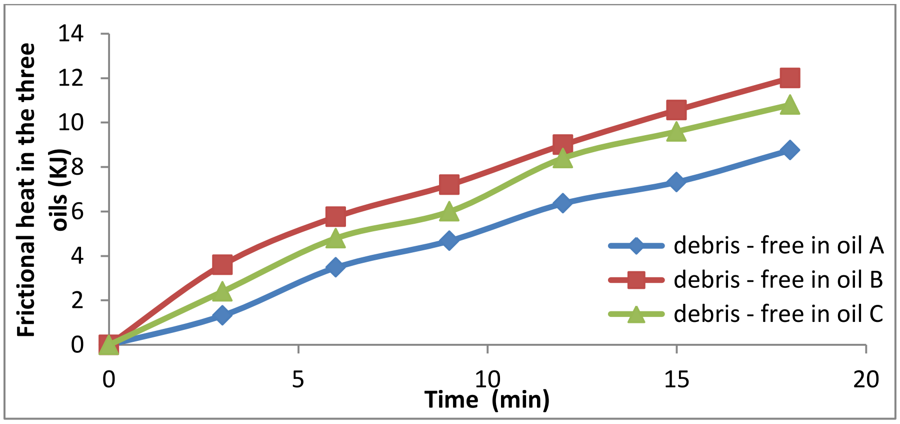


Figure 4: Comparisons of the frictional heat generated in the three oils.

From the figure 4, oil 'B' absorbed the highest frictional heat because its molecular movement was the highest. So, the generated frictional heat was easily transferred uniformly in it. The molecules of oil 'B' were not strongly bonded together and so they moved faster than others. The mass of a molecule of oil 'B' and its intermolecular bond were smaller than those of oils 'A' and 'C'. So, they moved faster than the molecules of oil 'A' and oil 'C'. Also, the specific heat capacity of the oil 'B' was greater than those of oil 'C' and oil 'A'. Figure 4 shows that frictional heat in the three oils ('B', 'A' and 'C') increases as time of heat generation increases.

II. Change in Temperature in a Mitsubishi Journal Bearing for Debris-Free Conditions in the Three Oils.

The results of change in temperature in a Mitsubishi journal bearing when there was no debris in the contact in the three oils were presented in figure 5.

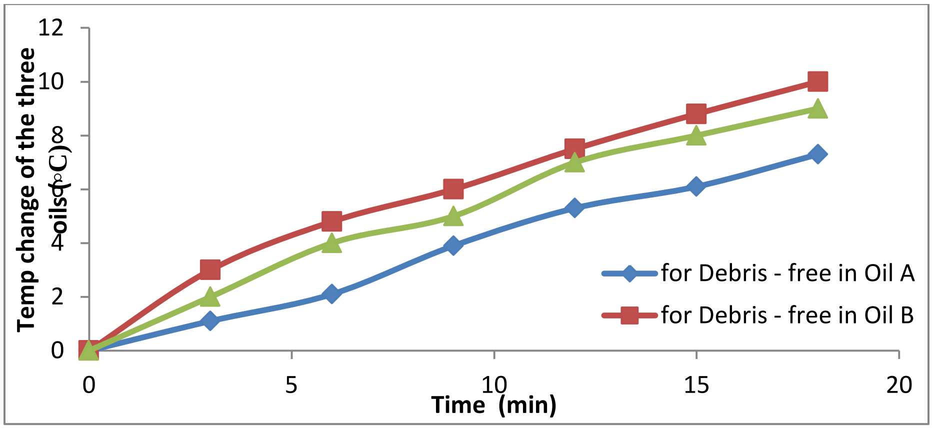


Figure 5: Comparisons of change in temperature with time in the three debris-free local oils.

From figure 5, oil 'B' has the highest temperature. The velocity of the molecules of oil 'B' was the highest because of its lower molecular mass and weak intermolecular bond. The inertia of the molecules of the other oils was too high. So, they could not move very fast. The change in temperature-time curve of oil 'B' was similar to the one in another literature (Macek and Emrich, 2011). The temperature-time curves of the oils showed that the molecules of the oils did not absorb frictional heat at the same time. The shear stress of the oil 'B' was the least and its molecules moved very fast. This movement helped to transfer the frictional heat and increase the temperature of the oil 'B'.

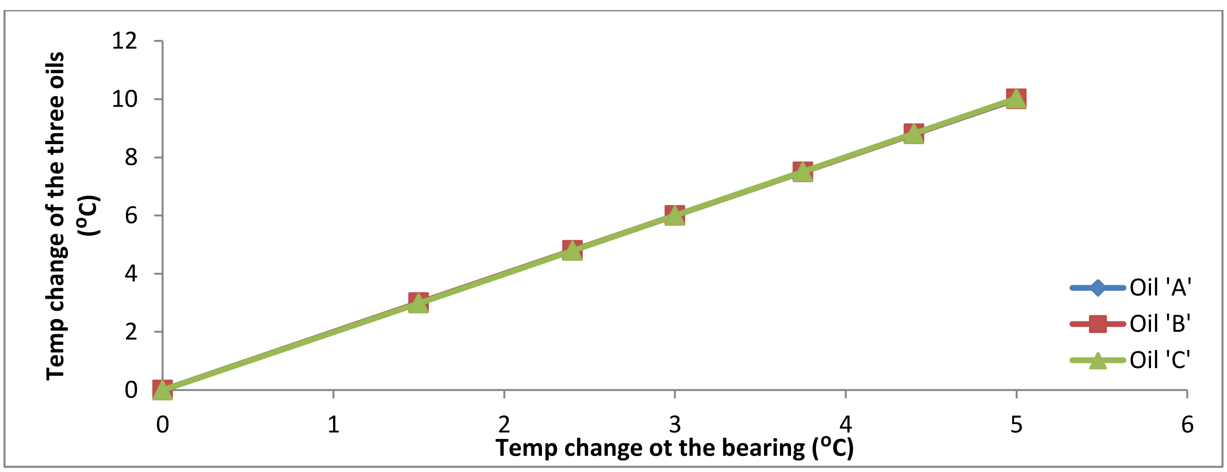


Fig 6: The oil-bearing temperature relationship

The temperature relationship of the oil and the bearing is shown in the figure 6. The temperature change of the oil varied linearly with that of the bearing's surface. The molecules gained kinetic energy once the heat was absorbed from the surface. The heat was transferred through conduction and convection in the oil. The same shape of the graph was obtained in the three oils. The vibrational movement of the molecules of the journal bearing helped to transfer the frictional heat among themselves one after the other. When one molecule absorbed the frictional heat, it vibrated more than the nearby molecule which was in contact with it. In a solid, the molecules are closely packed together. So, the vibration of the nearby molecule caused the next molecule to start vibrating. Owing to this phenomenon, the two molecules vibrated while transferring the frictional heat to the third molecule and so on. The temperature change of the bearing increased linearly with that of the oil.

III. Heat Evaluation in a Mitsubishi Journal Bearing Generated in Oil 'A' for the Three Debris Conditions.

The results of the heat generated in a Mitsubishi journal bearing when it was immersed in oil 'A' while considering the three debris conditions are shown in the table 1.

Table 1: Tabulated Values of frictional heat generated in oil 'A'.

S/N	Time t(min)	Heat Q (kJ) in debris-free condition	Heat Q (kJ) in sand debris condition	Heat Q (kJ) in iron debris condition
1.	0	0.00	0.00	0.00
2.	3	1.32	3.01	2.40
3.	6	3.48	5.41	6.01
4.	9	4.68	7.81	9.01
5.	12	6.36	10.22	11.41
6.	15	7.32	12.62	12.85
7.	18	8.76	15.03	15.01

From table 1, as the journal rotated on the bearing, the molecules of oil 'A' gradually gained kinetic energy due to the heat generated in the contact. The viscosity of oil 'A' was the highest among the three oils and so it restricted the movement of the hot debris in it. This was due to high shear stress of the oil. The frictional heat distribution in it was not uniform. The entropy of the molecules of oil ‘A’ was the lowest. The amount of frictional heat generated in oil ‘A’ when there were sand debris and iron debris in the oil were greater than that of debris-free condition as seen in the table 1. Owing to the high shear stress of the molecules of oil ‘A’, the hot iron particles could not move easily in the oil. So, the amount of frictional heat transferred in the oil was not all that high when compared with that of oil ‘B’

IV. Change in Temperature in a Mitsubishi Journal Main Bearing Generated in Oil ‘A’ for the Three Debris Conditions.

The results of change in temperature of a Mitsubishi journal bearing generated in oil ‘A’ when the three debris conditions were considered are shown in table 2.

Table 2: Tabulated Values of Change in Temperature in oil ‘A’.

S/N	Time t(min)	Temperature change (^{0}C) in debris-free condition	Temperature change(^{0}C) when sand debris is present	Temperature change (^{0}C) when iron debris is present.
1.	0	0.00	0.00	0.00
2.	3	1.10	2.50	2.00
3.	6	2.10	4.50	5.00
4.	9	3.90	6.50	7.50
5.	12	5.30	8.50	9.50
6.	15	6.10	10.5	10.70
7.	18	7.30	12.50	12.50

According to table 2, the temperature increased when there was debris in the contact. The velocity of the molecules and its average kinetic energy increased gradually. The mobile free electrons on the outermost shell of iron helped to transfer the frictional heat and this affected the temperature change when iron particles were present. The average increase in temperature when there was debris in the contact was 2.5℃ while it was 1.0℃ when there was no debris in the mechanical contact. The increase in temperature was due to the fact that more kinetic energy was needed to overcome friction caused by the presence of debris (silicon IV oxide debris and iron particles debris) in the mechanical contact.

V. Heat Evaluation in a Mitsubishi Journal Bearing Generated in Oil ‘B’ for the Three Debris Conditions.

The results of heat evaluation in a Mitsubishi journal bearing generated in oil ‘B’ for the three debris conditions are shown in the table 3.

Table 3: Tabulated Values of frictional heat generated in oil ‘B’

S/N	Time t(min)	Heat Q (kJ) in debris-free condition	Heat Q (kJ) in sand debris condition	Heat Q (kJ) in iron debris condition
1.	0	0.00	0.00	0.00
2.	3	3.60	2.40	4.44
3.	6	5.76	6.01	8.05
4.	9	7.20	9.02	10.90
5.	12	9.00	11.42	13.81
6.	15	10.56	13.82	15.98
7.	18	12.00	15.87	18.02

From the table 3, the amount of frictional heat generated in oil ‘B’ was higher than those of other two oils. The frictional heat-time curve when iron particles were present was relatively a smooth curve. The entropy of the molecules of oil ‘B’ was the highest. Since, entropy is directly proportional to the amount or quantity of heat absorbed ($\Delta s = \frac{\Delta Q}{T}$). The degree of disorderliness of the molecules of oil ‘B’ helped to transfer the frictional heat in the oil. The shear stress of oil ‘B’ was the least and so it allowed the hot debris (sand and iron particles) to move easily in it, thereby increasing the temperature and the amount of frictional heat absorbed by the oil ‘B’. The shear stress of the molecules of oil ‘C’ was slightly higher than that of oil ‘B’ and so it slightly reduced the movement of hot debris in it. Owing to this effect, the amount of friction absorbed in oil ‘C’ was smaller than that of oil ‘B’.

VI. Change in Temperature in a Mitsubishi Journal Main Bearing Generated in Oil ‘B’ for the Three Debris Conditions.

The results of change in temperature in a Mitsubishi journal bearing generated in oil ‘B’ for the three debris conditions are shown in the table 4.

Table 4: Tabulated Values of Change in Temperature in oil 'B'.

S/N	Time t(min)	Temperature change (^{0}C) in debris-free condition	Temperature change(^{0}C)when sand debris is present	Temperature change (^{0}Cs) when iron debris is present.
1.	0	0.00	0.00	0.00
2.	3	3.00	2.00	3.70
3.	6	4.80	5.00	6.70
4.	9	6.00	7.50	9.30
5.	12	7.50	9.50	11.50
6.	15	8.80	11.50	13.50
7.	18	10	13.20	15.00

From the table 4, the change in temperature when iron debris was present was higher than others. The same explanations that were used in the analysis of the frictional heat in oil 'B' were applicable in temperature change and so they have the same temperature-time curves. The degree of disorderliness of the molecules of oil 'B' was the highest. The temperature change when there were iron particles in the mechanical contact was greater than those of sand debris condition and debris-free condition. Hot iron debris moved easily in the oil because of its low viscosity and shear stress. So, they transferred frictional heat uniformly and easily in the oil. This made the temperature-time curve of oil 'B' to be a smooth curve when there were iron particles in the mechanical contact.

VII. Heat Evaluation in a Mitsubishi Journal Bearing Generated in Oil 'C' for the Three Debris Conditions

The results of heat evaluation in a Mitsubishi journal bearing generated in oil 'C' for the three debris conditions are shown in the table 5.

Table 5: Tabulated Values of frictional heat generated in oil 'C'.

S/N	Time t(min)	Heat Q (kJ) in debris-free condition	Heat Q (kJ) in sand debris condition	Heat Q (kJ) in iron debris condition
1.	0	0.00	0.00	0.00
2.	3	2.40	4.80	3.61
3.	6	4.80	7.21	7.21

S/N	Time t(min)	Heat Q (kJ) in debris-free condition	Heat Q (kJ) in sand debris condition	Heat Q (kJ) in iron debris condition
4.	9	6.00	9.01	10.81
5.	12	8.40	12.02	13.21
6.	15	9.60	13.82	15.38
7.	18	10.80	15.99	17.06

From the table 5, it is shown that frictional heat increased when there was debris in the journal bearing. The molecules of oil 'C' gained kinetic energy and moved with high velocity. Their velocity and kinetic energy were highest when iron debris was present. The above explanations based on the charge distribution on the surface of oil 'C' molecules and the mobile free electrons of iron particles were also applicable in this oil. The entropy of the molecules of oil 'C' was higher than that of oil 'A' but it was lower than that of oil 'B'. The shear stress of the oil 'C' was slightly higher than that of oil 'B' but it was less than that of oil 'A'. So, hot particles could not move easily in the oil to transfer the frictional heat uniformly.

VIII. Change in Temperature in a Mitsubishi Journal Main Bearing Generated in Oil 'C' for the Three Debris Conditions

The results of change in temperature in a Mitsubishi journal main bearing generated in oil 'C' for the three debris conditions are shown in the table 6.

Table 6: Tabulated Values of Change in Temperature in oil 'C'.

S/N	Time t(min)	Temperature change (^{0}C) in debris-free condition	Temperature change(^{0}C) when sand debris is present	Temperature change (^{0}Cs) when iron debris is present.
1.	0	0.00	0.00	0.00
2.	3	2.00	4.00	3.00
3.	6	4.00	6.00	6.00
4.	9	5.00	7.50	9.00
5.	12	7.00	10.00	11.00
6.	15	8.00	11.50	12.80
7.	18	9.00	13.30	14.20

From the table 6, the temperature change of oil ‘C’ was shown. The change in temperature increased when there was debris in the oil. It showed that the oxygen in silicon IV oxide reacted with the oil and so it reduced the molecular movement of the oil, while increasing its heat capacity. The presence of oxygen bond and silicon carbide formed would help to increase the heat content, thus increasing the change in temperature of the oil. Oxygen is an electronegative element and it has high polarizing ability. It would make the oil ‘C’ to become slightly polar and possess more distributed charges on its molecules. This effect was initially great but it was reduced after 6mins due to the reduction in the concentration of sand particles present in the contact. The presence of debris increased the amount of friction in the mechanical contact and it has to be overcome before the rotating shaft maintained its motion.

IX. Cooling Curves of the three Oils Due to Debris-Free Condition.

The results of the cooling rates of the three oils in debris-free condition are shown in figure 7.

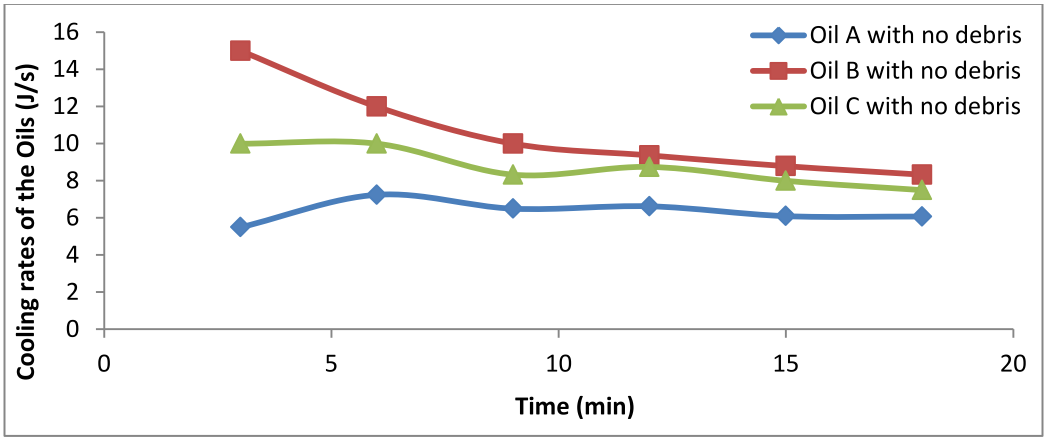


Figure 7: Comparisons of the cooling rates of the three local oils in debris free condition.

From figure 7, when the frictional heat was absorbed by the oil ‘B’, its intermolecular covalent bonds got broken. The molecules moved with a very high velocity and kinetic energy. This molecular movement helped to transfer the absorbed heat from the surface of the bearing to other parts of the oil. The bond energy of oil ‘C’ was higher than that of oil ‘B’ but less than that of oil ‘A’, so its molecular velocity and kinetic energy were smaller than those of oil ‘B’ but higher than oil ‘A’. Oil A has the strongest intermolecular covalent bond, lowest heat capacity, lowest kinetic energy and lowest charge distribution. This thus is the reason, it has poor heat conduction and convection (see figure 7).

X. Cooling Curves of Three Local Oils due to the Iron Particle Contamination

The results of the cooling rates of the three oils due to the iron particles are shown in figure 8.

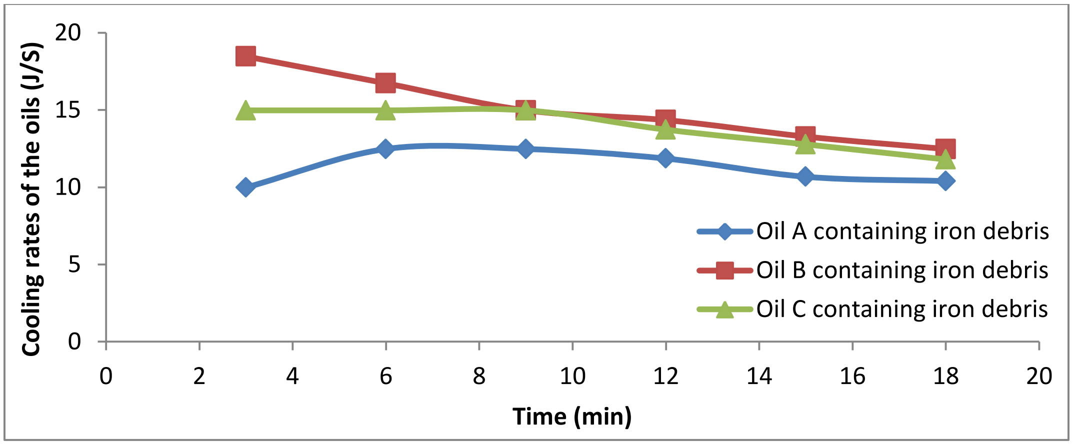


Figure 8: Cooling rates of the three oils due to iron debris contamination.

From figure 8, the molecules of oil 'B' moved far apart from one another, so, its cooling rate decreased. The bond energy of the molecules of oil 'C' was stronger than that of oil B. In figure 8, the cooling rate of oil 'C' remained constant for some time. This was due to the fact that the absorbed heat was used to break some bonds in oil 'C'. The bond energy of oil 'A' was the strongest of the three oils. So, its molecular movement was reduced and it could not conduct much heat from the bearing. The charge distributions on the surface of the molecules of oil 'B' were the highest among the three oils. The mobile free electrons of the iron particles helped to conduct the heat through the oils and so the curves were relatively smooth when compared with other cooling curves.

XI. Cooling Curves of Three Oils Due to the Sand Particle Contamination.

The results of the cooling rates of the three oils due to the presence of sand particles are shown in figure 9.

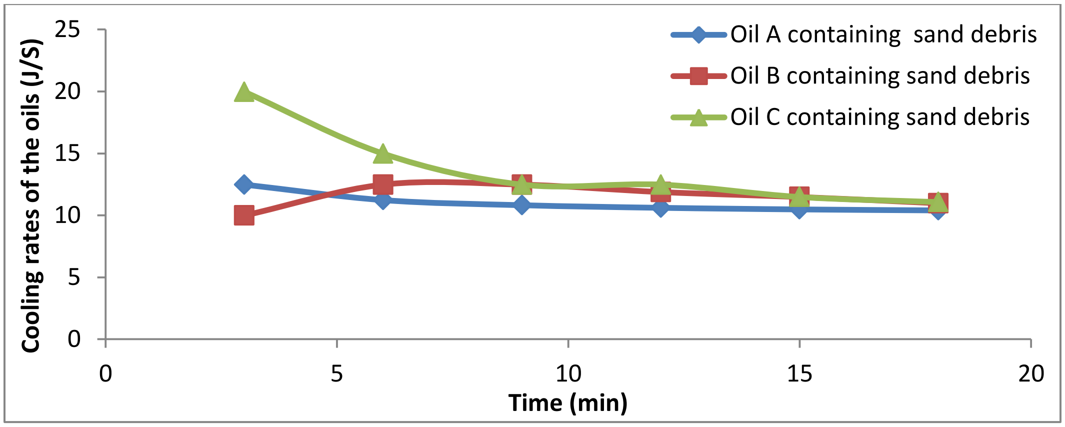


Figure 9: Comparisons of cooling rates of the three oils in sand debris condition.

From figure 9, the cooling rate of oil 'B' was affected strongly due to the chemical reaction and new molecules that were formed. The formed molecules have larger mass and this increased their inertia. Also, this reaction reduced its charge distribution. These effects reduced the heat transferring ability of oil 'B'. There was little reaction with oil 'C', so the heat absorbed by oil 'C' was the highest at the start but later, it decreased because of the breaking down of its molecular bonds. Also, silicon IV oxide has insulating ability and so it could not allow much heat to be extracted from the rubbing faces of the journal bearing. In the figure 9, it is shown that oil 'A' did not react with the silicon IV oxide. So, its cooling rate decreased uniformly.

4.CONCLUSION

For heavily contaminated systems, the amount of frictional heat generated in a Mitsubishi journal bearing depends on nature of the debris in the contact. The amount of frictional heat absorbed depends on the chemical compositions of lubricants. The molecular movement and the heat capacity of the lubricants play a vital role in the cooling ability of the oils. The covalent intermolecular bonds of the three oils studied differ and that affects conduction and convection of frictional heat in Mitsubishi main journal bearing. The cost of lubricating oil depends on quality and performance of the oils. The performance of lubricating oil does not depend on how viscous the oil is by mere looking at it. With debris or no debris, the frictional heat generated in a mechanical contact (bearing) varies linearly with the change in temperature. The amount of frictional heat generated in a mechanical contact depends on the nature of the materials of the bearing. Steel bearing generates heat easily than the bearings which are made of alloys that have very high specific heat capacity. The temperature of the oil film varied linearly with the surface temperature of the bearing. This correlated with the result in Tribology Handbook (Khurmi and Gupta, 2012). The performance of the lubricating oil depends largely on the charge distributions on the surface of the molecules of the oils.

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