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Evaluation of Frictional Heat and Oil Cooling Rate in Mechanical Contact Due to Debris Formation

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Abstract- This paper evaluated experimentally, the amount of frictional heat generated in a Mitsubishi main journal bearing and the cooling performance of the lubricating oils A, B and C. 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 and speed 1440rpm, 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 the oil was obtained at each time interval. The vibrating movement of the molecules helped to transfer the frictional heat to the lubricant and the calorimeter. This effect caused the temperature of the system to rise. The frictional heat generated at 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 1.2-1.80C at interval of 3minutes in oil B, 10C in oil C and 0.8-1.20C in oil A. When there was sand debris in the contact, the temperature changed within the range of 2-2.50C at interval of 3minutes in oil B, 1.5-20C in oil C and 20C in oil A. Oil B has the best cooling performance based on the three local lubes used and was equally the most expensive. Mechanical failures like galling, fatigue and surface indentation occurred when the vibrational force (energy) of the molecules were greater than the binding force or energy of the atomic lattice of the bearing.

Keywords: Cooling rate, Debris, Frictional heat, Journal bearing, Lubricant, Mechanical contact, Temperature

1. Introduction

Friction has a 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 welded junctions shear at the areas of contact. The use of a lubricant such as oil or grease between the surfaces reduces the frictional force but does not entirely eliminate it. So, it seems that friction is undesirable, wasteful of energy (frictional heat) and costly in terms of the wear it creates and the power expended in machines to overcome it.

Microscopic particles are the most harmful form of contamination in lubricants. They can irreversibly damage gear and bearing surfaces, shorten the service life of the equipment, and cause unexpected breakdown [1]. 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 [2]. Mechanical devices do fail due to the wear of the rubbing surfaces of their bearings and journals. Debris is characterized into ferrous and non-ferrous particles in which sand, atmospheric contaminants and eroded particles from the bearing belong [3]. The wear of the surfaces can theoretically be eliminated by introducing a material weak in shear (i.e. lubricant) between them. If the film of lubricant is deep enough, the surfaces will be sufficiently far apart to prevent the formation of any welded 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.

Related works were thermo-mechanical analysis of dry clutches under different boundary conditions [4], synthesis versus mineral fluids, evaluation of engine parts using nano lubricant in agricultural tractors [5], experimental analysis of lubricant for the prediction of contact surface behaviour of metals [6], experimental evaluation of ball bearings diagnosis by contamination [7], diesel engine lubricant contamination and wear. Estimation of temperature and effects of oxidation in thermal elasto-hydrodynamic lubrication [8], the use of textured surfaces to mitigate sliding friction and wear of lubricated and non-lubricated contacts, the effects of different cooling and lubrication Techniques on material machinability in machining [9], kinetic model and reaction kinetics to analyze the debris in plain bearing [10], and the thermal behaviour of engine oil, they were carried out using experimental methods and modeling.

A bearing is one of the fundamental elements in the machine; even the simplest machine, the lever, must have a bearing or fulcrum [11]. 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 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 some time due to the failures of mechanical contacts when there are insufficient lube supply and rapid degradation of the quality of the lubricating oils. Mechanical failures that occur in mechanical contact 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 paper, the experimental evaluation of heat released in a Mitsubishi main journal bearing due to different types of debris in it was carried out. Cooling rates of different lubricating oils were evaluated experimentally while considering no debris and when infused with different types of debris in the mechanical contact.

2. Materials and Methods

2.1. Materials

The materials used are Mitsubishi main journal bearing (size: 0.25 from Mitsubishi engine of model number 4G32N24232), copper calorimeter (mass: 200g; specific heat capacity: 400J/kgK), thermometer (mercury-in-glass: 00C to 3600C), stop clock (unicon-1), digital weighing machine (SF-400: 1g to 7000g), electric motor (model no. 5000/99; 0.75kW), lubricating oils (SAE 20W 50), frictional heat and cooling rate evaluation apparatus. The lubricants used are oil A, oil B and oil C. The test rig has adjustable journal bearing fixed at its lower end (see Figure 1).

2.2. Debris Characterization

Two kinds of debris were used in the experiment; 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. The method of debris characterization is mechanical characterization (see Table 1).

Table 1: Mechanical characterization of the debris

Properties	Sand	Iron filings
Brittleness	Very brittle	Ductile
Tensile strength (10^9N/m^2)	No value	(180-210)
Chemical constituents	Fragments of coral, limestone, shell and silicon iv oxide.	Iron
Young's modulus$(10^9 pa)$	130-185	210
Thermal conductivity (W/mK)	0.71	79.5
Specific heat capacity (J/gK)	0.73	0.42
Thermal diffusivity (m^2/s)	1.4	2.3

2.3. Methods

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 experiment was performed with three lubricating oils using different types of debris in the contact. Seven 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; digital weighing machine, thermometer, stop watch, lubricants (oils 'A', 'B' and 'C'), lagging material (cotton wool) etc. The mass of the bearing (M1) and the mass of the empty calorimeter (M2) were measured and recorded. A known volume (V) of the lubricating oil 'A' was poured into the calorimeter. The mass of the calorimeter and its content (M3) was equally taken. The initial temperature of the calorimeter and its content was recorded. The oil and the calorimeter will have the same initial and final temperatures according to the Zeroth law of thermodynamics [12], [13]. The temperature of the bearing is approximately mid-way between the temperature of the oil film [14]. 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, electro-hydrodynamic lubrication EHL. The motor and the stop watch were started at the same time and the final temperatures, were read and recorded at an interval of 3minutes respectively. The quality of heat energy released cannot be measured with an instrument directly but can be calculated with the elementary formula [12], [13], were M = mass, C = specific heat capacity of the substance, 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 third experiments with Silicon IV oxide debris and Iron fillings debris introduced in the mechanical contact respectively. The above procedures were replicated for oil 'B' and 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.

$$Q_T = Q_1 + Q_2 + \cdots + Q_n \quad (1)$$

Where: Q_1 = quantity of heat absorbed by the bearing.

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

Where: 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.

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

Where: M_2 = mass of the copper calorimeter (kg); C_2 = Specific heat capacity of copper calorimeter (J/kgK); M_3 = mass of oil +

calorimeter; M_2 = mass of the empty calorimeter; C_3 = specific heat capacity of the lubricating oil = 2.09J/kgK.

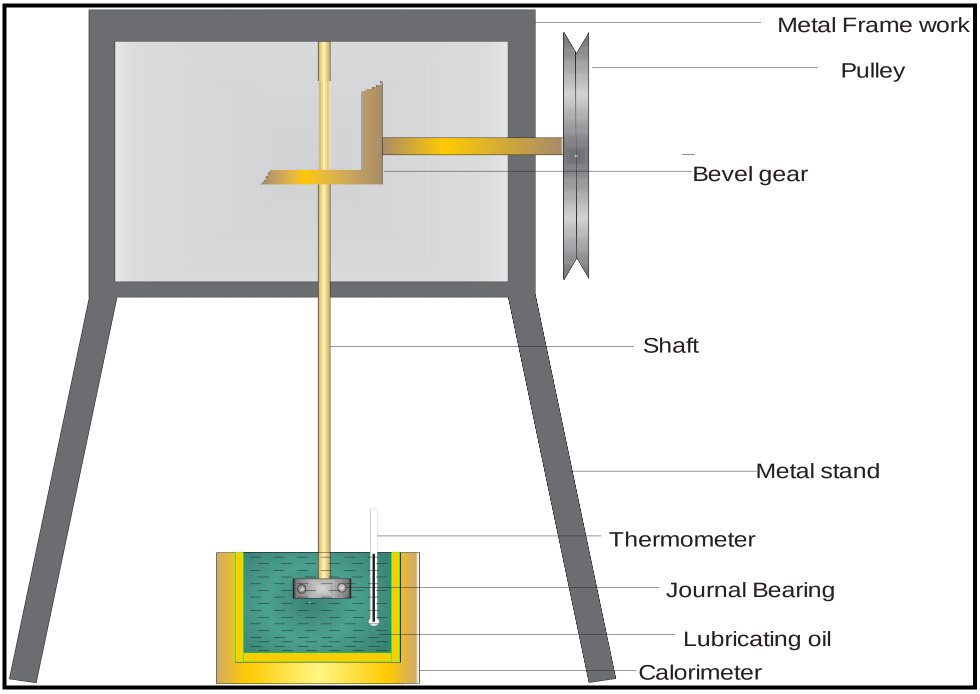

Figure 1: Schematic of the Frictional Heat and Cooling Rate Evaluation Apparatus

3. Results and Discussion

The results of the change in temperature in a Mitsubishi journal bearing when there was no debris in the contact in the three oils are shown in Figure 2.

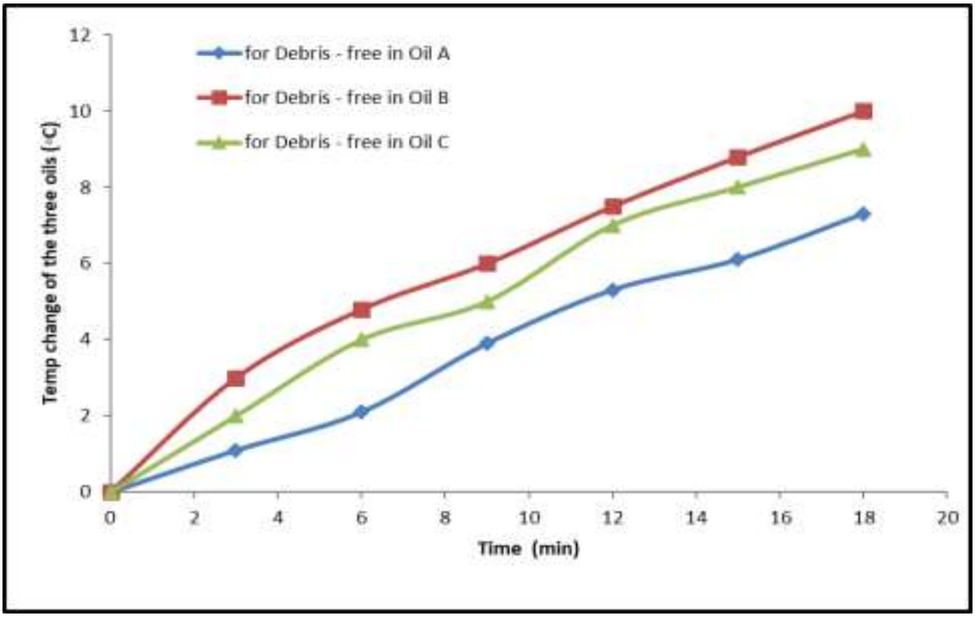

Figure 2: Comparison of change in temperature with time in the three debris-free oils

From Figure 2, oil 'B' showed the highest temperature change than the other oils. This was because the hot molecules of oil 'B' have higher kinetic energy than those of other oils. Since temperature is the measure of the average kinetic energy of the molecules of fluid [15]. The entropy of the hot molecules of oil 'B' was higher than that of oil A and oil C. Entropy is directly proportional to the quantity of heat absorbed [15]. The increased molecular movement helped to maintain a uniform temperature in the mechanical contact. The velocity of the hot molecules of oil 'B' was highest because of its low molecular mass and weak intermolecular bond. The inertia of the molecules of the other oils was too high, so the molecules could not move very fast. The change in the temperature-time curve of oil 'B' was similar to the one proposed by [16]. 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 oil 'B' was the least and its molecules move faster than those of oils 'C' and 'A'. This movement helped to transfer the frictional heat and increase the temperature of the oil 'B'.

The results of the change in temperature of a Mitsubishi journal bearing generated in oil 'A' when the three debris conditions were considered are shown in figure 3.

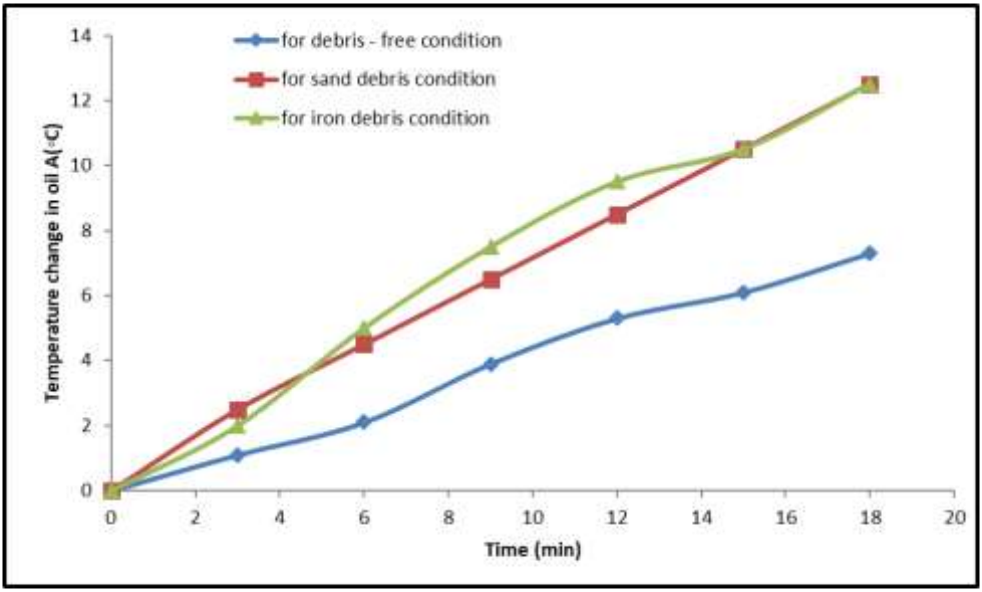

Figure 3: Comparison of temperature change in oil 'A' for the three debris conditions

It could be seen from Figure 3 that the temperature increased when there was debris in the contact. The velocity of the molecules and the 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 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 in the contact. The change in temperature due to the presence of sand debris was reduced and that of iron filings started to increase above that of sand debris immediately after 4.6minutes. Until after 15minutes, the increase in change in temperature became equal due to the fact that the quantity of iron particles present in the contact has an equivalent effect with the available sand debris in the contact. The iron particles have free mobile electrons in their outermost shell, so it helped to transfer the heat. The charge distribution on the surface of the molecules of oil 'A' was very small thus facilitating heat transfer.

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

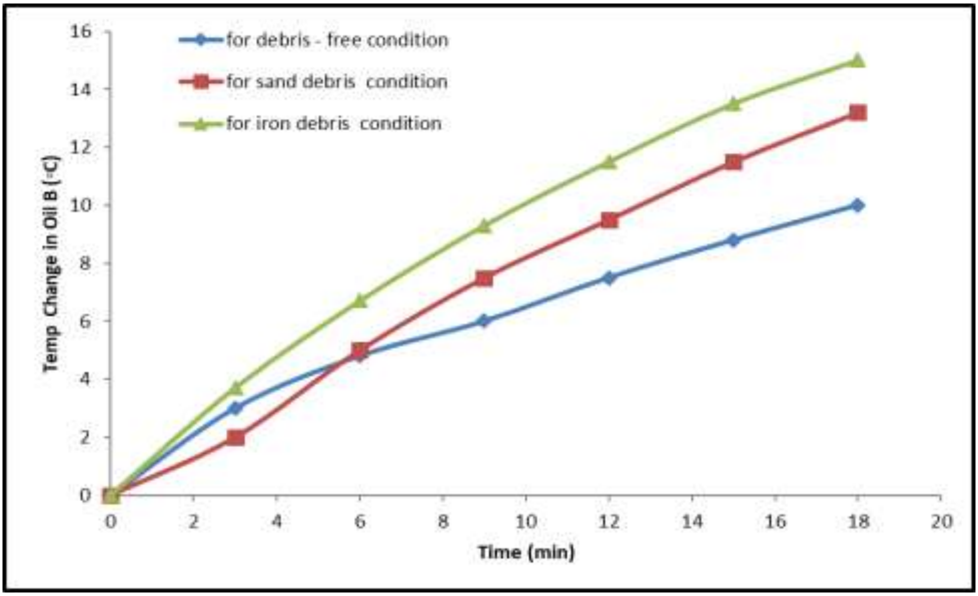

Figure 4: Comparison of temperature change in oil 'B' for the three debris conditions

From Figure 4, the change in temperature when Iron debris was present was higher than others. The same explanations that were adduced in the analysis of the frictional heat in oil 'B' are applicable in temperature change and so both have the same temperature-time curves. The degree of disorderliness of the hot molecules of oil 'B' was the highest. The temperature changes 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 'B' because of its low viscosity and shear stress such that the hot iron particles 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 contact. The change in temperature generated in oil 'B' when Iron particles were present in the oil was the highest. The intermolecular bond strength of oil 'B' was the smallest when compared with the other two oils thus, its molecules moved faster than the molecules of the other two oils. The mass of a molecule of oil 'B' was smaller than those of the other two. The mobile free electrons of the iron particles helped to transfer uniform temperature coupled with the charge distribution on the surface of the molecules of the oil 'B'. It could be deduced from this experiment that the hot molecules of the oil 'B' have the highest charge distribution. Also, the heat capacity of the oil 'B' was higher than the other two oils. The viscosity of oil 'B' was the smallest among the three oils and so it allowed the debris to move faster in it such that the hot particles transferred the frictional heat uniformly in the oil.

The results of the change in temperature in a Mitsubishi journal main bearing generated in oil 'C' for the three debris conditions are shown in Table 5. The temperature changes of oil 'C' is presented in Figure 5. The change in temperature increased when there was debris in the oil. It shows 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 helped to increase the heat content, thus increasing the change in temperature of the oil. Oxygen is an electronegative element and it has a high polarizing ability. It made 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 6minutes 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 contact and it had to be overcome before the rotating shaft maintained its motion.

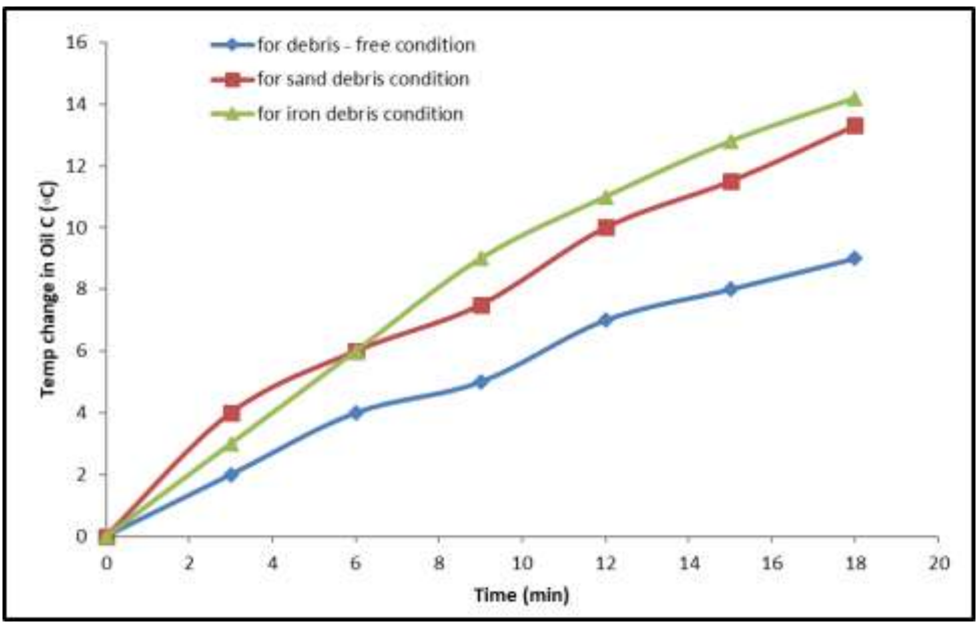

Figure 5: Comparison of the change in temperature of oil 'C' due to the three debris conditions

From Figure 5, the change in temperature when Silicon IV oxide debris was present in the oil is greater than that of the debris-free condition but less than that of iron-particle contaminated oil after 6minutes. The kinetic energy of the rotating shaft was converted into heat. The temperature of the oil was found to increase after the energy transformation. The movement of hot particles in the oil also helped to transfer the frictional heat in the oil. The mobile free electrons of the Iron particles and the oil's charge distribution helped to increase the temperature of the oil. This change in temperature was the highest.

The results of variations in viscosity with temperature in the three oils are shown in Tables 2 – 4.

Table 2: Variations of Absolute viscosity of oil 'A' with Temperature

Absolute viscosity (kg/m-s)	Temperature (^{0}C)
0.422	29.2
0.363	31.0
0.352	32.0
0.321	33.4
0.305	34.2
0.282	35.4

Table 3: Variation of Absolute Viscosity of Oil 'B' with Temperature

Absolute viscosity (kg/m-s)	Temperature (^{0}C)
0.309	34.0
0.274	35.8
0.254	37.0
0.231	38.5
0.211	39.8
0.196	41.0

Table 4: Variation of Absolute viscosity of oil 'C' with Temperature

Absolute viscosity (kg/m-s)	Temperature (^{0}C)	Absolute viscosity (kg/m-s)	Temperature (^{0}C)
0.330	33.0	0.238	38.0
0.289	35.0	0.223	39.0
0.271	36.0	0.209	40.0

From Table 2, absolute viscosity of lubricating oil decreased with an increase in temperature. As the temperature of the oil increased, hot molecules of oil 'A' gained kinetic energy and velocity. Their intermolecular bonds were broken as the temperature increased. When the molecules were very far apart from one another, its absolute viscosity decreased. The absolute viscosity of oil 'A' was higher than those of oil 'B' and oil 'C' but its performance was not better than those of oil 'B' and oil 'C'. From table 3, the absolute viscosity of oil 'B' decreased with an increase in temperature. The absolute viscosity of oil 'B' was smaller than that of oil 'A' at a given temperature when compared with results in table 2. The same explanations proffered above are applicable in the case of oil 'B' and oil 'C'. The table of values of absolute viscosity of oil 'C' with temperature is shown in table 4. The values in the tables 3 & 4 are slightly different because their intermolecular covalent bond and their molecular velocity are slightly different. As the temperature of oil 'C' was increased, the degree of its molecular disorderliness increased also. The covalent bonds of the molecules were broken and so its viscosity reduced as shown in Table 4.

The results of the heat generated in a Mitsubishi journal bearing when there was no debris in the contact in the three local oils are shown in Figure 6. During the experiment, heat energy was generated as the journal rotated on the surface of the bearing as powered by an electric motor of 0.75kW. This was due to the conversion of mechanical energy of the motor into frictional heat which was absorbed by the lubricants. It made the molecules of the bearing to vibrate about their mean positions. This molecular vibration helped to transfer the frictional heat energy through the bearing to the lubricant, its housing and the calorimeter. The vibrational movement of the molecules increased as the frictional heat increased. This heat was absorbed by the bearing, it's housing, lubricant and the calorimeter.

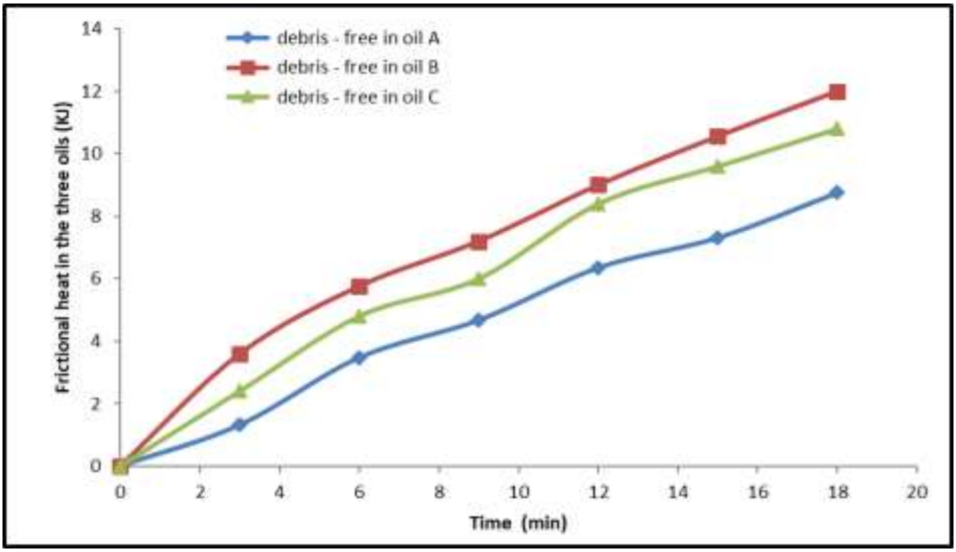

Figure 6: Comparison of the frictional heat generated in the three oils

From Figure 6, oil ‘B’ absorbed the highest frictional heat because its molecular movement was the highest hence the generated frictional heat was easily transferred uniformly in it. It is noteworthy that the molecules of oil ‘B’ were not strongly bonded together and so its molecules moved faster than others. The mass of a molecule of oil ‘B’ and its intermolecular bond was smaller than those of oil ‘A’ and oil ‘C’ because the average speed of the hot molecules of oil ‘B’ was greater than those of oil ‘A’ and oil ‘C’. It is for this reason that the hot molecules of oil ‘B’ moved faster than those of 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 6 shows that frictional heat in the three oils (‘B’, ‘A’ and ‘C’) increased as the time of heat generation increased.

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 Figure 7. It could be asserted that 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 the 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 and Iron debris in the oil was greater than that of debris-free condition. 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'.

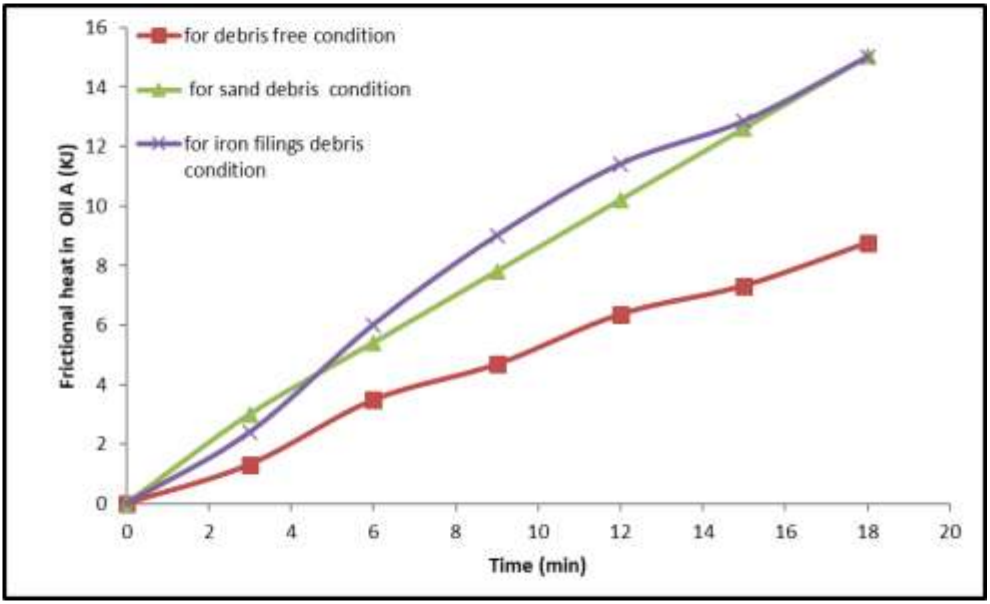

Figure 7: Comparison of frictional heat generated in oil 'A' due to the three debris conditions

From Figure 7, the hot molecules increased translational, rotational and vibrational movements due to the fact that the frictional heat increased gradually. These molecular movements increased when there were debris particles present in the journal bearing. The number of sand particles in the contact with the journal bearing was larger than that of Iron filings of the same mass since the density of sand is less than that of iron. The initial frictional heat generated in the contact by the Silicon IV oxide debris was slightly higher than that of iron. Surprisingly, the sand debris was crushed into tiny particles by the rotating shaft and some escaped through the clearance of the bearing as such, its frictional heat was reduced and that of iron filings started to increase above that of sand debris immediately after 4.6minutes. However, after 15minutes, the increase in the generated frictional heat became equal due to the fact that the amount of iron particles present in the contact has equivalent effect with the available sand debris in the contact. The iron particles have free mobile electrons in their outermost shell, so it helped to transfer the heat. The charge distribution on the surface of the molecules of oil 'A' was very small thus helping in heat transfer.

The results of heat evaluation in a Mitsubishi journal bearing generated in oil 'B' for the three debris conditions are shown in Figure 8. The amount of frictional heat generated in oil 'B' was higher than those of the 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. 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'

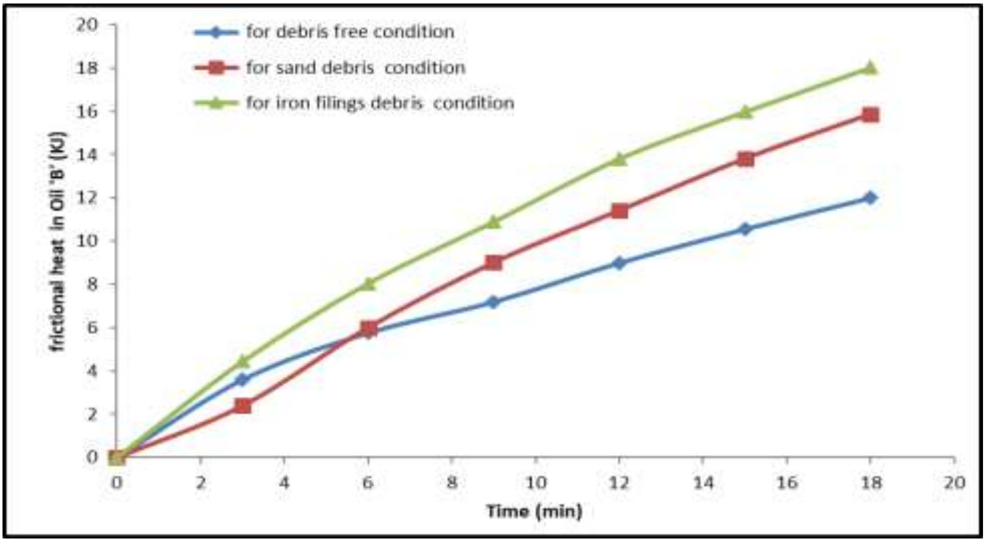

Figure 8: Comparison of frictional heat generated in oil 'B' for the three debris conditions

From Figure 8, the frictional heat generated in oil 'B' when iron particles were present in the oil was the highest. The intermolecular bond strength of oil 'B' was the smallest when compared with the other two oils thus its hot molecules moved faster than the molecules of the other two oils. The mass of a molecule of oil ‘B’ was smaller than those of the other two oils so, it had little inertia to move and transfer the frictional heat. The mobile free electrons of the iron particles helped to transfer heat in conjunction with the charge distribution on the surface of the molecules of oil ‘B’. The molecules of oil ‘B’ have the highest charge distribution also the heat capacity of oil ‘B’ was higher than those of the other two oils.

The results of heat evaluation in a Mitsubishi journal bearing generated in oil ‘C’ for the three debris conditions are shown in figure 9. The frictional heat increased when there was debris in the journal bearing. The molecules of oil ‘C’ gained kinetic energy and moved with high velocity. The velocity and kinetic energy of the hot molecules of oil ’C’ was highest when iron debris was present in the oil. This was illustrated in Figure 9. These explanations are 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’ thus hot particles could not move easily in the oil to transfer the frictional heat uniformly.

From Figure 9, the particles of silicon IV oxide was crushed into a fine powder and its concentration was reduced in the bearing. Iron particles are not brittle like the sand particles, so the iron particles were not easily crushed into a fine powder. The iron debris curve intercepted the sand debris curve after 6minutes. This was because the same amount of frictional heat was generated in the journal bearing. The amount of sand particles present in the bearing has an equivalent effect with the iron particles present at that time.

The results of the cooling rates of oil ‘A’ due to the three debris conditions are shown in Figure 10. The cooling rates decreased non-uniformly with the time taken. This was because the intermolecular force and the covalent bond between the molecules of oil A were very high such that the molecular movement of oil ‘A’ was reduced. This reduction affected the transfer of frictional heat extracted from the surface of the bearing to the other molecules of the oil. The amount of heat absorbed by the oil ‘A’ when there was debris in the contact was higher than that of no debris condition. This was because more frictional heat was generated in the contact. In the same vein, more kinetic energy was needed to overcome friction in the contact. The amount of frictional heat absorbed by the oil from the surface of the bearing when there was debris in the contact would increase also.

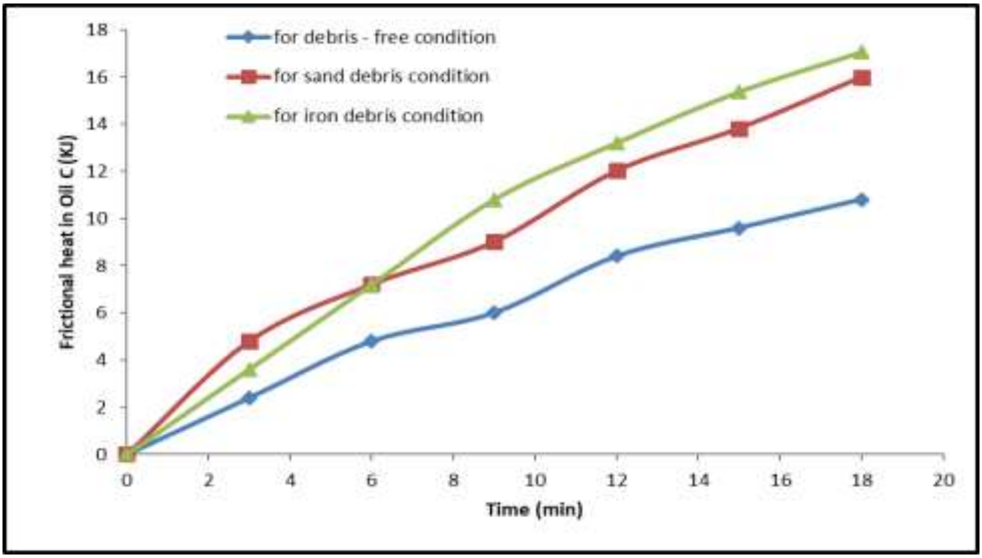

Figure 9: Comparison of frictional heat in oil ‘C’ for the three debris conditions

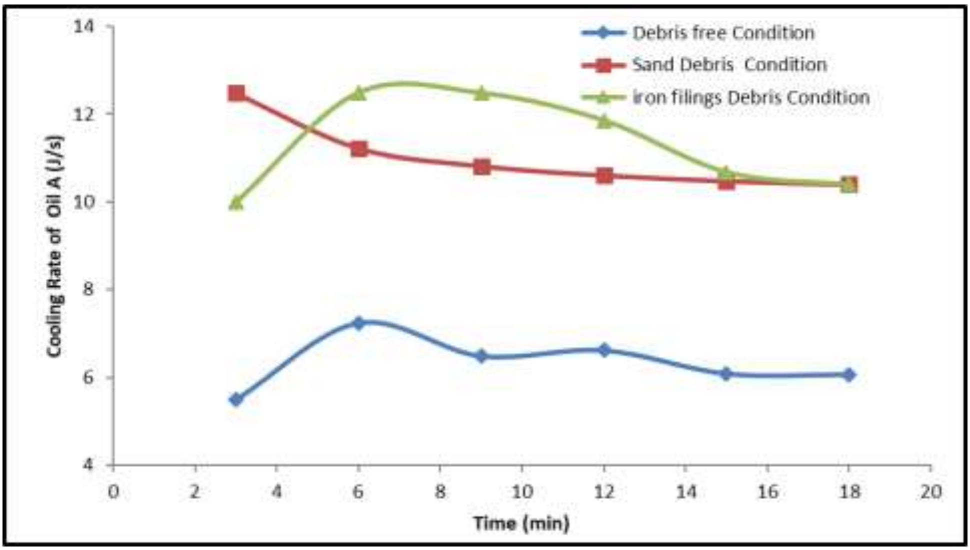

Figure 10: Comparison of cooling rates of oil ‘A’ due to different debris conditions

It could be derived from Figure 10 that the amount of heat absorbed by the oil when iron particles were present initially decreased and then subsequently increased. This was because iron is a metal and it conducts heat very fast. The cooling rate of oil ‘A’ decreased non-uniformly as the temperature increased. This was because the heat generated was absorbed into the intermolecular domain which was used to break the covalent bonds of the oil. Also, all the molecules of the oil did not absorb the frictional heat at the same time. This affected the viscosity and heat capacity of the oil. In sand particle contamination, there was an increase in the amount of heat generated and so its cooling rate was higher than that of debris free condition. The amount of sand debris in the contact was higher than that of iron particles of the same mass since the density of iron is greater than the density of sand. But, in each case, the cooling rate decreased with time. The mobile free electrons on the surface of iron particles helped to generate more frictional heat.

The results of the cooling rates of oil 'B' when considering the three debris conditions are shown in Figure 11. The cooling rate of oil 'B' due to the three debris conditions decreased with time. According to the values, in oil 'B', it showed that the amount of frictional heat absorbed from the surface of the bearing was higher than that of oil 'A' so the heat capacity of oil 'B' is higher than the heat capacity of oil 'A'. The hot iron particles moved freely in oil 'B' while carrying a large amount of frictional heat through the oil owing to its low shear stress. The heat carried by the hot iron particles was absorbed by the oil so the amount of heat absorbed by the oil 'B' when there was iron debris in it was the greatest. The degree of disorderliness of the molecules of oil 'B' was increased when it absorbed more frictional heat. This disorderliness promoted the breaking down of the covalent bonds of its molecules and so it decreased the cooling rate of the oil.

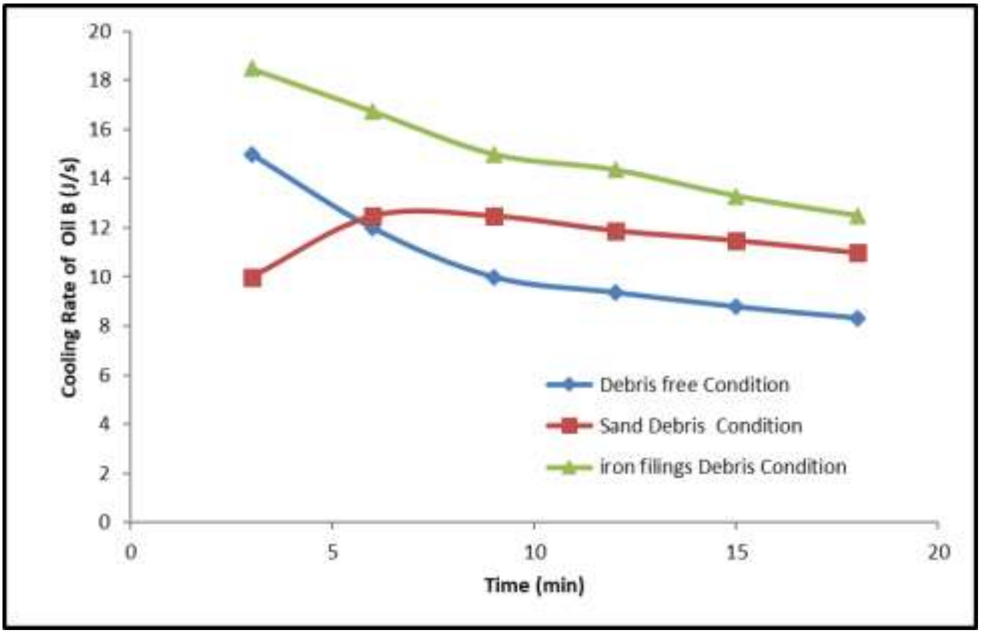

Figure 11: Comparison of cooling rates of oil 'B' due to three debris conditions

In Figure 11, Silicon IV oxide reacted with the oil 'B' and it formed larger molecules which reduced their molecular velocities. This affected the amount of heat transferred by the oil. As the temperature increased, the molecular bond broke down. The breaking apart of the intermolecular bond due to the amount of heat absorbed prompted the reduction of the cooling rate. The molecules became far apart from one another. The amount of heat carried by each molecule was smaller compared with when they clustered together. The charge distributions on the surface of the molecules of oil 'B' were higher than that of oil 'A'. Mechanical failure of the surface of the bearing occurred when the vibrational kinetic energy of its molecules was greater than the binding energy of the bearing lattice. This made the atomic particles to break out from the surface of the bearing. It took a long time to occur when there was no debris in the mechanical contact than when there was debris in the contact. Silicon IV oxide is not a good conductor of heat and so it acted as an insulator. This phenomenon could not allow much heat to be extracted from the surface of the journal bearing.

The results of the cooling rates of oil 'C' when considering the three debris conditions are shown in Figure 12. The cooling rates decreased with time because the intermolecular bonds of oil 'C' molecules were broken. The hot molecules moved away from one another such that the heat absorbed when they clustered together was higher than when they were scattered apart. When there was debris in the contact, the frictional heat absorbed by the oil increased. At some points, the cooling rate remained constant because the frictional heat absorbed was used to break the inter-molecular bond and such could not be detected by the thermometer.

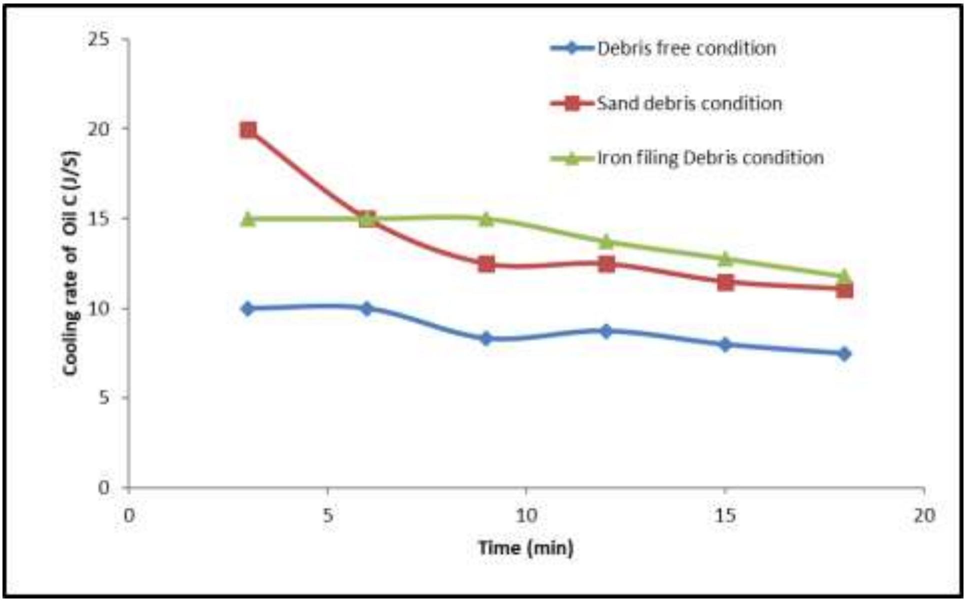

Figure 12: Cooling curves of oil 'C' due to different debris contamination

From Figure 12, when the molecules of oil 'C' were far apart, the molecules could not conduct much heat away from the surface of the bearing. As the hot molecules moved away from one another when their bonds were broken, their cooling rates decreased with time. The cooling rates in debris-free condition were smaller than the other two conditions. There was an increase in frictional heat generated in the journal bearing due to the debris contamination. There were constant cooling rates because the heat absorbed by the oil was used to break some intermolecular bonds, this is in line with Nasiri-khuzani et al., [17]. The shapes of some curves resembled that of Newton's cooling curve.

4. Conclusion

The amount of frictional heat generated in a Mitsubishi journal bearing depends on the nature of the debris in the contact and 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 investigated differ and this 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 and the performance of lubricating oil does not depend on how viscous the oil appears to be but it depends on how its viscosity decreases over a range of temperature. The presence of debris in a mechanical contact reduces the bearing life cycle and thus causes the failure of the machine element. Apart from frictional heat generated in the bearing, other effects of debris are galling, abrasion, adhesion, erosion and indentation of the mechanical contact. The temperature of the oil film varied linearly with the surface temperature of the bearing. The performance of lubricating oil also depends on the charge distributions on the surface of the molecules of the oils. The frictional heat will be evenly distributed on the surface of the molecules due to the presence of charge distribution. The viscosity of lubricating oils decreases with time due to the fact that the molecules move far apart from one another after bond breaking.

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