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Investigation of Inlet Oil Temperature in Gearbox Performance with Journal Bearings

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ABSTRACT: Lubrication is the process of using the lubricants (oil, grease, etc.) to reduce friction and wear between two surfaces in contact. A suitable selection of lubrication oil properties and proper quantity of lubricant supply is important for performance of gearbox and journal bearings. Hydrodynamic journal bearings depend on lubrication oil to support rotating shafts. The lubricant must be chosen in such a way that it should remove the heat generated in gearbox, should not degrade the gears or bearings and should have stability in operation. Lubrication (proper cooling) of gears in motion and bearings, especially in case of journal bearings, should be ensured for proper functioning of gearbox. Inlet lubrication oil temperature plays a nominal role in gearbox performance. In this paper, the effect of change in performance of gearbox with journal bearings is investigated with respect to change in inlet oil temperature.

KEYWORDS: Lubrication, Gearbox, Inlet oil temperature, Gearbox efficiency, Gearbox performance, Journal bearing

I. INTRODUCTION

Gearbox is a power transmission device used to transmit energy from one system to another with reduction in speed (rise in torque) or increase in speed (decrease in torque) and it comprises of gears arranged inside a housing. Lubrication oil temperature has an important effect not only in gearbox, but also in all other mechanical components. For gearboxes working under harsh conditions and high-power transmissions, lubrication oil plays a very important role. The heat generated by the gearbox is removed by lubrication oil and hence selection of suitable lubrication oil with correct specifications is a critical factor. Some of the importance of lubrication oil in gearbox are, removing the heat, reducing wear, reducing friction, preventing corrosion, separating metal surfaces (gear tooth surfaces), removing contaminants. Gear dynamics and power characteristics also depend on these lubrication oil properties.

The hydrodynamic journal bearings depend on the properties of the lubrication oil for its effective performance. Generally, journal bearings consist of a rotating shaft (journal) which rotates freely inside the outer bearing surface without any rolling elements. In hydrodynamic journal bearings, the journal surface is separated from the bearing outer shell surface by lubricant oil film which supports the rotor. These bearings are widely used in heavy gearboxes, since they have high load carrying capacity and lightweight.

The selection of gearbox with hydrodynamic journal bearings with proper inlet lubrication oil is an important factor in the performance of gearbox, (i.e.), if a slight deviation in the range of inlet lubrication oil temperature may cause dramatic effect in gearbox performance and its working since change in temperature of oil may cause changes in viscosity, specific heat and other oil parameters. The scope of this paper is to investigate the change in performance of gearbox and oil-lubricated journal bearings with respect to change in inlet lubrication oil temperature.

II. EFFECT OF INLET LUBRICATION OIL TEMPERATURE

It is necessary to select proper lubrication oil temperature with its correct specifications. If this suitable selection gets failed, it may lead to improper circulation of oil, overheating of gearbox, malfunctioning of gearbox, occurring of wear in gear tooth, surface fatigue failure of gear teeth (pitting), micro pitting, scuffing, gear tooth damage, catastrophic damage in bearing systems (especially in case of journal bearing), breakdown of gearbox, reduction in life of gearbox and bearings and decrease in overall efficiency of gearbox. If viscosity of lubrication oil increases, starvation of the oil flow increases, which results in decrease in overall gearbox efficiency. On the other hand, if the viscosity of inlet lubrication oil decreases, wear in gears may occur.



Hydrodynamic journal bearings depend mainly on lubrication oil characteristics such as viscosity, density and specific heat. Also, oil film thickness (clearance) plays a very important role in bearing performance. A slight deviation in the specified parameters may lead to change in bearing performance such as power loss and efficiency.

In this paper, overall performance of the gearbox with journal bearing is studied with respect to change in inlet oil temperature using theoretical calculations. In order to study the effects of this change, the following calculations were done to compare the deviation in Gearbox performance.

For better understanding of the effects of changes in inlet oil temperature, following cases were studied:

- a) Inlet oil temperature 43 °C
- b) Inlet oil temperature 45 °C
- c) Inlet oil temperature 47 °C
- d) Inlet oil temperature 50 °C

III. OIL PROPERTIES AND THE EFFECT OF TEMPERATURE CHANGE IN OIL PARAMETERS

Table 1 shows the lubrication oil specifications used for the calculations.

| Temperature(°C) | Kinematic Viscosity(cSt) | Density (kg/m ³) | Specific Heat capacity (kJ/kgK) |
|-----------------|--------------------------|------------------------------|---------------------------------|
| 43 | 42 | 861.8 | 2.1 |
| 45 | 38.087 | 860.5 | 2.110 |
| 47 | 35 | 859.2 | 2.12 |
| 50 | 32 | 857.26 | 2.13 |

Table 1. Lubrication Oil Specifications

Due to the change in oil inlet temperature, the density, specific heat and kinematic viscosity changes are shown in Table 1. The importance of change in these parameters with respect to temperature is discussed below.

Importance of Density

Density of oil plays a very crucial role in GB lubrication system. The oil flow is necessary for both gear tooth mesh contact and bearing lubrication. Higher density than the required value can lead to scuffing of mesh area/gear tooth and oil starvation of bearings leading to drastic reduction in estimated life of GB and overall performance of gearbox.

The following graph (Refer Fig. 1a) shows the deviation in density with respect to change in temperature using the standard oil parameters.

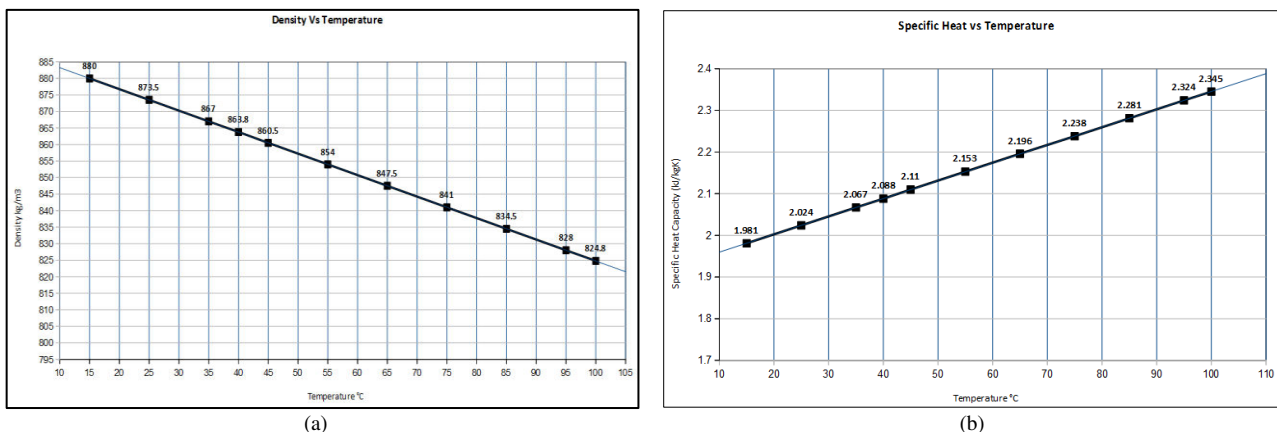


Fig. 1. (a) Variation of Density with respect to Temperature. (b) Variation of Specific heat with respect to Temperature



The linearity in graph shows that density linearly decreases with increase in temperature with a negative slope.

Importance of Specific Heat

Specific heat capacity is defined as the amount of heat required to raise the temperature of 1 kilogram of a substance by 1 Kelvin. It is well understood that heat generated due to high loads needs to be carried away by oil apart from primary role of reduction of friction. The specific heat capacity increases linearly with increase in temperature (Refer Fig. 1b)

Importance of Kinematic Viscosity

Viscosity is an important fluid property when analysing liquid behaviour and fluid motion near solid boundaries. As the temperature decreases, the resistance to flow (Kinematic viscosity) increases, as shown in Figure 3.

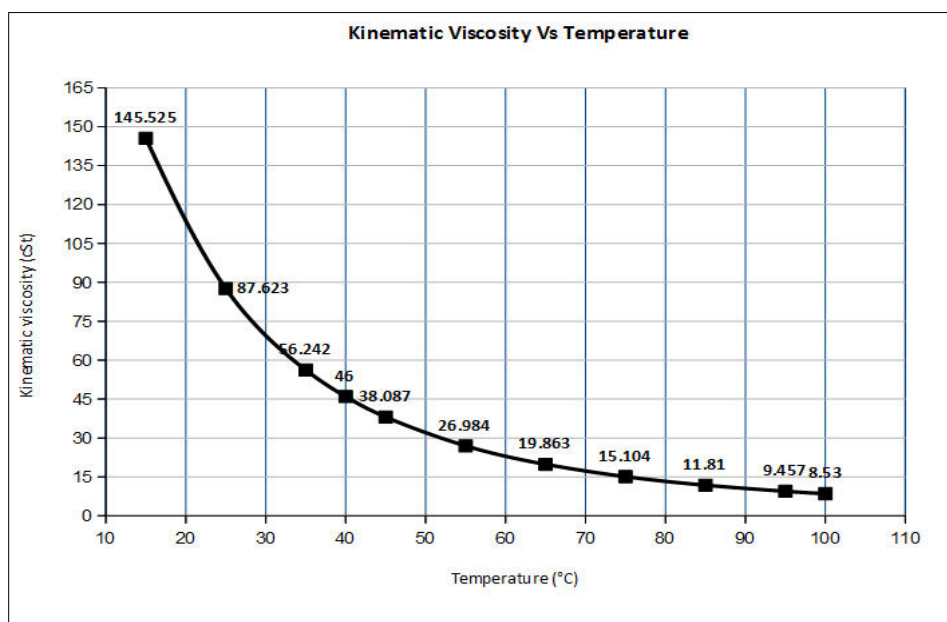


Fig.2. Variation of Kinematic viscosity with respect to Temperature

Viscosity is an important fluid property when analysing liquid behaviour and fluid motion near solid boundaries. Kinematic viscosity is a measure of a fluid's internal resistance to flow. As the temperature decreases, the resistance to flow (Kinematic viscosity) increases, as shown in Figure 2.

IV. CALCULATION AND COMPARISONS

Based on the fluid parameters discussed, all the important fluid parameters in Gearbox (like Oil outlet temperature, Total power loss, Total oil flow required, Overall efficiency etc..) were estimated for four cases -- inlet temperatures 43°C, 45°C, 47°C and 50°C.

All these parameters were compared and checked for the performance of the Gearbox.

Journal Bearing Oil Outlet Temperature and Minimum Film Thickness

Figure 3 show the Oil outlet temperatures and Minimum Film Thickness for all the Journal bearings for the four different cases of Oil-inlet temperature (43°C, 45°C, 47°C and 50°C) at heavy load.

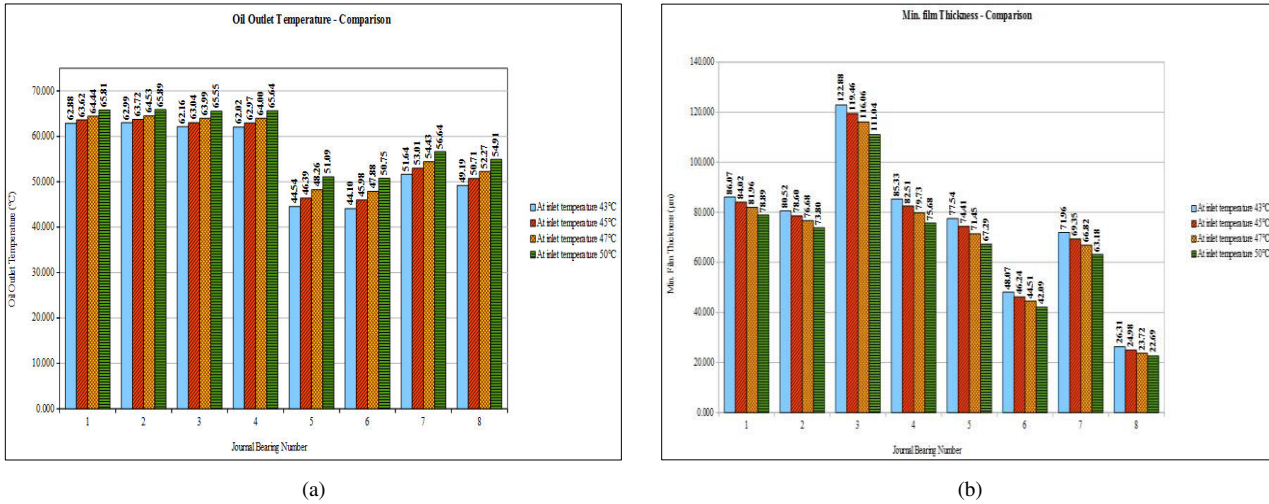


Fig. 3. (a) Oil-outlet temperature for Journal bearings at different Oil-inlet temperature. (b) Minimum film thickness for Journal bearings at different Oil-inlet temperature

Figure 3a shows that the temperature decreases with decrease in inlet temperature for the hydrodynamic journal bearings used in gearbox. Approximately 0.7°C is reduced in outlet temperature per 2 °C reduction in oil-inlet temperature is estimated. Figure 3b shows that the minimum film thickness increases with decrease in oil inlet temperature. Approximately an increase of 2 microns occurs per 2 °C reduction in inlet temperature.

Journal Bearing – Surface Temperature

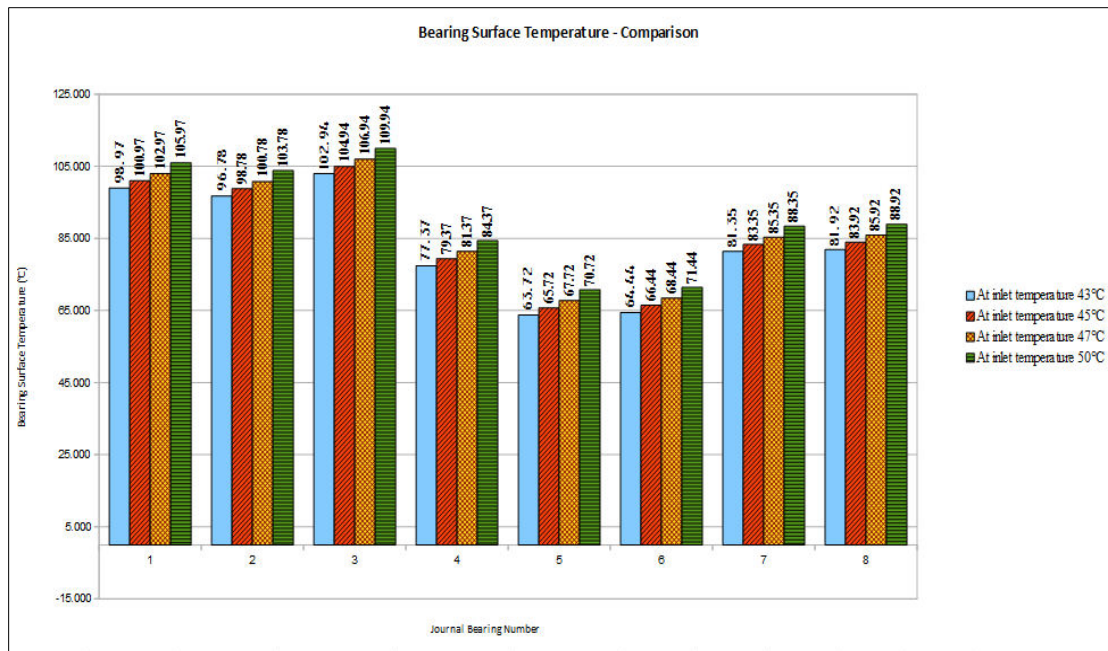


Fig. 4. Journal Bearing surface temperature at different Oil-inlet temperature

Journal bearing surface temperature decreases with decrease in inlet temperature. Approximately, 2°C reduction in bearing surface temperature per 2 °C reduction in inlet temperature is estimated.



Journal Bearing Oil Outlet Temperature

The comparison of Power loss and Efficiency of Gearbox for different oil-inlet temperature considering all the heat losses (due to mesh loss, bearing heat loss, Splash and windage heat losses) is found and is shown graphically in Fig. 5.

Figure 5 and 6 show graphically the variation of Total Power loss, Total Oil flow rate (LPM) and efficiency with respect to decrease in Oil inlet temperature.

Total Power Loss Estimation and Gearbox Efficiency

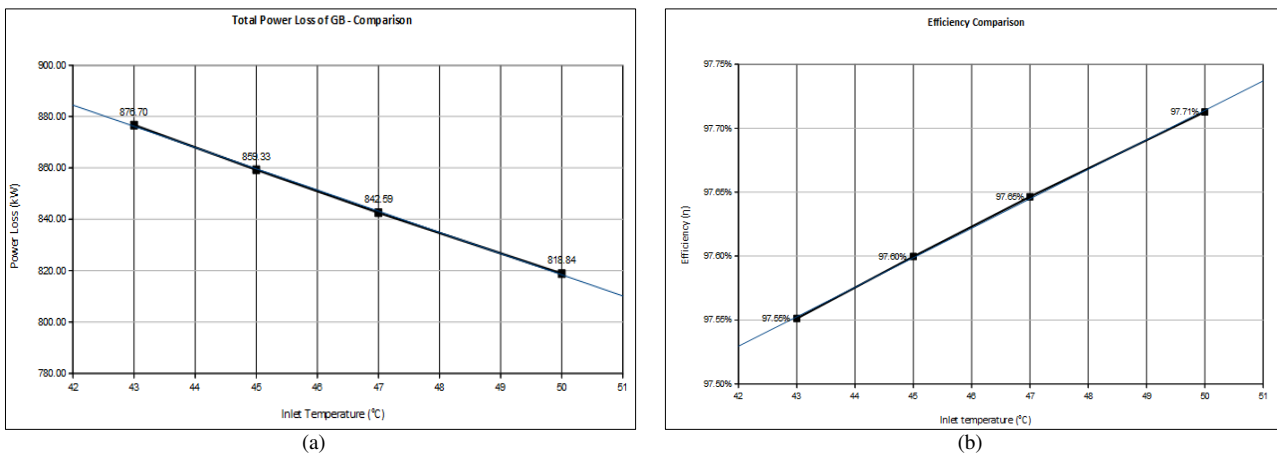


Fig. 5. (a) Total power loss with respect to different Oil inlet temperature. (b) Efficiency with respect to different Oil inlet temperature

Due to change in viscosity, density and changes in coefficient of friction, the total power loss increases with decrease in inlet oil temperature. Approximately a difference of 15 kW per 2 °C reduction in temperature is estimated.

Total Oil Flow Rate in Gearbox

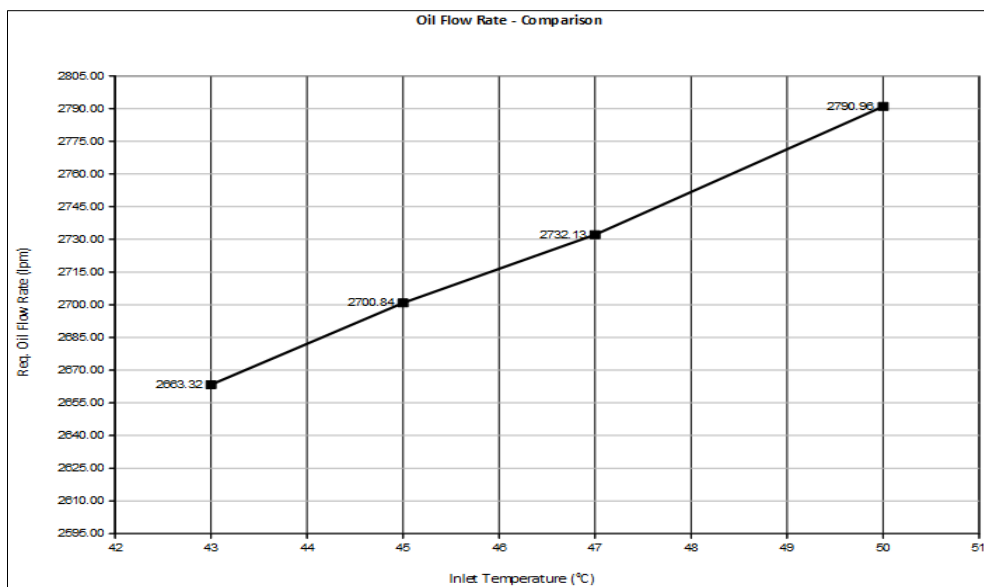


Fig.6. Total oil flow rate (LPM) with respect to different Oil inlet temperature



Figure 6 shows that due to decrease in Oil inlet temperature, the total LPM is estimated to decrease. Approx. 35 LPM difference per 2 °C reduction in temperature.

V. INFERENCE

The effect of change in Bearing performance, Power loss, Flow rate and Efficiency was studied due to the change in inlet oil temperature (50°C 47°C, 45°C & 43°C). The result of the calculations is tabulated below.

| S. No. | Effect on Journal bearing parameters due to inlet oil temperature | Magnitude of change |
|--------|---|--|
| 1 | Oil Outlet temperature in bearings decreases with decrease in inlet oil temperature | Approx. 0.7°C reduction in outlet temperature per 2 °C reduction in inlet oil temperature |
| 3 | Min. Film thickness Increases with decrease in inlet oil temperature | Approx. Increase of 2 microns occurs per 2 °C reduction in inlet oil temperature |
| 4 | Bearing surface temperature decreases with decrease in inlet oil temperature | Approx. 2°C reduction in bearing surface temperature per 2 °C reduction in inlet oil temperature |

Table 2. Effect on Journal Bearing parameters due to change in Inlet oil temperature

| S. No. | Effect on Gear Box Performance parameters | Magnitude of change |
|--------|--|---|
| 1 | Total power loss increases with decrease in inlet oil temperature | Due to change in viscosity, density, coefficient of friction for the change in inlet oil temperatures, approximately power loss increases by 15 kW per 2 °C reduction in inlet oil temperature. |
| 2 | Flow rate (LPM) decreases with decrease in inlet oil temperature | Approximately 35 LPM reduction for Gearbox is estimated per 2 °C reduction in inlet oil temperature. |
| 3 | Efficiency of the Gearbox decreases with decrease in inlet oil temperature | Due to decrease in inlet oil temperature and subsequently the power loss; approximately 0.5 % reduction in efficiency is estimated per 2 °C reduction in oil temperature. |

Table 3. Effect on Gear Box Performance Parameters Due to Inlet Oil Temperature Change

By calculating the gearbox performance with some general calculations, the final results are shown in the table 3.

VI. CONCLUSION

In this study, theoretical analysis is used to find the power loss, efficiency, oil flow and all other parameters in gearbox with journal bearings. Hence exact calculation method is necessary to find the range of inlet oil temperature for the gearbox. Since, hydrodynamic journal bearings performance depends on the oil parameters, it is necessary to



estimate the exact inlet temperature of lubrication oil used. From the results, it is confirmed that even small change in inlet oil temperature has a significant effect in gearbox and journal bearing operating condition.

Thus, this paper clearly explains the change in gearbox performance with respect to change in inlet oil temperature. From the gearbox calculation analysis and hydrodynamic journal bearing calculation methodology, it is precisely understood that decrease in inlet oil temperature leads to reduction in efficiency of gearbox due to increase in total power loss of gearbox. But, at that lower temperature, oil flow required will be very less. If the inlet oil temperature goes below 43°C, it may lead to starvation of oil flow in gearbox and results to malfunctioning of gearbox.

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