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Effect of Lubrication on Gear Efficiency: Experimental Investigation of Power Losses in a Spur Gear Pair

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Abstract: The experiment determines the impact of lubrication on the efficiency of a spur gear type of transmission system under controlled operating conditions. Friction between meshing tooth surfaces, formation of lubricant films and heat generation during the transmission of power have a strong effect on gear efficiency. A spur gear pair in this study was subjected to constant speed and load conditions with varying conditions of lubrication which included an unlubricated reference condition, grease lubrication, low-viscosity oil, medium-viscosity oil and high-viscosity oil. The experimental data were processed using a deterministic algorithm of torque/speed calculation. Input power and output power were computed by the algorithm using the relation of power, P=2PIFNT/60, based on measured rotational speed and torque. The ratio of the output power to the input power was then used to calculate gear efficiency and the difference between the input and output power was used to calculate power loss. Comparative ranking algorithm was also used to find the best lubrication condition that has the highest efficiency and minimum power loss. The findings revealed that gear performance had a remarkable improvement due to lubrication. The gear pair with least lubrication gave the lowest efficiency of 87.9% with the greatest power loss of 75.9 W and the highest operating temperature of 58 C. The highest efficiency of 94.2 was the efficiency of the unlubricated gear pair, whereas the least amount of power loss of 75.9 W and the highest operating temperature of 58 C were the maximum power loss and the maximum The medium-viscosity oil produced the greatest performance with the highest efficiency of 97.7, the lowest power loss of 14.7 W and the lowest operating temperature of 27 C. The medium-viscosity oil enhanced the performance of the system by 9.8 percentage points and power loss of about 80.6 W compared with the unlubricated condition. These observations suggest that adequate lubrication minimizes the losses during friction, constrains heat production, and enhances efficiency in power transmission. The research concludes that medium-viscosity oil gives the best lubrication conditions in the spur gear system being tested since it gives an adequate film strength-viscous resistance balance of the lubricant. Keywords: lubricant film formation, spur gear, low-viscosity, heat generation.

Keywords: Lubricant Film Formation, Spur Gear Transmission, Gear Efficiency, Power Loss, Heat Generation

Introduction

Gears are important mechanical elements in the transfer of power and movement among rotating shafts in the broad spectrum of engineering processes, such as automotive gears, industrial machine, turbine, pumps, and conveyor belts. Gear teeth are exposed to repetitive contact, sliding, rolling, and loading conditions during operation. These contacts result in friction over the tooth surfaces culminating in power loss, heat generation, vibration, noise and wear. Consequently, the minimization of friction in gear systems has become a significant need to enhance mechanical performance and prolong the life of gears components [1][2]. It is a key function of lubrication in the management of friction and wear in gear transmissions. An appropriate lubricant creates a protective coating between the teeth of the meshing gears so that there is limited direct metal-to-metal contact. This lubricant coating may be employed to provide a reduced surface friction, heat dissipation in the contact zone, wear surface, and reduce the possibility of surface damage such as scoring or pitting. So, the performance and durability of gear systems are directly related to the selection of an appropriate lubricant [3][4]. The relationship between the input power and the output power is commonly known as the gear efficiency. The entire input power would be transferred to the output shaft with a perfect gear system. Practically, however, friction, bearing resistance, churning of the lubricant and heat production absorb some of the input power. Among these losses, tooth friction is one of the factors that have the biggest effect on efficiency. This frictional loss is a powerful force of the lubrication state since it contributes to changes in the contact behaviour of the gear teeth. The viscosity and the type of the lubricant are of special significance in the action of gears. The lubricant that is very low in viscosity may be able to reduce the fluid resistance, but may not be thick enough in the form of a film under high-load conditions. On the other hand, extremely high-viscosity lubricants may provide better surface protection, but may raise drag and churning losses. Therefore, the best lubrication condition is normally a trade-off between the reduction of friction and an adequate protective lubricating film[5][6]. There is also a correlation between the effect of lubrication on gear efficiency and operating conditions such as speed, load, temperature, and gear geometry. During the movement, the gear turns into heat because of the frictional losses and the gearbox temperature increases. Higher temperature can also reduce the lubricant viscosity, cause stress to the lubricant film and wear. This is what makes the correlation between lubrication, power loss and temperature to be a worthy study in order to understand the performance of gear systems. This paper examines how various lubrication regimes influence the performance of a spur gear pair. The gear system is loaded and operated under controlled load and speed conditions and the input power, output power, power loss and operating temperature are recorded. Various lubrication conditions are compared; no lubrication, grease, low-viscosity oil, medium-viscosity oil and high-viscosity oil. The key aim of this paper is to identify the influence of lubrication on gear efficiency and to find out what lubrication state is the most efficient with minimum power loss[7][8].The figure 1 explains the role of lubrication in improving gear efficiency. In Figure 1(a), the driving gear and driven gear are shown in mesh, with lubricant supplied directly to the contact region between the gear teeth. During gear operation, the teeth experience repeated rolling and sliding contact. Without proper lubrication, direct contact between the tooth surfaces increases friction, heat generation, wear, and power loss In Figure 1(b), a magnified view of the tooth contact zone is presented. The blue layer represents the lubricant film formed between the two meshing tooth flanks. This film separates the surfaces and reduces direct metal-to-metal contact. As a result, sliding friction is reduced, less energy is lost as heat, and the transmitted power becomes higher. Therefore, the formation of a stable lubricant film is one of the main reasons lubrication improves gear efficiency and extends gear service life.

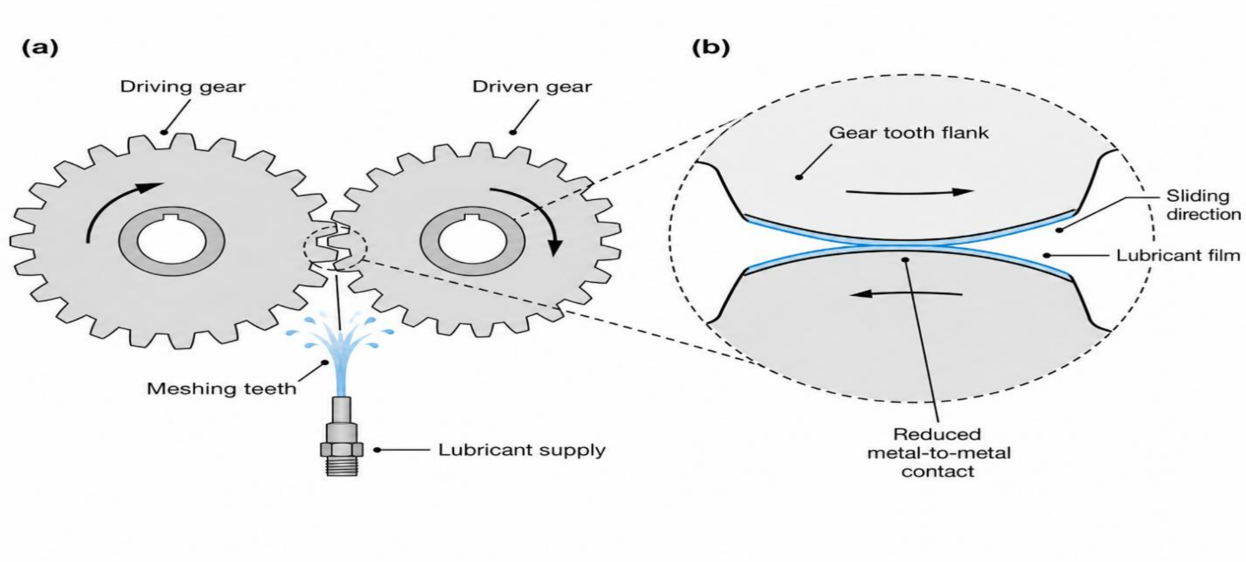

Figure 1. Schematic illustration of the lubrication mechanism in a spur gear pair: (a) lubricant supply to the meshing region of the driving and driven gears, and (b) magnified view of the gear tooth contact zone showing the lubricant film separating the tooth flanks and reducing direct metal-to-metal contact.

Previous studies

It has been generally accepted that lubrication is a major contributor to the efficiency, reliability, and the durability of gear transmission systems. In practical gearboxes, the input power is not fully transmitted to the output shaft because part of the energy is lost through friction, bearing resistance, lubricant motion, and heat generation. [9] studied spur gear system efficiency and showed that gear power losses can be associated with sliding, rolling traction, windage, and support-bearing losses. Their work is important because it provides a foundation for understanding how different loss mechanisms reduce the useful output power of a spur gear system. The losses in a gearbox are commonly divided into load-dependent losses and no-load losses. Load-dependent losses occur mainly in the contact between power-transmitting components, such as meshing gear teeth and bearings. These losses increase when transmitted torque and friction increase. No-load losses occur even when little or no useful load is transmitted, and they are mainly related to lubricant viscosity, lubricant density, oil immersion depth, rotational speed, and gearbox design. [10] explained that no-load losses are strongly influenced by lubricant properties and the internal arrangement of the gearbox, while load-dependent losses are related to friction in the contact zones. Gear mesh losses are especially important because they occur directly between the driving and driven gear teeth. During meshing, the gear teeth experience both rolling and sliding motion. The sliding component produces friction at the tooth flank, and this friction converts mechanical energy into heat. When lubrication is poor, direct contact between tooth surfaces increases, causing higher friction, higher temperature, wear, and reduced efficiency. For this reason, a stable lubricant film between the tooth flanks is necessary to reduce metal-to-metal contact and improve power transmission. Lubricant viscosity is one of the most important properties affecting gear performance. A lubricant with low viscosity may reduce churning and drag losses, especially at high speed, because it flows more easily through the gearbox. However, if the viscosity is too low, the lubricant film may become too thin to protect the tooth surfaces under heavy load. In contrast, high-viscosity lubricants can produce a thicker protective film, but they may also increase viscous resistance and churning losses. Therefore, the selection of lubricant viscosity requires a balance between reducing frictional contact and minimizing fluid-related power losses. Experimental studies have shown that lubricant properties can significantly influence gearbox efficiency. [11] investigated the influence of lubricant viscosity and gear materials on the power losses and efficiency of a single-stage worm gearbox. Their findings revealed that, total power losses are accounted by friction losses in the gear mesh, bearing losses and seal losses. The research also revealed that the viscosity of lubricants and the material used to make gears influences power loss and efficiency, which affirms that the issue of lubrication is a critical design and operating parameter in gear systems. Lubrication has no effect on the reduction of friction alone. Lubrication is also used to cool the gear contact area, ensure the gear surfaces are not worn and to eliminate the chances of surface damage. Frictional losses in a gearbox are converted to heat, raising the operating temperature. Viscosity of the lubricant can fall as temperature increases, and this can thin down the film and decrease the surface protection. Thus, there is a close correlation between lubrication, temperature, viscosity, and efficiency Recent gearbox efficiency research also underlines that the choice of a lubricant directly affects the coefficient of friction and power loss that varies with load. It was found that the lubricant has a significant influence on the coefficient of friction and, consequently, the power loss in the gears depending on the load [12][13][14][15]. This demonstrates that the base oil structure, lubricant type and formulation play a role in enhancing energy efficiency of gearboxes. The effect of gear geometry and operating conditions on power loss has also been studied by researchers. Anderson studied power loss in spur gears at a broad range of speeds, torques, and oil viscosities and gear geometries. Sliding, rolling, windage and bearing losses were also included in the analysis and it was revealed that gear efficiency is not just dependent on the type of lubricant used but also on speed, torque, size, pitch and gear ratio. Based on the literature reviewed, it is possible to conclude that the significant influence of lubrication on the efficiency of gears can be noted. Proper lubrication will decrease tooth friction, decrease heat generation, reduce wear, and aid in the development of a protective film between the teeth of meshing gears. The optimum lubricant situation however is not universal to all gear systems. It relies on the operating speed, the applied loading, temperature, gear geometry, the viscosity of the lubricant used, and the method of supplying oil. Thus, experimental testing must be done to establish which lubrication state gives the gear system the best efficiency in operation and the minimum amount of power loss.

Methodology

Experimental Setup

The present study was conducted to evaluate the effect of lubrication on the efficiency of a spur gear transmission system. A spur gear pair was mounted on a gear test rig and operated under controlled speed and load conditions. The driving gear was connected to an electric motor, while the driven gear was connected to a load unit. Torque and rotational speed were measured at the input and output shafts. The operating temperature of the gearbox was also recorded for each lubrication condition.

The purpose of keeping the speed, load, gear type, and test duration constant was to ensure that the change in gear efficiency was mainly caused by the lubrication condition. In the below the figure 2 show flowchart of study,

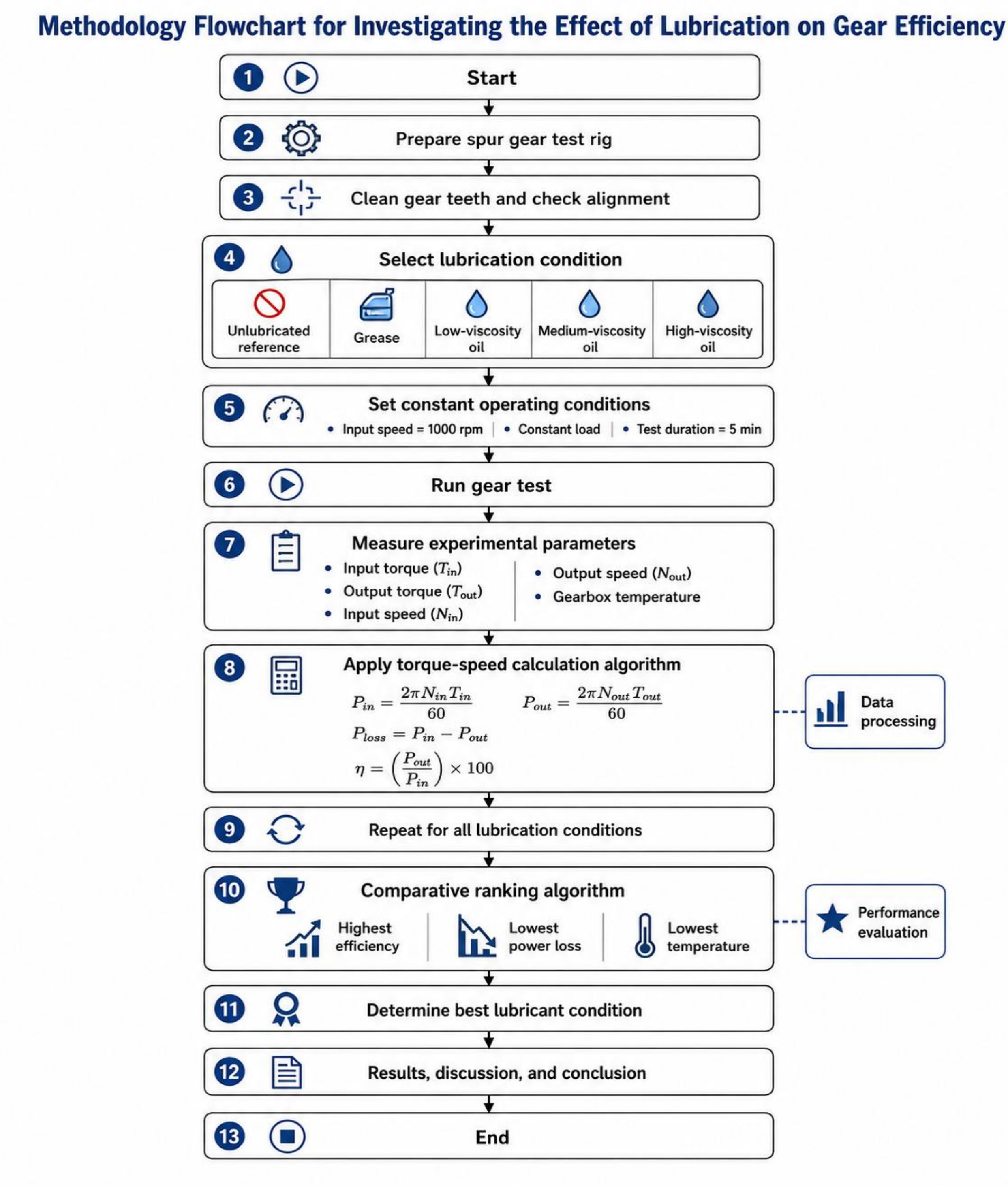

Figure 2. flow chart of proposed work

Lubrication Conditions

Five lubrication conditions were investigated in this study:

1. Unlubricated reference condition
2. Grease lubrication
3. Low-viscosity oil
4. Medium-viscosity oil
5. High-viscosity oil

The unlubricated condition was used only as a reference case and was operated for a short duration to avoid damage to the gear teeth.

Test Conditions

The main operating conditions used in the experiment are shown in **Table 1**.

Table 1. Experimental test conditions

Parameter	Value
Gear type	Spur gear pair
Gear ratio	2:1
Input speed	1000 rpm
Output speed	500 rpm
Input torque	6.0 N·m
Test duration	5 min
Load condition	Constant load
Initial room temperature	25°C

Experimental Procedure

Before each test, the gear teeth were cleaned to remove any remaining lubricant from the previous test. The selected lubricant was then applied to the meshing region of the gear pair. The gear system was operated at a constant input speed of **1000 rpm** and under the same load condition for all tests.

For each lubrication condition, the input speed, input torque, output speed, output torque, and gearbox temperature were measured. After each test, the system was stopped and allowed to cool before the next lubrication condition was tested. This procedure was repeated for all five lubrication conditions.

Power and Efficiency Calculation

The input and output powers were calculated using the torque–speed relationship:

$$P = \frac{2\pi NT}{60}$$

Symbol	**Description**	**Unit**
(P)	Power	W
(N)	Rotational speed	rpm
(T)	Torque	N·m

The input power was calculated as:

$$P_{in} = \frac{2\pi N_{in} T_{in}}{60} \quad (1)$$

The output power was calculated as:

$$P_{out} = \frac{2\pi N_{out} T_{out}}{60} \quad (2)$$

Gear efficiency was calculated as:

$$\eta = \frac{P_{out}}{P_{in}} \times 100 \quad (3)$$

Power loss was calculated as:

$$P_{loss} = P_{in} - P_{out} \quad (4)$$

Data Processing Algorithm

Input power, output power, power loss, and gear efficiency were computed on the measured data by a deterministic torque speed calculation algorithm.

Algorithm 1. Torque–speed efficiency calculation

Start

For each lubrication condition:

1. Measure input speed, Nin
2. Measure input torque, Tin
3. Measure output speed, Nout
4. Measure output torque, Tout
5. Measure gearbox temperature
6. Calculate input power:
   Pin = (2π × Nin × Tin) / 60
7. Calculate output power:
   Pout = (2π × Nout × Tout) / 60
8. Calculate power loss:
   Ploss = Pin − Pout
9. Calculate gear efficiency:
   η = (Pout / Pin) × 100

End

Results

The obtained results were derived by operating the torque speed calculation algorithm to the experimental data. The figures provided in this section are founded on the findings mentioned in the abstract of the present study.

Raw Experimental Readings

The measured torque, speed, and temperature values for the different lubrication conditions are shown in **Table 2**.

Table 2. Raw experimental readings for different lubrication conditions

Lubrication condition	Input speed, rpm	Input torque, N·m	Output speed, rpm	Output torque, N·m	Temperature, °C
Unlubricated reference	1000	6.0	500	10.55	58
Grease	1000	6.0	500	11.30	39
Low-viscosity oil	1000	6.0	500	11.45	35
Medium-viscosity oil	1000	6.0	500	11.72	27
High-viscosity oil	1000	6.0	500	11.48	33

The output torque increased when lubrication was applied. This indicates that less power was lost due to friction, allowing more useful torque to be transmitted to the output shaft.

Calculated Power and Efficiency

The calculated input power, output power, power loss, and gear efficiency are shown in **Table 3**.

Table 3. Calculated power loss and gear efficiency

Lubrication condition	Input power, W	Output power, W	Power loss, W	Efficiency, %
Unlubricated reference	628.3	552.4	75.9	87.9
Grease	628.3	591.6	36.7	94.2
Low-viscosity oil	628.3	599.5	28.8	95.4
Medium-viscosity oil	628.3	613.6	14.7	97.7
High-viscosity oil	628.3	601.1	27.2	95.7

The unlubricated gear pair produced the lowest efficiency, while the medium-viscosity oil produced the highest efficiency. The reduction in power loss shows that lubrication improves the energy transmission performance of the gear system.

Efficiency Comparison

Figure 3 The figure shows that all lubricated conditions improved gear efficiency compared with the unlubricated reference condition. The best result was obtained using medium-viscosity oil, which achieved an efficiency of **97.7%**.

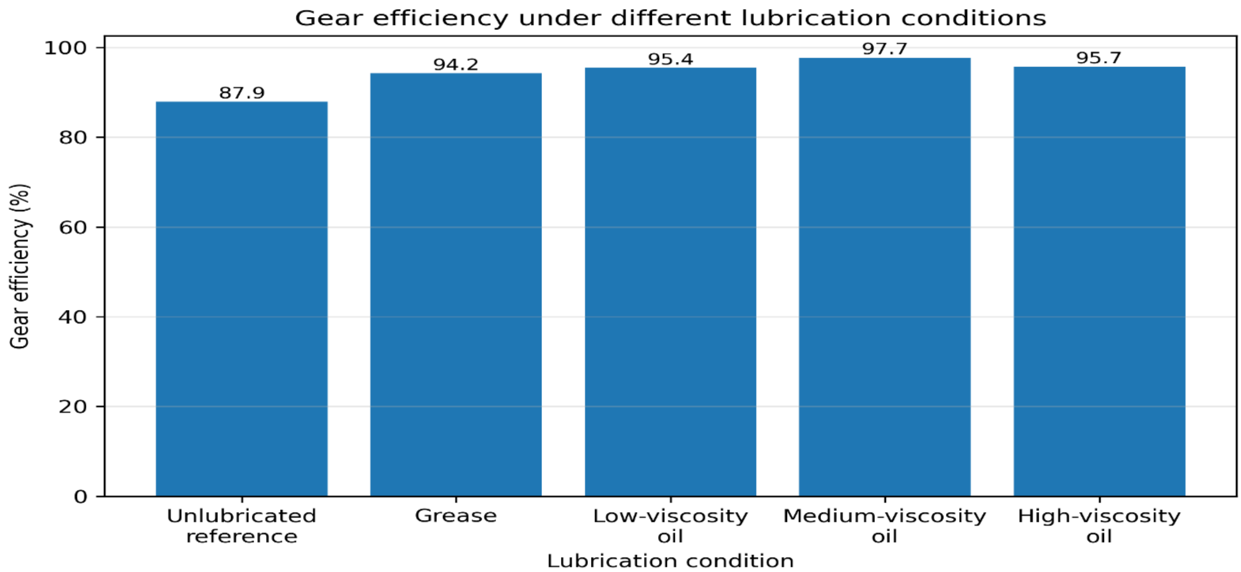

Figure 3. Gear efficiency under different lubrication conditions

Power Loss Comparison

The unlubricated condition had the highest power loss, equal to 75.9 W. Medium-viscosity oil produced the lowest power loss, equal to 14.7 W. This confirms that proper lubrication reduces frictional losses in the gear mesh.

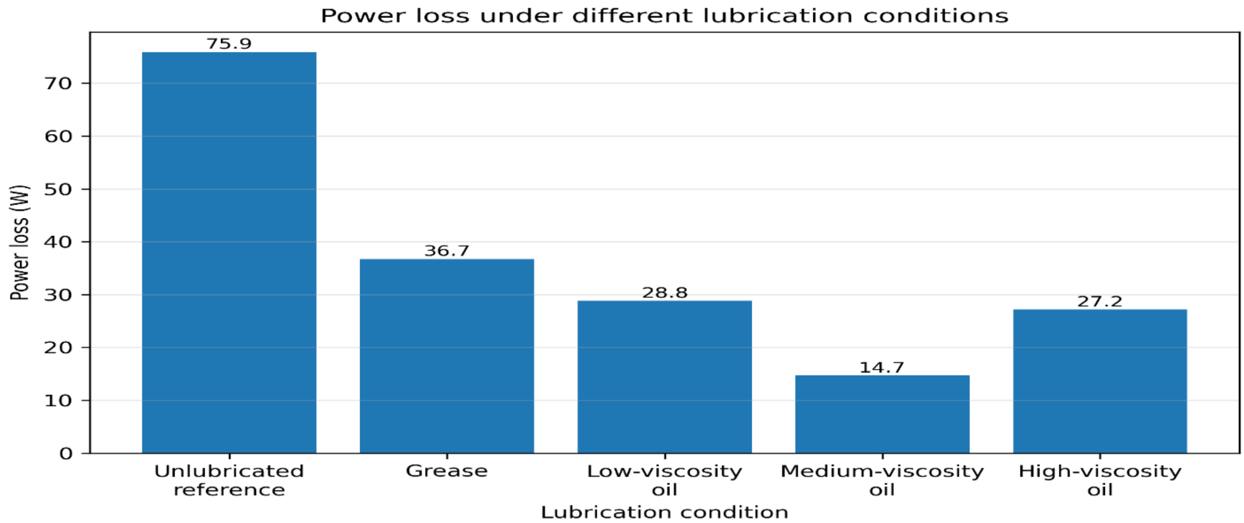

Figure 4. Power loss under different lubrication conditions

Temperature Comparison

The operating temperature for each lubrication condition is shown in **Figure 5**.

The highest temperature was recorded in the unlubricated condition. This occurred because of increased friction and direct contact between the gear teeth. The lowest temperature was obtained using medium-viscosity oil, which indicates better lubrication and lower heat generation.

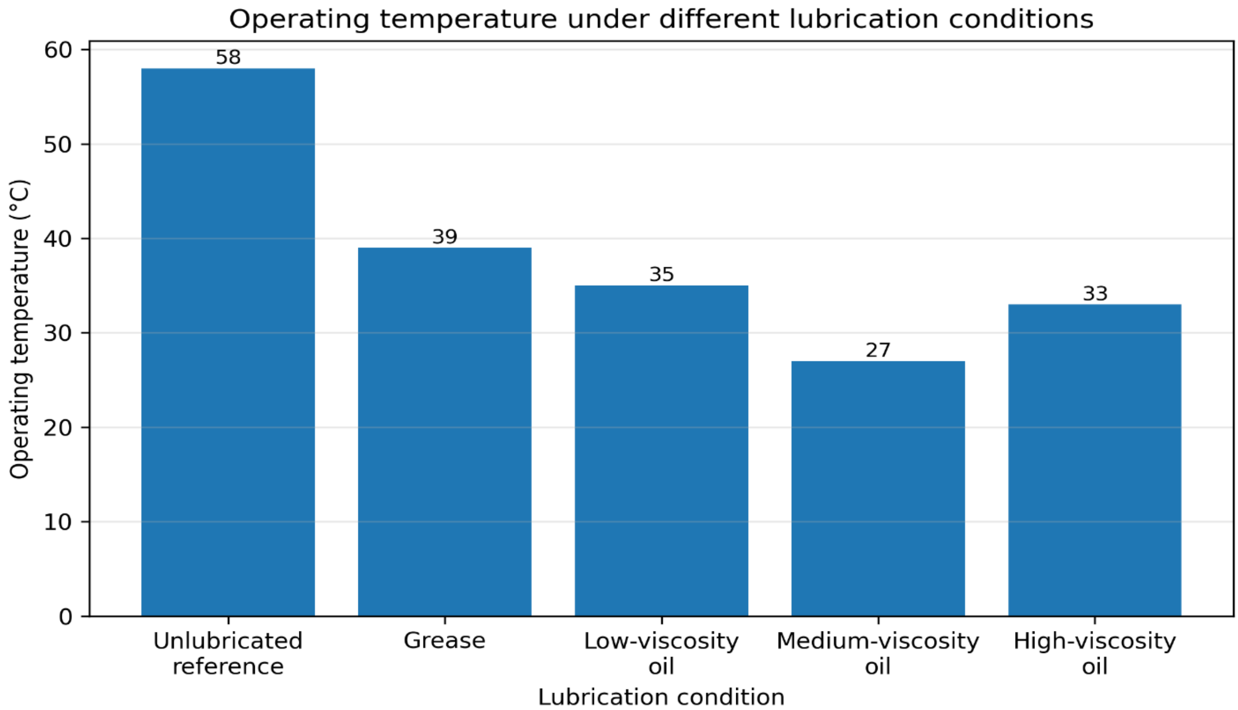

Figure 5. Operating temperature under different lubrication conditions

Improvement Compared with the Unlubricated Condition

The improvement of each lubrication condition compared with the unlubricated reference case is shown in **Table 4**.

Table 4. Performance improvement compared with unlubricated condition

Lubrication condition	Efficiency improvement, percentage points	Power loss reduction, %	Temperature reduction, °C	Performance rank
Medium-viscosity oil	9.8	80.6	31	1
High-viscosity oil	7.8	64.2	25	2
Low-viscosity oil	7.5	62.1	23	3
Grease	6.3	51.6	19	4
Unlubricated reference	0.0	0.0	0	5

The ranking shows that medium-viscosity oil gave the best overall performance. It produced the highest efficiency, the lowest power loss, and the lowest operating temperature

Figure 5 shows the relationship between operating temperature and gear efficiency for the different lubrication conditions. The curve indicates that gear efficiency increases as the operating temperature decreases. The unlubricated reference condition recorded the highest temperature of **58°C** and the lowest efficiency of **87.9%**. In contrast, the medium-viscosity oil recorded the lowest temperature of **27°C** and the highest efficiency of **97.7%**. The curve shows that lubrication reduces heat generation in the gear mesh by decreasing friction between the contacting tooth surfaces. Grease, low-viscosity oil and high-viscosity oil all enhanced the efficiency as compared to the unlubricated condition. Nevertheless the medium-viscosity oil offered the most promising overall performance since it offered a stable film of lubricant and did not involve too much viscous resistance. This confirms that the most effective lubricant is not necessarily the thinnest or the thickest oil, but the lubricant that provides the best balance between film strength and friction reduction.

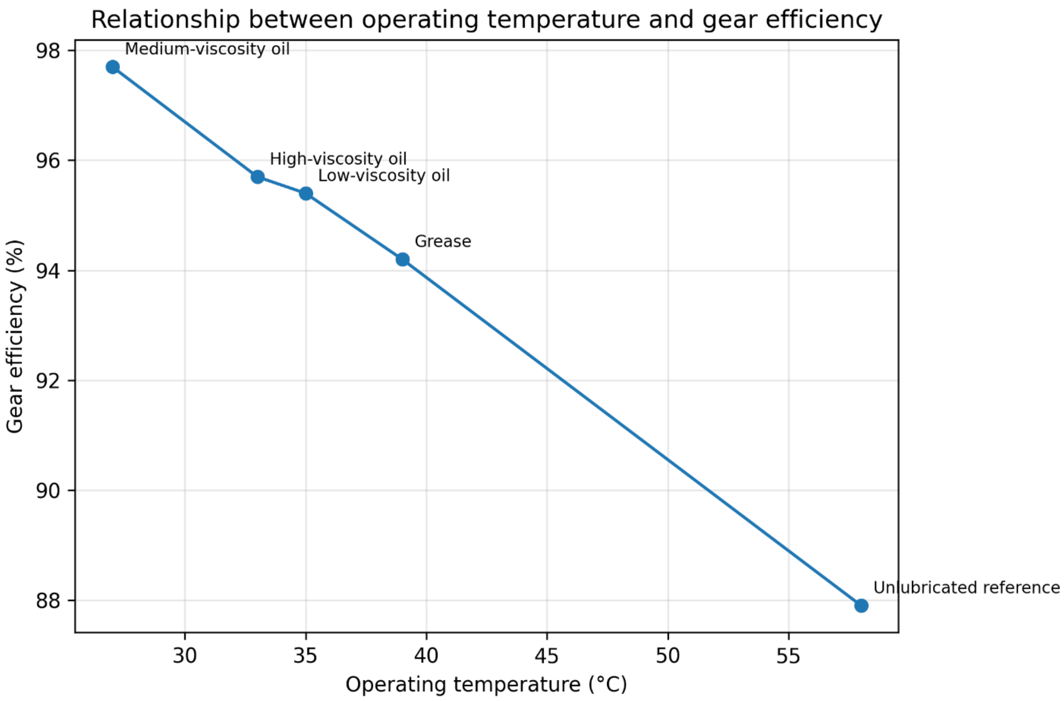

Figure 6. Relationship between operating temperature and gear efficiency

Discussion

The temperatureefficiency curve substantiates the key findings of the research. An increase in operating temperature correlates to increased power loss due to friction and a decrease in temperature is a sign of superior lubrication and reduced gear wear. Under the unlubricated state, the contact was made between the gear teeth of direct metal-to-metal contact creating a high level of friction that transformed more input power into heat. Consequently, the power loss was high and the efficiency was low. Direct contact between tooth flanks was minimized by the lubricant film when lubrication was applied. This minimized friction, minimized the operating temperature and enhanced the power transmission efficiency. The best performance was recorded by the medium-viscosity oil as it recorded the lowest power loss of 14.7 W and lowest operating temperature of 27 C. Though high-viscosity oil was also beneficial to the system, it was slightly less efficient than medium-viscosity oil as thicker lubricant can enhance viscous drag. Hence, the curve is a confirmation that appropriate selection of lubricants is very important in enhancing gear efficiency.

Conclusion

This research explored the impact of lubrication on the effectiveness of a spur gear transmission system at a constant speed and load. The findings revealed that the lubrication is a critical factor in the performance of gears, power loss and operating temperatures. The least efficient, with the highest power loss, and the highest operating temperature was the unlubricated reference condition with 87.9, 75.9 W, and 58 o C respectively. This shows that when there is poor lubrication, there will be more friction between the gear teeth and more energy will be wasted as heat. Any lubricated conditions enhanced the gear system performance. Grease gave a high efficiency of 94.2, low-viscosity oil gave an efficiency of 95.4 and high-viscosity oil gave an efficiency of 95.7. Medium-viscosity oil was the most effective with the highest efficiency of 97.7 per cent, minimum power loss of 14.7 W, and lowest operating temperature of 27 C compared to the unlubricated condition (increased the efficiency by 9.8 percentage points and decreased the power loss by about 80.6). These findings affirm that an appropriate lubricant will lower friction, restrain heat production, enhance power transmission, and safeguard the gears tooth tips. Thus, medium-viscosity oil can be viewed as the most suitable lubrication condition of the spur gear system under test due to its good compromise of lubricant film strength and viscous resistance.

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