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Evaluating the triboelectric performance of trimethylolpropane trioleate grease

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KEYWORDS

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Electric
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ABSTRACT

The study compared the triboelectric performance of trimethylolpropane trioleate (TMPO) grease with perfluoropolyether (PFPE) grease, both formulated with polytetrafluoroethylene (PTFE) as a thickener. Thermogravimetric analysis (TGA) revealed that TMPO grease exhibits 8.8% better thermal stability than PFPE grease. TMPO grease shows a 22.1% improvement in friction over PFPE without electricity. Under a 2 A current flow, both greases show reduced frictional performance, though the TMPO grease maintains a 9.8% lower friction compared to PFPE. The better friction performance of TMPO is attributed to its conductivity compared to PFPE, despite both greases utilizing a non-conductive PTFE thickener.

1.0 INTRODUCTION

Greases serve as semisolid lubricants that are applied between two surfaces to reduce friction, transfer heat, carry contaminants, protect the surface from corrosion, and reduce noise and shock (Donley, 2012). Greases are commonly made of base oil, thickener, and additives. The base oil used in the grease formulation can be synthetic, mineral, or vegetable oil with soap or non-soap thickener. In general, grease is used in heavy industries, especially in the automotive industry. In the automotive industry, environmental effects have always been the focus, and electric vehicles (EVs) have recently become the highlight to counter these issues (Sperling, 2018). According to

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the International Energy Agency IEA, the sales of EVs are expected to grow up to 30% by 2030. Within the field of EV development, the most dominant niches are related to the optimization of batteries (Miao et al., 2022; Y. Tian et al., 2021) and energy management strategies (Dong et al., 2022; Zhang et al., 2020).

Importantly, the efficiency and reliability of EVs are directly related to the electric motor bearing system, which is typically lubricated by greases. Recently, the tribological needs in EVs have been detailed (Farfan-Cabrera, 2019; Holmberg & Erdemir, 2019; Shah et al., 2021a) with the challenges are highlighted. Most of the bearings in the EV motors are similar to those in the conventional internal combustion engine (ICE) but the operating conditions are different, especially in terms of the motor operating speed (Calderon Salmeron et al., 2022; Karki et al., 2020; Shah et al., 2021b). The electrical power train of EVs undergoes continuous electrical current discharge and operates under intricate voltage conditions (He et al., 2020). Moreover, these systems are grounded via the bearings, leading to heat accumulation within them (Melka et al., 2019; Wang & Su, 2016). Such elevated temperatures can disrupt the microstructure of the greases used in these bearings, causing thermal degradation and accelerating grease oxidation (Andrew, 2019). Addressing these extreme operating conditions represents a significant challenge in grease lubrication technology, aiming to prolong the service life of the motor. This challenge arises because the current generation of greases likely lacks adequate thermal and electrical properties (Chen et al., 2020; Chen & Liang, 2020; He et al., 2020).

Advancements in the automotive grease industry have prompted the development of new grease formulations aimed at minimizing friction and degradation losses. Researchers have found that greases for EVs should ideally be formulated with base oil with low viscosity and synthetic oils are preferred due to their superior oxidation stability (Andrew, 2019). However, the cost for synthetic oils is more expensive compared to conventional mineral grease (Japar et al., 2018). Taking account of the environmental aspect, biodegradable base oil has become the alternative, and vegetable oil, in particular, has shown potential especially in the formulation of grease (Hamimi Abdul Razak et al., 2023; C. Tian et al., 2024).

Regarding thickeners, soap-based options like lithium, sodium, and aluminium are widely used due to their ability to maintain the fluid structure of the base oil (Rahman et al., 2021). However, most of these thickeners are non-environmentally friendly, and the higher demand for EVs has created a supply imbalance (Andrew, 2019). Consequently, non-soap organic thickeners have gained popularity, particularly in EV motors subjected to high-temperature conditions (Japar et al., 2018), offering better tribological performance. Polytetrafluoroethylene (PTFE) has emerged as one of the potential candidates as a good thickener due to its ability to withstand extreme temperatures (Vyavhare & Aswath, 2019), and reduce wear and friction (Fan et al., 2018). PTFE is also commonly used in the electronic and semiconductor industry (Farfan-Cabrera, 2019), without degradation.

While thickeners offer advantages, it is crucial to recognize that base oils are more prone to oxidation, especially in triboelectric environments. Thus, careful selection of base oil and thickener, along with proper relubrication practices, is essential for ensuring efficient grease performance. This study aims to investigate the impact of trimethylolpropane trioleate (TMPO) grease on triboelectric performance compared to commercially available perfluoropolyether (PFPE)-based grease. Both samples utilize polytetrafluoroethylene (PTFE) powder as a thickener, with the TMPO grease being lab-produced. The study evaluates thermal stability, frictional performance, and wear properties, hypothesizing that vegetable-derived grease can match synthetic grease performance under triboelectric conditions while offering better environmental sustainability.

2.0 EXPERIMENTAL PROCEDURE

2.1 Sample Preparation

In this study, the tested grease was produced by mixing trimethylolpropane trioleate (TMPO), purchased from Wilmar Oleochemicals, with a standard 5-10 µm polytetrafluoroethylene (PTFE) powder with 98-100% purity, supplied from HDD Technology Sdn. Bhd, Johor Bahru, Malaysia The production process for the TMPO grease was modified from the procedure outlined in references (Fan et al., 2014; Kumar et al., 2020). TMPO base oil and PTFE powder were mixed in a 50:50 ratio. Firstly, TMPO was mechanically stirred at room temperature at 500 rpm for 2 minutes, followed by a decrease to 400 rpm during the addition of the PTFE powder process. The powder was added gradually to ensure proper incorporation. The mixture was then heated up to 80 °C while being stirred at 1000 rpm for 30 minutes. Subsequently, the final product was cooled to room temperature without stirring and passed through a two-roller mill three times for homogeneity. The resulting TMPO-based PTFE grease is given in Figure 1 (a). For comparison, the performance of the lab-produced TMPO grease was compared with a commercially available grease, namely GPL 205 from Krytox™ (denoted as PFPE), which uses the same type of thickener (PTFE) but with synthetic perfluoropolyether (PFPE) as its base oil. The properties of the base oil are tabulated in Table 1.

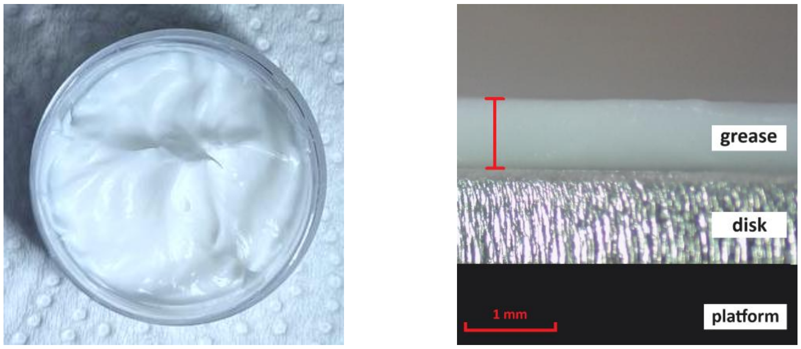
Table 1: Properties of studied greases

Base oil	Base oil density (g/mL)	Base oil kinematic viscosity (cSt)		Viscosity index
	15 °C	40 °C	100 °C	
TMPO	0.915	41.0	8.6	194
PFPE*	-	160.0	18.0	125

*data provided by the supplier

2.2 Pre-Treatment Process for Wear Disks

The friction tests used a set of 50 mm disks (AISI 304 2B stainless steel, 1 mm thickness) and a 6 mm ball (AISI 52100 steel). Before the test, the disks and balls were cleaned using water and ultrasonicating in acetone to remove residuals from the cutting and machining process. Then, the disks were immersed in ethanol before oven-dried to evaporate the ethanol. The disks were then cooled to room temperature before they were used for the test. The processes were to ensure better surface wettability (Mohamed Ariffin, Lee, et al., 2024). The balls were stored in an air-tight bag filled with silicone gel to maintain their integrity and avoid rust. Following pre-treatment, the TMPO grease was uniformly spread on the disk surface as in Figure 1 (b), adopting a manual blade coating approach. The thickness of the grease was measured to be around 0.7 – 0.8 mm thickness. Such thickness is selected to ensure a fully flooded friction testing condition.



(a) (b)

Figure 1: TMPO grease (a) as the final product and (b) daubed on the disk.

2.3 Characterisation

Several standard tests were carried out to characterize the grease. The thermogravimetry thermal analysis (TGA) following ASTM E1131 was carried out using TA Instrument Q500 between room temperature and 1000 °C under atmospheric air flow at a heating rate of 10 °C/min. The oil separation test (ASTM D1742) was conducted to observe the grease condition in storage after one month.

2.4 Friction Test

In this study, the triboelectric performance of the grease was accessed based on the friction performance under electrical current discharging conditions following the procedure of ASTM G99. A purpose-built tribometer illustrated in Figure 2 was integrated with a grounded current flow path, extended across the point contact between the ball and the disk. The friction test was conducted under 500 rpm speed with normal load varying from 0.8 – 1.6 N with 0.2 N increments for each iteration. Each test was run for approximately 255 seconds to achieve 200 m of distance (Mohamed Ariffin et al., 2024). An initial run-in trial was conducted on each disk using a 0.6 N load at 1000 rpm rotational speed for 60 seconds to stabilize the system. The estimated Hertzian pressure is around 0.48 to 0.70 GPa. The tests were conducted under two electrical current discharging conditions: 0A (no current) and 2 A. Each test was repeated three times with a repeatability margin of less than 5% deviation. After completing the test, the wear scar diameter on the steel ball and wear track width on the disk were captured using an optical microscope.

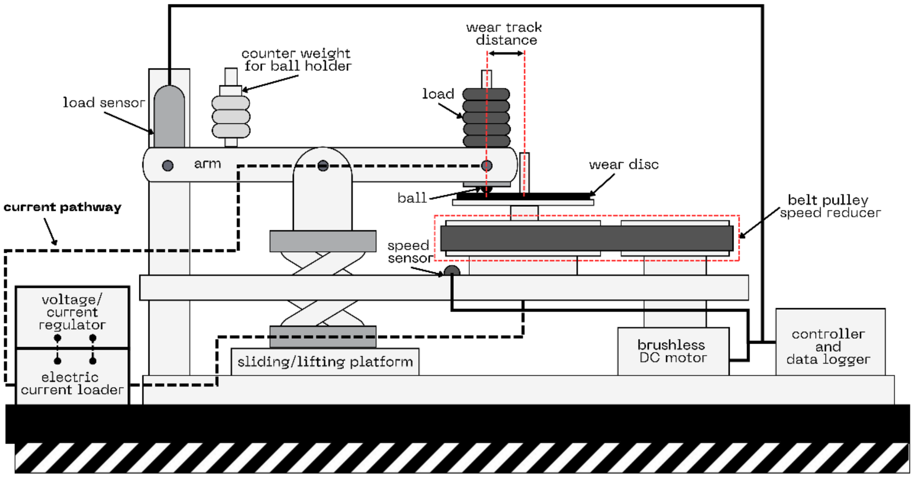


Figure 2: Purpose-built tribometer.

3.0 RESULTS AND DISCUSSION

3.1 Grease Characterisation

The thermal stability of the samples was determined using the TGA thermogram in Figure 3, where the decomposition onset temperature of the samples was obtained. For both samples, the decomposition process happened in two weight steps, which is particularly for base oil and grease decomposition (Rahman et al., 2021). The first weight step evaporates the hydrocarbon with low molecular weight, and the second step presents the evaporation of a higher molecular weight compound (Santos et al., 2017; Tripathi & Vinu, 2015). Based on the thermogram, the base oils started to decompose after reaching 280 °C and the samples almost fully decomposed above 600 °C. Therefore, it is highly recommended that the suitable operating temperature for both greases be below 280 °C for optimum performance.

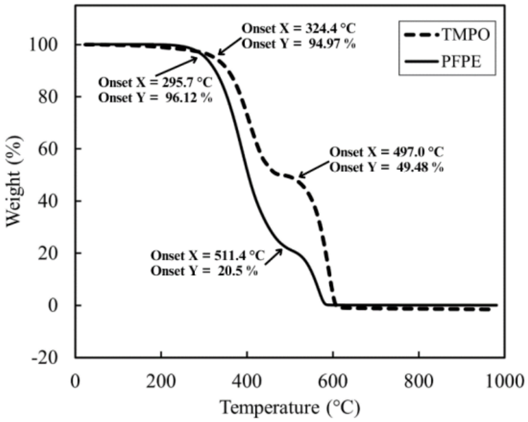
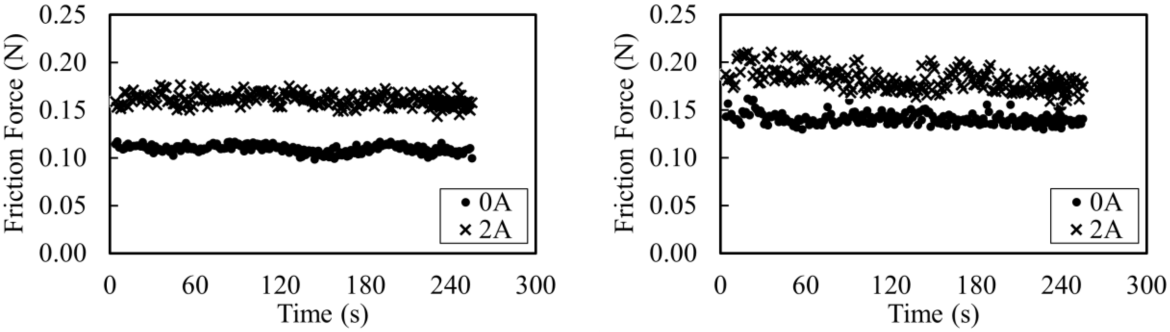


Figure 3: TGA thermogram.

Comparing both data, the onset temperature for TMPO grease is 324.4 °C, slightly higher than PFPE grease at 295.7 °C. This shows that TMPO grease has higher thermal stability and TMPO, as the base oil only starts to decompose after 320 °C. After the first step, the TMPO grease underwent thermal degradation with a total mass loss of around 45.5%. Meanwhile, PFPE grease degrades with a bigger mass loss of up to 72.6%. Typically, the operating temperature for engine lubricant is around 230 to 260 °C (Lee et al., 2022). Thus, both samples have higher thermal stability and can be categorized as medium volatile greases because they can withstand temperatures more than 150 °C (Mohd Sofi et al., 2019).

3.2 Frictional Performance

Figure 4 displays the friction force measurement of the studied greases under 1.0 N loading over 255 seconds of duration, under various current configurations. The data for both samples presented a concentrated and consistent trend, indicating a stable friction measurement with minimal vibrations. The acquired data is generally considered satisfactory, showing a deviation rate below 10%. In the case of the transverse current condition, the vibration did not interrupt the current flow. Thus, this degree of accuracy and precision confirms the effectiveness of the tribometer in delivering consistent measurements of friction force across various setups throughout the testing period.

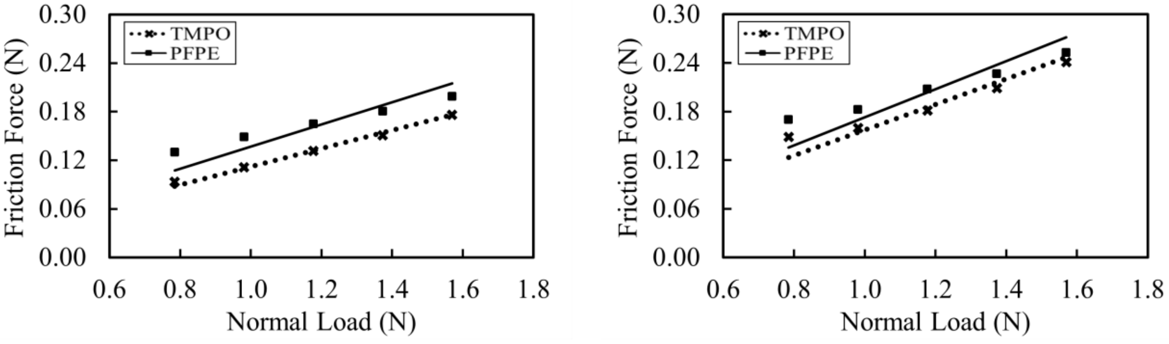


(a) (b)

Figure 4: Friction force against the testing period for (a) TMPO grease and (b) PFPE grease.

Figure 5 shows the friction force against the normal load of both studied samples under two conditions: 0 A (no current) and 2 A. In both cases, the friction data was fitted with a linear regression model and the coefficient of determination (R^2) values ranged around 0.98 – 0.99, showing a good linear fit, supporting Amonton's Law, where the friction force and load are linearly proportional. The results have a standard deviation of less than 5%, thus error bars are excluded.

Under no-current conditions in Figure 5 (a), TMPO grease showed better frictional performance as compared to PFPE grease. Increasing the current to 2 A in Figure 5 (b), the friction force for both samples increased for TMPO grease and PFPE grease, respectively. This highlights the impact of current on friction forces within the mechanical system, indicating that the magnitude of current influences friction force behaviour.



(a) (b)

Figure 5: Friction force against normal load for (a) 0A and (b) 2A current condition.

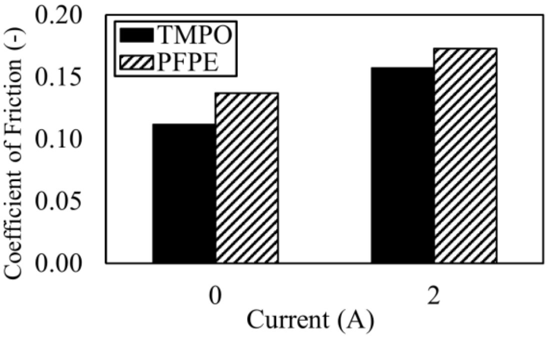
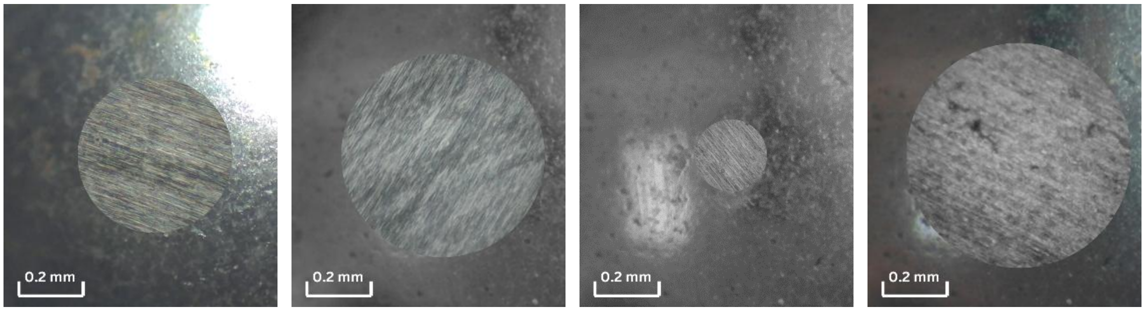


Figure 6: CoF of TMPO and PFPE grease for 0 A and 2 A current condition.

Figure 6 shows the coefficient of friction for both samples under no-current and 2 A current. The coefficient of friction is derived from the slope of the friction force against the normal load and all measured values are lower than in dry conditions, which is around 0.36 (Mohamed Ariffin, Lee, et al., 2024). Under the no-current condition, TMPO grease has 22.1% better frictional performance than PFPE grease. Introducing 2 A of current increases the CoF values for both greases but TMPO grease still manages to outperform PFPE grease by 9.8%. This behaviour is most likely influenced by the properties of the base oil because TMPO has electrical conductivity around 0.255 – 0.375 W/mK (Ruliandini et al., 2020) and PFPE is known to be an insulator. Thus, TMPO grease provides a better electrical conductivity, resulting in better friction performance.

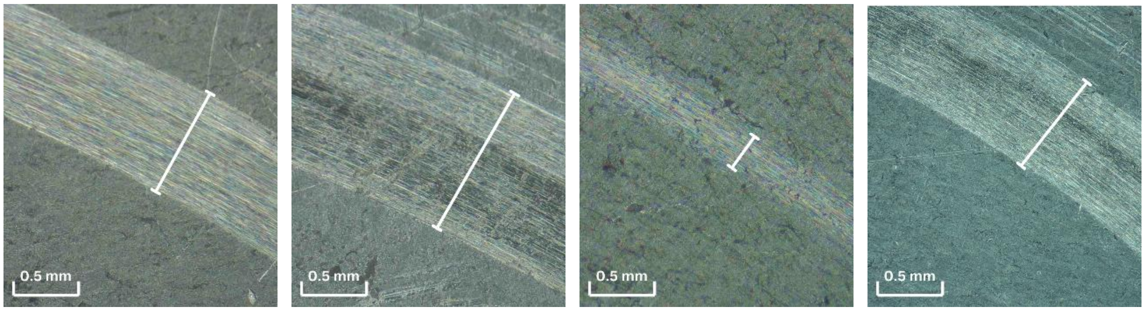
3.3 Wear Performance

Figure 7 and Figure 8 show the ball scar diameter and the wear track width on the disk, respectively for TMPO grease and PFPE grease under no-current and 2 A current conditions. All of the data are summarized in Figure 9: Summary of (a) ball scar diameter and (b) wear track width. The wear scar diameter on the steel ball and wear track width on the disk were captured using an optical microscope. Notably, the surface roughness of the new disk and ball is approximately 0.3 µm and 0.15 µm, respectively.



(a) (b) (c) (d)

Figure 7: Ball scar diameter for TMPO grease at (a) 0 A and (b) 2 A and PFPE grease at (c) 0 A and (d) 2 A.



(a) (b) (c) (d)

Figure 8: Wear track width for TMPO grease at (a) 0 A and (b) 2 A and PFPE grease at (c) 0 A and (d) 2 A.

From Figure 9Figure 7, the ball scar diameter and wear track width of PFPE grease are smaller compared to TMPO grease. At no current condition, the ball scar diameter of PFPE grease is 38.8% smaller than TMPO grease while the wear track width is 67.3% narrower. With the current increased to 2 A, the ball scar diameter of TMPO grease expands by 43.5%, whereas the PFPE grease's ball diameter undergoes an even greater increase, growing by 69.0% compared to the no-current condition. A similar pattern emerges for the wear track width, with TMPO grease showing a modest 27.2% increment while the PFPE wear track widens by 63.5% compared to the no-current condition. This trend suggests that PFPE demonstrates promise as a wear reducer initially, but ultimately experiences a more significant loss of effectiveness under transverse current conditions.

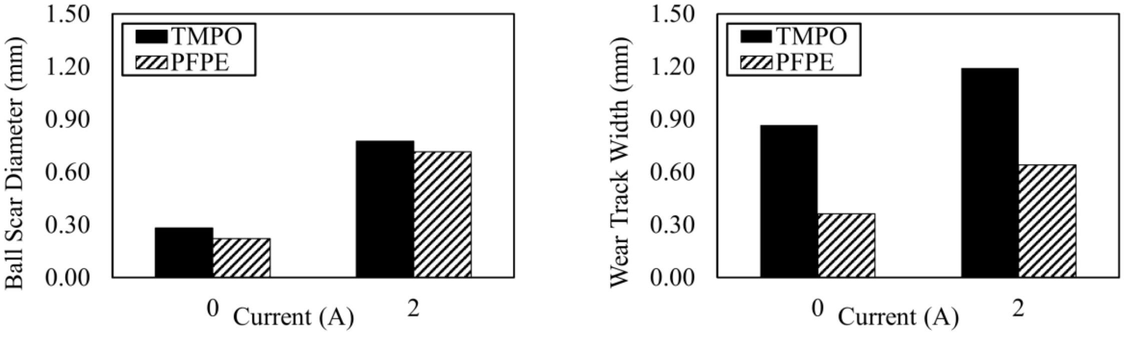
CONCLUSIONS

This study assesses the triboelectric potential of TMPO-based grease with PTFE thickener and compares it to commercially available PFPE-based grease. The objective is to demonstrate that vegetable-based grease can match the performance of synthetic-based grease under triboelectric conditions while also being environmentally friendly. Accessing the TGA thermogram, TMPO grease shows better thermal stability than PFPE grease by approximately 8.8%, ensuring its application under elevated temperature conditions without oxidizing the sample.

In terms of friction force, TMPO grease demonstrates superior performance under both no-current and 2 A current conditions, exhibiting reductions of 22.1% and 9.8%, respectively. This can be attributed to the conductive nature of TMPO base oil compared to the insulating properties of PFPE. Nevertheless, the introduction of 2 A current leads to a range of 26.3 - 40.4% increase in friction force for both samples, highlighting the significant impact of current magnitude on frictional performance.

Regarding wear performance, PFPE grease shows promise as a wear reducer with up to 38.8% and 67.3% better performance on ball and disk, respectively compared to TMPO grease under no-current conditions. However, when subjected to 2 A current, the ball scar and wear track increases more significantly up to 69.0% for PFPE grease. This shows that PFPE as base oil, loses more of its potential to maintain low wear when there is current flowing through the system compared with TMPO.

This study provides valuable insights into the performance of different base oils under electrical operating conditions, driving innovation in the grease industry to develop products suitable for EV operating conditions, particularly those influenced by electrical current flow, thereby enhancing motor efficiency and lifespan.



(a) (b)

Figure 9: Summary of (a) ball scar diameter and (b) wear track width.

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REFERENCES

Andrew, J. M. (2019). The future of lubricating greases in the electric vehicle era. Tribology & Lubrication Technology, 38–44.

Calderon Salmeron, G., Leckner, J., Schwack, F., Westbroek, R., & Glavatskih, S. (2022). Greases for electric vehicle motors: thickener effect and energy saving potential. Tribology International, 167. https://doi.org/10.1016/j.triboint.2021.107400

Chen, Y., Jha, S., Raut, A., Zhang, W., & Liang, H. (2020). Performance Characteristics of Lubricants in Electric and Hybrid Vehicles: A Review of Current and Future Needs. Frontiers in Mechanical Engineering, 6, na. https://doi.org/10.3389/FMECH.2020.571464

Chen, Y., & Liang, H. (2020). Tribological Evaluation of Electrical Resistance of Lubricated Contacts. Journal of Tribology, 142(11). https://doi.org/10.1115/1.4045578

Dong, P., Zhao, J., Liu, X., Wu, J., Xu, X., Liu, Y., Wang, S., & Guo, W. (2022). Practical application of energy management strategy for hybrid electric vehicles based on intelligent and connected technologies: Development stages, challenges, and future trends. Renewable and Sustainable Energy Reviews, 170. https://doi.org/10.1016/j.rser.2022.112947

Donley, E. (2012). Handbook of Advances in Additive Lubricants and Grease Technology. Auris Reference.

Fan, X., Li, W., Li, H., Zhu, M., Xia, Y., & Wang, J. (2018). Probing the effect of thickener on tribological properties of lubricating greases. Tribology International, 118, 128–139. https://doi.org/10.1016/j.triboint.2017.09.025

Farfan-Cabrera, L. I. (2019). Tribology of electric vehicles: A review of critical components, current state and future improvement trends. In Tribology International (Vol. 138, pp. 473–486). Elsevier Ltd. https://doi.org/10.1016/j.triboint.2019.06.029

Hamimi Abdul Razak, I., Ali Ahmad, M., Hajar Abdullah, S., Hazim Farahi Mohd Hazani, M., & Alam, S. (2023). Rheological and tribological behaviors of bio-grease based on palm ester thickened with calcium complex thickener. In Jurnal Tribologi (Vol. 38).

He, F., Xie, G., & Luo, J. (2020). Electrical bearing failures in electric vehicles. In Friction (Vol. 8, Issue 1, pp. 4–28). Tsinghua University Press. https://doi.org/10.1007/s40544-019-0356-5

Holmberg, K., & Erdemir, A. (2019). The impact of tribology on energy use and CO2 emission globally and in combustion engine and electric cars. Tribology International, 135, 389–396. https://doi.org/10.1016/j.triboint.2019.03.024

Japar, S. A., Aizudin, M., Aziz, A., Razali, N., Waheeda, N., & Rahman, A. (2018). Grease and its Application on Electrical Equipment: a Review. In International Journal of Engineering & Technology (Vol. 7, Issue 3). www.sciencepubco.com/index.php/IJET

Karki, A., Phuyal, S., Tuladhar, D., Basnet, S., & Shrestha, B. P. (2020). Status of pure electric vehicle power train technology and future prospects. In Applied System Innovation (Vol. 3, Issue 3, pp. 1–28). MDPI AG. https://doi.org/10.3390/asi3030035

Lee, C. T., Lee, M. B., Hamdan, S. H., Chong, W. W. F., Chong, C. T., Zhang, H., & Chen, A. W. L. (2022). Trimethylolpropane trioleate as eco-friendly lubricant additive. Engineering Science and Technology, an International Journal, 35. https://doi.org/10.1016/j.jestch.2021.09.014

Melka, B., Smolka, J., Hetmanczyk, J., & Lasek, P. (2019). Numerical and experimental analysis of heat dissipation intensification from electric motor. Energy, 182, 269–279. https://doi.org/10.1016/j.energy.2019.06.023

Miao, Y., Liu, L., Zhang, Y., Tan, Q., & Li, J. (2022). An overview of global power lithium-ion batteries and associated critical metal recycling. Journal of Hazardous Materials, 425. https://doi.org/10.1016/j.jhazmat.2021.127900

Mohamed Ariffin, N. A. A., Foong, S. Y., Chong, W. W. F., Lam, S. S., Ng, J.-H., & Zhang, H. (2024). Ionic liquid lubricity enhancement with bio-oil derived from microwave pyrolysis of bamboo. Industrial Crops and Products, 214, 118543. https://doi.org/10.1016/j.indcrop.2024.118543

Mohamed Ariffin, N. A. A., Lee, C. T., Lee, M. B., Halid, I., Hamdan, S. H., Ismail, M. I., Chong, W. W. F., & Zhang, H. (2024). Enhancing boundary friction and wear reduction through adsorption control in protic ionic liquid and carbon mixtures. Journal of Materials Science. https://doi.org/10.1007/s10853-023-09257-x

Mohd Sofi, S. N. A., Abd Aziz, M. A., Anang Japar, N. S., Abdu Rahman, N. W., Abdulhalim, A. R., & Mohd Yunus, M. Y. (2019). Preparation and characterization of grease formulated from waste transformer oil. IOP Conference Series: Materials Science and Engineering, 702(1). https://doi.org/10.1088/1757-899X/702/1/012034

Rahman, N. W. A., Ying, S. S. Y., & Aziz, M. A. A. (2021). Grease formulation and characterization from waste automotive engine oil with the use of complex thickener. IOP Conference Series: Materials Science and Engineering, 1195(1), 012014. https://doi.org/10.1088/1757-899x/1195/1/012014

Ruliandini, R., Nasruddin, Tokumasu, T., & Supriyadi. (2020). Thermal conductivity of trimethylolpropane trioleate (TMPTO) based bio-lubricant using molecular dynamic simulation. AIP Conference Proceedings, 2255. https://doi.org/10.1063/5.0014122

Santos, J. C. O., Santos, I. M. G., & Souza, A. G. (2017). Thermal degradation of synthetic lubricating oils: Part III–TG and DSC studies. Petroleum Science and Technology, 35(6), 540–546. https://doi.org/10.1080/10916466.2016.1269127

Shah, R., Tung, S., Chen, R., & Miller, R. (2021a). Grease performance requirements and future perspectives for electric and hybrid vehicle applications. Lubricants, 9(4). https://doi.org/10.3390/lubricants9040040

Shah, R., Tung, S., Chen, R., & Miller, R. (2021b). Grease performance requirements and future perspectives for electric and hybrid vehicle applications. Lubricants, 9(4). https://doi.org/10.3390/lubricants9040040

Sperling, D. (2018). Electric vehicles: Approaching the tipping point. Bulletin of the Atomic Scientists, 74(1), 11–18. https://doi.org/10.1080/00963402.2017.1413055

Tian, C., Xu, H., & Dong, J. (2024). Development of environmentally friendly lubricant using natural resources: Layered double hydroxide gels. Industrial Crops and Products, 208. https://doi.org/10.1016/j.indcrop.2023.117879

Tian, Y., Zeng, G., Rutt, A., Shi, T., Kim, H., Wang, J., Koettgen, J., Sun, Y., Ouyang, B., Chen, T., Lun, Z., Rong, Z., Persson, K., & Ceder, G. (2021). Promises and Challenges of Next-Generation "beyond Li-ion" Batteries for Electric Vehicles and Grid Decarbonization. In Chemical Reviews (Vol. 121, Issue 3, pp. 1623–1669). American Chemical Society. https://doi.org/10.1021/acs.chemrev.0c00767

Tripathi, A. K., & Vinu, R. (2015). Characterization of thermal stability of synthetic and semi-synthetic engine oils. Lubricants, 3(1), 54–79. https://doi.org/10.3390/lubricants3010054

Vyavhare, K., & Aswath, P. B. (2019). Tribological Properties of Novel Multi-Walled Carbon Nanotubes and Phosphorus Containing Ionic Liquid Hybrids in Grease. Frontiers in Mechanical Engineering, 5. https://doi.org/10.3389/fmech.2019.00015

Wang, W., & Su, Y. (2016). Leakage current study for dielectric breakdown in electrowetting systems. 90(Icmeme), 227–230. https://doi.org/10.2991/icmeme-16.2016.43

Zhang, F., Wang, L., Coskun, S., Pang, H., Cui, Y., & Xi, J. (2020). Energy management strategies for hybrid electric vehicles: Review, classification, comparison, and outlook. Energies, 13(13). https://doi.org/10.3390/en13133352