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Enhancing Lubrication and Energy Efficiency in Refrigeration Systems Through Ultra-Dispersed Nano-Diamond Additive Implementation

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Keywords: Ultra-Dispersed nano-Diamond (UDD), Lubrication Improvement, Energy Efficiency, Wear Resistance, Refrigeration Systems.

ABSTRACT

This research intricately explores the potential of Ultra-Dispersed nano-Diamond (UDD) additives in augmenting the lubrication performance of refrigeration oil within refrigeration cycle systems, with a spotlight on enhancing energy efficiency and wear resistance. The experiment bifurcates into analyzing RL 32H refrigeration oil with and without the UDD additive, unraveling that the latter, especially with a 300 ppm concentration, minimizes wear scar diameter. Consequently, implementing UDD additive presents a novel and viable pathway towards energy conservation in refrigeration systems. After 527 hours of refrigeration system operation on two identical refrigerators, the power consumption for RL 32H without UDD additive was measured at 30.3 kWh, while for RL 32H with 15% of UDD additive, it was significantly lower at 21.5 kWh. This indicates that the addition of UDD additives resulted in a 29% reduction in power consumption.

INTRODUCTION

With the substantial growth of the global economy, there has been a concomitant increase in environmentally harmful substances, pollution, and ecological damage, which have significantly contributed to the rise in global temperatures. This escalation in global warming has led to extreme weather, rising sea levels, and serious threats to ecosystems, particularly in the Arctic region. The has stressed the urgent need for action against unchecked global warming and environmental pollution, prompting a surge in green environmental practices and the development of green industry technologies, including green economies, energy transitions, and energy conservation (Cohen et al., 2014; Mandal et al., 2022; Wang et al., 2022).

In the 21st century, the issue of energy consumption in buildings, particularly from Heating, Ventilation, and Air-Conditioning (HVAC) systems, has become increasingly critical. The refrigeration compressor, a vital and energy-intensive component of refrigeration cycle systems, plays a crucial role in lubricating various components, such as cylinders, pistons, connecting rods, and crankshafts, ensuring their long-term and effective operation. Refrigerants, when combined with additives, exhibit good solubility and enhance heat conduction and transfer properties. Nanoparticles can reduce the friction coefficient and wear in refrigeration cycle systems (Rasheed et al., 2016; Azmi et al., 2017). Babarinde et al. (2022) demonstrated the efficacy of multi-walled carbon nanotube lubricant additives in reducing electricity consumption and enhancing cooling capacity in refrigerators. Yang et al. (2020) found that graphene nanosheets in refrigeration oil significantly reduced energy consumption in domestic refrigerators.

Furthermore, recent research by Sanukrishna and Jose (2022) indicates that CNT-PAG nanolubricants hold significant potential as lubricants for refrigeration compressors, potentially enhancing energy efficiency and performance of refrigeration systems. In a similar vein, Pico et al. (2020) observed that diamond nanoparticles in refrigeration oil can improve cooling capacity, with optimal performance in terms of friction and wear. This study aims to explore the use of Ultra-Dispersed nano-Diamond (UDD) additives in refrigeration oil in household refrigeration and air conditioning systems, focusing on lubrication and wear performance, as well as analyzing the energy efficiency of the refrigeration oil with the addition of UDD. Other isomers of

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carbon are also studied. Chebattina et al. (2021) found that length and weight% of MWCNTs strongly impact the stability, anti-wear and anti-friction properties of the oil.

The exploration of advanced lubrication techniques has become crucial for improving energy efficiency and operational reliability in refrigeration systems. Recent studies, such as those by Ta et al. (2021), highlight the significant potential of nano-lubricants in enhancing tribological properties through the use of ionic liquids combined with nanoparticles. Furthermore, the research by Horng et al. (2022) demonstrates the complex load-sharing capabilities and tribological characteristics at the point-contact interface within three-body mixed lubrication environments, which are essential for understanding the interactions in refrigeration systems. These findings provide a strong foundation for the integration of ultra-dispersed nano-diamonds, positing them as a transformative additive that could substantially mitigate wear and enhance the lubrication efficiency in various mechanical systems.

METHODOLOGY

The explorative approach of this study is divided into two experimental groups: the first employs RL 32H refrigeration oil without additives, while the second uses RL 32H oil augmented with a UDD additive. A meticulous investigation of the wear, energy savings, and wear resistance performance of the refrigeration cycle system during prolonged operational periods was conducted.

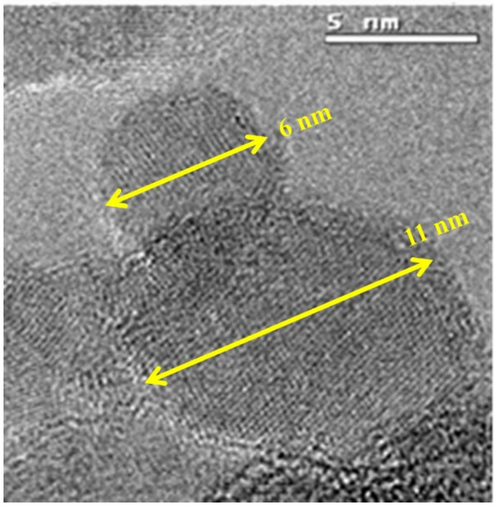
Instrumentation and equipment, such as the Iron Powder Concentration Meter (COSMOS SDM-73) and Wear Testing Machine, have been deployed to ascertain the iron powder concentration in oils and conduct wear testing, respectively. Furthermore, viscosity variations of the refrigeration oil, with and without UDD additive, at different temperatures (40°C and 100°C) are studied to delineate the lubrication characteristics.

EXPERIMENTAL SETUP

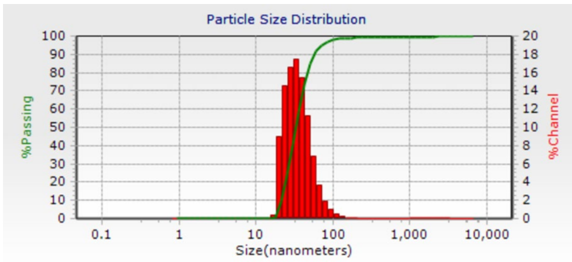
Refrigeration Oil and UDD Additives

The environmentally friendly refrigeration oil RL 32H, depicted in Fig. 1, is used in this study and is enhanced with UDD additives. UDD particles are created through a detonation process, leading to the formation of nano-diamond particles. These particles, ranging in size from 10 to 100 nm, have a smooth surface akin to ball bearings found in mechanical systems. Fig. 2(a) displays the TEM image of nano-diamond particles, while Fig. 2(b) shows the chart of nano-diamond particle size distribution (Hsin et al., 2011). The nano-diamonds used in this study are identical to those in the Hsin et al. (2011) study. When two metal surfaces come into contact, these nano-diamonds promote a rolling effect, thereby reducing friction and wear and potentially repairing surface imperfections.

Fig. 1 Refrigeration lubricant RL 32H



(a)



(b)

Fig. 2. (a) TEM image of nano-diamond particles; (b) Chart of nano-diamond particle size distribution (Hsin et al., 2011).

Energy Efficiency Assessment

Two refrigeration systems operating under the same conditions were utilized to evaluate the energy-saving effects of UDD-added refrigeration oil. Two refrigerators were used in the energy efficiency assessment. The model of the refrigerator used for the experiment is the SAMPO SR-L05, as shown in Fig. 3. One of these systems was treated with UDD additives, while the other was not. The amount and concentration of the UDD added to the RL 32H refrigeration oil were 100 ml and 300 ppm, respectively. The refrigerant used in the refrigerator is R-134a. In its liquid state, at 25°C, the density of R-134a is typically around 1207 kg/m³ or 1.207 g/ml. Therefore, 41.4 ml of liquid R-134a were compressed into the refrigeration system to ensure that 50 grams of R-134a were compressed into the system. The duration of the test was 527 hours. The power consumption of the testing refrigerator was measured with a watt-hour meter.

Other physical properties such as viscosity, moisture content, iron particle concentration, and wear were also measured to compare the energy efficiency and lubrication performance of the UDD additive.

Fig. 3 SAMPO SR-L05 Refrigerators

Equipment Used

1. **Karl-Fischer Moisture Titrator (MKS-500)**

This device is utilized to determine the total moisture content percentage in the oil, as shown in Fig. 4.

Fig. 4 Karl-Fischer Moisture Titrator (MKS-500)

2. **Metrohm 702 SM Titrino (Potentiometric Titrator)**

This device is used for measuring the acid value of the oil in the unit of mgKOH/g, as shown in Fig. 5.

3. **Rheometer (TA AR-2000ex)**

This equipment assesses the fluid viscosity shear changes in the oil, as shown in Fig. 6.

Fig. 5 Metrohm 702 SM Titrino (Potentiometric Titrator)

Fig. 6 TA AR-2000ex Rheometer

4. **Oil Steel Dust Checker (COSMOS SDM-73)**

This device detects the concentration of iron particles in the oil, as shown in Fig. 7.

Fig. 7 COSMOS SDM-73 Oil Steel Dust Checker

5. **Wear Testing Machine**

This equipment is used to evaluate the wear characteristics of the refrigeration oil with and without UDD additives, as shown in Fig. 8.

Fig. 8 Wear Testing Machine

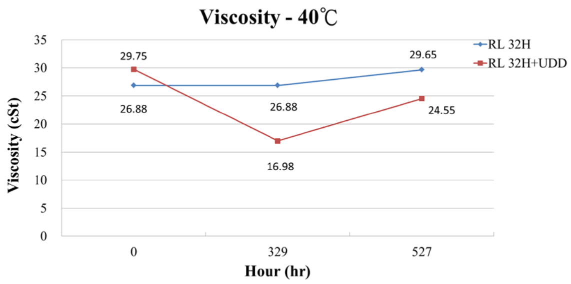
Test Procedure

1. **Preparation of Oil Samples**: Refrigeration oil samples, both with and without UDD additives, were prepared. The UDD concentration in the treated samples was carefully measured to ensure consistency across all experiments.
2. **Conducting Tests**: Various tests were conducted using the above-mentioned equipment. Moisture content, acid value, viscosity changes, and iron particle concentration were measured to assess the impact of UDD additives on these properties.
3. **Wear Analysis**: The wear testing machine was used to analyze the wear characteristics of the refrigeration oil. This involved assessing the wear scar diameter on steel balls used in the test to determine the wear-reducing properties of the UDD additives.
4. **Data Collection and Analysis**: Data from the tests were meticulously collected and analyzed. The findings were used to assess the impact of UDD additives on the lubrication and energy efficiency of the refrigeration systems.

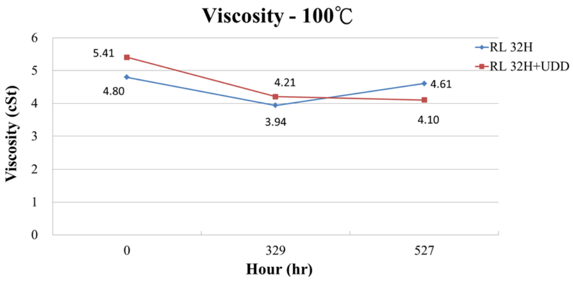
RESULTS AND DISCUSSIONS

Fig. 9 presents the viscosity changes of refrigeration oil in a refrigeration system at 40°C and 100°C, with and without the addition of UDD additives. Viscosity, being a critical property of lubricants, plays a vital role in the efficiency and reliability of refrigeration systems.

At 40°C, which is closer to typical operating temperatures for many refrigeration systems, the viscosity of the refrigeration oil directly impacts lubrication quality. The UDD additives could alter the oil's viscosity, thereby affecting its flow and lubrication properties. The additives, due to their unique nanostructure, may enhance the lubrication by forming a protective layer on the metal surfaces, reducing friction and wear. However, an increase in viscosity could also lead to higher energy consumption due to greater resistance in oil flow. The balance between enhanced lubrication and energy efficiency is crucial in this temperature range. At 100°C, a higher temperature typically associated with extreme or stressed operational conditions, the viscosity behavior of the refrigeration oil can provide insights into the thermal stability of the lubricant. In this scenario, the UDD additives may play a role in maintaining or even enhancing the stability of the oil. The additives might prevent the breakdown of oil at high temperatures, ensuring consistent lubrication and protecting the system's components. The evaluation of viscosity changes at this temperature is essential to understand the oil's performance under high thermal stress.



(a)



(b)

Fig. 9. Viscosity changes of refrigeration oil in the refrigeration system at (a)40°C and (b)100°C, with and without the addition of UDD additives.

The analysis of viscosity changes at 40℃ and 100℃ in the presence of UDD additives shows the viscosity is lower than the viscosity without UDD added. This could result in lower viscous energy dissipation, beneficial for reducing energy consumption, provided that lubrication performance remains adequate. Variations in metal concentration can serve as evidence of whether the lubrication performance remains effective.

Fig. 10 shows the moisture content variation in refrigeration oil versus time, with and without the addition of UDD additives. Initially, the moisture content of RL 32H refrigeration oil without UDD was measured at 0.0012015%, and with UDD (RL 32H+UDD), it was slightly lower at 0.0011265%. This indicates that the initial addition of UDD additives does not significantly impact the moisture content in the refrigeration oil.

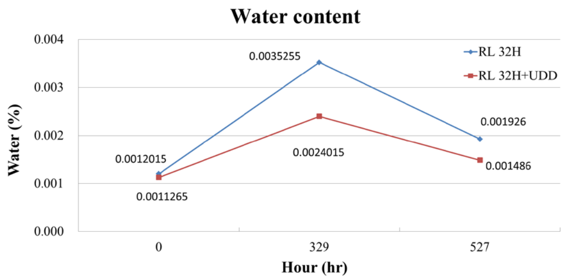


Fig. 10. Moisture content variation in refrigeration oil versus time, with and without the addition of UDD additives.

However, after 527 hours of operation, the difference in moisture content becomes more pronounced. The RL 32H refrigeration oil without UDD showed an increase in moisture content to 0.001926%, while the oil with UDD additives (RL 32H+UDD) had a lower moisture content of 0.001486%. This suggests that over longer operating periods, UDD additives are effective in reducing the moisture content in refrigeration oil. The advantage of lower moisture content lies in its ability to reduce the likelihood of oil emulsification and corrosion in equipment, which is crucial for maintaining the efficiency and lifespan of refrigeration systems.

These findings indicate that UDD additives have potential benefits in improving the quality of refrigeration oil, especially under long-term operating conditions. By reducing the accumulation of moisture, UDD can help maintain the lubrication performance of the oil, lessen wear and corrosion, thereby enhancing the reliability and efficiency of the overall refrigeration system.

Fig. 11 shows the changes in Total Acid Number (TAN) value of refrigeration oil in a refrigeration cycle system with and without the addition of UDD additives. Initially, the TAN values for RL 32H refrigeration oil without UDD and with UDD (RL 32H+UDD) were 0.01 and 0.03, respectively, indicating a lower acid value for the oil without the UDD additive.

After 527 hours of operation, the RL 32H oil had a TAN value of 0.1, while the RL 32H+UDD oil had a TAN value of 0.07. This finding suggests that the addition of UDD additives improved the oil's resistance to the increase of TAN value, which is an essential factor in preserving oil quality over time. Lower TAN values in oils are desirable as they indicate less oxidation and degradation of the oil, which can lead to better lubrication quality and longer oil life. The addition of UDD additives seems to enhance the stability of the refrigeration oil, reducing the likelihood of acid buildup and hence prolonging the useful life of the oil. This result is significant for refrigeration systems, where maintaining oil quality is crucial for efficient operation and longevity of the system. The UDD additives not only improve the lubrication properties but also contribute to the stability of the oil by reducing the rate of acid value increase. This can be particularly beneficial in applications where the oil is subjected to prolonged use or harsh operating conditions, helping to maintain system efficiency and reduce maintenance costs over time.

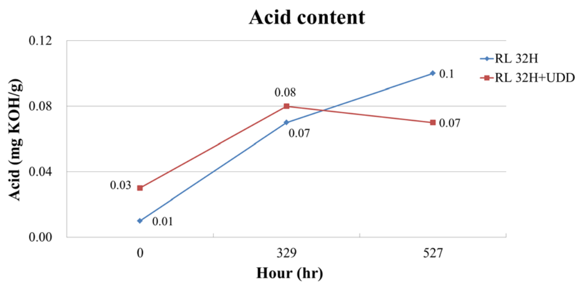


Fig. 11. Changes in Total Acid Number (TAN) value of refrigeration oil in a refrigeration cycle system with and without the addition of UDD additives.

Fig. 12 shows the variation of iron particle concentration in refrigeration oil within a refrigeration cycle system, with and without UDD additives. Initially, both RL 32H (without UDD) and RL 32H+UDD (with UDD) refrigeration oils showed a zero concentration of iron particles. This finding was consistent after 527 hours of operation, indicating that no significant wear in mechanical components. The iron particle concentrations in oil samples with or without UDD additive are all very low or even zero concentration suggest that the addition of UDD does not negatively impact the wear resistance of the refrigeration oil. In refrigeration systems, the presence of iron particles in oil is typically indicative of mechanical wear, as these particles are often generated from the friction between moving parts in the compressor.

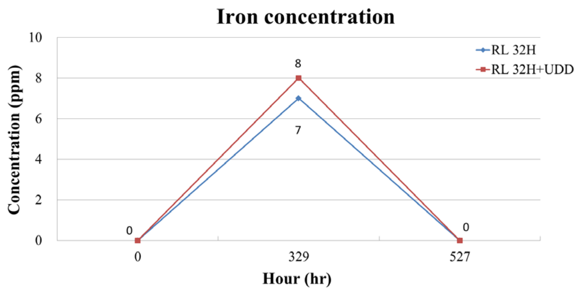


Fig. 12. Variation of iron particle concentration in refrigeration oil within a refrigeration cycle system, with and without UDD additives.

The low concentration of iron particles in both the UDD-added and non-UDD samples after 527-hour operation implies that the refrigeration oil, irrespective of the UDD additive, effectively protects against wear and maintains the integrity of mechanical components. This result is crucial in the refrigeration system maintenance and efficiency. Refrigeration oils that maintain low levels of iron particles contribute to the longevity and reliability of the system by minimizing internal wear. The study demonstrates that the use of UDD additives does not compromise this aspect of oil performance and may offer additional benefits without increasing the risk of mechanical wear.

Fig. 13 shows the power consumption changes of the two refrigerators one with UDD additives and the other one without UDD. This data is crucial for understanding the impact of UDD additives on the energy efficiency of refrigeration systems. Initially, up to the first 100 hours of operation, the power consumption of refrigeration oil with and without UDD additives (RL 32H and RL 32H+UDD) did not show significant differences. This period is considered as the "run-in" or "break-in" phase, where the new oil, regardless of the addition of UDD, is adapting to the compressor's operational environment, and the lubrication effects are not yet fully realized. During this phase, the refrigeration system's components are likely undergoing a process of mutual adaptation and surface smoothing, resulting in similar energy consumption patterns for both oil types.

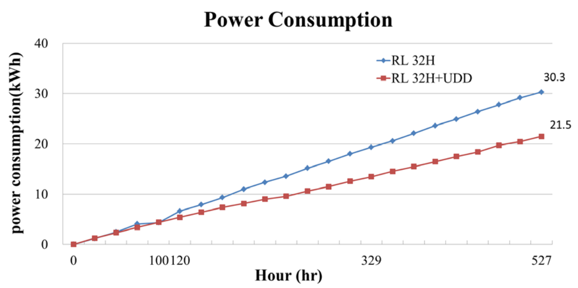


Fig. 13. shows the power consumption changes of the two refrigerators one with UDD additives and the other one without UDD.

However, post the initial 100 hours, particularly around the 120-hour mark, the benefits of the UDD additives in enhancing lubrication start to become evident. RL 32H+UDD showed a notably lower increase in power consumption compared to RL 32H. After 527 hours of operation, the power consumption for RL 32H was measured at 30.3 kWh, while for RL 32H+UDD, it was significantly lower at 21.5 kWh. This indicates that the addition of UDD additives resulted in a 29% reduction in power consumption.

The reduction in energy consumption with the use of UDD additives can be attributed to their lubrication properties. The UDD particles possibly form a protective film on the metal surfaces within the compressor, reducing friction and wear between mechanical components. This reduction in friction and wear not only improves the system's efficiency but also contributes to lower energy consumption. By minimizing internal resistance, the compressor operates more smoothly, requiring less energy to achieve the same refrigeration effect. This finding is particularly relevant to energy conservation and sustainability in refrigeration systems. The use of UDD additives not only enhances the lubrication quality of the refrigeration oil but also plays a significant role in reducing energy consumption, which is a critical factor in the global effort to reduce energy usage and carbon footprint. Incorporating UDD additives in refrigeration oil can be an effective strategy for improving the energy efficiency of refrigeration systems, thereby contributing to more environmentally friendly and cost-effective operations.

Fig. 14 shows the results after the 4-ball wear test of the refrigeration oils with the addition of UDD additive at different concentrations. This experiment was crucial to understand the optimal concentration of UDD additives in refrigeration oil for the anti-wear capability under extreme pressure condition. The experiment was conducted by the wear testing machine shown in Fig. 8 and adhered to the ASTM D 2266 standard, The test parameters are:

1. Rotational speed: 1200 rpm
2. Starting oil temperature: 75℃
3. Test load: 40 kgf (392.4 N)
4. Testing time: 60 minutes.
5. Material code of test balls: SUJ2
6. Diameter of test balls: 1/2" steel balls.

The key finding from the 4-ball wear test was the variation in the diameter of the wear scars on the steel balls after the experiment, indicating the level of wear protection provided by the refrigeration oil with varying UDD concentrations. Significantly, the refrigeration oil with a 15% concentration of UDD additive showed the smallest wear scar diameter at 563 μm. This result suggests that at this specific concentration, the UDD additives are most effective in reducing wear and tear, as evidenced by the minimal wear scar diameter.

The reduced wear scar diameter with the addition of UDD additives can be attributed to the unique properties of the ultra-dispersed diamonds. These nanoparticles, due to their hardness and thermal conductivity, can create a protective film over the metal surfaces, effectively reducing direct metal-to-metal contact and thereby minimizing wear. Additionally, the spherical shape of these nano-diamonds might play a role in facilitating a rolling effect, which further reduces friction and wear, as reported in (Hsin et al., 2011). The experiment's results highlight the significance of determining the optimal concentration of UDD additives in refrigeration oil. Too little additive may not provide sufficient protection, while too much could not only be more expensive, but also potentially alter the oil's physical properties, such as viscosity, which can impact the system's efficiency. Finding the right balance is crucial for enhancing lubrication performance without compromising other essential characteristics of the oil.

The findings from Fig. 14 thus provide valuable insights for the development and application of UDD additives in lubricants, specifically in the context of refrigeration systems. The ability to fine-tune the concentration of additives like UDD opens up possibilities for creating more efficient and durable refrigeration systems, aligning with the broader goals of energy efficiency and sustainability in the HVAC (Heating, Ventilation, and Air Conditioning) industry.

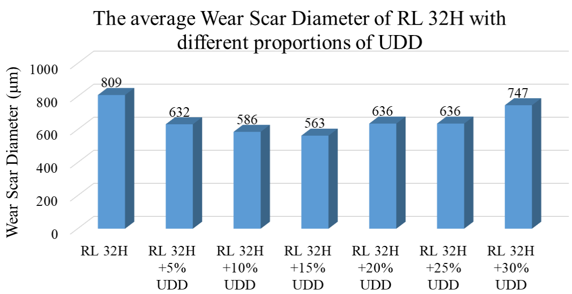


Fig. 14. shows the results after the 4-ball wear test of the refrigeration oils with the addition of UDD additive at different concentrations.

CONCLUSIONS

This study experimentally emphasizes the effectiveness of Ultra-Dispersed nano-Diamond (UDD) additives in enhancing lubrication and energy efficiency in refrigeration systems. It confirms that incorporating UDD additives into RL 32H refrigeration oil significantly enhances system performance by reducing component wear, lowering acid values and moisture content, and stabilizing the friction coefficient. This research highlights that the optimal concentration of UDD additives is crucial for maximizing lubrication effectiveness. A 300 ppm concentration of UDD additives was found to be both the most cost and performance effective, yielding the smallest wear scar diameter. This balance ensures that the refrigeration systems benefit from enhanced lubrication properties without any adverse effects on the oil's other characteristics. After 527 hours of refrigeration system operation on two identical refrigerators, the power consumption for RL 32H without UDD additive was measured at 30.3 kWh, while for RL 32H+UDD, it was significantly lower at 21.5 kWh. This indicates that the addition of UDD additives resulted in a 29% reduction in power consumption.

Moreover, the study practically reveals that UDD additives contribute to energy efficiency in refrigeration systems. After the initial 100-hour 'run-in' phase, refrigeration oil with UDD additives demonstrated a significant reduction in power consumption compared to oil without additives. This reduction is attributed to the improved lubrication quality provided by UDD additives, which decreases the internal resistance of the system, leading to more energy efficient operation.

The findings of this research are significant for the development of more sustainable and efficient refrigeration technologies. UDD additives can be a vital component in refrigeration systems, enhancing lubrication performance and reducing energy consumption. This aligns with the broader goals of sustainability in the HVAC industry, offering a pathway to more environmentally friendly and cost-effective refrigeration solutions.

REFERENCES

Azmi, W.H., Sharif, M.Z., Yusof, T.M., Mamat, R., and Redhwan, A.A.M., "Potential of nanorefrigerant and nanolubricant on energy saving in refrigeration system – A review," *Renewable and Sustainable Energy Reviews*, Vol. 69, March 2017, pp. 415-428.

Babarinde, T.O., Akinlabi, S.A., Madyira, D.M., and Ekundayo, F.M., "Enhancing the energy efficiency of vapour compression refrigerator system using R600a with graphene nanolubricant," *Energy Reports*, Vol. 6, 2020, pp. 1-10.

Chebattina, KodandaRama Rao, Srinivas, V., and Mohana Rao, N., "Influence of Size and Weight Fraction of Multi-Walled Carbon Nanotubes Dispersed in Gear Oils for Improvement of Tribological Properties," *Journal of the Chinese Society of Mechanical Engineers*, Vol.42, No.1, pp 63~71 (2021)

Choi, T.J., Kim, D.J., Jang, S.P., Park, S., and Ko, S., "Effect of polyolester oil-based multiwalled carbon-nanotube nanolubricant on the coefficient of performance of refrigeration systems," *Applied Thermal Engineering*, Vol. 192, June 2021, pp. 116941.

Cohen, J., Screen, J.A., Furtado, J.C., Barlow, M., Whittleston, D., Coumou, J., Francis, J., Dethloff, K., Entekhabi, D., and Overland, J., "Recent Arctic amplification and extreme mid-latitude weather," *Nature Geoscience*, Vol. 7, No. 9, September 2014, pp. 627-637.

Hsin, Y.L., Chu, H.Y., Jeng, Y.R., Huang, Y.H., Wang, M.H., and Chang, C.K., "In situ de-agglomeration and surface functionalization of detonation nanodiamond with the polymer used as an additive in lubricant oil," *Journal of Materials Chemistry*, Vol. 21, 2011, pp. 13213–13222.

Horng, J.H., Yu, C.C., Chen, Y.Y., "Tribological characteristics and load-sharing of point-contact interface in three-body mixed lubrication," ASME Transaction, Journal of Tribology, Vol.144 (5), 052201.

Mandal, S., Islam, M.S., Biswas, M.H.A., and Akter, S., "A mathematical model applied to investigate the potential impact of global warming on marine ecosystems," *Applied Mathematical Modelling*, Vol. 101, January 2022, pp. 19-37.

Pico, D.F.M., Silv, L.R.R., Mendoz, O.S.H., and Filho, E.P.B., "Experimental study on thermal and tribological performance of diamond nanolubricants applied to a refrigeration system using R32," *International Journal of Heat and Mass Transfer*, Vol. 152, May 2020, pp. 119493.

Rasheed, A.K., Khalid, M., Javeed, A., Rashmi, W., Gupta, T.C.S.M., Gupta T.C.S.M., and Chan A., "Graphene based nanofluids and nanolubricants – review of recent developments," *Renewable and Sustainable Energy Reviews*, Vol. 63, 2016, pp. 346-362.

Rasheed, A.K., Khalid, M., Javeed, A., Rashmi, W., Gupta T.C.S.M., and Chan A., "Heat transfer and tribological performance of graphene nanolubricant in an internal combustion engine," *Tribology International*, Vol. 103, 2016, pp. 504-515.

Saidur, R., Kazi, S.N., Hossain, M.S., Rahman, M.M., and Mohammed, H.A.M., "A review on the performance of nanoparticles suspended with refrigerants and lubricating oils in refrigeration systems," *Renewable and Sustainable Energy Reviews*, Vol. 15, No. 1, January 2011, pp. 310-323.

Sanukrishna, S.S., and Jose, V.M., "Evaluation of thermal and rheological characteristics of CNT-PAG nanolubricant for the development of energy efficient refrigeration systems," *Materials Today: Proceedings*, Vol. 58, 2022, pp. 114-120.

T.N. Ta, S.Y. Chern, J.H. Horng, "Tribological behavior of ionic liquid with nanoparticles," *Materials*, Vol.14 (21), 6318.

Wang, Y.R., Hessen, D.O., Samset, B.H., and Stordal, F., "Evaluating global and regional land warming trends in the past decades with both MODIS and ERA5-Land land surface temperature data," *Remote Sensing of Environment*, Vol. 280, October 2022, pp. 113181.

Yang, S., Cui, X., Zhou, Y., and Chen, C., "Study on the effect of graphene nanosheets refrigerant oil on domestic refrigerator performance," *International Journal of Refrigeration*, Vol. 110, February 2020, pp. 187-195.

Zhai, W., Srikanth, N., Kong, L.B., and Zhou, K., "Carbon nanomaterials in tribology," *Carbon*, Vol. 119, August 2017, pp. 150-171.

奈米鑽石添加劑對提升冷凍系統之潤滑與節能效能之研究

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摘 要

本研究深入探討超分散奈米鑽石（UDD）添加劑在冷凍系統中冷凍機油的潤滑性能提升及其節能效果。實驗將分析不含添加劑的RL 32H冷凍機油與含有UDD添加劑的冷凍機油，特別是探討含300 ppm濃度UDD添加劑的樣本，其磨損減少顯著。該實驗通過對兩台相同型號的冷凍機進行527小時的長期運行測試，結果顯示，含有300 ppm UDD添加劑的RL 32H冷凍機油的能耗比無添加劑的低29%。這證明了UDD添加劑不僅可以改善冷凍機油的潤滑性能，降低磨損，還可以顯著提高能效，為冷凍系統提供一種節能的新途徑。