Experimental Study: The Effects of Using Nano-Lubrication on the Performance of Refrigeration Systems

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Abstract. An experimental apparatus was built to investigate the performance of a refrigeration system based on the coefficient of performance (COP) and energy consumption of an air conditioning device. Enhancement of performance of a window unit air conditioning device was sought by mixing nanoparticles with mineral oil (MO 4E) to act as a lubricant, using R22 refrigerant as a working fluid. Different concentrations of Al2O3/Mineral Oil (MO 4E) were mixed by using ultrasonic and other mixing devices. The results showed that the COP was increased and energy consumption decreased when nano lubricant was used, and that the optimum concentration was 0.05% Al2O3 by mass, where the enhancement in COP was 25% compared to plain MO 4E; the energy consumption in the compressor was also lower. Thus, enhancing the coefficient of performance (COP) of the system by adding a small percentage of nanoparticles to the lubricant oil appears to be feasible.

Key words: Mineral oil, Nano-Lubricant, Al2O3, Coefficient of Performance (COP), energy consumption, air conditioning.

1. Introduction

Nano lubricant is an advanced lubrication type with increased capabilities in terms of reduction of friction losses and heat transfer enhancement. Nanoparticles (1 to 100 nm in diameter) are added to oil to make nano lubricants, and these can then be used in applications such as the compressors of refrigeration systems. A considerable number of studies on the applications or thermal properties of nano refrigerants have been done. Bi et al. [1] conducted a study on refrigeration using R134a/TiO2 nano refrigerant, with results that indicated the COP was better and the energy savings were 26.13% at a 0.1% mass fraction. Peng et al. [2] studied the influence of mixing CuO nanoparticles with R113 pure refrigerant on the pressure drop inside a horizontal tube; the results showed that the pressure drop was increased by a maximum of 20.8% when using this nano fluid. Henderson et al. [3] conducted an investigation into the effects of nanoparticles in R134a/polyol-ester mixtures with SiO2 at 0.05% and 0.5% volume concentrations. The results indicated that the convective boiling heat transfer coefficient was decreased by as much as 55%. Peng et al. [4] studied the effect of CNT in R113/oil mixture on nucleate pool boiling heat transfer characteristics. They found that the R113/oil/CNTs nano refrigerant increased the nucleate pool boiling heat transfer coefficient by 61%. Abdel-Hadi et al. [5] conducted a study on a vapor-compression system using CuO/R134a nano refrigerant. They found that the maximum heat transfer enhancement was 0.55%. Kedzierski [6] used Al2O3 nanoparticles with R134/ PAG at various mass fractions (0.5%, 1%, and 2%), and the results indicated that heat transfer was enhanced for mixtures with nano refrigerant compared with pure R134a/ PAG. Kumar and Elansezhian [7] performed experimental studies on a vapor-compression refrigeration system to show the effects of an R134a/Al2O3/PAG oil mixture on freezing capacity and energy consumption. The results showed that the energy consumption was reduced by 10.32% and the COP was increased when using a 0.2% concentration nano refrigerant. Sun and Yang [8] investigated the effects of different nanoparticles (Cu, Al, CuO, and Al2O3) on flow boiling heat transfer, and found that the Cu-R141b nano refrigerant gave the maximum heat transfer coefficient, while the minimum heat transfer coefficient occurred when using R141b/CuO. Bandgar et al. [9] carried out an experimental study of VCRS-R134a, investigating the
performance when using SiO₂ Nanoparticles mixed with POE oil/mineral oil as a lubricant at 0.5%, 1.5% and 2% mass fractions; the optimum concentration was the 0.5% mass fraction, where the performance was 12.16% greater than that of pure POE oil and the power consumption was 13.89% less than with pure POE oil. Zhelezny et al. [10] experimentally investigated the viscosity, density, and solubility of R600a-mineral oil with nanoparticles of Al₂O₃ and TiO₂. The results indicated that the addition of nanoparticles to the lubricant led to increases in solubility, viscosity, and density, as well as reducing the surface tension.

In the present study, a window-mounted air conditioning system has been selected to test the effects of nano lubricant on COP and energy consumption. The range of mass fractions for the alumina (Al₂O₃) particles used stretches from 0.01% to 0.2%.

2. Methodology
The performance of the system under investigation can be represented by the coefficient of performance COP for the system, which is equal to the acquired heat from the evaporator \( q_\text{L} \) divided by the energy consumption in the compressor \( w_\text{in} \), as shown in figure 1 (p-h diagram); thus, energy consumption inversely effects the COP, which can be calculated from the following equations[11]:

\[
q_\text{L} = h_1 - h_4 \\
w_\text{in} = h_2 - h_1
\]

... (1)

... (2)

![Figure 1: p-h Diagram of the refrigerant R22 n refrigeration cycle.](image)

The enthalpy is found from the recorded temperature by utilising a refrigerant R22 table, and thus the COP can be calculated as [11]

\[
\text{COP} = \frac{q_\text{L}}{w_\text{in}} = \frac{h_1 - h_4}{h_2 - h_1} 
\]

... (3)

3. Experimental work
An air conditioning system of the type used in windows was used as an experimental rig as shown in Figure 2. It consisted of a compressor, evaporator, condenser, and capillary tube with the addition of necessary
minor parts such as the section fan, discharge fan, fan motor, vacuum pump, and air compressor, as well as relevant measuring devices such as pressure gauges, a thermometer, an ammeter, a voltmeter, an electronic weight for charging refrigerant gases, and a sensor for leaks. Eight thermocouples of type K were used with four pressure gauges to capture experimental data. The schematic diagram of this system is shown in Figure 3. There are two different pressures within the closed system; after the compressor, pressure rises while expanding through the capillary tube, so the refrigerant flows into the evaporator at low pressure and into the condenser at high pressure. Two fans pass air over both evaporator and condenser to force heat transfer through them; these work on the same motor, with the shaft being longer on one side. Compressed air was used to charge the system with a pressure higher than standard to test for any leaks, and a vacuum pump device was used to discharge air from the system before charging it with the refrigerant, R22 gas. Figure 4 shows that the procedure of discharging and charging of the nano lubricant involves the compressor being separated from the system and placed upside down to discharge the oil already inside. Then, the mixture with nano lubricant is inserted into the compressor before its return to the system.
Figure 2. Experimental rig
Figure 3: Schematic diagram cycle

Figure 4: The procedure of charging oil into the compressor
4. Preparing the Nano lubricant

Nano lubricants are mixtures of nanoparticles and lubricant oil: mineral oil 4E with Al2O3 at 20 nm was used in this experimental study. The appropriate quantity of nanoparticles, \( \varnothing \), to be mixed with the base fluid was determined using equation 4 [12]. Table 1 outlines the properties of the nanoparticles.

\[
\varnothing = \frac{m_n}{m_o + m_n}
\]  

... (4)

| Type of material | Density Kg/m³ | Specific heat capacity J/Kg-K | Size nm | Morphology | Purity | Colour |
|-----------------|---------------|-------------------------------|--------|------------|--------|--------|
| \( \gamma \)-Al2O3 | 3890          | 880                           | 20     | Nearly spherical | 99+% | White  |

The nano lubricant was prepared in a conventional manner for nano fluids: a specific quantity of nanoparticles of type Al2O3 was mixed with mineral oil using an ultrasonic device for 10 min at 40 °C, as shown in figure 3a. Then, the blend was placed under an electrical mixing device for 30 min. Figure 5b shows the mixture process.
5. Results and Discussion

This study involved a comparison between two types of oil, POE oil, and MO 4E, to examine which was more effective in terms of heat exchange and energy saving. Then, the best oil was used as a basis for adding nanoparticles to test the effectiveness of such nanoparticles in terms of improving the transfer of heat and reducing the energy consumed. The latter process was done for different concentrations of nanomaterials in order to study the effect of increasing the concentration of nanoparticles.

a. Comparison Results

The comparison process was conducted based on values of the coefficient of performance, COP. The results showed that the COP and energy consumption per unit mass of MO 4E was better than that of POE, as indicated in Figure 6 and Figure 7.

![Figure 6. Energy consumption per unit mass KJ/Kg](image1)

![Figure 7. Coefficient of performance](image2)

b. Different concentrations of nano lubricant

Based on the initial results, mineral oil (MO 4E) was found to be more effective than POE oil, so this was selected for the addition of Al2O3 nanoparticles. Five different concentrations were tested (0.01, 0.05, 0.1, 0.15, and 0.2 % Al2O3 mass fractions), with MO 4E used as a lubricant in each case. Figure 8 shows the outlet temperatures from the compressor at different concentrations; at 0.15% Al2O3 mass fraction, the outlet temperature was lowest at 83.5 °C.
Figure 8. The outlet temperature of the compressor unit.

Figure 9 shows the effects of nano lubricant (Al2O3 with MO 4E) on the energy consumption in the compressor unit, which was lowest at a concentration of 0.05% Al2O3/MO 4E mass fraction at 35.56 KJ/Kg.

Figure 9. Energy consumption per unit mass in the compressor unit
By using nano lubricant, the COP was improved. **Figure 10** shows the enhancement in COP for different concentrations; the best concentration was 0.05% Al2O3, where a value of 6.092.

![Figure 10. Coefficient of performance.](image1)

The enhancement in the performance of air conditioning as a result using nano lubricant was also investigated. The results of increasing COP for different concentrations of nano lubricant are shown in **Figure 11**. The optimum value was 25.61% when using the 0.05% Al2O3 mass fraction.

![Figure 11. Enhancement of the coefficient of performance](image2)
6. Conclusions

From this experimental study, it can be noted that

1. A comparison between two lubricant oils (MO 4E and POE) found that the mineral oil (MO 4E) was more effective than POE oil in terms of the COP and energy consumption per unit mass.

2. Adding Al2O3 to the lubricant oil of a compressor leads to an increase in COP of air conditioning. The optimum COP was 6.092 at a lower energy consumption when using 0.05% Al2O3/MO 4E mass fraction concentration as a lubricant oil.

3. Mixing nanoparticles with lubricant decreases the energy consumption and increases the heat transfer in an evaporator through enhancing the thermal properties of the fluid as well as reducing friction losses between the parts of the compressor.

7. References

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