Experimental study of a domestic refrigerator using (SiO₂/PAG oil/R-134a) nano-refrigerant as a replacement for pure R-134a

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1. Introduction

The working fluid of a vapor compression refrigeration system (VCRS) changes from liquid to vapor at the heat absorption section (evaporator) and then back to liquid at the heat rejection section (condenser). The Coefficient of Performance is the ratio of the heat absorption section's refrigeration effect to the compressor's work input. COP increases by decreasing the compressor's work input or raising the heat removal rate. Nano-fluids are a new type of heat transfer fluid that emerged due to fast advancements in nanotechnology. Nano-fluids are a unique fluid consisting of a main fluid suspended in nano-sized particles (1–100 nm). The Nano-fluids are mixes of the base liquid and Nanoparticles at particular concentrations. Lubricating oil, water, or refrigerant can be used as the main base fluid. CuO, ZrO₂, SiO₂, and other Nanoparticles are combined to create a colloid solution known as Nano-fluid. Nanoparticles have recently been employed in refrigeration systems to increase the COP and dependability of vapor compression refrigeration systems due to their better heat transfer capabilities. It lowered the amount of energy necessary to achieve the cooling effect. K nil Achari, and Dr.Smt.G.Prashanthi [1].

1.1. Literature survey

Kedzierski [2] investigated using (CuO) nanoparticles of 30 nm diameter to 1% and 0.5% volume fractions respectively, suspended in R-134a and Polyolester mixture on a roughened horizontal flat surface to compute the boiling performance. The results showed a 0.5% increase in boiling heat transfer. Ghobani et al [3] explored experimentally the effect of adding CuO nano-particles in R600a refrigerant. The work was validated with three different working fluids including: Pure R-600a, R-600a-POE oil, and R-600a-oil-CuO with concentrations of 0.5 %, 1 %, and 1.5 %. The results showed an increase in the heat-transfer coefficient by 4.1 %, 8.11 %, and 13.7 %, respectively. Senthilkumar and Praveen [4] experimentally described the method to energy efficiency of refrigeration retorting system’s improvement that used the R600a refrigerant along with CuO nano particles. According to the findings, when CuO-R600a is used at concentrations of 0.1% and 0.5% and 11.83 and 17.88 % of energy was
saved, respectively while CuO-R600a had a faster freezing time than the pure R600a. Shashikumar and Mysamy [5] investigated the performance of nanoparticles with an equivalent nanoparticle weight ratio and nanorefrigerant replacement fractions of (0.005, 0.01, 0.015% weight proportion) in a VCRS. R134a, was combined with a variety of copper oxide, titanium oxide, silicon oxide, and aluminum oxide compositions (50nm). As a consequence of this investigation, the consumed power was reduced, and the COP of the system was enhanced (2.656 actual COP at 0.015%). It was found that the use of a nano-refrigerant was both ecologically friendly and safe. Kristen Bartelt et al [6] investigated the CuO nanoparticles to see how they affect the flow-boiling of an (R134a/POE oil) mixture in a plane tube. Along with synthetic-ester and copper oxide nanoparticles dissolved in the mix at 4% concentration. The heat-transfer coefficient improved by 42 to 82% when utilizing a nano-lubricant mass fraction of 1% compared to a refrigerant-oil combination that without nanoparticles. When the mass fraction was increased to 2%, the heat-transfer coefficient enhanced by 50% to 101%. Gill et al [7] investigated the energy and exergy characteristic of a household refrigeration system. Employing R134a, and the liquefied Petroleum Gas refrigerants with various oils (Polyester, Mineral oil, and TiO₂, SiO₂, and Al₂O₃ nanoparticles dispersed in mineral oil). Among the evaluated nano-lubricants, the household refrigerator employing LPG refrigerant at 40 g charge with TiO2-MO (0.2 g/L TiO2) lubricant exhibited the greatest COP and second lowest efficiency (56.32 % and 47.06 %, respectively, greater than R134a/POE). With the least energy and exergy performance analysis of the domestic refrigerator. Henderson et al [8] quantified the effect of using nanoparticles like SiO₂/CuO on the flow-boiling of pure R134a and R134a/POE-oil mixes throughout mass-fluxes between 100 kg/m²s and 400 kg/m²s. The results showed using SiO₂ nanoparticles with R-134a, the heat-transfer coefficient decreased by up to 55%. When CuO nanoparticles were utilized with an R-134a/Polyester mixture, the heat-transfer coefficient rose by 100%. Bandgar et al [9] determined which type of lubricating oil performs best with SiO₂ nanoparticles with Polyester (POE) oil, and Mineral oil in the refrigeration field, at concentrations of 0.5%, 1%, and 1.5%. When a mixture of Mineral-oil and 0.5% Silica nano-particles were used with R-134a refrigerant, resulted an enhancement in the freezing time and a reduction of power consumption by 13.89. Nano lubricants can help to save energy while also raising the Coefficient of Performance (COP) by 12.16%. The present research studies the possibility of SiO₂ nanoparticles to improve vapor compression refrigeration system performance when used at different concentrations (0.1 %, 0.3 %, and 0.5 %) with an R-134a refrigeration gas and PAG oil. A nano-refrigerant of SiO₂ nanoparticles (50nm) blended with 200ml of refrigeration oil and refrigerant gas was pumped into the system. The goal of this study is to compare the power consumption and coefficient of performance of working with a pure refrigerant vs working with a nano-refrigerant.

2. Experimental setup

This part deals with the process of construction the vapor compression refrigeration system, preparing, and charging of the nano-lubricant. The main components of the test rig are:

**Table 1. Components of test rig**

| Component   | Details |
|-------------|---------|
| Compressor  | Reciprocating compressor with a single-cylinder capacity of 120 W. |
| Condenser   | Pipe of 6.35 mm diameter and 8 meters. |
| Filter drier|         |
| Capillary tube |        |
| Evaporator  | Evaporator's surface area: 0.152 m² |
| Energy meter| Two at the inlet (low pressure gauge) and outlet (high pressure gauge) of the compressor. |
| Pressure gauge| Five Thermocouples Type k sensors for different locations. |

![Figure 1. Components of test rig](image1.png)

![Figure 2. Vapor compression refrigeration system test rig](image2.png)

**Nomenclature:**

- \( C_{ph} \): specific heat of water (J/kg K)
- \( COP \): coefficient of performance
- \( D \): diameter of the tank water (m)
- \( H \): height of the tank water (m)
- \( E_r \): Readings output of the energy meter (kWh)
- \( E_i \): Readings input of the energy meter (kWh)
- \( P \): density of pure water (g/m³)
- \( M_w \): Mass of water in the tank (g)
- \( dT \): Temperature difference (°C)
- \( RE \): Refrigeration effect (KJ)

![Figure 3. Diagram of test rig](image3.png)
Along with the nano-fluid preparation and charging devices:

- Mechanical stirrer
- Ultra-sonic device
- Nano-fluid injector

2.1. Nano-fluids Preparation and charging method

Nanoparticles are not immediately injected inside the refrigeration system. Instead, they must be thoroughly mixed in the lubricating oil. In general, there are two methods for preparing nanofluids: one-step and two-step procedures. The two-step technique was chosen for this study. In the present case, the lubrication oil was PAG oil. SiO2 nano-particles were blended with lubricating oil according to refrigerant quantity. Stir for 2-3 hours to ensure appropriate mixing of nano-particles with lubricating oil. The nanoparticles are then stabilized in an ultrasonicate and fed into the refrigeration system through a compressor using a nano injector device after thoroughly mixing or completely disseminating in lubricating oil.

Table 2. Thermo-physical properties of SiO2

| Thermo-physical properties   | SiO2 |
|------------------------------|------|
| Specific heat capacity (J/kg.K) | 745  |
| Density (kg/m³)              | 2220 |
| Thermal conductivity (W/m.K) | 1.4  |

3. Results and discussions

This part shows the results of the coefficient of performance, power consumption, and refrigeration effect when using different concentrations of nano-refrigerant. Compare it with the pure R-134a refrigerant.

Fig. 4 shows that when using pure R-134a refrigerant with PAG oil, COP of the system was 2.3. However with the addition of different concentration of SiO2 nanoparticles, the coefficient of performance increases to 2.81 at a concentration of 0.5%. The COP of the system increased by 18.14% at concentration of 0.5%.

Figure 3. SiO2/ PAG oil preparation procedure: a) mechanical stir, b) ultra-sonic device, c) Nano-fluid injector
Figure 5. Power consumption and different concentrations of SiO2 nanoparticles when temperature of water inside the evaporator is: (a) 40°C; (b) 50°C

Fig. 5 shows that when using pure R-134a refrigerant with PAG oil, the power consumed by the compressor was 608.69 KJ. However with using nano-refrigerant, this value was reduced to 567.22 KJ at a concentration of 0.5%

Figure 6. Refrigeration effect and different concentrations of SiO2 nanoparticles at different temperature of water inside the evaporator

Fig. 6 shows that when using pure R-134a refrigerant with PAG oil, the refrigeration effect was 1850 KJ. However, with using nano-refrigerant, it had been increased to 2062 KJ at a concentration of 0.5%

4. Equations

a. Mass of water
\[ m = \rho \cdot V \cdot g \]  

b. Volume of water tank
\[ V = \pi/4 D^2 h \cdot m^3 \]  

c. Refrigeration effect
\[ RE = m \cdot c_{pw} \cdot DT \cdot KJ \]  

d. Power input to compressor
\[ P = (E_o - E_i) \cdot 3600 \cdot KJ \]  

e. Coefficient of performance
\[ COP = \frac{m \cdot c_{pw} \cdot DT}{(E_o - E_i) \cdot 3600} \]  

5. Conclusion

The current work, showed an overall improvement in the VCRS when using different concentrations of SiO2/PAG oil/R-134a nano-refrigerant, because of the nanoparticles thermo-physical properties. In the present work the size of nanoparticles (SiO2) that has been used 50 nm at three concentrations (0.1%, 0.3%, and 0.5%), with three temperatures of water in the evaporator (40°C, 50°C, and 60°C). The observations of this work are the following:

1) Increment in the refrigeration effect, where \( RE = 1850 \text{ KJ} \) in the case of pure refrigerant (R-134a), while increased to \( 2062 \text{ KJ} \) at a concentration of 0.5%. The refrigeration effect maximum increase was at concentration of 0.5% by 12.2%.

2) Reduction in the consumed power, where it was \( 608.69 \text{ KJ} \) in the case of pure refrigerant (R-134a), while decreased to \( 567.22 \text{ KJ} \) at a concentration of 0.5%. The consumed power maximum decrease was at concentration of 0.5% by 6.81%.

3) Increment in the coefficient of performance, where \( COP = 2.3 \) in the case of pure refrigerant (R-134a), while increased to \( 2.81 \) at a concentration of 0.5%. The COP maximum increase was at concentration of 0.5% by 18.14%.

6. Recommendations

The science of nanotechnology is still a new science on the scene, which would greatly increase the efficiency of refrigeration systems. Therefore, my advice to the next researcher is to search for new types of nanoparticles in order to use them in the refrigeration system so that there are more and broader studies on the subject. And also to find solutions to the problems of sedimentation and instability in these materials, in order to use the refrigeration system by adding nanomaterials in reality.

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