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Experimental study of a domestic refrigerator using (SiO_2/PAG oil/R-134a) nano-refrigerant as a replacement for pure R-134a

Dalya Shaker Qaid* and Abbas Alwi Sakhir

Department of Mechanical Engineering, Collage of Engineering, University of Al-Qadisiyah, Ad-Diwaniyah, Iraq

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A B S T R A C T

This research studies the influence of using SiO_2 nano-particles of 50nm in a Vapor Compression Refrigeration System (VCRS), along with Poly-alkylene Glycol (PAG) oil and R-134a mixed to create a nano-refrigerant. The methodology used in this work, the nano-particles were performed in three different concentrations (0.1%, 0.3%, and 0.5%) and mixed with 200ml of PAG oil. A VCR system was built at the mechanical engineering department laboratory in Al-Qadisiyah University. In order to study the Coefficient of Performance (COP) and the consumed energy by the compressor in the two cases of adding the nano-particles and using a pure refrigerant. The paper showed an increase in the system's COP from 2.3 to 2.81 when using a concentration of 0.5% of SiO_2/PAG oil/R-134a, increasing the refrigeration effect and decreasing the consumed power.

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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 solution with 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, ZrO_2, SiO_2, 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.Prasanthi [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. Ghorbani 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

* *Corresponding author.*
E-mail address: dalyashaker1997@gmail.com(dalya shaker qaid)

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Nomenclature:

Cp_w	specific heat of water (J/ kg·K)	E_i	Readings input of the energy meter (kwh)
COP	coefficient of performance	P	density of pure water (g/m³)
D	diameter of the tank water (m)	M_w	Mass of water in the tank (g)
H	height of the tank water (m)	dT	Temperature difference (C°)
E_o	Readings output of the energy meter (kwh)	*RE*	Refrigeration effect (KJ)

saved, respectively while CuO-R600a had a faster freezing time than the pure R600a. Shashikumar and Mylsamy [5] investigated the performance of nanoparticles with an equivalent nano particle weight ratio and nano-refrigerant 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 nano-particles 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 nano-particles 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 nano-particles. 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 TiO_2, SiO_2, and Al_2O_3 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 SiO_2/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 SiO_2 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 SiO_2 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 SiO_2 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 SiO_2 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 Material: copper
Energy meter	
Pressure gauge	Two at the inlet (low pressure gauge) and outlet (high pressure gauge) of the compressor.
Temperature sensor	Five Thermocouples Type k sensors for different locations.

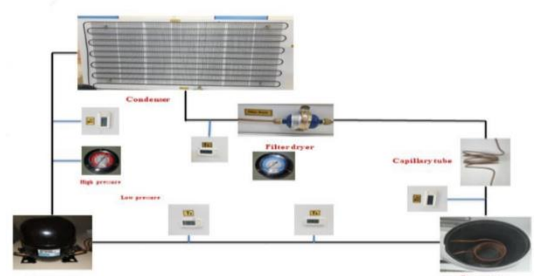


Figure 1. Components of test rig

Figure 2. Vapor compression refrigeration system test rig

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

(a)

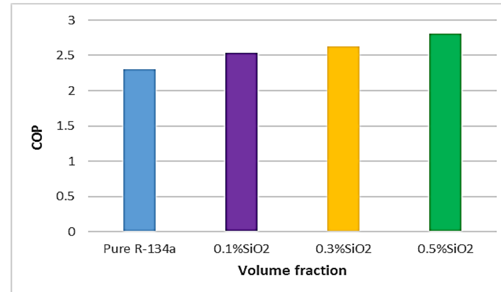
(b)

(c)

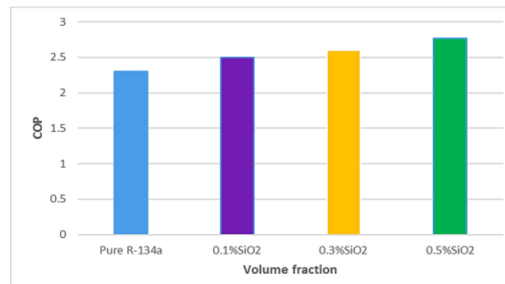
Figure 3. SiO_2 / PAG oil preparation procedure: a) mechanical stir, b) ultra-sonic device, c) Nano-fluid injector

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.



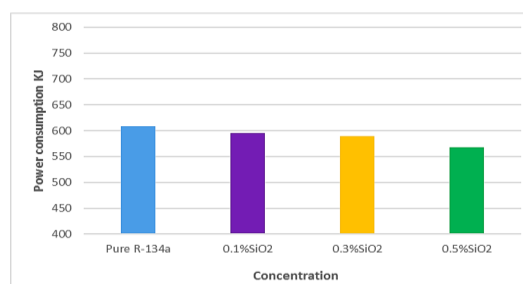
(a)



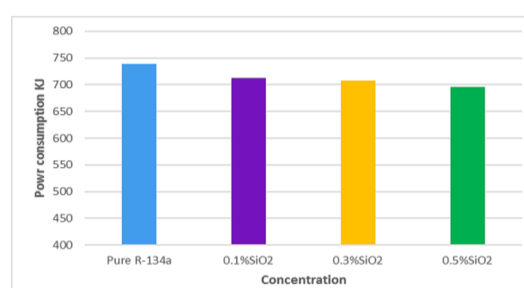
(b)

Figure 4.COP and different volume fractions of SiO2 nanoparticles when temperature of water inside the evaporator is: (a) 40C◦ ; (b) 50C◦

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%.



(a)



(b)

Figure 5. Power consumption and different concentrations of SiO2 nanoparticles when temperature of water inside the evaporator is: (a) 40C◦; (b) 50C◦

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 0.5%

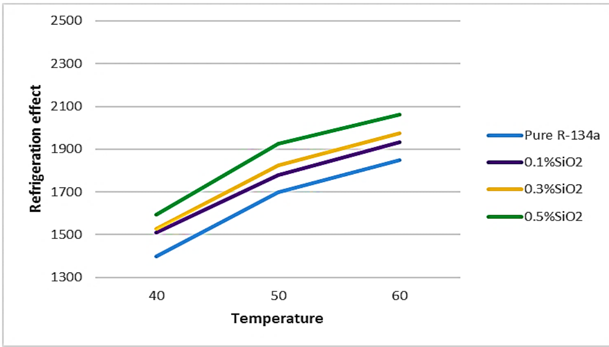


Figure 6. Refrigeration effect and different concentrations of SiO2 nanoparticles at different temperature of water inside the evaporator

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

$$m = \rho . v \quad , g \qquad (1)$$

b. Volume of water tank

$$V = \pi / 4 D^2 h \quad , m^3 \qquad (2)$$

c. Refrigeration effect

$$RE = m_w \, cp_w \, dT \quad , KJ \qquad (3)$$

d. Power input to compressor

$$P = (E\boldsymbol{o} - E_i).3600 \quad , KJ \qquad (4)$$

e. Coefficient of performance

$$COP = \frac{mw \; cpw \; dT}{(Eo - Ei).3600} \qquad (5)$$

5. Conclusion

The current work, showed an overall improvement in the VCRS when using different concentrations of SiO_2/PAG oil/R-134a nano-refrigerant, because of the nanoparticles thermo-physical properties. In the present work the size of nanoparticles (SiO_2) that has been used 50 nm at three concentrations (0.1%, 0.3%, and 0.5%), with three temperatures of water in the evaporator (40C◦, 50C◦, and 60C◦). The observations of this work are the following:

1) Increment in the refrigeration effect, where RE was 1850 KJ in the case of pure refrigerant (R-134a), while increased to 2062 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 KJ in the case of pure refrigerant (R-134a), while decreased to 567.22 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 was 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%.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

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