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Enhancing the Performance of a Vapour Compression Refrigerator System Using R134a with a CuO/CeO_2 Nano-refrigerant

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Most studies report that dispersing nanoparticles into refrigerants and lubricating oils leads to performance improvements in refrigeration systems, due to improvements in the thermal physics properties of a pure refrigerant, which leads to reduced energy consumption. Using nanoparticles in a refrigeration system is associated with many difficulties, such as the cost of preparing and obtaining a stable and homogeneous mixture with less agglomeration and sedimentation. Most current studies focus on the use of metals, metal oxides, and a hybrid of oxides as nanoparticles in refrigeration systems. In this research, nanoparticles were prepared in an inexpensive and easy way as a single oxide and as a mixture consisting of copper and cerium oxides. The results of nanoparticle preparation using X-ray diffraction and scanning electron microscopy prove that the particles of the samples were spherical in shape, with suitable average diameters ranging from 78.95 nm, 79.9 nm, 44.15 nm and 63.3 nm for copper oxide, cerium oxide, the first mixture, and the second mixture, respectively. Cerium oxide has not been used in a refrigeration system; this study preferred the implementation of a theoretical study using Ansys Fluent software to verify the possibility of improving the performance of the refrigeration system. The results confirmed that copper oxide enhanced the coefficient of performance of the refrigeration system by 25 %, and cerium oxide succeeded in improving the performance of the. system by a lesser value. The mixture containing a higher percentage of copper oxide yielded better results.
Keywords: vapour compression refrigeration system, coefficient of performance, nano-refrigerant, nanoparticles

Highlights
- *The performance vapour compression refrigeration system that works using R134a was studied experimentally and theoretically as a first step without nanoparticles, and the agreement between the experimental and theoretical results was close to 98 %.*
- *This study provided an inexpensive method for preparing nanoparticles using distilled water, ammonia, copper nitrate, and cerium nitrate.*
- *Nanoparticles were prepared as follows: CuO, CeO_2; Mixture 1 consisted of 50 % CuO + 50 % CeO_2; Mixture 2 consisted of 60 % CuO + 40 % CeO_2; Mixture 3 consisted of 70 % CuO + 30 % CeO_2; Mixture 4 consisted of 40 % CuO + 60 % CeO_2; Mixture 5 consisted of 30 % CuO + 70 % CeO_2.*
- *The concept of nanoparticles as a mixture can improve the performance of refrigeration systems.*

0 INTRODUCTION

The world is facing a major challenge in the energy sector, due to its diminishing resources and a large increase in energy consumption, especially in refrigeration and air conditioners. Various studies have improved the efficiency of thermal systems. This can be accomplished in two ways: first by improving the design of the heat exchanger to include thee shell and tube type, plate type, microchannel, and so on, and second by using new kinds of working fluids **[1]**. In 1873, Maxwell dispersed particles ranging in diameter from millimetres to micrometres into a pure to enhance the thermophysical properties of the fluid; however, this attempt encountered several problems including stability, clogging, and erosion. **[2]** to **[4]**. Nanofluids have attracted the attention of many researchers in various scientific fields in recent years. Researchers used a new concept of working fluids known as "nanofluids" for the first time, which contain particles of less than 100 nm, called "nanoparticles", to improve the heat transfer characteristics of various fluids. Recently, the concept of nanofluids has been developed to include refrigerants **[2]** to **[4]**. A nanofluid is divided into three categories depending on the composition of nanoparticles: (i) mono-nanofluids, which consist of similar nanoparticles, (ii) hybrid nanofluids, which consist of dissimilar nanoparticles, and (iii) hybrid nanofluids, which consist of composite nanoparticles **[1]**. Four conditions are required for the successful preparation of the nanofluid: (i) the dispersibility of nanoparticles, (ii) the stability of nanoparticles, (iii) the chemical compatibility of nanoparticles, and (iv) the thermal stability of

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nanofluids. These conditions will create a nanofluid that has the best heat transfer properties between solid particles and fluids [5]. Practically, there are two methods to prepare the nano-refrigerants: a one-step method and a two-step method. The two-step method is commonly used for preparing nano-refrigerants, in which the nanoparticles are manufactured as a powder and then added to the base fluid, followed by several types of dispersion methods, such as agitation either by ultrasonic or magnetic force, homogenizing, and high shear mixing to disperse nanoparticles inside a mixture. The one-step method is based on condensing vapour nanophase powders into liquid by reducing the pressure and then dissolving them inside the liquid immediately [6].

The literature review is classified into two sections. The first evaluates the performance of the vapour compression refrigeration system based on nano-refrigerant and nano-lubricant, and the second evaluates the basic properties of nano-refrigerant and nano-lubricant such as thermal conductivity, viscosity, specific heat, and density. Vijayakumar et al. [7] evaluated the performance of refrigerators based on nano-lubricants consisting of an aluminium dioxide added to polyol ester oil, and 60 g of R602a was used as a refrigerant. The results showed that the refrigerating effect increased by 6.09 %, the compressor work decreased by 15.78 %, and the coefficient of performance (COP) increased by 20.09 %. Choi et al. [8] evaluated the performance of refrigerators based on nano-lubricants consisting of 0.1 wt.% multi-walled carbon nanotubes (MWCNTs) that were dispersed into the polyol ester oil, and R134a was charged as a refrigerant. The results showed that the power consumption of the compressor decreased by 17 %. Senthilkumar et al. [9] evaluated the performance of a refrigeration system based on nano-lubricants consisting of Al_2O_3 and SiO_2 hybrid nanoparticles at two different concentrations of 0.4 g/l and 0.6 g/l; 40 g and 60 g of R600a were charged as a refrigerant. The results indicated that COP and the refrigerating effect increased by 30 % and 25 % respectively, while the power consumption decreased by 80 W. Senthilkumar et al. [10] evaluated the performance of a vapour compression refrigeration system based on hybrid nano-lubricants consisting of CuO and SiO_2 at 0.2 g/l and 0.4 g/l concentrations, and 40 g and 60 g of R600a were charged as a refrigerant. The results indicated that the COP improved by 35 % and refrigeration effects by 18 % while the power consumption decreased by 75 W. Senthilkumar and Anderson [11] evaluated the performance of a refrigeration system based on nano-lubricants consisting of 0 g/l, 0.2 g/l, 0.4 g/l, and 0.6 g/l SiO_2 mixed with polyol ester oil; 30 g, 40 g, 50 g, 60 g and 70 g of R410A were used as refrigerants. The results indicated that 0.4 g/l SiO_2 and 40 g refrigerant achieved a high refrigeration effect, decreased compressor work by 80 W, and enhanced COP by 1.7. Senthilkumar et al. [12] evaluated the performance of a refrigeration system based on hybrid nano-lubricants consisting of 0.4 g/l \ ZnO/SiO_2 with 40 g R600a and 0.6 g/l ZnO/SiO_2 with 60 g R600a. The results indicated that 0.6 g/l ZnO /SiO_2 achieved a high refrigeration effect of 180 W, and enhanced COP by 1.7, while the lower compressor work was 78 W. Senthilkumar et al. [13] evaluated the performance of a vapour compression refrigeration system based on hybrid nano-lubricants consisting of 0.2 g/l, 0.4 g/l and 0.6 g/l CuO /Al_2O_3, and 70 g of R600a was used as a refrigerant. The results showed that the addition of CuO/Al_2O_3 enhanced COP by 27 % and increased the refrigeration capacity by 20 % while reducing the power consumption by 24 %. Javadi and Saidur [14] evaluated the performance of refrigerators based on nano-lubricants consisting of 0.1 wt.% Al_2O_3. The results indicated that 0.1 wt.% Al_2O_3 decreased the power consumption by 2.69 %. Gill et al. [15] evaluated the performance of a domestic refrigerator based on nano-lubricants consisting of 0.2 g/l, 0.4 g/l, and 0.6 g/l TiO_2 added to Capella D oil as an alternative to R134a. Various charges of liquefied petroleum gas from 40 g to 70 g were used as refrigerants. The results indicated that the refrigeration effect and COP were higher than R134a by approximately 18.74 % to 32.72 % and 10.15 % to 61.49 %, respectively. In addition, the compressor power input was lower than R134a by approximately 3.20 to 18.1. Additionally, the results reported that 40 g liquefied petroleum gas refrigerant with 0.4 g/l TiO_2 achieved the best energy performance of the refrigerator. Karthick et al. [16] evaluated the performance of a vapor compression refrigeration system based on four samples of nano-lubricant: Sample 1 (mineral oil + 0.02 vol.% Al_2O_3 + 0.01 vol.% TiO_2), Sample 2 (mineral oil + 0.01 vol.% Al_2O_3 + 0.005 vol.% TiO_2), Sample 3(mineral oil + 0.05 vol.% Al_2O_3), and Sample 4 (mineral oil + 0.02 vol.% Al_2O_3 + 0.02 vol.% ZnO), and R600a was charged as a refrigerant. The results indicated that COP improved by 14.61 %. All nano-lubricants exhibited a higher COP, which reduces the power consumption. Adelekan et al. [17] Investigated the performance of a domestic refrigerator based on nano-lubricants consisting of 0.2 g/l, 0.4 g/l, and 0.6 g/l TiO_2. The safe mass charge of liquefied petroleum gas was charged as a refrigerant. The results showed that all various concentrations of nanoparticles achieved a reduction in power consumption by 14 %, 9 %, and 8 %, respectively. Mineral oil achieved the highest power consumption whereas 0.2 g/l TiO_2 achieved the lowest. The refrigeration effects based on 0.4 g/l and 0.6 g/l were higher, while those based on 0.2 g/l were lower. Subhedar et al. [18] evaluated the performance of a vapour compression refrigeration system based on nano-lubricants consisting of 0.05 vol.%, 0.075 vol.%, 0.1 vol.%, and 0.2 vol.% Al_2O_3 mixed with mineral oil, and R134a was charged as a refrigerant. The results indicated that 0.075 vol.% achieved the maximum enhancement in COP of approximately 85 % and saved approximately 27 % compressor power. Additionally, it was reported that 0.075 vol.% was the best concentration. Babarinde et al. [19] investigated the performance of a refrigerator based on nano-lubricants consisting of 0.4 g/l and 0.6 g/l TiO_2 mixed with mineral oil, and R600a was used as a refrigerant as an alternative to R134a. The results indicated that 0.4 g/L TiO_2 achieved the highest COP and lowest power consumption. Selimefendigil and Bingölbalı [20] evaluated the performance of a vapour compression refrigeration system based on nano-lubricants consisting of 0.5 vol.%, 0.7 vol.%, 0.8 vol.%, and 1 vol.% TiO_2 mixed with poly alkylene glycol oil, and R134a was used as a refrigerant. The results indicated that 0.5 vol.%, 0.8 vol.%, and 1 vol.% achieved improvements of COP of approximately 1.43 %, 15.72 %, and 21.42 %, respectively; 1 vol % reduced energy consumption by 15 %. Sundararaj and Manivannan [21] investigated the performance of a vapour compression refrigeration system based on nano-lubricants consisting of 0.1 vol. % Au, 0.2 vol.% Au, 0.1 vol.% $HAuCl_4$, 0.2 vol.% $HAuCl_4$, 0.1 vol.% Au and 0.05 vol.% carbon nanotubes (CNT), 0.2 vol.% Au, and 0.02 vol.% of CNT added to poly alkylene glycol oil, and R134a was used as a refrigerant. The results indicated that 0.2 vol.% Au and 0.02 vol.% CNT achieved the lowest power input compared to other compositions, the greatest cooling capacity, and the maximum value of COP. Therefore, it is preferred to run the system using 0.2 vol.% Au and 0.02 vol.% of CNT as volume fractions. Peyyala et al. [22] investigated the performance of a vapor compression refrigeration system based on nano-lubricants consisting of 0.1 vol.% to 0.2 vol.% Al_2O_3 mixed with mineral oil, and R410a was used as a refrigerant. The results indicated an increase in the COP value with increasing nanoparticle concentrations, and the maximum value was observed at 0.2 vol.% Al_2O_3. Babarinde et al. [23] investigated the performance of a vapor compression refrigeration system based on nano-lubricants consisting of 0.2 g/l, 0.4 g/l, and 0.6 g/l graphene added to mineral oil, and 50 g to 70 g of R600a which were used as a refrigerant. The results indicated that the nano-lubricant based on 60 g of R600a and 0.2 g/l graphene exhibited the lowest power consumption, and the highest COP. Adelekan et al. [24] evaluated the performance of a domestic refrigerator based on nano-lubricants consisting of 0.1 g/l, 0.3 g/l, and 0.5 g/l TiO_2, mixed with mineral oil, and 40 g, 60 g, and 80 g of R600a were used as refrigerants. The results showed that the highest COP and refrigerating effects were 4.99 kJ/kg and 290.83 kJ/kg based on 40 g 0.1g/l nano-lubricant. Ajayi et al. [25] evaluated the performance of a vapor compression refrigeration system based on 0.5 g/l Al_2O_3 mixed with Capella D oil, and 100 g of R134a was used as a refrigerant. The results showed that nano-lubricants achieved a higher refrigeration effect, better performance, and improved energy consumption. Senthilkumar and Anderson [26] evaluated the performance of a vapor compression refrigeration system, based on nano-lubricants consisting of 0.2 g/l, 0.4 g/l, and 0.6 g/l SiO_2, added to polyol ester oil, and 30 g, 40 g, 50 g, 60 g and 70 g R410A were used as refrigerants. The results indicated that 40 g of R410A and 0.4 g/l of SiO_2 achieved better refrigerating effects and reduced power consumption. This leads to an enhanced COP. Pawale et al. [27] evaluated the performance of a vapor compression refrigeration system based on nano-refrigerant consisting of 0.5 wt.%, and 0.1 wt.% Al_2O_3, and a particle size diameter of 50 nm was dispersed into R134a. The results showed that 0.5 wt.% improved the performance; however, the increase in nanoparticle concentration will lead to a decrease the performance of the system. Kumar et al. [28] evaluated the performance of a vapor compression refrigeration system based on nano-refrigerant consisting of (1 g of ZnO / 1 g SiO_2), (1.5 g of ZnO / 0.5 g of SiO_2), and (0.5 g of ZnO /1.5 g of SiO_2) dispersed into 0.5 kg of R134a. The results showed that COP increased approximately 26 %. Manikanden and Avinash [29] investigated the performance of domestic refrigerators based on nano-refrigerants consisting of CuO, pure nano-CuO, and Ag-doped nano-CuO dispersed into R290. The results indicated that Ag-doped nano-CuO achieved the best performance of the system compared to pure nano-CuO. The COP of Ag-doped nano-CuO increased up to 29 %, while the power consumption of a system reduced up to 28 %. Kundan and Singh [30] evaluated the performance of a vapour compression refrigeration system based on nano-refrigerant consisting of 0.5 wt.% to 1 wt.% Al_2O_3 dispersed into R134a, with a particle size diameter of 20 nm The results based on volume flow rates of refrigerants showed that 6.5 l/h and 11 l/h achieved improvements of COP from 7.20 % to 16.34 % respectively at 0.5 wt.% Al_2O_3; however, 1 wt.% Al_2O_3 caused a reduction in COP at the same volume flow rates. Nagaraju and Reddy [31] evaluated the performance of a vapour compression refrigeration system based on nano-refrigerants consisting of 0.05 wt.% to 0.8 wt.% CuO particle sizes ranging from 10 nm to 70 nm dispersed into R134a..The results showed that 0.8 wt.% of CuO was the optimal concentration that achieved the highest heat transfer enhancement, enhanced COP, and reduced power consumption Kumar and Tiwari [32] evaluated the performance of a vapor compression refrigeration system based on R134a / poly alkylene glycol oil, R600a / poly alkylene glycol oil and Cu nanoparticles dispersed into R600a. The results showed that R600a achieved a higher COP and refrigeration effect of approximately 27.12 % and 25 % respectively, while the reduction in power consumption was 1.69 % which was less than that of R134a. Moreover, dispersing 0.5 wt.%, 1 wt.%, and 1.5 wt.% Cu into R600a improved the COP and refrigeration effect compared to pure R600a, and reduced power consumption Kumar et al. [33] investigated the performance of a vapour compression refrigeration system based on 0.01 vol.% and 0.06 vol.% ZrO_2, and a particle size diameter of 20 nm was dispersed into both R134a and R152a. The results indicated an improvement in COP of 33.45 % based on the 0.06 vol.% ZrO_2-R152a nano-refrigerant. The application of R152a as a refrigerant was environmentally beneficial due to its properties such as zero ozone depletion potential and very low global warming potential. Mahdi et al. [34] evaluated the performance of a vapour compression refrigeration system based on a nano-refrigerant consisting of 0.01 vol.% and 0.02 vol.% Al_2O_3, and a diameter of 20 nm to 30 nm was dispersed into R134a. The results showed that the rising nanoparticle concentration caused the improvement of COP by 3.33 % to 12 %, respectively, and the reduction of power consumption was nearly 1.6 % and 3.3 %, respectively. Singh [35] evaluated the performance of a vapor compression refrigeration system based on 0.2 vol. %, 0.4 vol. %, and 0.6 vol. % TiO_2, and a particle size diameter of 30 nm to 50 nm was dispersed into R134a.The results showed that the nano-refrigerant based on 0.4 vol.% of TiO_2 achieved an improvement of COP of by approximately 11.1 % at 20 °C, 25 °C, and 30 °C evaporator temperatures. Additionally, an increase or decrease in power consumption has not been observed, which shows that nanoparticles were completely dissolved in the refrigerant.

Thermal conductivity is the most important of the thermophysical properties of nano-refrigerants due to its effects on the boiling and convective heat transfer coefficients. This explains why most researchers focus on studying thermal conductivity. Recently, interest in the study of viscosity has begun to appear to extend to other thermophysical properties to form a clear idea of the heat transfer properties [4]. Kedzierski et al [36] evaluated the thermophysical properties of nano-lubricants based on nanoparticle size diameters of 127 nm and 135 nm of Al_2O_3 and ZnO respectively mixed with polyol ester oil at atmospheric pressure with temperatures ranging from 288 K to 318 K, and various mass fractions of Al_2O_3, and ZnO were used. The results showed that increasing nanoparticle concentrations led to increased viscosity, density, and thermal conductivity but decreased viscosity and density with increased temperature. Sanukrishna and Prakash [37] evaluated the thermal conductivity and viscosity of nano-lubricants based on 0.07 vol.% to 0.8 vol.% TiO_2 mixed with poly alkylene glycol oil at temperatures ranging from 20 °C to 90 °C. They found that increasing nanoparticle concentrations led to increasing these parameters; in contrast, they decreased with increasing temperature. Zawawi et al. [38] evaluated the thermal conductivity and dynamic viscosity of nano-lubricants based on 0.02 vol.% to 0.1 vol.% Al_2O_3/SiO_2, Al_2O_3/TiO_2, and TiO_2/SiO_2 mixed with poly alkylene glycol oil l at temperatures ranging from 303 K to 353 K. The results showed that 0.1 vol. % Al_2O_3/TiO_2 poly alkylene glycol oil enhanced the viscosity by 20.50 % at 303 K, while 0.1 vol. % Al_2O_3 / SiO_2 poly alkylene glycol oil improved the thermal conductivity by 2.41 % at 303 K.

As per previous studies the addition of nanoparticles into the refrigerant or lubricant oil in a vapour compression refrigeration system was conducted to improve the COP and thermophysical properties of the fluid as a metal, metal oxide, and hybrid nanoparticles This research presents a new concept of nanoparticles as a single oxide and as a mixture that was prepared an inexpensive and easy way using, distilled water, ammonia, copper nitrate, and cerium nitrate. The nanoparticles were prepared as follows: CuO, CeO_2: Mixture 1 consisted of 50 % CuO + 50 % CeO_2; Mixture 2 consisted of 60 % CuO + 40 % CeO_2; Mixture 3 consisted of 70 % CuO + 30 % CeO_2; Mixture 4 consisted of 40 % CuO + 60 % CeO_2; and Mixture 5 consisted of 30 % CuO + 70

% CeO_2. The application of nanoparticles in a vapour compression refrigeration system is challenging due to factors such as high cost, instability, and agglomeration. Fortunately, the method of preparation used in this research used materials from which nanoparticles are prepared can be commonly found in all chemistry laboratories. Therefore, the cost barrier, which is one of the major obstacles to using nanoparticles, is broken. Consequently, the desired increases in the thermal conductivity achieved by these nano particles can be obtained at a reasonably affordable cost.

1 MATERIALS AND METHODS

This section is divided into three parts. In the first part, an experiment was conducted on a vapour compression refrigeration system using R134a as a refrigerant and SUNISO as a mineral oil of a compressor, and the coefficient of performance was calculated based on the change in the enthalpy of the refrigerant. Thereafter, Ansys Fluent software version 19.0 was used to calculate the coefficient of performance theoretically to make a comparative study between an experiment and theoretical results. In the second part, seven types of nanoparticles were prepared, and the preparation process will be explained in detail later, Finally, in the third part, the nanoparticles were added to the refrigeration system to verify their effect on the COP of the system.

1.1 Experimental Work

An experiment was carried out in a laboratory under normal conditions at Yildiz Technical University in Istanbul, Turkey. The system was charged with refrigerant R134a and compressor oil. Digital meters were used to monitor the temperatures and pressures at the inlets and exits of a compressor, a condenser, and an evaporator. A digital wattmeter was used to monitor power consumption, and a digital flow meter was used to monitor the mass flow rate of R134a. Heat loss to the surroundings and the changes in the kinetic and potential energy were neglected. Every experiment was conducted three times to obtain the highest accuracy and steady-state performance. Table 1 shows the technical details of the experimental system. An experimental set up and its schematic diagram are presented in Fig. 1. The experiment consists of a compressor, condenser, evaporator, and expansion valve.

Table 1. *Technical details of the experimental system*

No	Components	Characteristics
1	Compressor	Bitzer compressor 1/2 HP
2	Condenser	Air cooled condenser 1/2 HP
3	Evaporator	Emersion coil 1/3 HP
4	Expansion valve	Automatic expansion valve
5	Voltage rating	220V AC voltage supply
6	Suction line	3/8 inch copper pipe
7	Discharge line	1/4 inch copper pipe
8	Frequency rating	51 Hz
9	Defrost unit	Automatic
10	Door type	Single closed door

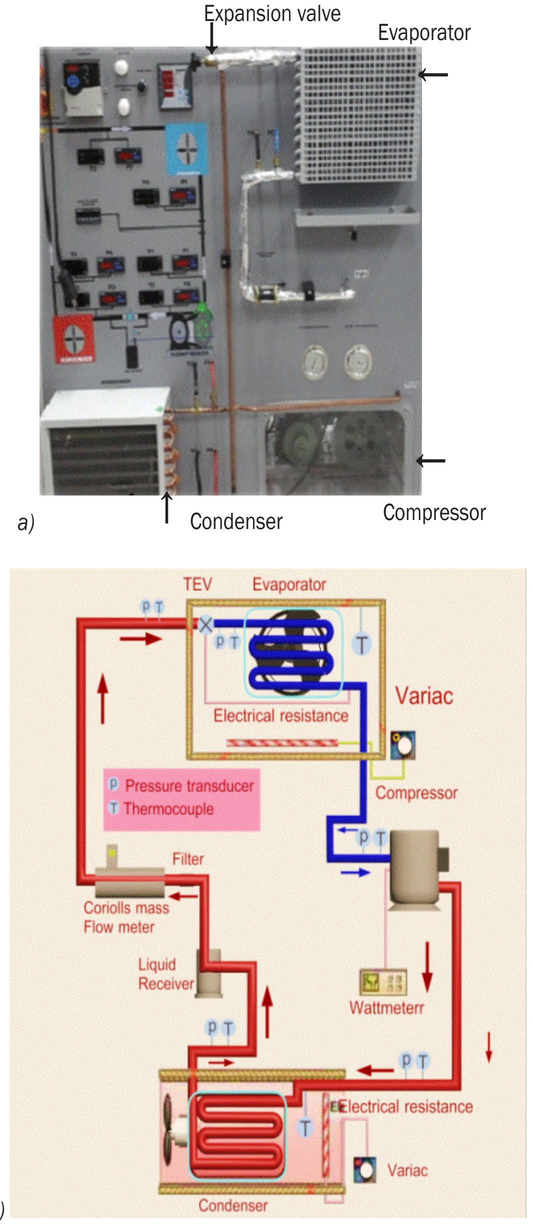


Fig. 1. *a) Experimental work and b) corresponding schematic diagram of the experiment*

1.1.1 Experimental Procedure

Using the Engineering Equation Solver (EES), the temperatures and pressure were measured at the inlet and outlet of the evaporator, condenser, and compressor to read the enthalpy of R134a. This software aids in determining the enthalpy of the gas and the change in the gas phase, where two states of the gas cycle were recorded in the system, specifically superheated vapour enthalpy ($h1$, $h2$) at the inlet and the exit of the compressor, superheated vapour enthalpy ($h3$) at the inlet of the condenser, compressed liquid enthalpy ($h4$) at the exit of the condenser, compressed liquid enthalpy ($h5$) at the inlet of the evaporator, and superheated vapour enthalpy ($h6$) at the exit of the evaporator The listed governing equations have been employed for analysis [33]. Characteristics of R134a utilized in the experimental setup are given in Table 2.

$$\dot{W} = \dot{m}\left(h2 - h1\right), \tag{1}$$

$$Q_{evaporator} = \dot{m}\left(h6 - h5\right), \tag{2}$$

$$Q_{condenser} = \dot{m}\left(h3 - h4\right), \tag{3}$$

$$COP = \frac{\left(h6 - h5\right)}{\left(h2 - h1\right)}. \tag{4}$$

Table 2. *Characteristics of R134a* [39]

No	Characteristics	
1	Name	1,1,1,2 tetrafluoroethene
2	Chemical formula	CF3CFH2
3	Molecular weight	102.03 g/mol
4	Composition	pure
5	ASHRAE safety classification	A1
6	Ozone depletion potential	zero
7	Lifetime in the atmosphere	13
8	Critical temperature	101.1 °C
9	Critical pressure	4.06.3 MPa
10	Normal boiling point NBP	-26.4 °C
11	Saturated vapor pressure at 20 °C	774.3 kPa
12	Latent heat of vaporization	198.6 kJ/kg
13	Liquid density	1294.8 kg/m^3
14	Vapor density	14.43 kg/m^3
15	Liquid Cp	1.341 kJ/(kg °C)
16	Vapor Cp	0.90 kJ/(kg °C)
17	Liquid thermal conductivity at 25 °C	0.0824 W/(m K)
18	Vapor thermal conductivity at 25 °C	0.0145 W/(m K)
19	Liquid viscosity at 25 °C	0.202 mPa s
20	Vapor viscosity at 25 °C	0.012 mPa s

1.1.2 Simulation of Vapor Compression Refrigeration System

Ansys Fluent version 19.0 software was chosen to make the mathematical model of the refrigeration system based on the real dimensions of the condenser and the evaporator and these two parts of the system were chosen to study the effect of average the temperature of each of them on the performance of the refrigeration system. The stages of designing the mathematical model were as follows: 1) Geometry, where the evaporator and condenser were drawn based on the real dimensions using a solid works program, and the drawn models were exported to Ansys Fluent, where the solid works helped to draw quickly and accurately; 2) Mesh, where the tubes of the evaporator and condenser were divided into many elements and nodes, and the change in the number of elements stops when the temperature inside the tube does not change and is close to the experimental value. The equations that were used to calculate the theoretical temperatures and pressures and the amount of heat absorbed and rejected are the continuity, momentum, and energy equations. The dimensions of the condenser and evaporator and their theoretical models are shown in Table 3 and Fig 2.

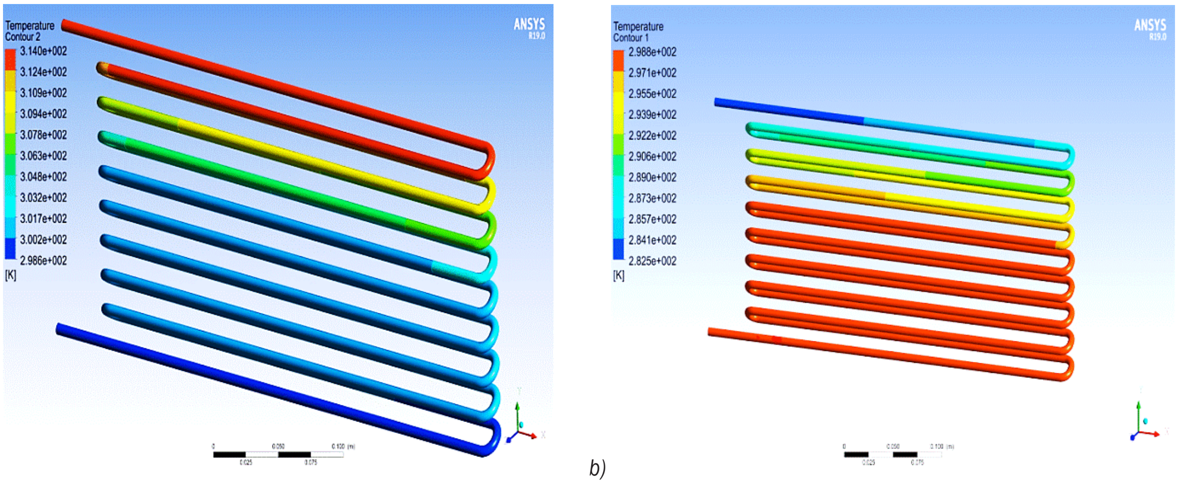
As shown in Fig. 2, the evaporator and condenser are designed so that the thermal gradient of the pipes appears at any point of entry. Also shown in the design is the gradient in the pressure and gradient in velocity to determine the velocity, pressure, and temperature of the refrigerant (R134a) while rotating inside the tubes. The colours shown in the drawing indicate that red gives the highest reading, blue the lowest reading, and the colours between red and blue are between the highest and the lowest in all cases of gradation, whether it is temperature, pressure, or velocity.

1.2 Preparation of Nanoparticles

The nanoparticles were prepared with nitrates, distilled water, and ammonia. A specified amount of copper nitrate was weighed in the case of preparing copper oxide and dissolving it in a specified amount of distilled water or deionized water. Similarly, a specified amount of cerium nitrate was weighed, in the case of preparing cerium oxide; and dissolving it in a specified amount of distilled water or deionized water. Distilled water is considered one of the cheapest and best solvents for all materials laboratories. As for preparing the mixture, specific quantities of both copper nitrate and cerium nitrate are weighed and dissolved in a specific amount of distilled water to

Table 3. *Dimensions of condenser and evaporator*

NO	Condenser Measurements	Dimensions	NO	Evaporator Measurements	Dimensions
1	Length	35 cm	1	Length	33 cm
2	Width	17 cm	2	Width	10 cm
3	Height	28 cm	3	Height	28 cm
4	Diameter of copper tube inside the condenser	0.25 inch	4	Diameter of copper tube inside the evaporator	0.25 inch
5	The twists and copper tube inside a condenser	18	5	The twists and copper tube inside an evaporator	18
6	Distance between one tube and another	5 cm	6	Area of evaporator	0.12 cm^2
7	Area of condenser	0.177 cm^2	7	Number of tubes	18
8	length of the tube inside the condenser	7.2 m	8	Fan speed	1300 rpm
9	The thickness of aluminium plate	0.3 mm	9	Air velocity	638 m/s
10	Number of plates	600	10	Evaporator type	emersion coil
11	Single plate dimensions	35 cm × 17 cm × 34 cm	11	Distance between one tube and another	3 cm
12	Fan speed	1300 rpm	12	Length of the tube inside the evaporator	6.48 m
13	Air velocity	638 m/s			
14	Condenser type	Air cooler			



a) *b)*

Fig. 2. *a) Theoretical model of condenser, and b) theoretical model of evaporator without nanoparticles*

begin preparation for the reaction until the oxide is obtained. The preparation process of the reaction is briefly described in the following steps:

1. Heating until 80 °C for 1 hour with a constant mixing speed of 375 rpm;
2. Adding ammonia at a constant temperature of 60 °C and a constant mixing speed of 375 rpm to reach Ph = 10 ± 1
3. Raising the temperature to 90 °C until copper oxide is deposited;
4. Cooling the solution to room temperature;
5. Filtration;
6. Drying in an electric oven at 110 °C for 1 hour;
7. Milling;
8. Screening; and
9. Packing.

According to the equations below, the nanoparticles were prepared as indicated clearly in Table 4 and their physical and chemical properties are shown in Table 5.

$$M = \frac{W}{M_W}, \tag{5}$$

$$C = \frac{n}{v}, \tag{6}$$

where M is mole [g/mol], W weight [g], M_W molecular weight [mol], C mole concentration [mol/l], n number of moles [-], and v volume [l].

Table 4 shows that the weights of substances involved in the reaction have been converted to moles by dividing the weight by the molecular weight as indicated in Eq. (5) then the molar concentration was calculated as indicated in Eq. (6) by dividing the number of moles by the volume of the solvent in litres.

Note that the molecular weights of the reactants were as follows:

$$Cu\ (NO_3)_2\ 3H_2O = 241.606$$

$$Ce\ (NO_3)_3\ 6H_2O\ Ce = 434.22$$

$$CuO = 79.5$$

$$CeO_2 = 172.12$$

Table 4. *The quantities obtained from the mixtures*

Mixture number	Percentages		Molar concentration		The Quantity [g]
	CuO [%]	CeO_2 [%]	$Cu(NO_3)_2$ 3H2O	$Ce(NO_3)_3$ $6H_2O$	
1	50	50	0.20867	0.09673	12.67
2	60	40	0.250408	0.07753	11.44
3	70	30	0.300075	0.05834	10.97
4	40	60	0.16694	0.11622	13.07
5	30	70	0.125687	0.135569	13.85

Table 5. *Nanoparticles properties* [40]

No	Nanoparticles	M_W [g/mol]	ρ [kg/m³]	K [W/(mK)]	Cp [J/(kgK)]
1	CuO	79.55	6320	32.9	536
2	CeO_2	172.1	6100	11.7	352
3	50 % CuO+50 % CeO_2	125.8	6210	22.3	444
4	60 % CuO+40 % CeO_2	116.5	6232	24.4	462
5	70 % CuO+30 % CeO_2	107.3	6254	26.5	481
6	40 % CuO+60 % CeO_2	135.1	6188	20.1	426
7	30 % CuO+70 % CeO_2	144.3	6166	18.0	407

where M_W is molar mass [g/mol], K is thermal conductivity [W/(m K)], ρ is density [kg/m³], and Cp specific heat [J/(kg K)].

1.3 Mathematical Models

After completing the geometry and mesh stages that are referred to in Section 1.1.2, the refrigeration system for this study is ready to receive the nanoparticles. This stage is called "setup" where the multiphase is used as the best model for the solution. The properties of both R134a are entered in the liquid and gaseous phase, and the nanoparticles with the proportions specified for it depending on the nanofluid equations and dealing with nanoparticles and R134a based on becoming one homogeneous material as shown below.

$$Keff = kbf\left(\frac{kp + 2kbf - 2(kp - kbf)\varphi)}{kp + 2kbf - (kp - kbf)\varphi)}\right), \qquad (7)$$

where *Keff*, *Kbf*, and *kp* are the thermal conductivities of the nano-refrigerant, base refrigerant in the liquid phase and particle, respectively, and φ is the particle volume fraction:

$$\mu_{nr} = \mu_r \frac{1}{(1-\varnothing)^{2.5}}, \qquad (8)$$

where μ_{nr} and μ_r are the dynamic viscosities of the nano-refrigerant and refrigerant, respectively.

The density and specific heat of the nano-refrigerant are shown in Eqs. (9) and (10).

$$\rho_{eff} = (1-\varnothing)\rho_f + \varnothing\rho_{np}, \qquad (9)$$

$$C_{pnf} = \frac{(1-\varnothing)(\rho cp)bf + \varnothing(\rho cp)np}{(1-\varnothing)\rho bf + \varnothing\rho np}, \qquad (10)$$

where –Ø, *ρbf*, ρ_{np}, *np*, *cp* are volume fraction of nanoparticles, density of base fluid, density of nanoparticles, specific heat of base refrigerant, and specific heat of nanoparticles, respectively, [41] and [42].

A multiphase model solves the momentum, continuity, and energy equations for the mixture, and solves the equation of volume fraction for the secondary phases [43] and [44]. A continuity equation for the volume fraction of one (or more) of the phases. For the q^{th} phase, this equation has the following form:

$$\frac{1}{\rho_q}\left[\frac{\partial}{\partial t}(\alpha_q\rho_q) + \nabla\cdot(\alpha_q\rho_q\vec{v}_q)\right] = S_{\alpha_q} + \sum_{\rho=1}^{n}(\dot{m}_{\rho q} - \dot{m}'_{\rho q}), \qquad (11)$$

where $\dot{m}_{\rho q}$ is the mass is transfer from phase ρ to q phase, $-\dot{m}_{\rho q}$ the mass transfer from phase q to phase ρ. A single momentum equation is solved throughout the domain; it is dependent on the volume fractions of all phases through the properties ρ and μ.

$$\frac{\partial}{\partial t}(\rho\vec{v}) + \nabla\cdot(\rho\vec{v}\vec{v}) = -\nabla\rho + \nabla\cdot\left[\mu\left(\nabla\vec{v} + \nabla\vec{v}^T\right)\right]\rho\vec{g} + \vec{F}. \qquad (12)$$

The energy equation, is also shared among the phases

$$\frac{\partial}{\partial t}(\rho E) + \nabla\cdot(\vec{v}(\rho E + P)) = \nabla\cdot(K_{eff}\nabla T) + S_h. \qquad (13)$$

The amount of nanoparticles that was added to R134a was 2.6 g, while the amount of R134a was 1039 g, as this was the amount that the system was operating within the first part of the experiment to become a mass fraction of 0.25 wt.%. The theoretical results obtained by adding a quantity of nanoparticles are presented and their effects on the performance of the refrigeration system are discussed in the discussion section.

2 RESULTS AND DISCUSSION

This section is divided into three parts; the first part includes a discussion of the results obtained by conducting an experiment on a vapor compression refrigeration system and comparing these results with a simulation that was done using Ansys Fluent 19.0 software program and calculating the accuracy rate. The second part includes discussing the results obtained from the preparation of nanoparticles by presenting nanoparticle screening tests using X-ray diffraction (XRD) and scanning electron microscope (SEM) methods. The third part includes discussing the results obtained from the theoretical study where nanoparticles were introduced to a vapour compression refrigeration system to investigate their effects on the coefficient of performance of the system.

2.1 Comparison of Experimental and Theoretical Results of a Vapor Compression Refrigeration System

A theoretical model was designed for the evaporator and condenser with specifications similar to the experimental system; the results obtained were illustrated graphically to show the effects of the average temperature of both the evaporator and condenser on *COP*, and W_{comp} as shown in Fig. 3. The *COP* at varying evaporator temperatures is presented in Fig 3a; an increase in evaporator temperatures causes an increase in *COP* due to an increase in the refrigeration effect because of increase in both the enthalpy difference and mass flow rate of R134a through the evaporator, and a decrease in compressor work. The power consumption at varying evaporator temperatures is presented in Fig.

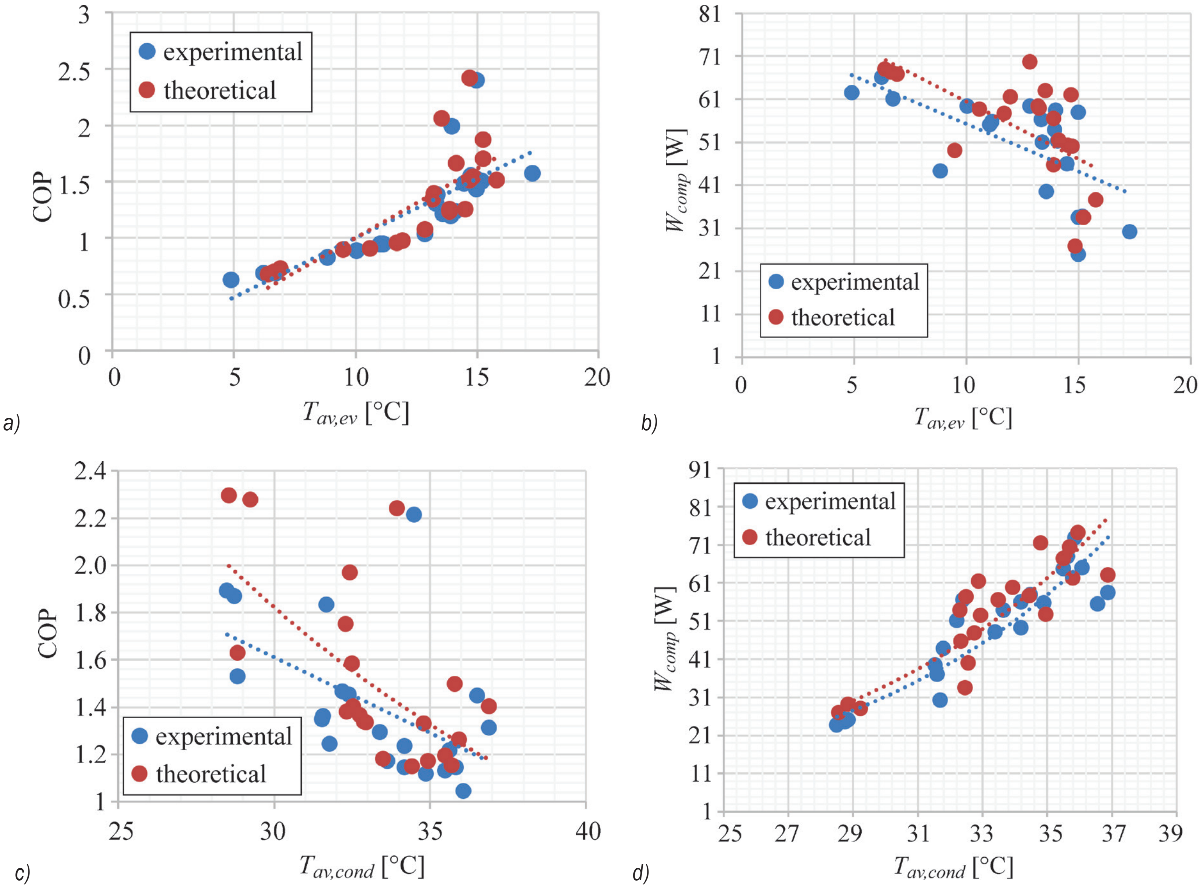


Fig. 3. *a) The effect of $T_{av,ev}$ on COP b) the effect of $T_{av,ev}$ on the power consumption W_{comp} c) The effect of $T_{av,cond}$ on COP, and d) The effect of $T_{av,cond}$ on the power consumption W_{comp}*

3b; an increase in evaporator temperatures causes a decrease in power consumption, due to an increase in suction temperature, which causes an increase in both vaporization pressure and density suction vapor entering the compressor, which leads to an increased mass flow rate of R134a through the compressor for a given piston displacement and decreased power consumption. The effects of the average temperature of the condenser on the COP are presented in Fig. 3c; it decreases as the condenser temperature increases due to a decrease in the refrigeration effect and an increase in compressor work. Increased condenser temperatures cause an increase in the heat rejection, due to the rise in enthalpy difference and mass flow rate of R134a through the condenser. In contrast, the increase in condenser temperature will cause an increase in power consumption, as presented in Fig. 3d. To achieve high accuracy, the experiment was divided into several cases, in which each case included five experiments. Each experiment was repeated three times. The experiment which gave the most convergence with the theoretical value calculated using Ansys Fluent was chosen to then capture all these points to be plotted with the average temperatures of the evaporator and condenser. As shown by the results and in agreement with previous studies, our results confirmed the increase in COP with the temperature of the evaporator and its decrease with the increase in temperature of the condenser, as well the decrease in energy consumption with an increase in the average temperature of the evaporator and increased with increasing the average temperature of the condenser

2.2 Characterization of Nanoparticles

Nanoparticle characterization was carried out at the Huazhong University of Science and Technology in China on September 24, 2019, by using XRD analysis and SEM images. The results of the nanoparticles are presented below in Fig. 4. The XRD pattern was scanned from 20 deg to 80 deg and the XRD profile confirmed the nanocrystalline nature of CuO. The characteristic diffraction peak was observed, and all of the peaks agreed in position and intensity with the database standard (JCPDS 00-045-0937) of the face-centred cubic CuO crystal with the fluorite structure. The absence of additional diffraction peaks confirms

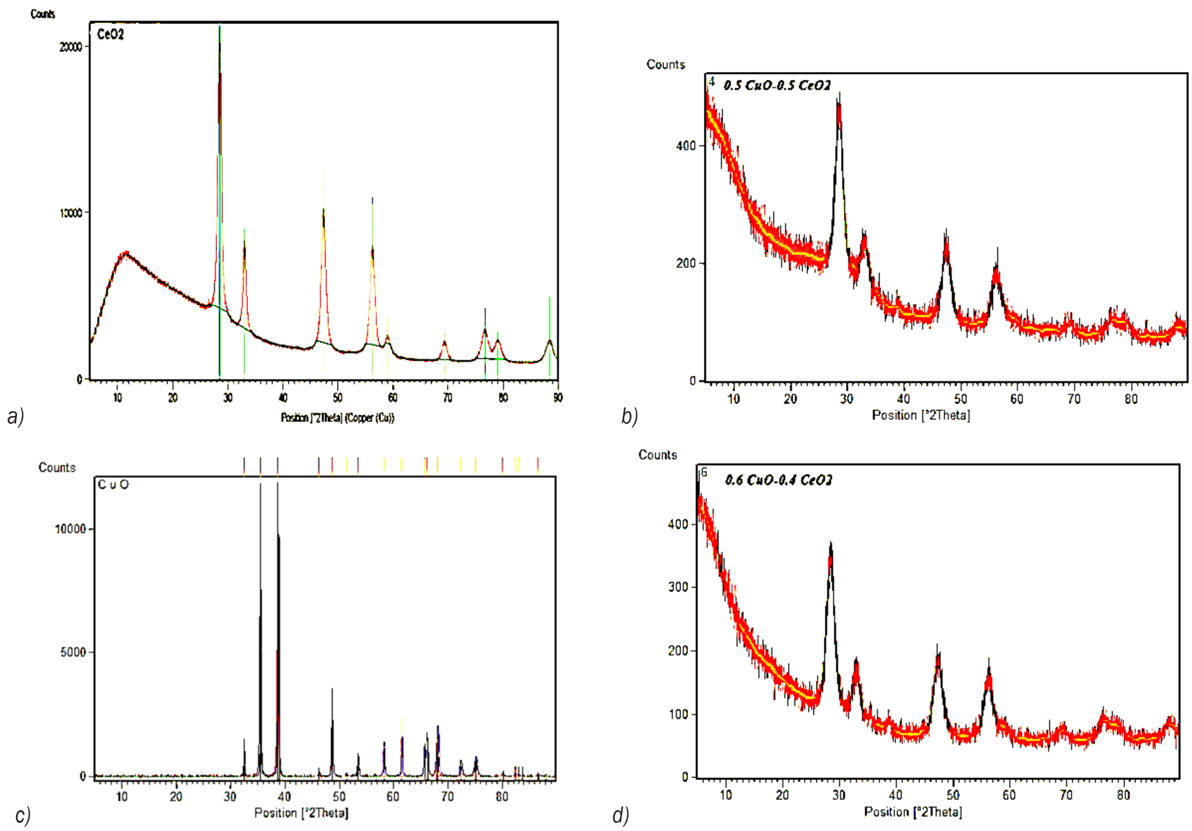


Fig. 4. *XRD Pattern of a) pure CuO, b) pure CeO_2, c) 0.5 % CuO, 0.5 % CeO_2, and d) 0.6 % CuO, 0.4 % CeO_2 nanoparticles*

the nanocrystalline nature and purity of the samples. The XRD pattern of CeO_2 was scanned from 20 deg to 80 deg, and the XRD profile confirmed the nanocrystalline nature of CeO_2. The characteristic diffraction peak was observed, and all of the peaks agreed in position and intensity with the database standard (JCPDS 00-004-0593) of the face-centred cubic CeO_2 crystal with the fluorite structure. The absence of additional diffraction peaks confirms the nanocrystalline nature and purity of the samples. The SEM images proved that the particles of the samples were approximately spherical in shape and the particle sizes of CuO, CeO_2, 0.5 % CuO + 0.5 % CeO_2, and 0.6 % CuO + 0.4 % CeO_2 were observed to be 78.95 nm, 79.9 nm, 44.15 nm, and 63.3 nm, respectively, based on the SEM images, as shown in Fig. 5. This research succeeded in preparing nanoparticles with suitable diameters. Cerium oxide was used for the first time to determine its effect on the performance of refrigeration system. It is expected that this study will open the door to future research to reveal new properties of cerium oxide as a mixture with copper oxide; in particular, the mixture consisting of both oxides was prepared by the same method in this experiment as a homogeneous substance

2.3 The Results Obtained from Adding Nanoparticles Theoretically into a Vapor Compression Refrigeration System

The results obtained from adding CuO are illustrated in Fig. 6 to show the effects of the average temperature of the evaporator on the *COP*, and W_{comp}. As it appears from the results, the addition of 0.25 wt.% CuO caused an increase in the temperature of the evaporator at its entrance and exit, which led to a rise in both the COP and the amount of heat absorbed inside the evaporator and thus a decrease in the amount of energy consumed by the compressor. This conclusion is consistent with previous studies, and the main reason for the occurrence of these changes is the high thermal conductivity of the refrigerant due to its mixture with CuO, which records an average thermal conductivity of 20 W/(mK) to 40 W/(mK). The addition of the

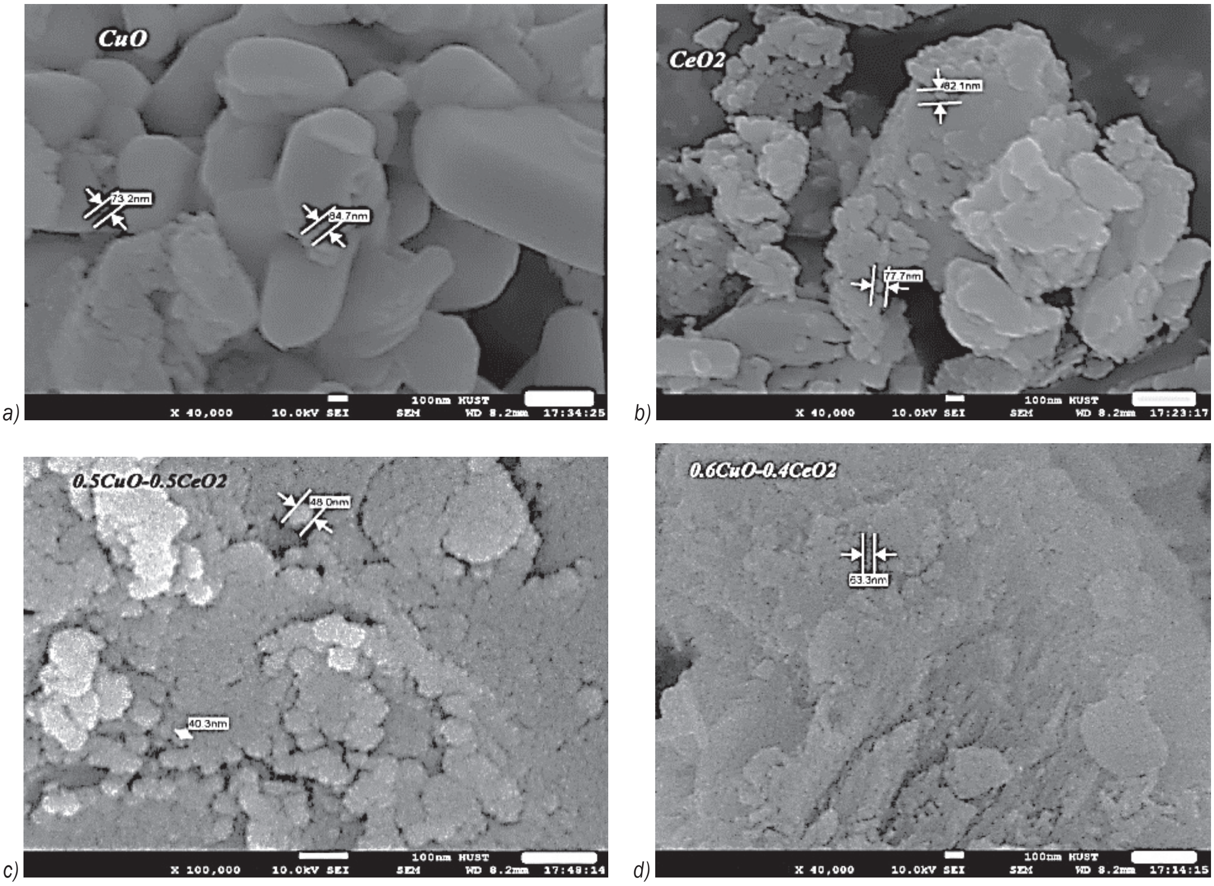
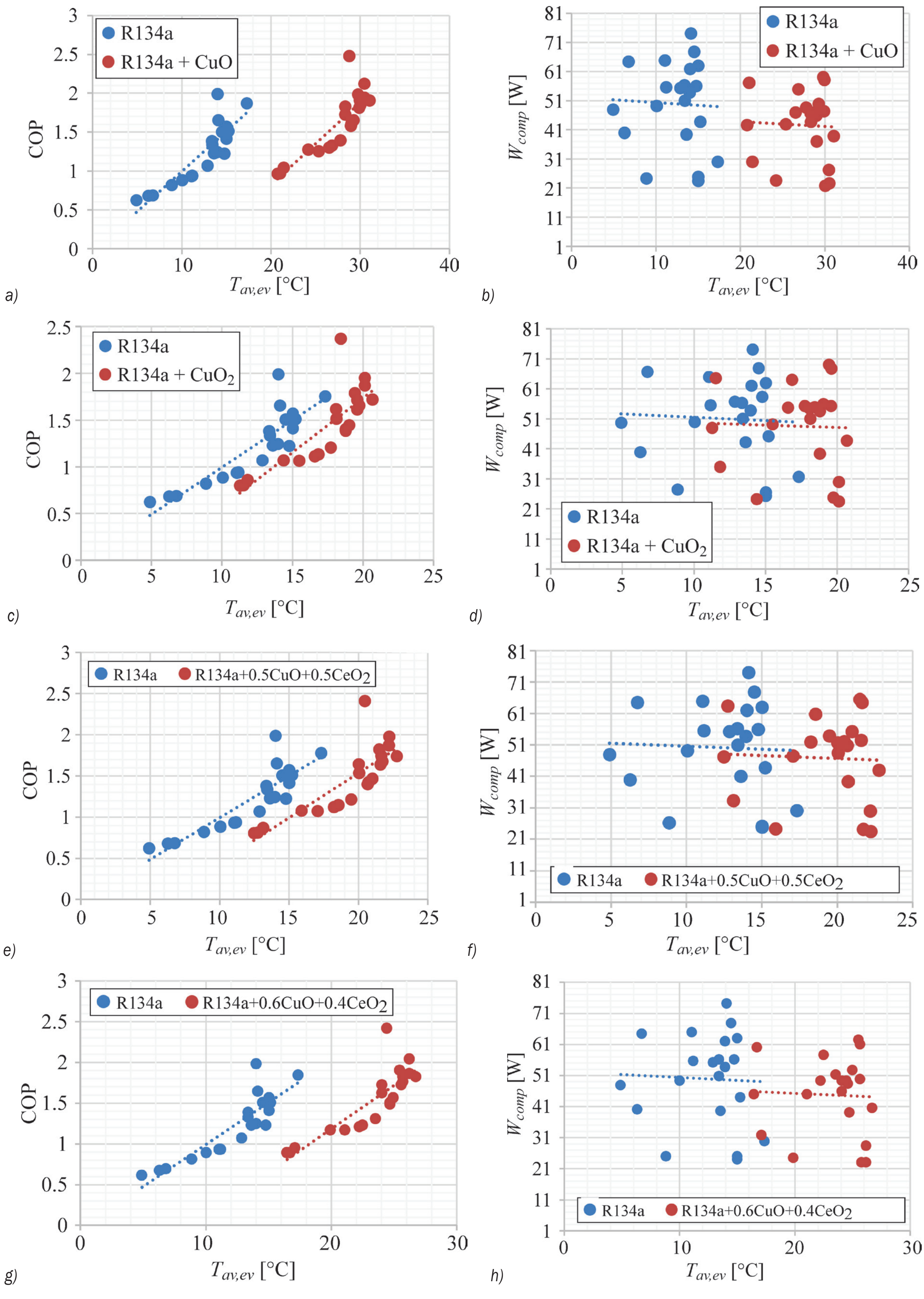
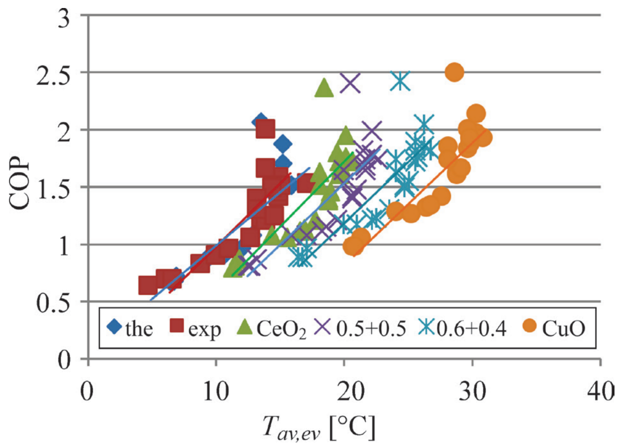


Fig. 5. *a) spherical CuO, b) spherical CeO_2, c) spherical 0.5 % CuO + 0.5 % CeO_2, and d) spherical 0.6 % CuO + 0.4 % CeO_2*


a)
R134a
R134a + CuO
COP
$T_{av,ev}$ [°C]
b)
R134a
R134a + CuO
W_{comp} [W]
$T_{av,ev}$ [°C]
c)
R134a
R134a + CuO_2
COP
$T_{av,ev}$ [°C]
d)
R134a
R134a + CuO_2
W_{comp} [W]
$T_{av,ev}$ [°C]
e)
R134a
R134a+0.5CuO+0.5CeO_2
COP
$T_{av,ev}$ [°C]
f)
R134a
R134a+0.5CuO+0.5CeO_2
W_{comp} [W]
$T_{av,ev}$ [°C]
g)
R134a
R134a+0.6CuO+0.4CeO_2
COP
$T_{av,ev}$ [°C]
h)
R134a
R134a+0.6CuO+0.4CeO_2
W_{comp} [W]
$T_{av,ev}$ [°C]



i)

Fig. 6. *The effect of $T_{av,ev}$ on COP and W_{comp} at constant mass fraction and comparing of the results of a vapor compression refrigeration system with nano and without nanoparticles*

same amount of CeO_2 caused an increase in the temperature of the evaporator at its entrance and exit, which led to a rise in both *COP* and the amount of heat absorbed inside the evaporator and thus a decrease in the amount of energy consumed inside the compressor. The main reason for the occurrence of these changes is the high thermal conductivity of the refrigerant due to its mixture with CeO_2, where it records an average thermal conductivity of 11.7 W/(mK). The addition of the same amount of 0.5 % CuO with 0.5 % CeO_2 caused an increase in the temperature of the evaporator at its entrance and exit, which led to a rise in both COP and the amount of heat absorbed inside the evaporator and thus a decrease in the amount of energy consumed inside the compressor. The main reason for the occurrence of these changes is the high thermal conductivity of the refrigerant due to its mixture with nanoparticles. The addition of the same amount of 0.6 % CuO with 0.4 % CeO_2 caused an increase in the temperature of the evaporator at its entrance and exit, which led to a rise in both the *COP* and the amount of heat absorbed inside the evaporator thus a decrease in the amount of energy consumed inside the compressor. The main reason for the occurrence of these changes is the high thermal conductivity of the refrigerant due to its mixture with nanoparticles. Since the most important factor in improving the performance of the refrigeration system after adding the nanoparticles is the temperature of the evaporator, all the results were plotted so that the effect of the average evaporator temperature on the *COP* of the system at a specific amount of nanoparticles is shown. Nagaraju and Reddy **[32]** proved that adding copper oxide to R134a improved the *COP* of the refrigeration system to a degree close to what was found in this study, and the method in which nanoparticles are prepared, the shape, diameter, and quantity added to the refrigerants play an important role in determining the result.

3 CONCLUSION

A new concept of nanoparticles was introduced in this research to open the door to answering many questions in the future, because cerium oxide was used with copper oxide as one material consisting of a mixture of both oxides. The results obtained for copper oxide agreed with previous studies, where copper oxide succeeded in improving the performance of the refrigeration system and increased COP by 25 %, and cerium oxide succeeded in improving the performance of the system by a lesser value. For the mixture, the results confirmed that the mixture containing a higher percentage of copper oxide gave better results. The door remains open for more experimental studies on the use of cerium oxide as a single oxide or as a mixture with other oxides to study its effect on the performance of the vapor compression refrigeration system and whether the refrigeration system will work safely. In addition, more experiments needed to study the effect of the mixtures mentioned in this research on the stability of nanoparticles with refrigerants and lubricant oils, as the problem of stability is one of the greatest obstacles to the application of nanoparticles in the refrigeration systems.

4 FUTURE WORK

In this study the method of preparing nanoparticles was simple and affordable and produced two types of oxides and five types of mixtures. Subsequently, the field of research remains open. This method succeeds in obtaining other oxides, especially oxides with high thermal conductivity, because the cost of nanoparticles increases as their thermal conductivity increases. Nevertheless, the theoretical results in this research encourage researchers to move forward with experimental studies This study recommends conducting experiments to verify the behaviour of cerium oxide in refrigeration systems and to monitor its behaviour at different temperatures for the evaporator, especially because the results of this research show that cerium oxide improved the performance of the refrigeration system due to its good thermal conductivity This study recommends mixing materials that have been prepared with other refrigerants and compressor lubricant oils to study their effect on the thermophysical properties of refrigerants and oils. Since the problem of the stability of nanoparticles with refrigerants is so important, a hybrid consisting of oxides was recently used to solve this problem. The mixture prepared from oxide succeed in obtaining better results, especially since the mixture consisting of 50% copper oxide and 50 % cerium oxide has already been mixed with R134a in the lab using the ultrasonic machine only for one hour; the result was a stable mixture for a whole day

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