ANKARA YILDIRIM BEYAZIT UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES



THERMODYNAMIC PERFORMANCE ANALYSIS FOR A VAPOR COMPRESSION REFRIGERATION SYSTEM BY USING REFRIGERANT WITH NANOPARTICLES

Ph. D Thesis by

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THERMODYNAMIC PERFORMANCE ANALYSIS FOR A VAPOR COMPRESSION REFRIGERATION SYSTEM BY USING REFRIGERANT WITH NANOPARTICLES

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Huda Elslam Abdali Salem MOHAMED

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Ph. D. THESIS EXAMINATION RESULT FORM

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2022, August **Huda Elslam Abdali Salem MOHAMED**

THERMODYNAMIC PERFORMANCE ANALYSIS FOR A VAPOR COMPRESSION REFRIGERATION SYSTEM BY USING REFRIGERANT WITH NANOPARTICLES

ABSTRACT

Using nanoparticles in a refrigerating cycle is associated with many difficulties, such as the cost of preparing and obtaining a stable and homogeneous mixture with less agglomeration and sedimentation. This research presents a simple, easy, and inexpensive method for the preparation process 0f nanoparticles based on distilled water, ammonia, copper nitrate, and cerium nitrate to synthesize nanoparticles as a single oxide and as a mixture. The results of nanoparticle preparation using X-ray diffraction and scanning electron microscopy prove that particles were spherical in shape, with suitable diameters of 78.95 nm, 79.9 nm, 44.15 nm, and 63.3 nm for copper oxide, cerium oxide, the first mixture, and second mixture, respectively. This study preferred the implementation of a theoretical study using Ansys Fluent software based on the real dimensions and the experimental results to simulate a simple vapor compression refrigeration system to charge nanoparticles theoretically to verify their effectiveness to improve the efficiency of the refrigerating cycle. The results confirmed that copper oxide enhanced the coefficient of performance of the refrigerating system by 25 %, and cerium oxide succeeded in improving it by a lesser value. The mixture containing a higher percentage of copper oxide yielded better results. Moreover, using the numerical equations available in the literature to calculate thermophysical properties proved an improvement in these properties with an increase in nanoparticle concentration

Keywords: Refrigeration system, Ansys Fluent 19.0, Nanoparticles, Nanorefrigerant

NANOPARTIKÜL SOĞUTUCU AKIŞKAN KULLANARAK BUHAR SIKIŞTIRMALI SOĞUTMA SISTEMIICIN TERMODINAMIK PERFORMANS ANALIZI

ÖZ

Bu çalışmada buhar sıkıştırmalı soğutma sistemlerinde R134a bazlı nano-akışkan hazırlanmasına yönelik olarak bakır oksit ve seryum dioksit küresel nano-partikül üretimi iki aşamalı olarak gerçekleştirilmiştir. Nümerik çalışma sonucunda, soğutma sistemlerinde basınç kaybı ile nano-soğutucu akışkanın ısıl iletkenlik artışını dengeleyecek nano-soğutucu akışkan içerisindeki optimum hacimsel partikül oranı tespit edilmiştir. Çalışmada, bakır oksit ve seryumoksit nano parçacıklarının R134a ile farklı konFigure ürasyonundan oluşan yedi farklı nano-soğutucu akışkan geliştirilmiştir. Bu bağlamda öncelikle, nano-parçacık katkılı soğutucu akışkan elde edilmesine yönelik olarak, çökeltme yöntemi ile düşük sıcaklıkta nano boyutta bakıroksit ve seryumoksit partikülleri sentezlenmiştir. Sonrasında elde edilen oksitlerin farklı hacimsel oranlarda karışımları kullanılarak yedi farklı nano-parçacık, katkılı soğutucu akışkan, iki aşamalı yöntem kullanılarak hazırlanmıştır. Çalışmada ayrıca soğutma sisteminin gerçek boyutlarına ve deneysel sonuçlara bağlı olarak simüle etmek amacıyla Ansys yazılımı da kullanılmıştır. Nanopartikül hazırlama süreci pahalı olduğundan, söz konusu araştırma bunların hazırlaması işlemi için basit, kolay ve ucuz bir yöntem sunmaktadır. Elde edilen parçacıklar X-ışını kırınım ve taramalı elektron mikroskobu kullanılarak incelenmiştir. İnceleme sonucunda parçacıkların çaplarının 78,95 nm, 79,9 nm, 44,15 nm and 63 nm olduğu gözlenmiştir. Bunlar sırasıyla bakır oksit, seryum oksit, birinci ve ikinci karışımdır. Teorik çalışma sonucunda hem bakır oksit hem seryum oksit hem de her ikisinden oluşan karışımın soğutma sisteminin performansını artırdığı ve enerji tüketimini de azalttığı görülmüştür. Bununla birlikte literatürde bulunan sayısal denklemler kullanılarak nano-partiküllerin R134a ile karışımın sistemin performansına olumlu katkı sunduğu belirlenmiştir.

Anahtar Kelimeler: Sogutma sistemi, Ansys akici 19.0, Nanopartikuller, Nanosogutcu

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NOMENCLATURE

Chemical vapor deposition	CVD
Chloro fluoro-carbons	CFCs
Coefficient of friction	COF
Coefficient of performance	COP
Density	ρ (kg m^{-3})
Density of nanoparticles	ρbp (Kg/ m^3)
Density of refrigerant	ρbF (Kg/ m^3)
Dynamic viscosity of nanorefrigerant	μ_{nr} (mPa.s)
Dynamic viscosity of refrigerant	μ_r (mPa.s)
Energy-dispersive x-ray spectroscopy	EDX
Fourier transform infrared spectroscopy	FTIR
Global Warming Potential	GWP
Hydrocarbons	HCs
Hydrochlorofluoro-carbons	HCFCs
Hydrofluorocarbons	HFCs
Hydrofluoroolefin	HFOs
inductively coupled plasma–optical emission spectroscopy	ICP-OES
inert-gas condensation	IGC
Liquefied Petroleum Gas	LPG
Mass fraction	Wt
Mass is transfer from phase ρ to phase q,	$\dot{m}_{\rho q}$ (kg/s)
Mass of nanoparticles and	m_n (kg)
Mass of pure refrigerant	m_r (kg)
Mass transfer from phase q to phase ρ	$\dot{m}_{qp}$ (kg/s)
Mineral Oil	MO
Mole	M (g/mol)
Mole concentration	C (mol/L)
Molecular weight	Mw (mol)

Normal Boiling Point	NBP
Number of moles	n (-)
Ozone Depletion Potential	ODP
Poly Alkylene Glycol	PAG
Polyol ester oil	POE
Scanning electron microscopy	SEM
Specific heat	Cp (J kg^{-1} K^{-1})
Specific heat of nanoparticles	C_{pnp} (J kg^{-1} K^{-1})
Specific heat of nanorefrigerant	C_{pnf} (J kg^{-1} K^{-1})
Specific heat of refrigerant	C_{pf} (J kg^{-1} K^{-1})
Thermal conductivity	K (W m^{-1} K^{-1})
Thermal conductivity liquid refrigerant	Kbf (W m^{-1} K^{-1})
Thermal conductivity nanoparticle	KP (W m^{-1} K^{-1})
Thermal conductivity of nanorefrigerant	Keff (W m^{-1} K^{-1})
Transmission electron microscopy	TEM
vapor compression refrigeration system	VCRS
Vibration sample magnetometer	VSM
volume	V (L)
Volume fraction	Vol
volume fraction	Φ (-)
Weight	W (g)
X-ray diffraction	XRD

CHEMICAL SYMBOLS

1,1 Difluoroethane	R152a
1,1,1,2 –Tetrafluoroethane	R134a
1,1,1,2,2,3,3- heptafluoro-3-methoxy-propane	HFE7000
2- Methyl pentane (Isohexane)	R602a
Alumina	Al
Aluminum Oxide	Al_2O_3
Carbon NanoTubes	CNT
Cerium nitrate	$Ce\ (NO_3)_3\ 6H_2O$
Cerium oxide	CeO_2
Chlorodifluoromethane	R22
Copper	Cu
Copper nitrate	$Cu\ (NO_3)_2\ 3H_2O$
Copper Oxide	CuO
Dichloro-1-fluoroethane	R141b
Freon 11 or Trichlorofluoromethane	R11
Freon 12 or Dichlorodifluoromethane	R12
Gold	Au
Hexagonal Boron Nitride	h-BN
Isobutane	R600a
Magnesium Oxide	MgO
Methylene Fluoride	R32
Multiwall Carbon Nanotubes	MWCNTS
Nickel	Ni
Pentafluoropropane	R245fa
Propane	R290
Puron , Forane or Ecofluor	R410A
Silicon	Si
Silicon Carbide Powder	SiC
Silicon Dioxide	SiO_2
Silver	Ag

Single walled Carbon Nanotubes	SWCNTS
Tanium Dioxide	TiO_2
Tetrachloro (hydrido) gold	HAuCL4
Zinc Oxide	ZnO
Zirconium Dioxide or Zirconia	ZrO_2

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CHAPTER 1

INTRODUCTION

A refrigerant is a substance that takes a liquid or gaseous form as it transfers heat from a low temperature source to a high temperature source while the refrigeration effects are subtracted [1, 2] Many refrigerants have been used in the past 150 years. The beginning of the use of refrigerants was not successful. For example, ammonia, due to its toxic properties. It continued to be used as a refrigerant until now in food freezing applications, because of its superior thermal and thermodynamic properties. Carbon dioxide has also been used as a refrigerant despite its high operating pressures. At the beginning of the past century, the use of HCs was stopped due to their flammability. However, they have recently returned successfully in small domestic refrigerators and freezers. In the late twenties, CFCs and HCFCs were discovered to make progress in the manufacture of refrigerants, due to their superior thermodynamic properties, being nonflammable, and nontoxicity, and their use continued for nearly seventy years until restrictions were imposed on them by the Montreal Protocol due to their contribution to the degradation of the ozone layer. CFCs have been replaced by HFCs, in the past two decades, because of their lack of effect on the ODP. Recently, the Kyoto Protocol dealing with GWP has placed restrictions on HFCs that have a high GWP, although they have no effect on the ozone layer. Recently, HFOs, have been discovered, which have a very low GWP and are expected to be an alternative to HFCs in many applications. [3].

1.1 Blends and Mixtures

Mixing different refrigerants results in blends or mixtures, as an alternative to conventional refrigerants. The mixtures are divided into three categories as follows [3, 4].

- **Azeotrope refrigerants**: consist of more than refrigerants that have the same boiling points, for example, R500, R502, R503, and R507.

- **Zeotrope refrigerants**: consist of more than refrigerants that have different boiling points, for example, R404a, and R407c , and
- **Near azeotrope refrigerants**: consist of more than refrigerants that have different boiling points, for example, R410a. [4].

1.2 The Optimal Properties of Refrigerants

- The suction pressure should be higher than the atmospheric pressure to facilitate detection of leakage and to prevent substances from entering the refrigeration system;
- The ratio of compression should be low to reduce the power consumed;
- For a large a refrigeration effect, the latent heat of vaporization should be high or the mass flow rate should be small;
- During compression operations, the increase in temperature should be moderate to prevent the chemical reactions between refrigerants , lubricant oils, and other materials that cause the overheating of the compressor;
- The specific heat capacity of the liquid phase should be low , but the specific heat of the vapor phase should be high [5];
- The thermal conductivity of both the liquid and vapor phases should be high to enhance heat transfer ;
- The viscosity of both the vapor and liquid phases should be low [3].

1.3 The Considerations of Refrigerants for Vapor Compression Cycles

i. The vaporization heat should be high;

ii. The gas phase has a high density;

iii. Safe in the sense that it is noncorrosive, nontoxic, and nonflammable;

iv. It has chemical stability under operating conditions;

v. suitable for refrigeration system materials and compressor oil [6,7];

vi. Appropriate working pressure not too high and nor too low in relation to atmospheric pressure;

vii. Cheap;

viii. Leak detection is made easier [6];

ix. Low environmental effects [6, 7].

There is no refrigerant that meets all requirements; each one may have some undesirable properties. Currently, most research focuses on mixing different types of refrigerants to reduce the effect of undesirable properties and improve the properties of refrigerants as a working fluid [8].

1.4 Refrigeration System

Ferdinand Carre invented a first version of the ‘aqua ammonia’ for production continuous cooling in 1859. In 1875, refrigeration systems that operate with ammonia appeared, and since that time, refrigeration technologies have developed rapidly, which has positively affected on human life. The classification of the refrigeration systems is presented in ***Figure 1.1***

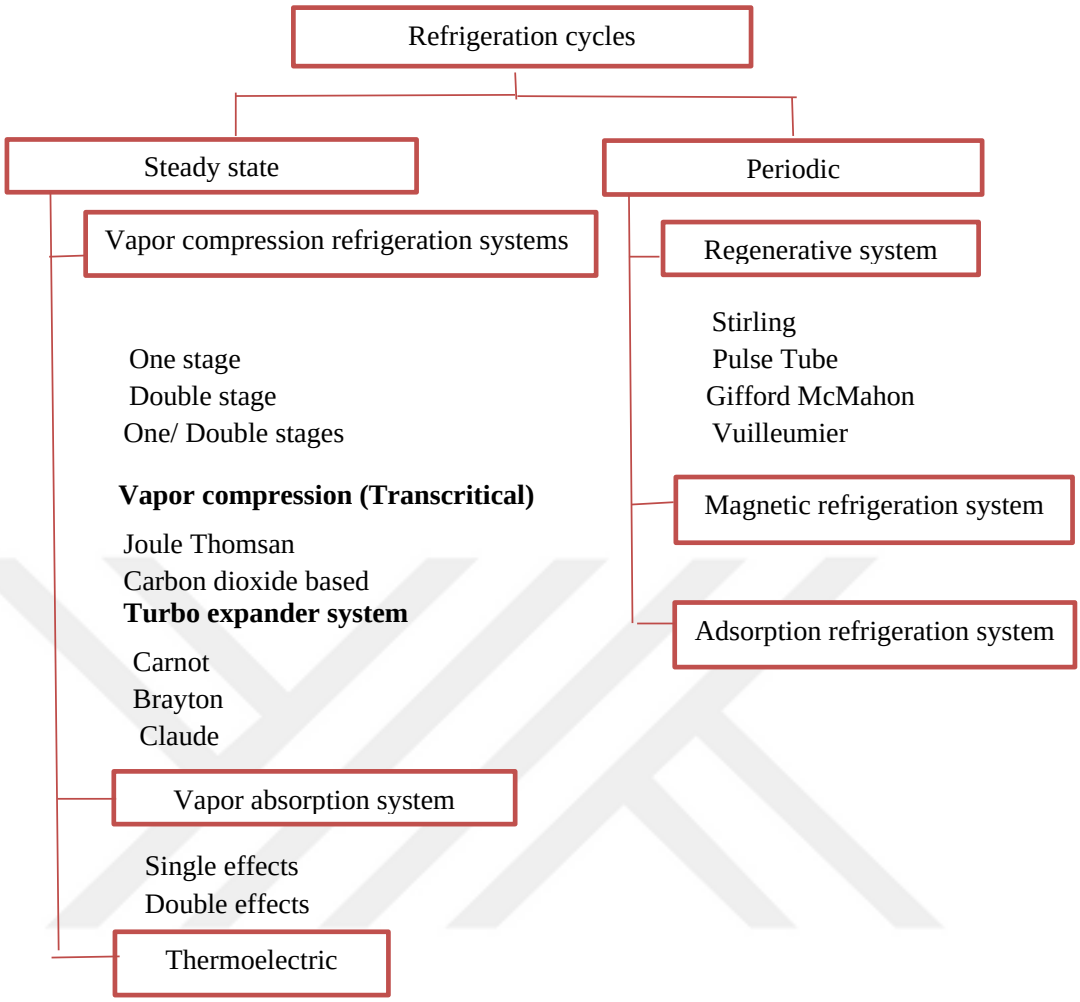


Figure 1.1 Classification of refrigeration methods [3, 7]

1.5 A vapor Compression Refrigeration System

The first machine to produce the cooling process was used in England in 1834.When electricity was available, the development of a refrigeration system began in 1897 [1]. The idea behind refrigeration techniques is that heat is rejected to the surroundings at higher temperatures and absorbed at lower temperatures [9] ***Figure 1.2*** depicts a simple vapor compression refrigeration system [10].

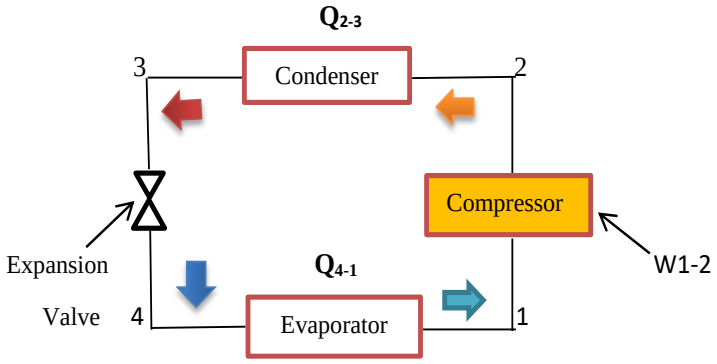


Figure 1.2 Simple vapor compression refrigeration system [3]

Many applications use VCRS, such as, domestic and industrial refrigeration ; air conditioners; automobile air conditioners; water chillers; food processing and storage; ;and medical refrigeration [7]. These systems consume a large amount of energy. Therefore, many studies have appeared that examine the possibility of reducing power consumption in refrigeration systems by improving COP of the system [9,3]. The COP can be improved either by decreasing compressor work or by increasing the refrigeration effect [9]. Compressor work can be decreased by using single-stage compression instead of multistage compression. Increasing the refrigerating capacity is achieved by transiting the refrigerants to subcooling after a condensation process and superheating after evaporation process [11].

The factors that improve the performance of VCRS are as follows:

i. Thermodynamic characteristics of the refrigerant;

ii. The different ratios of a refrigerant mixture that are used into a refrigeration system;

iii. Suction pressure ;

iv. Discharge pressure;

v. The proportion between evaporator and condenser pressure;

vi. Amount of the refrigerant pumped into the system and ;

vii. The diameter of capillary tubes [1].

1.6 Nanofluid Technology

Currently, most studies focus on enhancing the efficiency of refrigerating and air-conditioning systems to reduce power consumption caused by the poor thermal properties of all types of refrigerants in these sectors. In 1873, Maxwell diffused very small particles with diameters of millimeters to micrometers, into working fluids to enhance their thermal properties. Unfortunately, this attempt failed due to some problems, such as the stability of these particles inside the fluids. At the end of the last century, Choi added nanoparticles to primary fluid to enhance its thermal properties ; this is known as nanofluids [12.13].

Nanofluids are produced by dispersing nanoparticles with a diameter size of 1 to 100 nm into a base fluid, where nanoparticles have the highest thermal properties compared to pure fluid. The nanofluids are classified into different categories: (i) mono-nanofluids that contain the similar nanoparticles, (ii) hybrid nanofluids that contain different nanoparticles, and (iii) hybrid nanofluids that contain composite nanoparticles [12].

The success of nanofluid preparation requires the following conditions: (i) dispersability and stabilization of nanoparticle (ii) nanoparticle must be chemically compatible (iii) nanofluid must be thermally stable. All the mentioned circumstances produce nanofluid with the best thermal properties due to increasing the surface area of nanoparticles, and Brownian's predominant movement will also contribute to a better diffusion of the nanoparticles, which leads to less accumulation of particles and reduced power pump compared to the base fluid [14]. Recently, new nanofluids technology concepts have been developed, in which nanoparticles are dispersed into the refrigerant, known as nanorefrigerant, or nanoparticles are dispersed with lubricating oils, known as nanolubricant as shown in ***Figure 1.3*** [12, 14]. Two methods to produce nanorefrigerants exist: the **one-step method** and the **two-step method**. The two-step method is considered the most used for preparing nanorefrigerants, whereas nanoparticle is synthesized as a powder and mixed with a pure fluid to form a mixture, after that they use the dispersion technologies, which include ultrasound devices, excitation using magnetic fields, and homogenization ,to diffuse nanoparticles inside

the pure fluids. In the one-step method nanoparticles are manufactured using a physical or chemical method, where the condensation processes are carried out on a vapor nanophase powder to convert it into a liquid under lower pressures, and then it is dissolved in a liquid instantly, as shown in ***Figure 1.4*** [15]. Some types of refrigerants that have been mixed with nanoparticles are shown in ***Figure 1.5***. Using nanorefrigerants enhances COP and reduces compressor work as a result of improving thermal properties of refrigerants [14, 17]. Using nanolubricant improves the tribological properties such as lubrication; wear properties, high pressure conditions, COF, which achieves good wear properties, thus extending the life of the mechanical parts of the system [16].

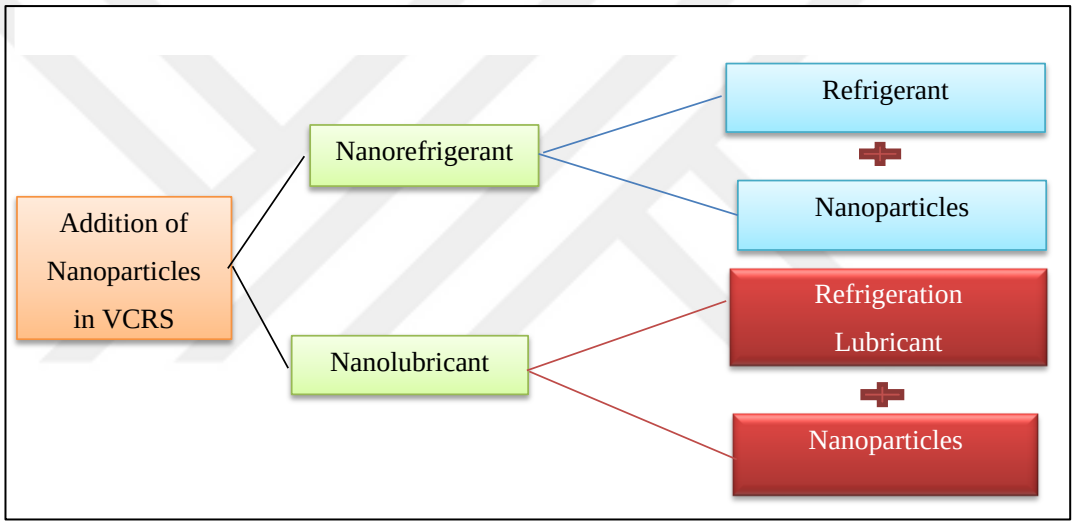


Figure 1.3 Two methods to dispersing nanoparticle into VCRS [16]

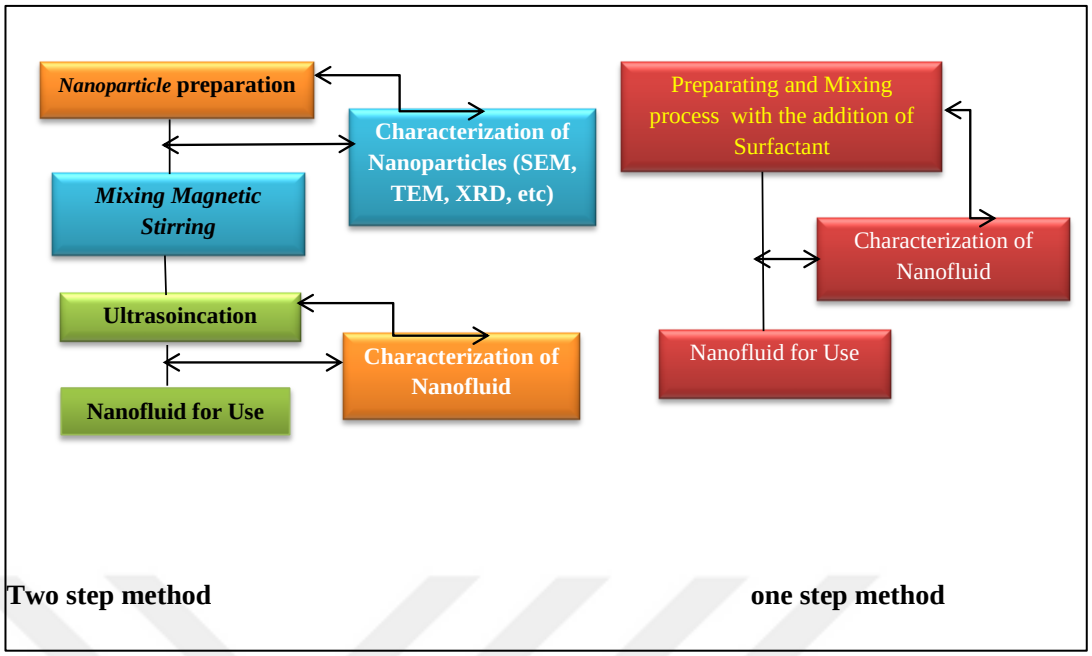


Figure 1.4 The flowchart for producing nanofluids [12]

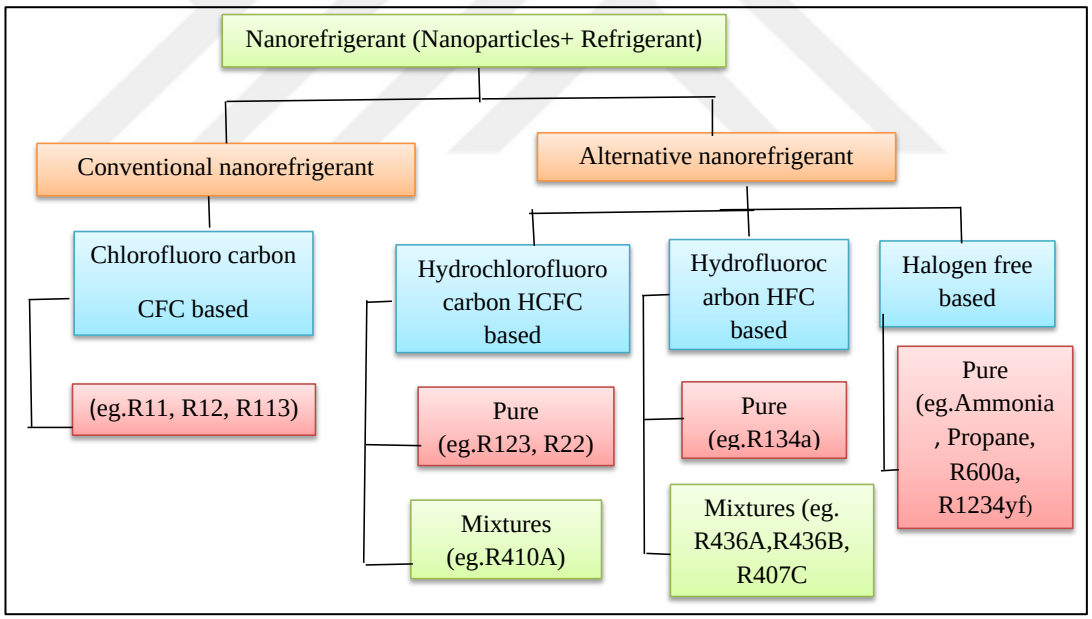


Figure 1.5 Nanorefrigerants classification according to refrigerant [17].

The use of nanoparticles includes metals, metal oxides, metal carbide, metal nitride, and carbon materials [18]. Sensitive electronic scale is used to weigh nanoparticles and then is dispersed into pure fluid using a mechanical stirrer for a specific time to stir followed by an ultrasonic device to form a stable nanofluid. Nanoparticle increases

the surface area and improves temperature distribution in nanofluids. ***Table1.1*** clarifies the thermal conductivity of some materials [14].

Table 1.1 The best materials in thermal conductivity [14]

Materials	Thermal Conductivities ($Wm^{-1} K^{-1}$)
Carbon nanotubes	1800 - 6600
Diamond	2200 - 2300
Copper	350 - 400
Alumina	200 - 250
Nickel	90 - 240
Silicon	100 - 150
Copper oxide	20 - 40
Zinc Oxide	10 - 50
Aluminum Oxide	30 - 40
Tanium Dioxide	0.4- 11.8
Oils	0.1 - 0.2
Refrigerants	0.01- 0.09

Methods for producing nanoparticles are classified into two classes: **physical methods and chemical methods**. The physical methods include IGC and mechanical grinding. Chemical methods include CVD, chemical sedimentation, microemulsions, thermal spray, and spray pyrolysis [19].The description of nanofluids includes the following: (i) chemical structure estimation, size of agglomeration, and (ii) stabilization of nanofluid. Nanoparticles' description techniques involve the following: TEM, XRD, VSM, EDX, thermal analysis TG-DTA, UV–V spectroscopy, FTIR, infrared absorption spectroscopy, SEM, and ICP-OES. Stability improves the thermal conductivity and a decreases the viscosity. Several techniques are used to enhance the stability of nanofluids, including ultrasound, surface tension, and magnetic mixer. A correct choice of surfactant is serious factor because the addition of a small amount of it causes the formation of an unstable mixture, while the addition of a large amount of it reduces the heat transfer performance of thermal systems. Hence the manufacturing methods and stability are important considerations when discussing nanofluids technologies [12].

1.7 Problem Statement

Practically, the use of nanoparticles faces many obstacles, the most important of which is its high cost and instability with refrigerants during its circulation inside a refrigerating system. Recently, hybrids have been used by researchers to enhance thermophysical properties and stabilization simultaneously, In this study, nanoparticles were synthesis as the following: copper oxide, cerium oxide, mixture1 consisted of 50% copper oxide with 50% cerium oxide, mixture2 consisted of 60% copper oxide with 40% cerium oxide, mixture3 consisted of 70% copper oxide with 30% cerium oxide , mixture 4 consisted of 40% copper oxide with 60% cerium oxide, and mixture5 consisted of 30% copper oxide with 70% cerium oxide to study their effectiveness in enhancing the efficiency of vapor compression refrigerating system and stability of nanoparticle, To test the stability, the mixing vessel was equipped in the laboratory, which was made from Pyrex, with a copper cover with an inner diameter of 4cm , welded to it with a copper tube L- shaped its length 6.5 cm inside a vessel and 2.5 cm outside a vessel with an extra length of 4 cm to be connected to a refrigerant transit valve. The mixing vessel was designed because it is not available inside Turkey, as it is considered expensive to import it from abroad. ***Table 1.2*** shows the design costs for each part of the designed vessel and ***Figure 1.6*** shows different forms of mixing vessels compared to the vessel designed in this study. In the vessel, a quantity of the sample of mixture No.1 was placed after it was weighed using an electric scale, closing the vessel tightly and emptying the air using a vacuum pump. To ensure that the vacuum processes did not cause any loss of nanoparticles, the vessel was weighed again. A leak test was conducted on the vessel to ensure that there was no leakage while mixing R134a with the nanoparticles, as shown in ***Figure 1.7***. To complete the mixing process, the sample was subjected to an ultrasound machine that operates at a power of 320 watts and a frequency of 35 Hz for an hour to obtain a homogeneous solution of refrigerant and nanoparticles for a whole day, with no precipitate formation observed, which gave an indication of the possibility of enhancing the stabilization of nanoparticles if used as a mixture. Fortunately, the materials that were used in the production of nanoparticles are available in every laboratory and are cheap. This study broke the cost barrier that prevents the use of nanoparticles in practice, and produces them with reasonable cost and good thermal

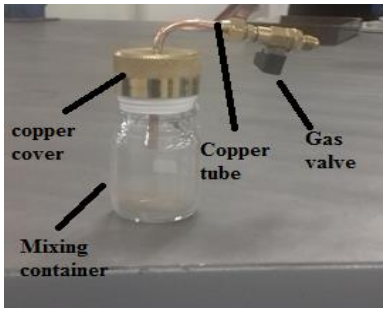
properties. It also presented an alternative to the hybrid, which is the mixture, especially since it was nixed with R134a and a homogeneous mixture was produced. Will the mixture be a solution to the stability problems?

Table 1.2 The cost of vessel that was designed in this study

No	Components	Costs
1	Laboratory bottles	20 TL
2	Copper cover	20 TL
3	Copper tube L shaped	10 TL



(a) (b) (c) (d)



(e)

Figure 1.6 (a-d) Some models of mixing vessel from literature review (e) Mixing vessel of this study



(a) (b)

Figure 1.7 (a) Mixing process, and (b) Mixing vessel of this research

1.8 The objective of This Research

- ✓ Evaluate the COP of VCRS without nanoparticles experimentally and theoretically and compare the results to obtain the highest accuracy among the obtained results.
- ✓ Ansys Fluent software was chosen to complete the theoretical study.
- ✓ Seven different types of nanoparticles were synthesized including CuO, CeO_2, and five mixtures of these oxides.
- ✓ The comparison of *COP* of the VCRS with and without nanoparticles theoretically.

1.9 The scope of the study

- ✓ To investigate a new concept of a nanoparticle as a mixture and whether these mixtures have the ability to enhance the COP of VCRS. This research provides an inexpensive method for the preparing the nanoparticles using distilled water, ammonia, copper nitrate to prepare copper oxide, cerium nitrate to prepare cerium oxide A mixture of cerium and copper nitrate in a specific proportion to prepare the mixture as a single homogeneous substance to investigate whether the nanoparticles as a mixture will reduce the instability and agglomeration.

1.10 The challenges faced by this study

- ✓ The simple vapor compression refrigeration system that was used does not contain a line to charge the nanoparticles with a refrigerant. To solve this problem, this study relied on simulating the system using the Ansys Fluent program to charge nanoparticles theoretically.

- ✓ Due to the lack of containers for mixing gas with nanoparticles, the container was designed at very cheap costs when compared to the mixing containers imported from abroad.

- ✓ This study used numerical equations to calculate the thermal properties of nanorefrigerants, as much research has recently used these equations for most gases due to the unavailability of devices for measuring the thermophysical properties of gases.

CHAPTER 2

LITERATURE REVIEW

The previous studies are categorized into two parts: the first part is a study of refrigerating systems that operate using nanorefrigerants or nanolubricants; and the second part is a study of the thermophysical properties of nanorefrigerants and nanolubricants.

2.1 Influences of Nanolubricants on the Performance of VCRS

Vijaya Kumar et al., 2021 investigated the influence of Al_2o_3 added to POE oil on the COP of refrigerators. A result confirmed improvements in refrigeration effects and COP by 6.09%, and 20.09%, while the power consumption decreased by 15.78% [20] .***Tae Jong Choi et al., 2021*** investigated the influence of MWCNTS added to POE oil on the COP of refrigerators. The results showed that the energy consumed decreased by 17% [21]. ***A. Senthil Kumar et al, 2021*** investigated the influence of Al_2o_3 / Sio_2 hybrid nanoparticles on the COP of refrigeration system. A result confirmed improvements in COP and refrigeration loads by 30 and 25%, whereas energy consumed decreased by 80 W [22]. *A.****Senthil Kumar et al, 2021*** investigated the influence of CuO / Sio_2 hybrid nanoparticles on the COP of refrigeration system. A result confirmed improvements in COP and refrigeration loads by 35% and 18%, whereas energy consumption decreased by 75 W [23]. *A.* ***Senthil Kumar et al. 2021*** investigated the influence of Sio_2 distributed inside POE oil on the COP of a refrigeration system. The results showed that 0.4 g/L Sio_2 carried out the highest refrigeration effects and improved COP by 1.7, while the reduction in energy consumption was 80 W [24] .*A.* ***Senthil Kumar et al., 2021*** investigated the influence of ZnO / Sio_2 hybrid nanoparticles on the COP of a refrigeration system. A result confirmed that 0.6 g/L ZnO / Sio_2 carried out the highest refrigeration loads by180 W, and improved COP by 1.7, whereas the lowest energy consumption was 78 W [25]. ***A. Senthilkumar et al., 2021*** investigated the influence of CuO /Al_2O_3 hybrid nanoparticles on the COP of a refrigeration system. A result confirmed improvements

in COP and refrigerating loads by 27% and 20% , whereas energy consumed decreased by 24% [26]. ***Farhood Sarrafzadeh Javadi et al., 2021*** investigated the influence of Al_2O_3 on the COP of refrigerators. The results showed that energy consumed decreased by 2.69 % [27]. ***Jatinder Gill et al 2019*** investigated the influence of TiO_2, distributed within Capella D oil on the COP of a domestic refrigerator with 40 to 70 g of LPG charged as an alternative to R134a .A result confirmed improvements in refrigerating loads and COP by 18.74-32.72 and 10.15-61.49%, higher than R134a, while energy consumption was less than R134a by 3.20-18.1.[28]. ***Munuswamy Karthick et al 2020*** investigated the influence of four samples on the COP of a refrigeration system as follows: No.1 (MO+ 0.02 vol% Al_2O_3 + 0.01 vol% TiO_2), No. 2 (MO + 0.01 vol% Al_2O_3 + 0.005 vol% TiO_2), No.3 (MO + 0.05 vol% Al_2O_3), and No. 4 (MO + 0.02 vol% Al_2O_3 + 0.02 vol% ZnO. A result confirmed improvements in COP by 14.61%, [29]. ***Damola S. Adelekan et al 2019*** investigated the influence of TiO_2 added to mineral oil on the COP of refrigerators. The results showed that, the energy consumed decreased by 14%, 9 %, and 8% [30]. ***Dattatraya G. Subhedar et al 2020*** investigated the influence of Al_2O_3 added to mineral oil on the COP of a refrigerator. A result showed that 0.075vol % carried out the improvements in COP by 85%, and reduced 27% from energy consumed [31].***T. O. Babarinde et al 2019*** investigated the influence of TiO_2 distributed inside mineral oil on the COP of a refrigerator. The results confirmed that 0.4 g/L TiO_2 carried out the maximum COP and minimum energy consumed [32] ***F. Selimefendigil et al 2019*** investigated the influence of TiO_2 added to PAG oil on the COP of a refrigeration system,. The results indicated that 0.5vol%, 0.8vol%, and 1vol% carried out enhancements in COP by 1.43%, 15.72%, and 21.42%, and 1vol% decreased power consumption by 15% [33]. ***S. Sundararaj et al* 2020** investigated the influence of Au, HAuCl4, and CNTs, mixed with PAG oil on the COP of a refrigeration system. The results showed that 0.2vol.% Au and 0.02vol.% CNTs carried out the minimum energy consumed, the maximum refrigeration effects, and the maximum COP compared to another composition [34]. ***Anusha Peyyala et al 2020*** investigated the influence of Al_2O_3 added to mineral oil on the COP of a refrigeration system. The results indicated that 0.2 vol.% Al_2O_3 carried out the maximum value of COP [35]. ***T.O. Babarinde et al 2019*** investigated the influence of graphene distributed inside mineral oil on the COP of a refrigeration system. The

results showed that 0.2 g/L graphene achieved minimum energy consumed, and maximum COP [36]. ***D.S Adelekan et al 2019*** investigated the influence of TiO_2, added to mineral oil on the COP of a refrigerator. A result confirmed that the best values of COP and refrigeration loads were 4.99 and 290.83kJ/kg [37]. ***Oluseyi O. Ajayi et al 2019*** investigated the influence of Al_2O_3 added to Capella D oil, on the COP of a refrigeration system. The results indicated that nanolubricants improved both of refrigeration capacity and COP; while power consumed decreased [38]. ***A. Senthil kumar et al 2020*** investigated the influence of Sio_2, distributed inside POE oil on the COP of a refrigeration system. A result confirmed that 0.4 g/L Sio_2 increased both of refrigeration capacity and COP, while power consumed decreased [39]. ***A. Senthilkumar et al 2020*** investigated the influence of Al_2o_3 / Sio_2 added to mineral oil on the COP of a refrigeration system. A result confirmed that nanolubricant achieved a higher refrigerating loads and COP by 25%, and 30%, and a minimum compressor work [40]. ***Damola S. Adelekan et al 2017*** investigated the influence of TiO_2 mixed with mineral oil on the COP of a refrigeration system. The results showed that 70 g of LPG with 0.2 g/L or 0.4 g/L achieved the lowest energy consumed; while 70 g LPG with 0.6 g/L achieved the best refrigeration loads .The maximum COP was achieved at 40 g LPG with 0.4 g/L of TiO_2. [41]. ***R.K Adyanshee Pattanayak et al 2015 2017*** studied the effect of Al_2O_3 added to PAG oil on the COP of a refrigeration system. The results showed that, COP increased by 12.14%, 27.8%, and 39.46% respectively. Additionally, the power consumption decreased by 10%, 20%, and 26.6% [42]. ***M.E. Haque et al 2016*** investigated the influence of Al_2O_3 and TiO_2 mixed with POE oil on the COP of a refrigeration system The results showed that the increases in COP were 19% and 22%. Using 0.1vol % Al_2O_3 and TiO_2 achieved 27.73% and 14.19% less energy consumption respectively than pure oil [43]. ***Ravinder Kumar et al 2017*** investigated the influence of ZnO added to mineral oil on the COP of a refrigeration system, and R290 / R600a (50/50) were chosen as refrigerants. A result confirmed that energy consumed decreased by 7.48 %, and the increase in COP was approximately 46 % [44]. ***Md Tarique Anwar et al 2020*** investigated the influence of Al_2O_3 with a diameter of 40 - 50 nm added to PAG oil on the COP of a refrigeration system. The results indicate that refrigeration effects and COP enhanced by 86.26% and 31%, at 0.3 wt% Al_2O_3 [45]. ***Nilesh S. Desai et al 2015*** investigated the influence of SiO_2

added to POE oil on the COP of a refrigeration system. The results showed that the enhancements in COP were by 7.61%, 14.05%, and 11.90%, respectively, while power consumed savings ranged from 7.03% to 12.30%, compared to pure oil [46] ***K.Dilip Kumar et al 2016*** investigated the influence of Al_2O_3 added to PAG oil on the COP of a refrigeration system .The results indicated that COP improved by 19.14%, 21.6%, and 11.22%, respectively, compared to pure oil [47]. ***Aly M. A. Soliman et al 2015*** investigated the influence of AL_2O_3 added to POE oil on the COP of a refrigeration system. The results indicated that COP improved by 10.5 % with 13.5 % less power consumption [48]. ***N. Kamaraj et al 2016*** investigated the influence of carbon black nanopowder added to POE oil on the COP of a refrigeration system. The results indicated that the performance of R134a with (POE / carbon black) was better than the conventional R134a with less power consumption [49]. ***Ravinder Kumar et al 2018 2016*** investigated the influence of CuO added to mineral oil with a diameter of 20 nm on the COP of a refrigeration system.The results indicated that COP was enhanced by 46%, while the power consumption decreased by 7% [50]. ***Jatinder Gill et al 2018*** investigated the influence of TiO_2, SiO_2, and Al_2O_3 added to mineral oil on the COP of a refrigeration system. The results indicated 0.2 g/L TiO_2 produced the minimum energy consumed and the maximum COP [51]. ***Gajanan Chaudhari et al 2015*** investigated the COP of a refrigeration system based on POE oil, SUNISO 3GS oil, and SUNISO 3GS with 0.06 wt. % Al_2O_3. The results showed that SUNISO 3GS decreased energy consumed by 18% when was used instead of POE oil and SUNISO 3GS with 0.06 wt. % Al_2O_3 decreased it by 25% and achieved the highest COP compared to other cases [52]. ***R. Reji Kumar et al*** **2013** studied the COP of a refrigeration system based on POE oil, mineral oil, and mineral oil with 0.06wt. % Al_2O_3, with a diameter of 50nm.. A result showed that compressor work decreased by 11.5% using nanolubricants instead of pure POE oil while COP increased by 19.6 % [53]. ***Subramani.N et al 2013*** studied the COP of a refrigeration system based on pure SUNISO 3GS oil with 0.06 wt.% Al_2O_3 SUNISO 3GS oil with 0.06 wt.% CuO, and SUNISO 3GS oil with 0.06 wt.%TiO_2. The results showed that energy consumed decreased by 15.4%, 11.9%, and 8.4%, while COP increased by 20%, 16%, and 11% for TiO_2, Al_2O_3 and CuO respectively, instead of SUNISO 3GS oil [54]. ***Vaishali P. Mohod et al 2017*** investigated the influence of Al_2O_3, with a diameter of 20 nm added

to POE oil on the COP of a refrigeration system. The results indicated that 0.06wt.% reduced power consumed by approximately 14.71% and increased COP by 28.93% [55]. ***Mohd Hazwan Syafiq Bin Harun 2012*** studied the effect of Al_2O_3 and CNTs added to POE oil on the COP of refrigeration system. The results showed that, CNTs and Al_2O_3 improved COP by approximately 8.29% and 13.8% respectively. Hence Al_2O_3 is more suitable than CNTs when mixed with POE oil [56]. ***R.Santhana Krishnan et al 2018*** investigated the influence of Al_2O_3, SiO_2, ZrO_2, and CNTs, added to POE oil on the COP of VCRS. The results indicated that adding 0.1wt.% SiO_2 to POE oil enhanced the COP by 21.8309 % . It is considered the best among the four samples [57]. ***Gudlavalleti et al 2018*** studied the COP of a refrigeration system using a magnetic power. Every magnetic was 11,800 Gauss between the exit of the condenser and the inlet of the capillary tube with 0.01vol.%, 0.015vol.%, 0.02vol.%, 0.025vol.% CuO mixed with PAG oil. The results indicated that COP improved up to 41.528% at the fourth magnetic set, 0.025 vol.% enhanced COP up to 31.99 [58]. ***Gill Jatinder et al 2019*** investigated the influence of TiO_2, on the COP of a domestic refrigerator. A result showed that power consumed by R600a was 33.33% lower than that of LPG. Moreover, the refrigerating effects and COP of R600 were higher than those of LPG, by 17.39% and 62.54% respectively. [59]. ***Olayinka S. Ohunakin et al 2017*** investigated the influence of TiO_2, SiO_2, and Al_2O_3 added to mineral oil on the COP of a refrigeration system. The results indicated TiO_2 and SiO_2 achieved 13 and 12% reductions in power consumed, whereas Al_2O_3 achieved higher power consumption. SiO_2, TiO_2, and Al_2O_3 had COP values of 2.97, and 2.91 respectively, indicating that Al_2O_3 was incompatible with hydrocarbon refrigerants due to its high power consumption [60]. ***R. Krishna Sabareesh et al 2012*** studied the influence of TiO_2, with a diameter of 30-40 added to mineral oil on the COP of a refrigeration system. The results showed that COP increased by 17%, whereas the power consumption decreased by 11%, [61]. ***Olayinka S. Ohunakinet al 2018*** investigated the effect of SiO_2 distributed inside mineral oil on the COP of a refrigerator. The results showed that 50 g of LPG with 0.4 g/L SiO_2 improved the COP by 2.05, and 60 g LPG with 0.2 g/L SiO_2 improved the COP by 2.65 .Additionally, a lower concentration of nanoparticles caused a reduction in power consumption, whereas a higher concentration caused an increase in power consumption [62]. ***M.S.Bandgar et al 2012***

investigated the influence of SiO_2 added to POE oil on the COP of a refrigeration system. The results showed 0.5wt.% SiO_2 reduced power consumed by 12.02% and the improvement in COP by 11.66% [63]. ***Tao Jia et al 2014*** investigated the influence of $MoFe_2O_4NiFe_2O_4$ compound and $MoFe_2O_4NiFe_2O_4$-Fullerene added to mineral oil on the COP of a refrigeration system. The results indicated that COP increased by 5.33%. [64]. ***M. Anish et al 2018*** investigated the influence of CuO added to Sanden SP-10 oil on the COP of a refrigerator. The results showed that COP increased from 0.58 to 0.62 [65]. ***Ali CanYilmaz*** *2020* studied the influence of both CuO and Cu/Ag alloy on the COP of a refrigeration system. The result indicated that COP improved by approximately 20.88% and 14.55% respectively [66]. ***R. Harichandran et al 2019*** investigated the influence of h-BN on the COP of a refrigeration system .The result indicated that COP increased up to 0.3vol% after that decreased. The maximum COP improvement was 60%. Additionally, the use of h-BN with lubricant did not harm the system, and it may be used in the future if its properties are specified [67]. ***David Fernando Marcucci Pico et al 2020*** investigated the influence of diamond with diameters of 3 and 6 nm on the COP of a refrigeration system. A result confirmed improvements in COP and refrigerating capacity by 0.5 and 5.0%, [68]. ***Vipin Nair et al 2020)*** investigated the influence of. Al_2O_3 with a diameter of 30 nm on the COP of a refrigeration system.The results indicated that COP increased approximately 6.5 % compared to pure lubricant [69]. ***K. Mohan et al 2020*** studied the effects of gold, HAuCl4, CNTs, on the COP of a refrigeration system. The results showed that 0.1% gold with 0.005% CNTs enhanced COP by 31.7% and consumed the lowest energy consumed. [70].

2.2 Influences of Nanorefrigerant on the Performance of VCRS

K. T. Pawale et al 2017 investigated the influence of Al_2O_3 distributed inside R134a on the COP of a refrigeration system. The results indicated that 0.5wt.% improved COP; however, increasing the concentrations reduced the COP of the system [71]. ***G.Sathesh Kumar et al 2018*** studied the influence of (1 g of ZnO with 1 g of SiO_2), (1.5 g of ZnO with 0.5 g of SiO_2), and (0.5 g of ZnO with 1.5 g of SiO_2) are diffused into 0.5 kg R134a on the COP of a refrigeration system .A result confirmed improvements in COP by 26 %.[72] ***V. S. Manikanden et al 2019*** investigated the

influence of CuO, nano-CuO, and Ag-doped nano-CuO scattered inside R290 on the COP of a domestic refrigerator. The results showed that Ag-doped nano-CuO increased COP by 29%, whereas the energy consumption decreased by 28% [73]. ***Lal Kundan et al 2019*** investigated the influence of Al_2O_3 dispersed into R134a, with a diameter of 20nm on the COP of a refrigeration system. The results depended on the volume flow rates indicated that COP increased from 7.20 % to 16.34 % at 0.5 wt.% Al_2O_3. However using 1 wt. % Al_2O_3 reduced COP at comparable flow rates [74]. ***M Nagaraju et al 2018*** investigated the influence of CuO, dispersed into R134a with diameters ranging from 10 to 70 nm on the COP of a refrigeration system .The results indicated that 0.8 wt.% Cuo carried out the best heat transfer properties, increased COP, and power consumed decreased [75]. ***Satyam Kumar et al 2019*** investigated the efficiency of a refrigerating system depended on R134a with PAG oil and R600a with (PAG oil mixed with 0.5wt%, 1wt%, and 1.5wt% of Cu). A result showed that COP and refrigerating capacity were higher than R134a by 27.12% and 25%, while the reduction in energy consumed was 1.69% less than R134a. [76]. ***V.P.Suresh Kumar et al 2016*** investigated the influence of ZrO_2, with a diameter of 20 nm which is diffused inside R134a and R152a.on the COP of a refrigeration system. The results indicated that COP increased by 33.45% depended on 0.06 vol.% of ZrO_2 with R152a. The application of R152a was environmentally beneficial as a result of its good properties for example, ODP and very low GWP [77]. ***Qasim S. Mahdi et al 2017*** investigated the influence of Al_2O_3 dispersed into R134a with diameters of 20-30 nm on the COP of a refrigeration system.The results indicated that COP increased by 3.33% to 12%, while power consumed decreased by 1.6% and 3.3%, respectively [78]. ***Pallav Pandey et al 2017*** investigated the effects of TiO_2 particles with diameters ranging from 30 to 50 nm diffused into R134a on the COP .The results indicated that 0.4 vol.% TiO_2 increased COP by 11.1. Also , no improvement or contraction in the power consumed was observed, it also gives an indication that the nanoparticles are completely dissolved in the refrigerant [79].***Tarun Sharma et al 2015*** investigated the influence of Al_2O_3, with diameters ranging from 20-30 nm, diffused into 100 g of R134a, on the COP of a refrigeration system. The results indicated that COP increased by 1.09% - 7.93% at the evaporator temperature ranging from 25 to 26 ^{0}C, while a reduction in the energy consumed was by 9.87% -12.04% [80]. ***Tarun Sharma et al***

2015 investigated the influence of Al_2O_3 dispersed into hydrocarbons (R290/R600a), with diameters ranging from 20-30nm on the COP of a refrigeration system. A result confirmed improvements in COP by 3.68% - 11.05% , and reduction in power consumption was by 13.6%-30.04% [81]. ***Qasim Kadhim Salman et al 2014*** studied the effect of CuO with a diameter of 20nm dispersed into R134a on the COP of a refrigeration system. The results showed 1.25wt.% enhanced COP by 20 % and compressor work reduced by 13% [82].***Kuljeet Singh et al 2014*** investigated the influence of Al_2O_3 with a diameter of 20nm dispersed into R134a on the performance of a refrigeration system .The results indicated that 0.5wt.% improved COP but 1wt% reduced it [83]. ***Shivangi Shrivastava et al 2017*** investigated the influence of Al_2O_3 particles with diameters ranging from 30 to 50 nm diffused into 200 g of R134a on the performance of a refrigeration system .The results indicated that COP improved by 1.17%–8.40% [84]. ***Sajjan Kawade et al 2015*** investigated the influence of SiO_2, with diameters of 15-20 nm, added into R134a and into mineral oil to prepare a nanorefrigerant and nanolubricant on the performance of a refrigeration system. The results indicated that COP of nanorefrigerant improved by 3.77%, 6.70%, and 9.86% , whereas COP of nanolubricant increased by 6.97%, 9.90% ,and 12.68% respectively [85]. ***D. Senthilkumar 2017*** studied the influence of SiC nanopowder and SiC cryogenically added into R134a.on the COP of a refrigerating system.The results indicated that R134a with 0.25wt.% SiC saves 20% power consumption while COP of R134a with SiC ,and COP of R134a cryo Sic were 1.81 ,and 2.0 respectively [86]. ***Shailendra Kumar 2016*** studied the effect of Al_2O_3, with a diameter of 20nm added into R134a on the performance of a refrigeration system. The results indicated that R134a with 0.4 wt.% Al_2O_3 and R134a with 0.8 wt.% Al_2O_3 improved COP by 2.45% and 5.37% respectively compared to pure refrigerant [87]. ***K.Veera Raghavalu 2016*** studied the effect of Al_2O_3 and TiO_2, with a diameter of 20 nm; added to R134a on the performance of a refrigeration system. The results indicated that Al_2O_3 and TiO_2 enhanced COP by 12.08%, and 21.18% respectively compared to R134a [88]. ***G Senthilkumar et al 2017*** investigated the influence of CuO added to R22 on the performance of a refrigeration system. The results indicated that 0.05 vol. %, decreased energy consumed and increased COP from 0.58 to 0.62 [89**]. *Pravesh Kumar Kushwaha et al 2016*** investigated the influence of Al_2O_3, added to R134a on the

performance of a refrigeration system. The results indicated that R134a with 0.25 wt.% Al_2O_3 and R134a with 0.50 wt. % Al_2O_3 improved COP up to 11.76% [90]. ***A.Senthilkumar et al 2015*** investigated the influence of CuO, added to R600a on the performance of a refrigerator. The results indicated that 0.1 and 0.5g/L saved 11.83% and 17.88% power consumption respectively and enhanced the COP of the system [91]

2.3 The Effects of Nanoparticles on Thermophysical Properties

M.A. Kedzierski et al2017 investigated the thermophysical properties of nanolubricants by adding Al_2O_3 and ZnO with diameters of 127 nm and 135 nm to POE oil at temperatures ranging from 288 to 318 K .A result confirmed improvements in viscosity, density, and thermal conductivity with increasing nanoparticle concentrations. However viscosity and density were reduced with increasing temperatures [92]. ***S.S. Sanukrishna et al 2018*** investigated the effect of TiO_2 mixed with PAG at temperatures ranging from 20 to 90 °C on the thermophysical properties of nanolubricants. The results indicated that improvements in thermal conductivity and viscosity with increasing nanoparticles concentration [93] ***N.N.M. Zawawi et al 2018*** investigated the effects of Al_2O_3/SiO_2, Al_2O_3/TiO_2, and TiO_2/SiO_2 hybrid nanoparticles added to PAG oil at 303 to 353 K on the thermophysical properties of nanolubricants. The results indicated that 0.1vol.% Al_2O_3/TiO_2 increased the viscosity by 20.50% at 303 K. While 0.1vol.% Al_2O_3/SiO_2 increased the thermal conductivity by 2.41% at 303 K [94] ***R. Harichandran et al 2019*** studied the effect of h-BN on thermophysical properties of nanolubricant. A result confirmed improvements density and viscosity with increasing nanoparticle concentration, whereas the viscosity reduced with increasing temperature. Additionally, the viscosity of nanolubricants at 0.4 vol. % was 14% more than that lubricant [67]. ***Munuswamy Karthick et al 2020*** investigated the influence, of four samples on the thermal conductivity of nanolubricants as follows :No.1 (MO + 0.02 vol.% Al_2O_3 + 0.01 vol.% TiO_2), No.2 (MO + 0.01 vol.% Al_2O_3 + 0.005 vol.% TiO_2) , No.3 (MO + 0.05 vol.% Al_2O_3),and No. 4 (MO + 0.02 vol.% Al_2O_3 + 0.02 vol.% ZnO).The results indicated that mineral oil containing of 0.05vol.% Al_2O_3 achieved a maximum increase in thermal conductivity ,and mineral oil containing of 0.01vol.% Al_2O_3 and 0.005 vol.% TiO_2 achieved a minimum increase in the thermal conductivity. Additionally, sample 1

achieved a maximum viscosity compared to other samples. [29]. ***Ravinder Kumar et al 2018*** investigated the influence of CuO on the viscosity of nanolubricants. A result confirmed that 0.2–1.0 wt. % CuO increased viscosity by 17%, whereas it decreased it with increase temperatures [50] ***Gill Jatinder et al 2019*** look into how TiO_2 affects the thermophysical properties of nanolubricants. A result confirmed that thermal conductivities were more than that of pure lubricant by approximately 14.37-41.25%, while the viscosity was more than that of pure lubricant by approximately 2–6%. [59]. ***S. A. Fadhilah et al 2014*** investigated the influence of CuO dispersed into R134a, on the thermal conductivity of nanorefrigerant. The results indicated that thermal conductivity increased from 0.0139 to 0.4477 W/mk. at (26◦C and 1 vol. %.).The viscosity of nanorefrigerant achieved an enhancement by approximately 44.45% compared to pure refrigerant [95]. Based on previous research, ***I.M. Mahbubul et al. 2015*** investigated the effects of 5 vol.% Al_2O_3 dispersed in R134a at 283 to 308 K on the thermophysical properties of nanorefrigerants**.** The results indicated that thermal conductivity, viscosity, and density improved by 28.58%, 13.68%, and 11%, while, the specific heat was less than that of R134a. [96]. ***M.Z. Sharif et al 2016*** investigated the thermophysical properties of nanolubricants when Al_2O_3 is added to PAG at temperatures ranging from 303.15 to 353.15 K A result confirmed improvements in thermal conductivity with increasing nanoparticle concentration and viscosity increases for concentrations higher than 0.3vol.%, but decreased with temperature [97]. ***I.M. Mahbubul et al 2013*** used some numerical equations to evaluate the thermophysical properties of nanorefrigerants depending on 1 to 5 vol.% Al_2O_3 being diffused into R134a .A result confirmed improvements in thermal conductivity with increasing the concentrations and temperatures but decreased with size of nanoparticles while the viscosity improved with increasing of concentrations [98]. ***Mark A. Kedzierski 2012*** studied the effect of spherical CuO with diameters of 30 nm, at 288 K to 318 K added to POE oil on the thermophysical properties of the nanolubricant .A result confirmed improvements in viscosity and density with increased nanoparticle concentration [99]. ***N.N.M. Zawawi et al 2017*** investigated the effects of Al_2O_3 / SiO_2 hybrid nanoparticles on the thermophysical properties of nanolubricants at temperatures ranging from 303 to 353 K. The results indicated that the maximum values of thermal conductivity and viscosity were by 2.41% and 9.71%

[100]. I***M. Mahbubul et al 2013*** investigated the effects of Al_2O_3 dispersed into R141b at 5 to 20 °C, with a diameter of 13 nm on the thermophysical properties of nanorefrigerants. The results confirmed improvements, in thermal conductivity with increasing nanoparticle concentrations and temperatures. The viscosity increased with increased concentration, but decreased with increased temperature.[101]. ***Omer A. Alawi et al 2014*** investigated the influence of CuO dispersed into R134a on the thermophysical properties of nanorefrigerants depending on the correlations from previous studies at 300 to 320 K.A result confirmed improvements in thermal conductivity with increased concentrations and temperature. Additionally, viscosity and density increase with increase the concentrations, while viscosity is reduced with increasing temperatures [102]. ***Omer A. Alawi et al 2015*** investigated the influence of SWCNTS dispersed into R134a on the thermophysical properties of nanorefrigerants depending on the correlations from previous studies at 300 to 320 K. A result indicated that improvements in thermal conductivity with increasing temperatures and concentrations, whereas the viscosity improves with increasing the concentrations [103]. ***Amin Asadi et al 2016*** investigated the influence of MWCNTS / MgO hybrid nanoparticles added to engine oil at 25 °C to 50 °C on the viscosity of nanolubricants .A result indicated that viscosity decreased with increasing temperatures while the increasing nanoparticle concentrations led to increasing the viscosity. The maximum increase in viscosity was by 65% at 2vol.% and 40 °C while the minimum increase was by 14.4% at 0.25vol.% and 25 °C [104]. ***A.A.M. Redhwan et al 2017*** studied the effect of SiO_2 added to PAG at 303 to 353 K and compared them with nanolubricants based on Al_2O_3 on the thermophysical properties of nanolubricants. A result indicated that improvements in viscosity and thermal conductivity with increasing concentrations and thermal conductivity based on 1.0 vol.% SiO_2 was higher than thermal conductivity based on Al_2O_3 [105]. ***Sanukrishna S. S et al 2017*** investigated the influence of CuO added to PAG oil on thermal conductivity of nanolubricants. A result confirmed that thermal conductivity ratio increases linearly with increasing concentrations and 0.1 vol. % achieved the highest value in the thermal conductivity by 12.67 % [106]. ***Ravinder Kumar et al 2017*** evaluated the viscosity of mineral oil with and without ZnO. The results showed that 0.2 wt.% and 60 °C improved the viscosity by 7.7 %, whereas, 0.4, 0.6, 0.8 and 1.0 wt.%, improved the viscosity

by15.87, 21.45, 22.9 and 25.1 % respectively., however viscosity decreased with increasing temperature, [44]. ***Qasim S. Mahdi et al 2017*** studied the effect of Al_2O_3 with diameters of 20-30 nm dispersed into R134a on thermophysical properties of nanorefrigerants .A result confirmed improvements in thermal conductivity by 11.5% and 14.2% with increasing concentrations, and the viscosity improved by 1.4% and 5.2% [78]. ***I.M. Mahbubul et al 2013*** investigated the effects of Al_2O_3 dispersed into R141b at 5 to 20ºC on the thermophysical properties of nanorefrigerants. The results indicated that thermophysical properties improved with concentrations, the minimum and the maximum values of thermal conductivity were 1.003 and 1.013 at (5ºC and 0.1vol %) and (20ºC and 0.4vol %), receptively. Moreover, viscosity decreases with increasing temperature [107]. ***Asif Faizanet al 2016*** studied the effect of Al_2O_3 dispersed into R245fa at 293 K on the thermophysical properties of nanorefrigerant, by using models from existing studies. The results showed that thermal conductivity increased but the specific heat decreased with increase concentrations. In addition, viscosity and density increased with increase the concentrations [108]. ***Mahidhar Duggal et al 2016*** studied the effect of ZnO and CuO at temperatures ranging from 180 K to 270 K on the thermophysical properties of R11, R12 and R141b using some numerical equations. A result confirmed improvements in the effective thermal conductivity, effective viscosity, and density, of R11, R12 and R141b with increasing concentration, while the specific heat of R11, R12 and R141b improved with increasing temperature and decreased with increasing concentration. Moreover, at various temperatures and concentration R141b had the highest value of effective thermal conductivity among others, R12 had the lowest value of effective viscosity, R141b had the lowest density and R141b had the highest specific heat values among others [109]. ***Ajay Sharma et al 2016*** used suitable correlations to estimate the thermophysical properties of nanorefrigerant based on 1vol.% to 5vol.% TiO_2 scattered into R141b .The results showed that thermal conductivity improved with increasing concentration, viscosity increased with increase concentrations, density increases with increase concentrations, , and specific heat decreases with increase concentrations [110] ***S.S. Sanukrishna et al 2018*** investigated the thermophysical properties of nanolubricants depending on PAG with Al_2O_3 at 20 to 90°C. A result indicated that the maximum thermal conductivities ratio and maximum viscosity ratio

were 1.48 and 18.42 at 0.6vol.% and temperature 20 °C respectively [111]. ***Subramani Narayanasarma et al 2019*** investigated the thermophysical properties of nanolubricants based on POE with SiO_2 at temperatures ranging from 25 to 85 °C. The results showed that thermal conductivity increased with increasing concentrations and temperature, with a maximum value of 1.109 at 0.2 wt% and 85 °C. Additionally, the viscosity improved with increase concentrations but reduced with temperature [112]. ***Dattatraya G. Subhedar et al 2020*** investigated the influence of 0.05 vol.%, 0.075vol%, 0.1vol.%, and 0.2vol.% Al_2O_3 on the viscosity of nanolubricant. The results indicated that the increase concentration of Al_2O_3, led to increase in the viscosity compared to pure lubricant [31]. ***Mohammad Hemmat Esfe 2020*** studied the effect of (20% MWCNTS/ 80 % ZnO) hybrid nanoparticles on the viscosity of nanolubricants based on SAE 50 engine oil at 25 to 50 °C .A result confirmed improvements in viscosity with increasing concentrations, while the viscosity decreases with increasing temperature [113]. ***N. N. M. Zawawi et al 2019*** investigated the thermophysical properties of nanolubricants containing 20:80, 40:60, 50:50, 60:40, and 80:20 Al_2O_3 / SiO_2 hybrid nanoparticles at 0.1 vol.% added to PAG oil at temperatures ranging from 30 to 80°C. The results indicated that thermal conductivity improved by 2.41% at 80 °C, while the highest improvement of the dynamic viscosity was 9.34% at 70 °C. Improvements in both parameters were observed for 50:50 nanoparticle ratios [114]. ***Songyuan Zhang et al 2020*** investigated the influence of Al_2O_3, TiO_2 and SiO_2 mixed with R141b on thermal conductivity at temperatures ranging from 278 to 298 K. A result indicated this property increased with increasing temperatures and concentrations, whereas decreased with increasing diameter size. [115]. ***P.B. Maheshwary et al 2018*** investigated the influence of ZnO mixed with R134a at temperatures ranging from 283 to 307 K on the thermophysical properties of nanorefrigerants. The results showed that, ZnO with R134a based on cubic shape has a higher value of the viscosity. Additionally, spheral and cubic shape of ZnO with R134a having a higher density but lower specific heat. The improvements of thermal conductivity of spheral and cubic shape of ZnO were 25.26% and 42.5 %, respectively [116]**.** ***M.R.M. Nawi et al 2018*** studied the effect of SiO_2 mixed with HFE7000 at temperatures ranging from 283 to 303 K on the thermophysical properties of nanorefrigerant. The results indicated that nanorefrigerants exhibited a high stability

with SiO_2 more than 90 days and thermal conductivity improved with increase concentrations. The highest improvements in the thermal conductivity was 27% at 0.02 vol. %. At the same time, the viscosity increases with increasing concentrations but decreasing with temperatures [117].

CHAPTER 3

METHODOLOGY

The methodology of this research has been divided into several parts, as follows: Part one: the experiment that was conducted on VCRS using R134a as a working fluid; so that the COP is calculated depending on the enthalpy of R134a. The second part: using Ansys Fluent program to determine the COP theoretically. In the third part, nanoparticles were prepared in a new, easy, and cheap way to be theoretically introduced into the refrigeration system and to investigate their effectiveness in enhancing the efficiency of the refrigerating system. The last part uses mathematical models to evaluate the thermophysical properties of nanorefrigerants.

3.1 Setup of Experiment

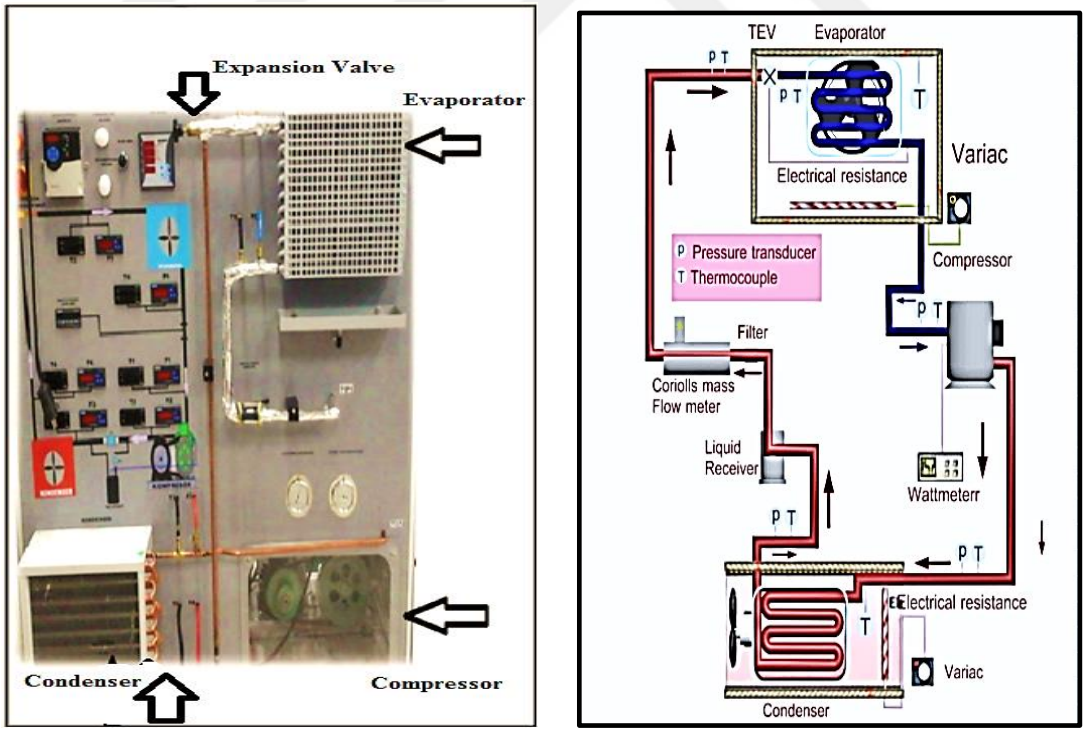
First, the refrigeration system is emptied to remove all suspended materials inside it that effect on the life of the system, then a leak test is conducted by pumping an amount of air and monitoring the pressure meter to ensure that the refrigeration system will operate without leakage.

In the laboratory of Yildiz Technical University in Istanbul, Turkey. Refrigeration systems use R134a as a refrigerant because of its good properties such as, compatible with all types of oxide, safety, no effect on the ozone layer, flammability, low cost, and most research relies on it in studying refrigeration systems. Relying on a set of gages installed at the entrance and exit of each component of the cycle, the change in pressure and temperature is monitored. The power consumed and mass flow rate are monitored using a wattmeter gage and a flow meter gage. The following hypotheses were formulated to complete the experiment (i) the system was isolated no heat gain to the system and no heat wastage to the surrounding (ii) neglecting the change in kinetic and potential energies (iii) the experiment was performed as a steady state under normal conditions. The experiments were divided into several cases, each case included ten experiments ,and each experiment was repeated many times to achieve high accuracy and wait 15 minutes to take the reading of the meters and reach a stable

reading state. ***Table 3.1*** shows the parts of the system that have been worked on and ***Figure 3.1.*** shows the real system and its theoretical simulations.

Table 3.1 Characteristics of refrigeration system of this study

Component	Specifications
Compressor	Bitzer 1/2 HP
Condenser	Air cooled 1/2 HP
Evaporator	Emersion coil 1/3 HP
Expansion valve	Automatic
Voltage	220 V AC
Suction lines	3/8-inch
Discharge lines	1/4-inch
Frequency	51 Hz
Defrost unit	Automatic
Door type	Single closed door



(a) (b)

Figure 3.1 (a) The real system and (b) theoretical simulations

3.1.1 Experiment procedure

The Engineering Equation Solver (EES) program is used in order to determine the enthalpy and the changes in the phase of R134a based on the reading of the gages of temperatures and pressures, where two phases were observed during its circulation in a refrigeration system superheated vapor and compressed liquid. The following equations were used [34].And the specifications of R134a are given in ***Table 3.2.*** and the process of the cycle is shown in ***Figure 3.2***

a) $\dot{W}_{comp} = \dot{m}\,(h_2 - h_1)$ **(3.1)**

b) $Q_{evap} = \dot{m}\,(h_6 - h_5)$ **(3.2)**

c) $Q_{cond} = \dot{m}\,(h_3 - h_4)$ **(3.3)**

d) $\text{COP} = \frac{(h6 - h5)}{(h2 - h1)}$ **(3.4)**

Table 3.2 Specifications of R134a [118]

Specifications	
1,1,1,2 Tetrafluoroethane	$P_{sat,v}$ at 20°C =774.3 kPa
CF_3CFH_2	hg =198.6 kJ/kg
M_W = 102.03 g/mol	$\rho_{,L}$ =1294.8 kg/m^3
pure	$\rho_{,v}$ =14.43 kg/m^3
ASHRAE , A1	$Cp_{,L}$ = 1.341 kJ/kg°C
ODP = zero	$Cp_{,v}$ = 0.90 kJ/kg°C
$GWP_{,100,year}$ =1300	$K_{,L}$ at 25°C =0,0824 W/m K
$T_{,critical}$ =101.1°C	$K_{,v}$ at 25°C =0,0145 W/m K
$P_{,critical}$ = 4.06.3 MPa	$\mu_{,L}$ at 25°C =0,202 mPa.s
NBP= -26.4 °C	$\mu_{,V}$ at 25°C =0,012 mPa.s

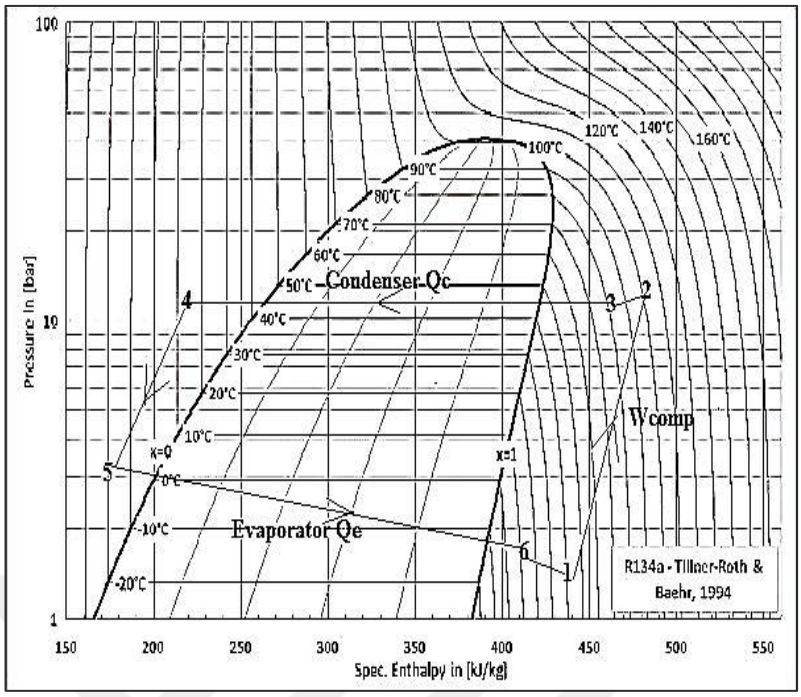


Figure 3.2 P-h diagram of the cycle of this study

3.1.2 Implementation of the mathematical model of (VCRS)

The requirements of the theoretical study were as follows: (i) The geometric design of both the evaporator and condenser was created using the Solid Works program based on their dimensions as shown in ***Tables 3.3***, this program aids in the complete of the design with high accuracy and speed and then saves it as Para Solid format for import into Ansys Fluent as shown in ***Figure 3.3 a*** (ii). The mesh is required for success of mathematical models and is regarded as an accuracy criterion; mesh independency is included in ***Table 3.4*** and is illustrated in ***Figure 3.3 b*** for 2809136 elements and 2971904 number of nodes. The Ansys Fluent program determines the gradients in temperature, pressure, and velocity of refrigerant while circulating inside the condenser and evaporator tubes in the form of contour. Inside each contour there are many colors, where each color represents a reading of pressure, temperature and velocity. The red colors represents the maximum values, the blue colors represents the minimum values other colors are between the highest and the lowest values (iii) The Fluent setup where the equations are prepared to solve the theoretical model, and these equations are continuity, momentum, and energy equations to obtain all theoretical values, which include (i) heat absorbed and rejected ;(ii) the energy consumed; and

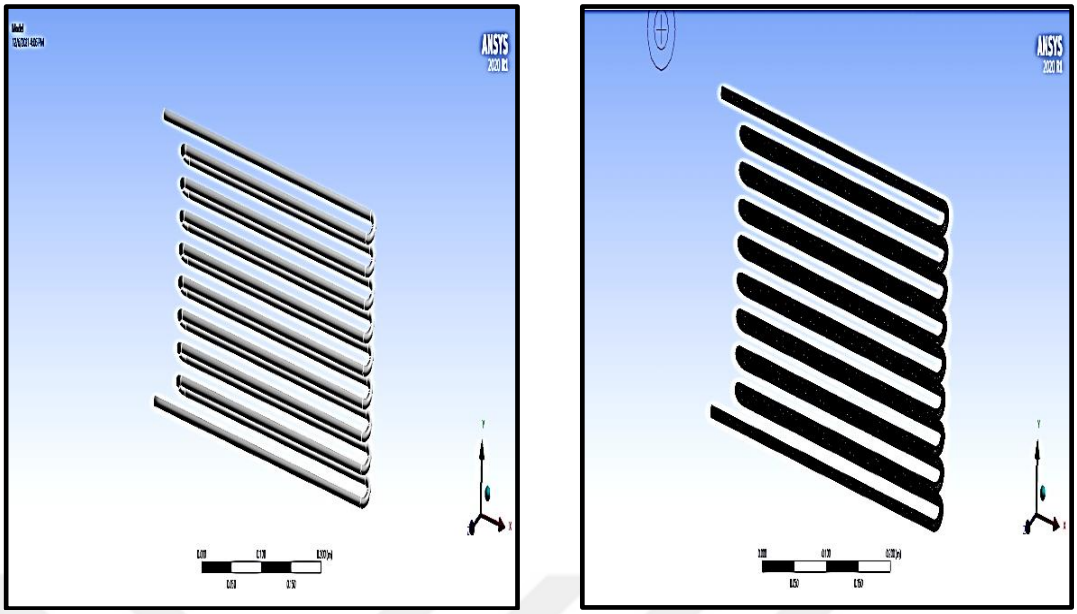
(iii) the temperature and pressure to compare them with the results obtained from the experiment ; and then go directly to the solution and get the results as shown in flow chart in ***Figure 3.4.*** All contours of velocity, pressure, and temperature of condenser and evaporator are shown in ***Figure 3.5 to 3.23***.

Table 3.3 Specifications of the condenser and evaporator

Condenser	Specifications	Evaporator	Specifications
Length	35cm	Length	33cm
Width	17cm	Width	10cm
Height	28cm	Height	28cm
Diameter of copper tube	0.25 inch	Diameter of copper tube	0.25 inch
Number copper tubes	18	Number of copper tubes	18
Distance between tubes	5cm	The area	$0.12cm^2$
The area	$0.177cm^2$	Number of tubes	18
Length of tube	7.2 m	Fan speed	1300 rpm
The thickness of aluminum plates	0.3mm	Air speed	638 m/s
Number of plates	600	Distance between tubes	3cm
Single plate dimensions	35*17*34 cm	length of tube	6.48m
Fan speed	1300 rpm		
Air speed	638 m/s		

Table 3.4 The independency mesh

Case	Elements	Nodes	Pressure. Pa
1	634783	823404	6.29
2	1323465	1534078	7.23
3	2026567	2102577	7.6
4	2809136	2971904	7.61



(a) (b)

Figure 3.3 a) The geometry of evaporator and condenser b) Mesh of evaporator and condenser

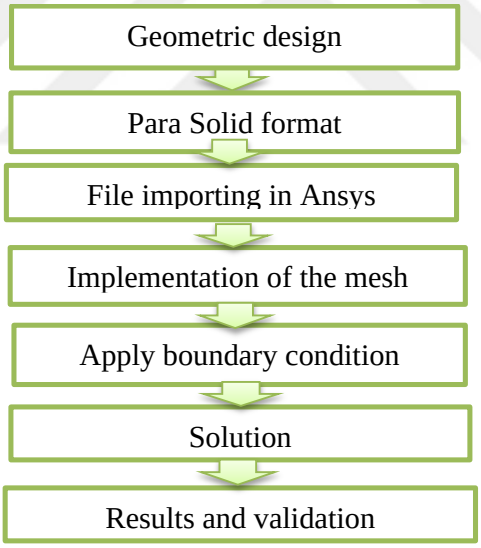
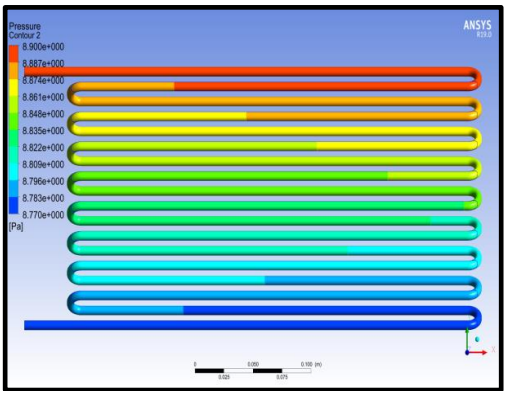
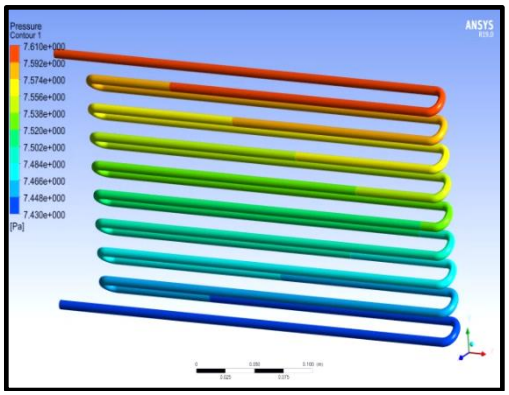


Figure 3.4 Flow chart diagram of this study

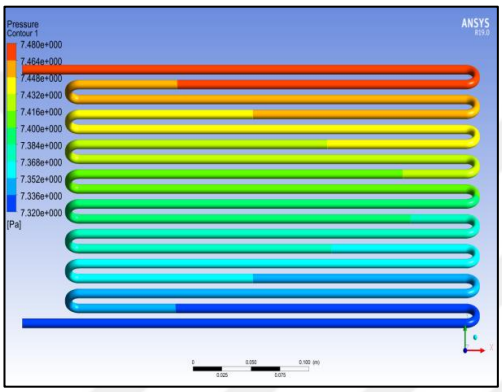
Case 1



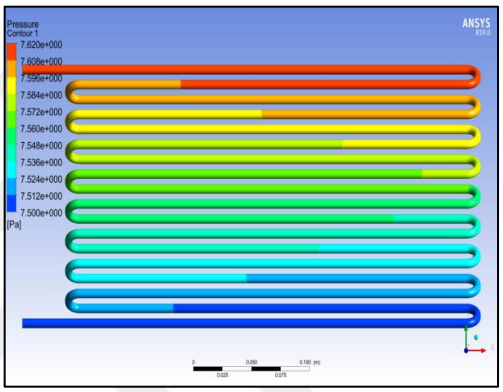
Case 50



Case 100



Case 150



Case 200

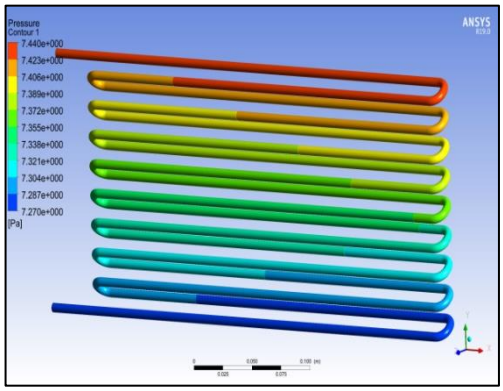
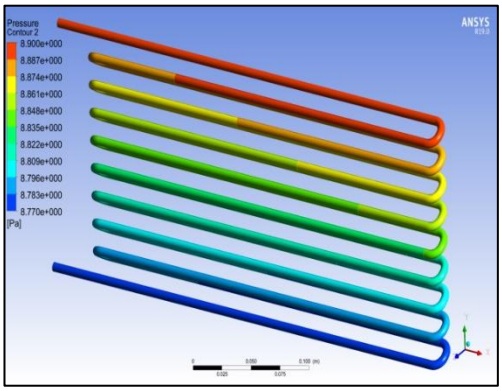
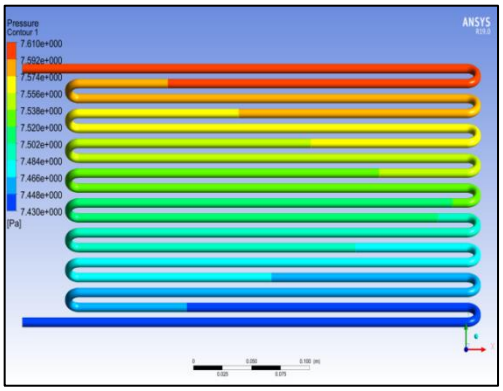


Figure 3.5 Contours plot of condenser based on pressure inlet

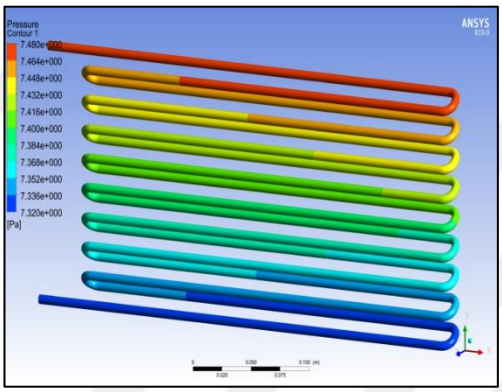
Case 1



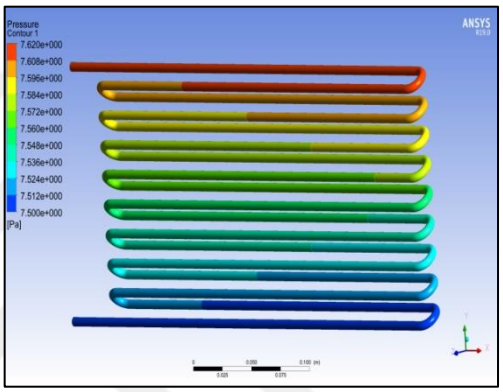
Case 50



Case 100



Case 150



Case 200

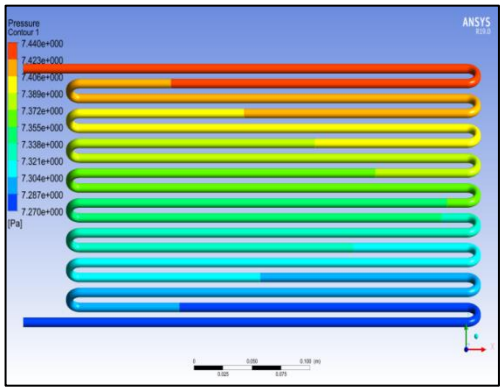
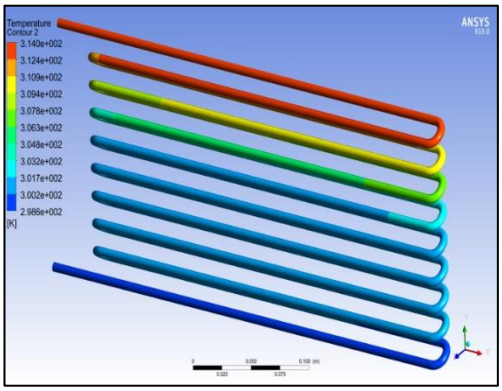
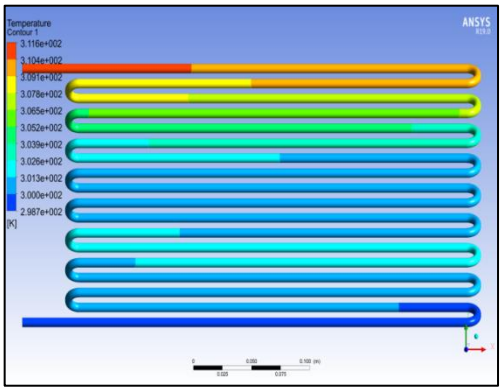


Figure 3.6 Contours plot of condenser based on pressure outlet

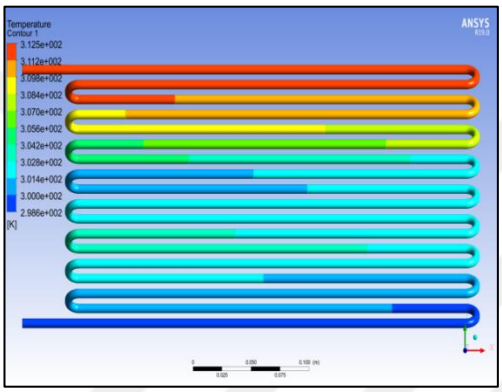
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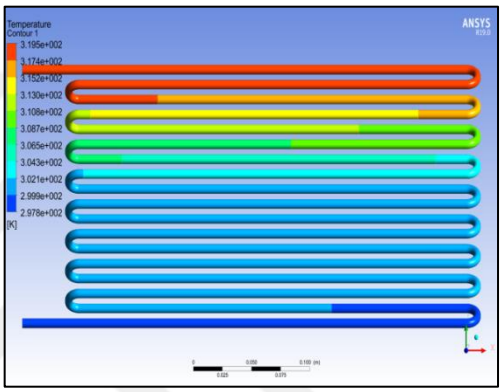
Case 50



Case 100



Case 150



Case 200

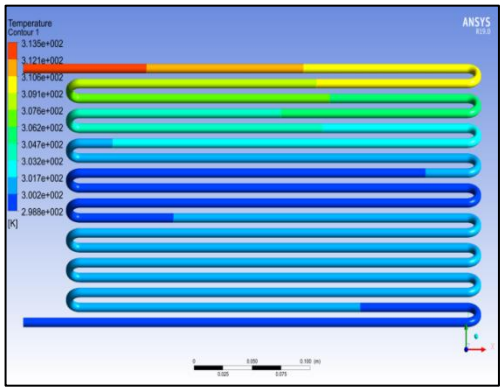
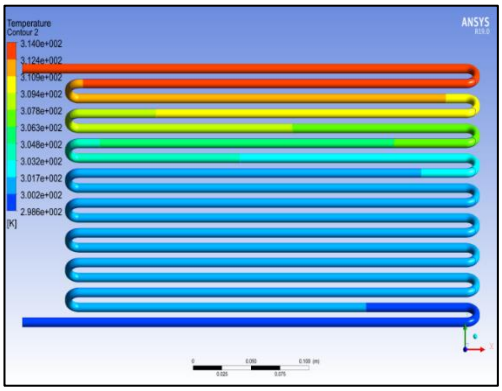
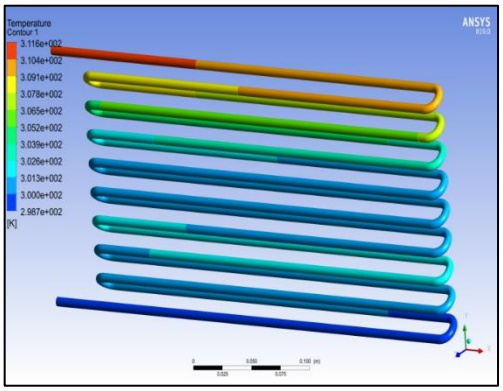


Figure 3.7 Contours plot of condenser based on temperature inlet

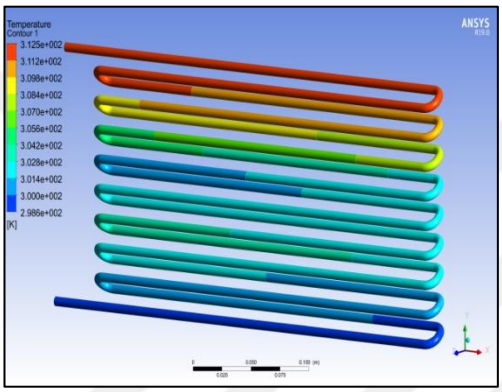
Case 1



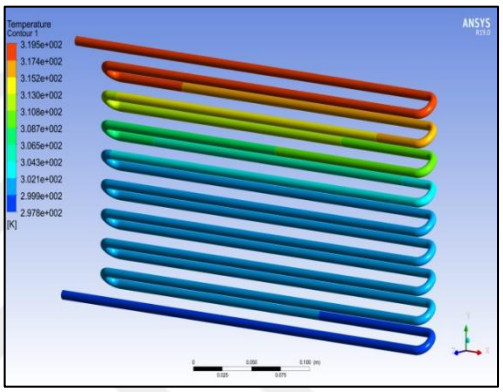
Case 50



Case 100



Case 150



Case 200

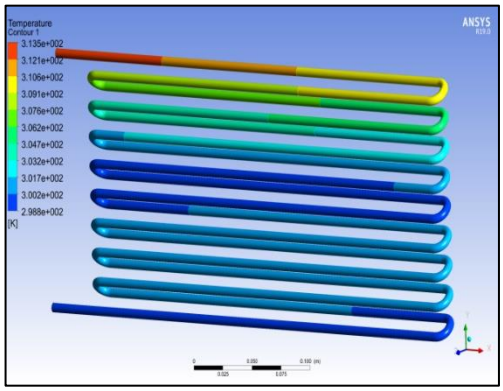
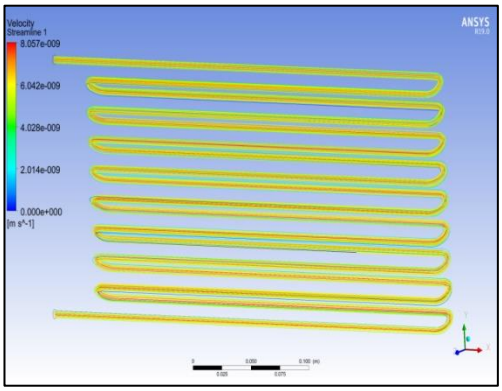
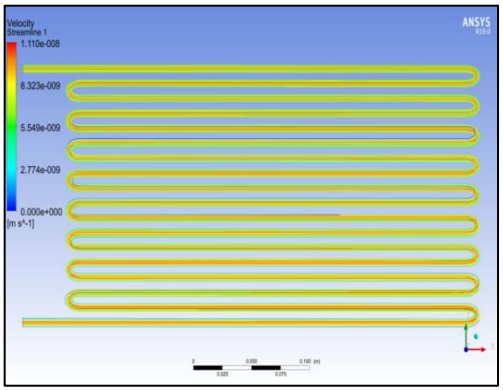


Figure 3.8 Contours plot of condenser based on temperature outlet

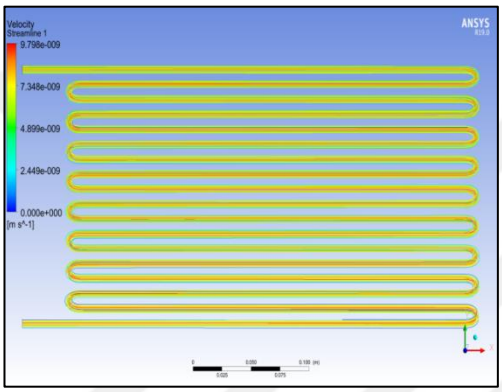
Case 1



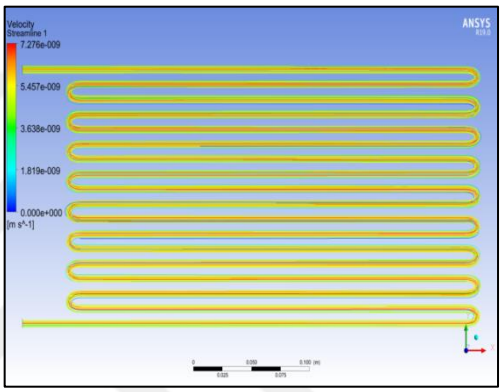
Case 50



Case 100



Case 150



Case 200

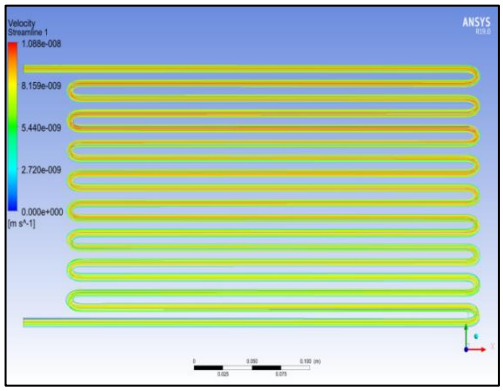
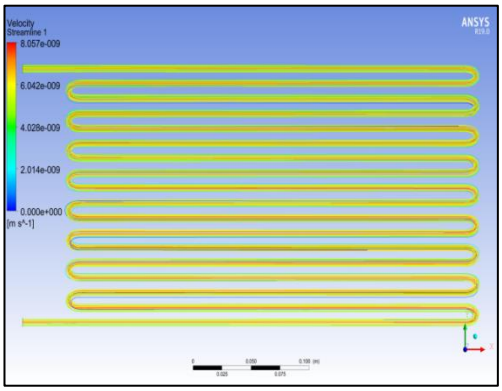
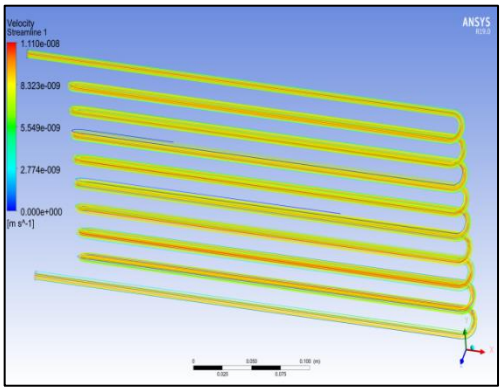


Figure 3.9 Contours plot of condenser based velocity inlet

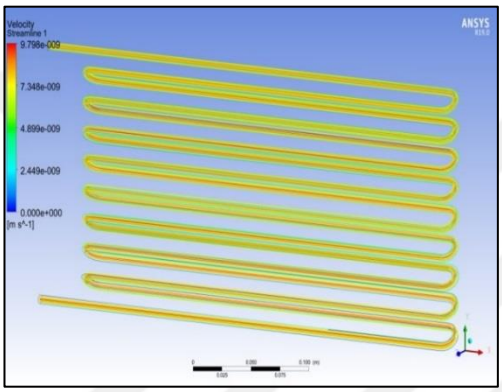
Case 1



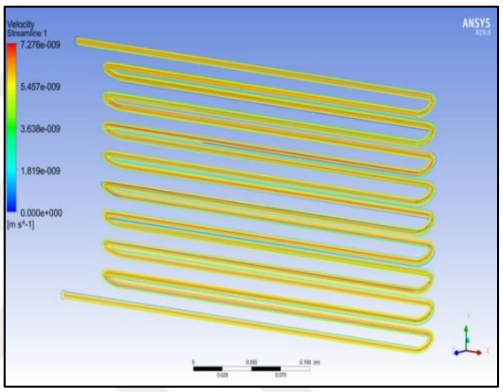
Case 50



Case 100



Case 150



Case 200

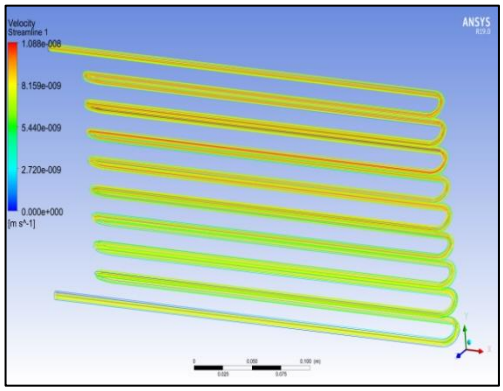
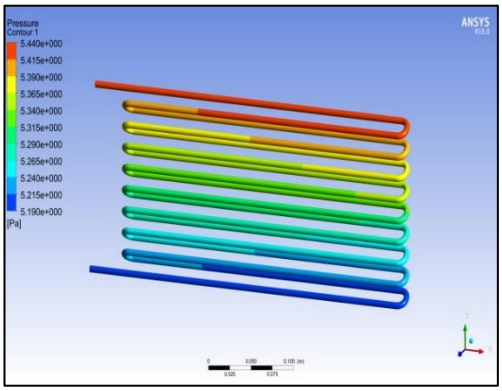
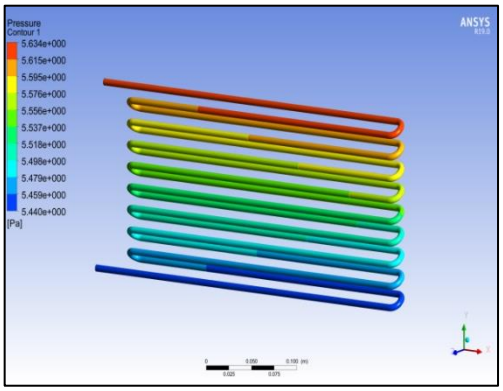


Figure 3.10 Contours plot of condenser based velocity outlet

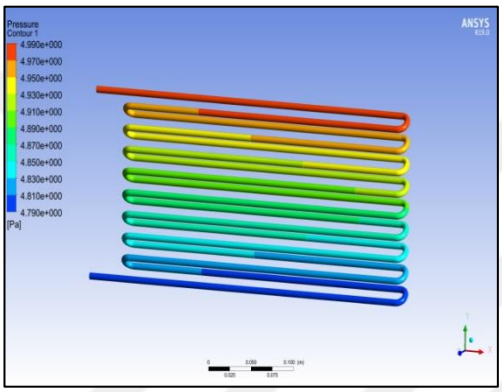
Case 1



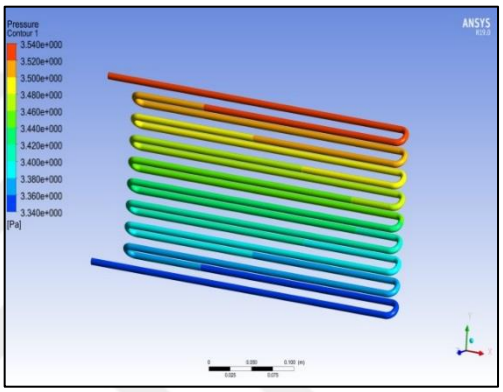
Case 50



Case 100



Case 150



Case 200

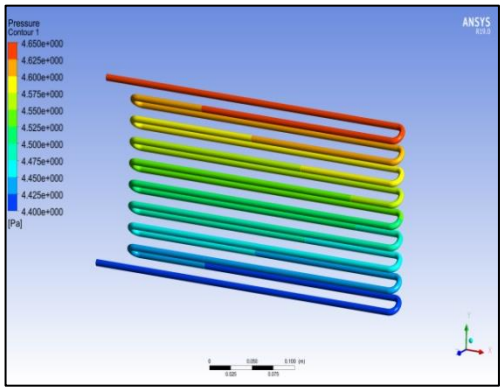
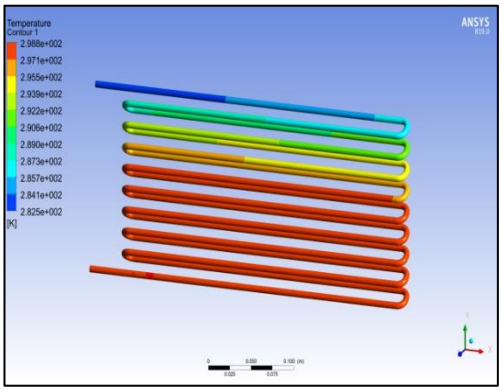
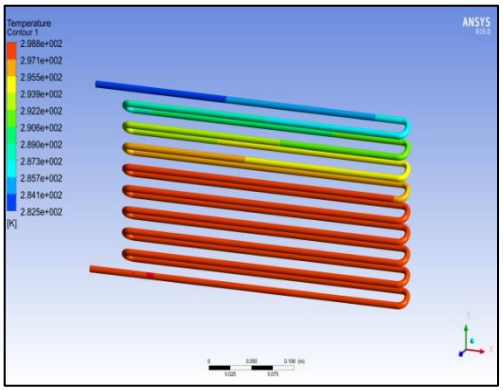


Figure 3.11 Contours plot of evaporator based on pressure

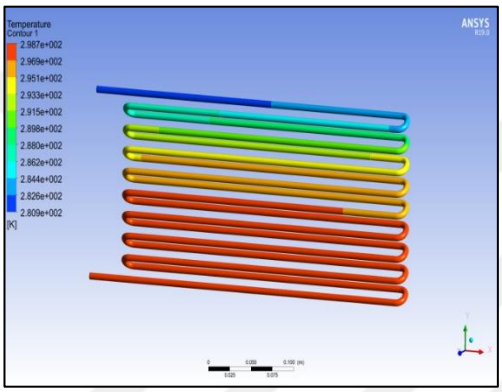
Case 1



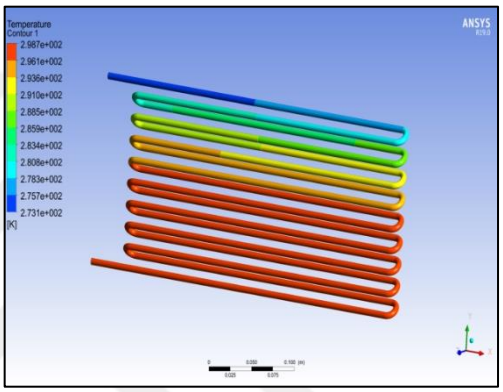
Case 50



Case 100



Case 150



Case 200

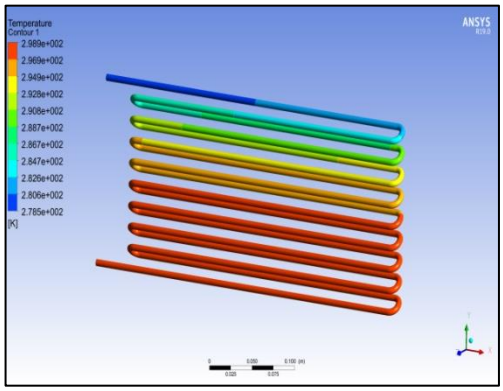
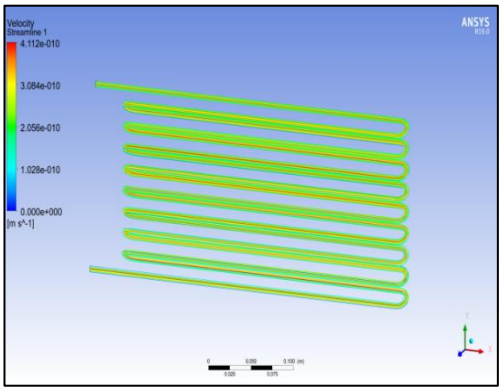
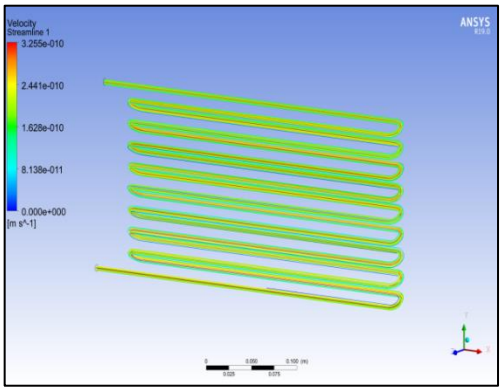


Figure 3.12 Contours plot of evaporator based on temperature

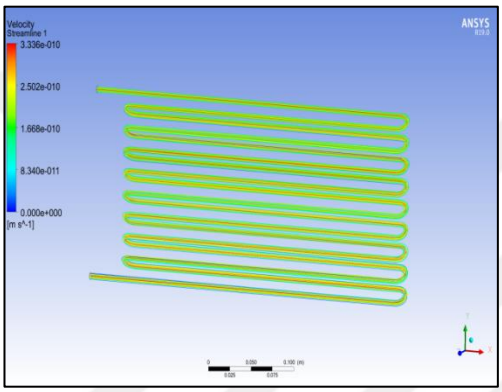
Case 1



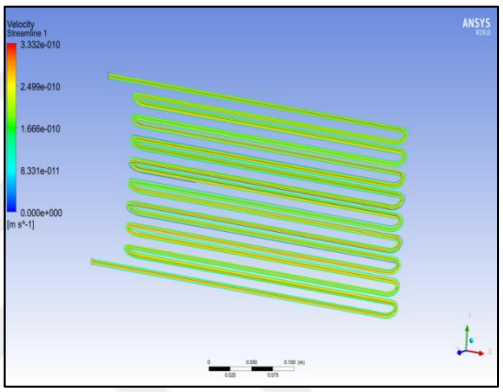
Case 50



Case 100



Case 150



Case 200

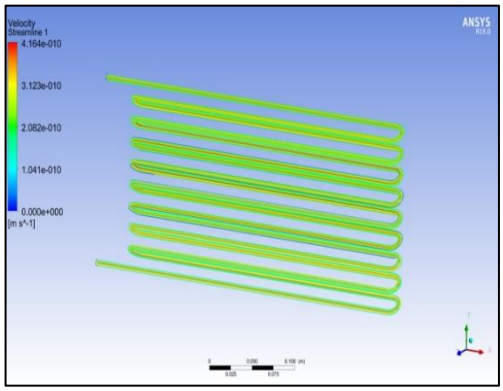
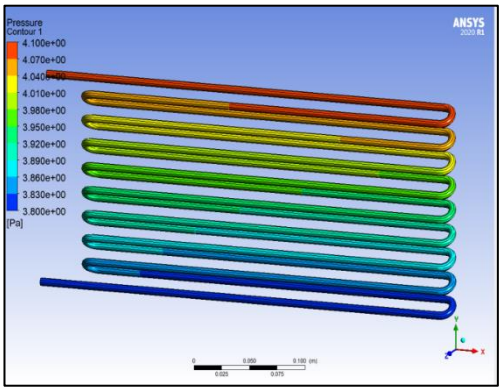
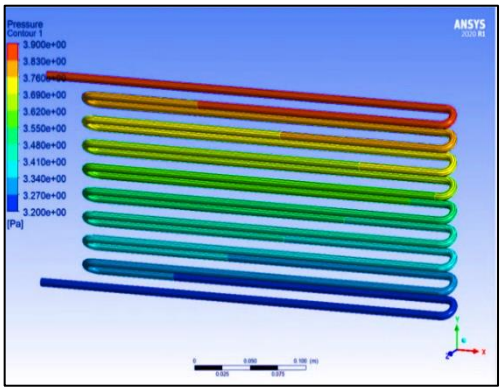


Figure 3.13 Contours plot of evaporator Based on velocity

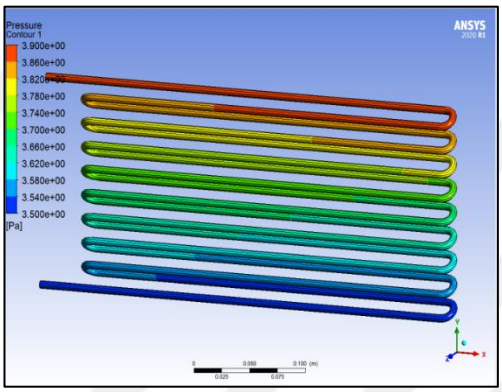
Case 1



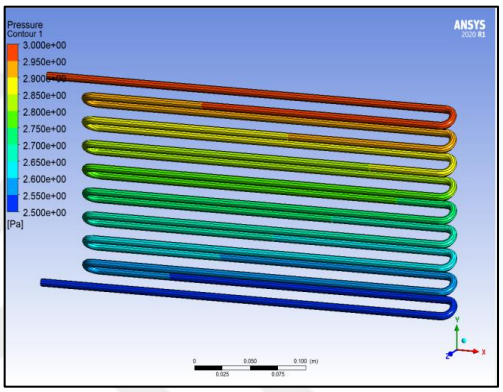
Case 50



Case 100



Case 150



Case 200

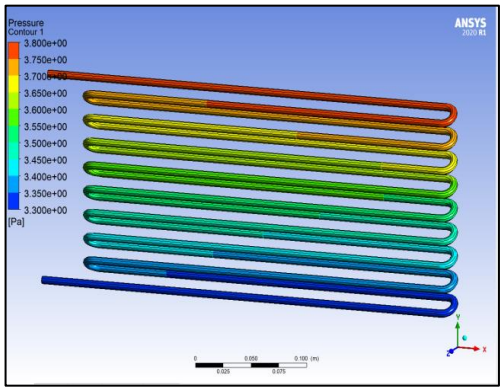
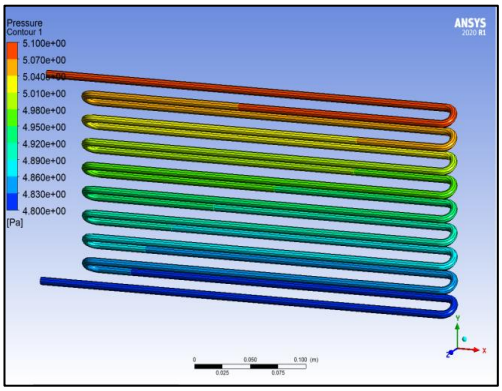
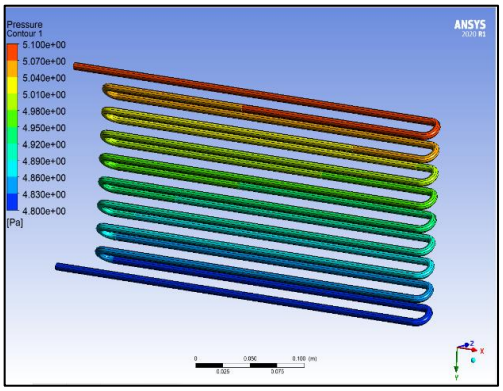


Figure 3.14 Contours plot evaporator based on pressure with CuO

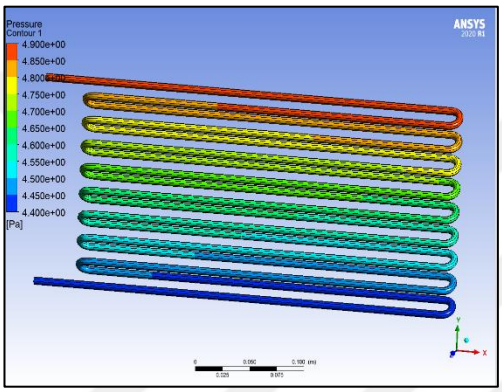
Case 1



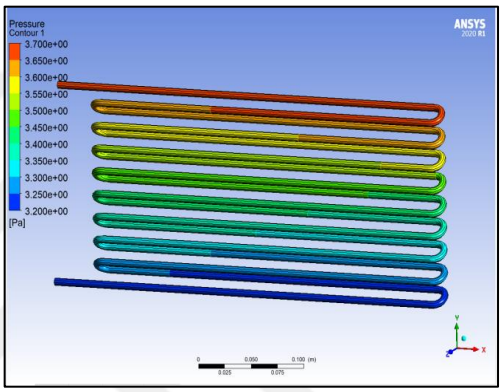
Case 50



Case 100



Case 150



Case 200

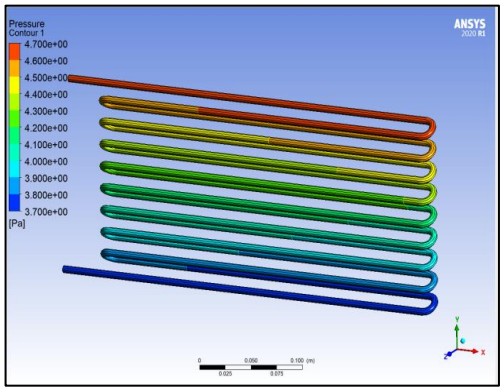
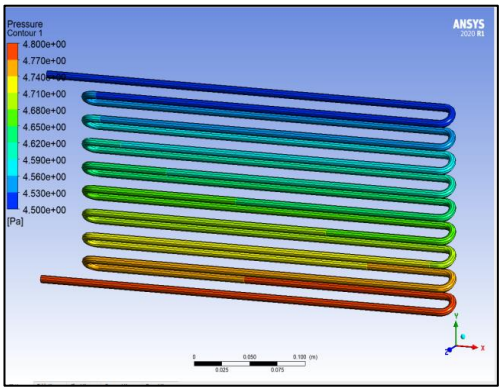
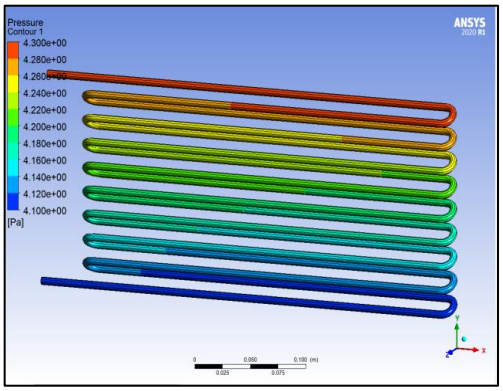


Figure 3.15 Contours plot of evaporator based on pressure with CeO_2

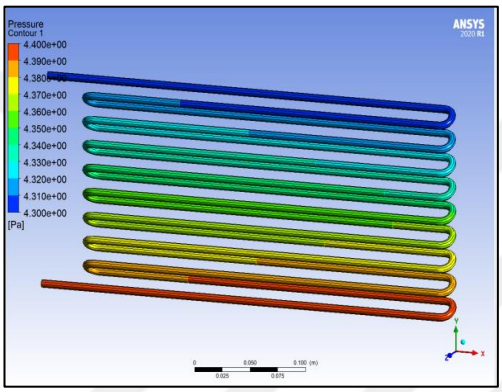
Case 1



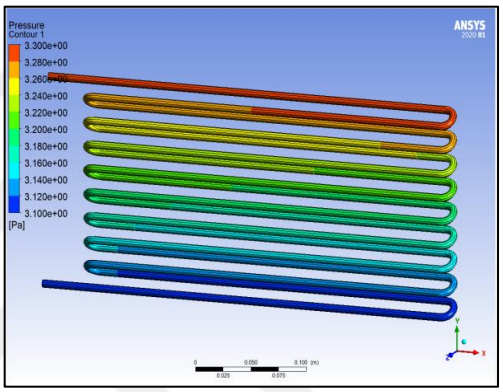
Case 50



Case 100



Case 150



Case 200

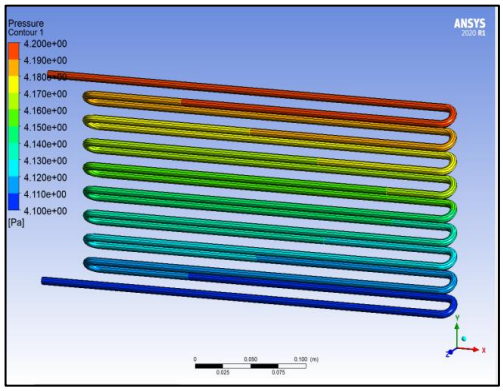
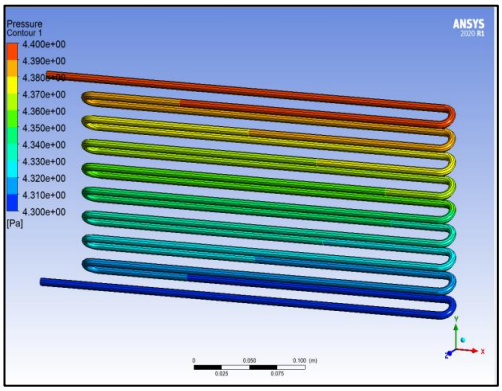
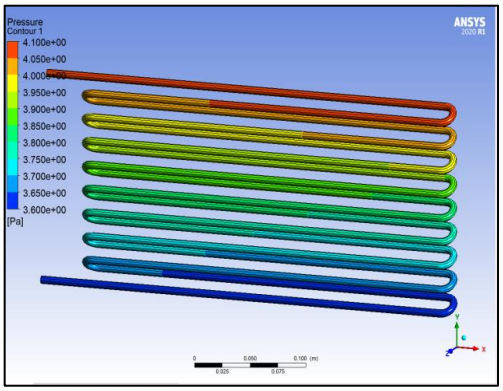


Figure 3.16 Contours plot evaporator based on pressure with 0.5% CuO + 0.5% CeO_2

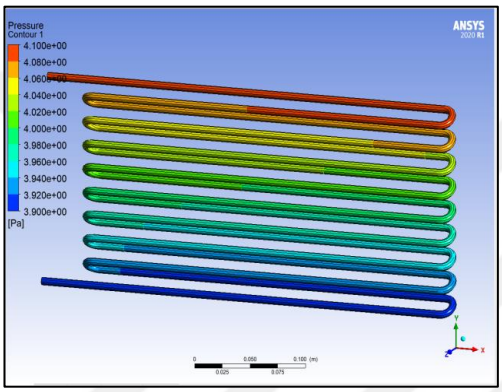
Case 1



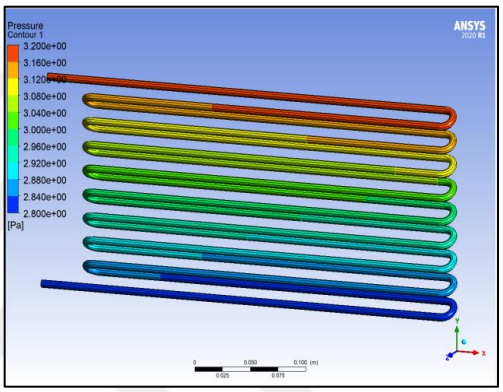
Case 50



Case 100



Case 150



Case 200

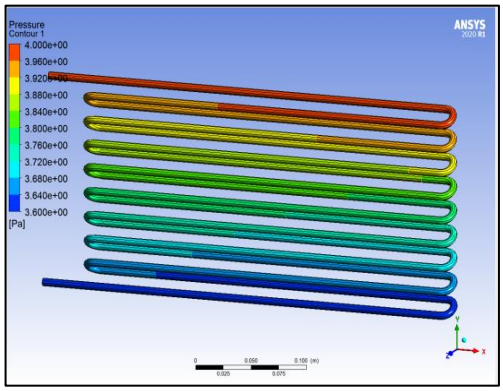
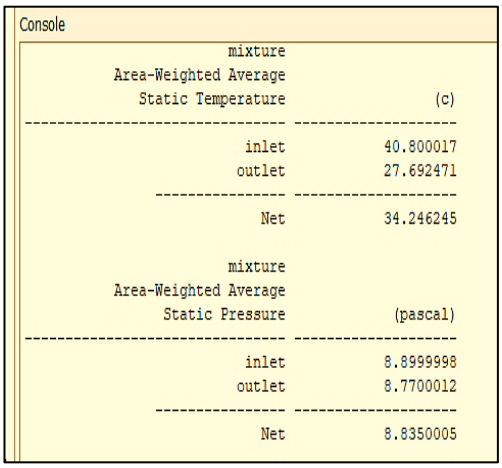
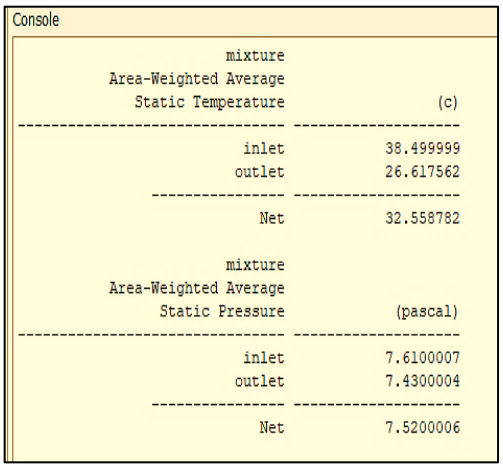


Figure 3.17 Contours plot evaporator based on pressure with 0.6% CuO + 0.4% CeO_2

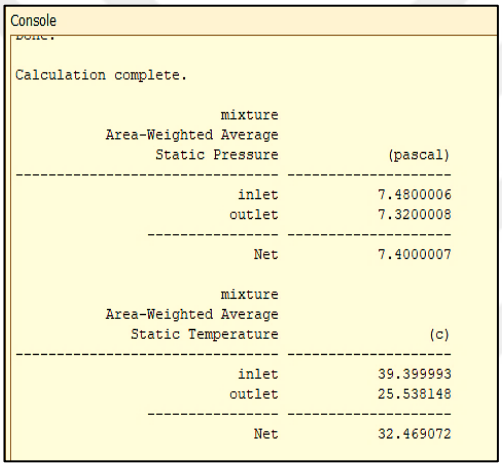
Case 1



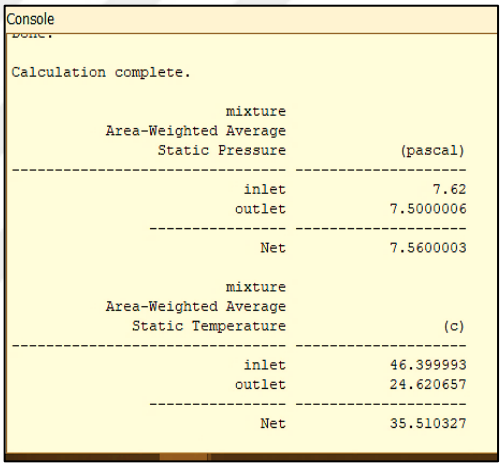
Case 50



Case 100



Case 150



Case 200

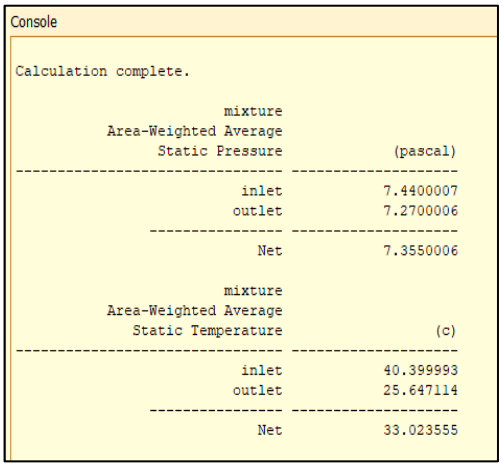


Figure 3.18 Some cases to calculate the theoretical pressure and temperature of condenser

Case 1

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	5.4400001
outlet	5.1900005
Net	5.3150003

mixture Area-Weighted Average Static Temperature	(c)
inlet	9.300017
outlet	25.615608
Net	17.457811

Case 50

mixture Area-Weighted Average Static Temperature	(c)
inlet	11.300017
outlet	25.494084
Net	18.397049

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	5.6339999
outlet	5.4400005
Net	5.5370002

Case 100

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	4.9899999
outlet	4.7900003
Net	4.8900001

mixture Area-Weighted Average Static Temperature	(c)
inlet	7.7000108
outlet	25.506564
Net	16.603286

Case 150

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	3.54
outlet	3.3400002
Net	3.4400001

mixture Area-Weighted Average Static Temperature	(c)
inlet	-1.498807e-06
outlet	25.513192
Net	12.756593

Case 200

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	4.6500002
outlet	4.4000004
Net	4.5250003

mixture Area-Weighted Average Static Temperature	(c)
inlet	5.3999925
outlet	25.788797
Net	15.594393

Figure 3.19 Some cases to calculate the theoretical pressure and temperature of evaporator

Case 1

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	4.0999999
outlet	3.8
Net	3.9499999

mixture Area-Weighted Average Static Temperature	(c)
inlet	21.499994
outlet	28.901634
Net	25.200814

Case 50

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	3.9000001
outlet	3.2
Net	3.5500001

mixture Area-Weighted Average Static Temperature	(c)
inlet	19.899988
outlet	26.849965
Net	23.374976

Case 100

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	3.9000001
outlet	3.5
Net	3.7

mixture Area-Weighted Average Static Temperature	(c)
inlet	19.999994
outlet	29.116518
Net	24.558256

Case 150

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	3
outlet	2.5
Net	2.75

mixture Area-Weighted Average Static Temperature	(c)
inlet	10.6
outlet	26.849946
Net	18.724973

Case 200

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	3.7999997
outlet	3.3
Net	3.5499998

mixture Area-Weighted Average Static Temperature	(c)
inlet	16.800012
outlet	28.023267
Net	22.41164

Figure 3.20 Some cases to calculate the theoretical pressure of evaporator based on CuO

Case 1

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	5.0999999
outlet	4.8000002
Net	4.95

mixture Area-Weighted Average Static Temperature	(c)
inlet	13.499994
outlet	26.036688
Net	19.768341

Case 50

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	4.8000002
outlet	5.0999999
Net	4.95

mixture Area-Weighted Average Static Temperature	(c)
inlet	23.069214
outlet	28.1
Net	25.584607

Case 100

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	4.9000001
outlet	4.4000001
Net	4.6500001

mixture Area-Weighted Average Static Temperature	(c)
inlet	12.200006
outlet	27.192377
Net	19.696191

Case 150

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	3.6999998
outlet	3.2
Net	3.4499999

mixture Area-Weighted Average Static Temperature	(c)
inlet	3.6
outlet	27.149224
Net	15.374612

Case 200

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	4.6999998
outlet	3.7
Net	4.1999999

mixture Area-Weighted Average Static Temperature	(c)
inlet	9.2000061
outlet	26.850065
Net	18.025036

Figure 3.21 Some cases to calculate the theoretical pressure of evaporator based on CeO_2

Case 1

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	4.5
outlet	4.8000002
Net	4.6500001

mixture Area-Weighted Average Static Temperature	(c)
inlet	23.877244
outlet	25.800012
Net	24.838628

Case 50

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	4.3000002
outlet	4.0999999
Net	4.2

mixture Area-Weighted Average Static Temperature	(c)
inlet	13.499994
outlet	27.849953
Net	20.674973

Case 100

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	4.3000002
outlet	4.4000001
Net	4.3500001

mixture Area-Weighted Average Static Temperature	(c)
inlet	22.532364
outlet	31.899988
Net	27.216176

Case 150

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	3.3
outlet	3.0999999
Net	3.1999999

mixture Area-Weighted Average Static Temperature	(c)
inlet	4.2000061
outlet	28.671365
Net	16.435686

Case 200

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	4.1999998
outlet	4.0999999
Net	4.1499999

mixture Area-Weighted Average Static Temperature	(c)
inlet	10.399988
outlet	27.854276
Net	19.127132

Figure 3.22 Some cases to calculate the theoretical pressure of evaporator based on 0.5% CuO + 0.5% CeO_2

Case 1

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	4.4000001
outlet	4.3000002
Net	4.3500001

mixture Area-Weighted Average Static Temperature	(c)
inlet	18.1
outlet	28.086096
Net	23.093048

Case 50

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	4.0999999
outlet	3.5999999
Net	3.8499999

mixture Area-Weighted Average Static Temperature	(c)
inlet	16.499994
outlet	28.188671
Net	22.344333

Case 100

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	4.0999999
outlet	3.9000001
Net	4

mixture Area-Weighted Average Static Temperature	(c)
inlet	16.6
outlet	29.38855
Net	22.994275

Case 150

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	3.2
outlet	2.8
Net	3

mixture Area-Weighted Average Static Temperature	(c)
inlet	7.2000061
outlet	28.502745
Net	17.851375

Case 200

mixture Area-Weighted Average Static Pressure	(pascal)
inlet	4
outlet	3.5999999
Net	3.8

mixture Area-Weighted Average Static Temperature	(c)
inlet	13.399988
outlet	28.359838
Net	20.879913

Figure 3.23 Some cases to calculate the theoretical pressure of evaporator based on 0.6% CuO + 0.4% CeO_2

3.2 Synthesis of Nanoparticles

The preparation of nanoparticles as oxides or as mixtures of oxides in the proportions previously mentioned requires the preparation of a solution of nitrate, which is dissolved in distilled or deionized water, and a deionizer is used to obtain deionized water as shown in ***Figure 3.24 a***. Distilled water was used because it is a good and cheap solvent, so that the mixture undergoes a series of chemical reactions until the oxide is obtained. The preparation process is summarized as follows:

1. The solution should be heated to a temperature of 80°C, keep the mixer speed at 375 rpm and the time is one hour.
2. Add ammonia at 60°C, and keep both mixer speed at 375 rpm, and PH at 10 ± 1
3. Raise the temperature to 90°C to obtain the oxides as shown in ***Fid 3.24 b***
4. The solution should be cooled at a normal temperature as shown in ***Figure 3.24 c***
5. Using the filtration system that was designed in the lab to complete the filtration process as in ***Figure 3.24 d&e***
6. Use the electric oven to complete the drying process at 110°C as shown in ***Figure 3.24 f***
7. Grinding as shown in ***Figure 3.24 g***
8. Sifting as shown in ***Figure 3.24 h*** ; and
9. Save until needed

As shown in Eq **(3.5)** the method of manufacturing nanoparticles relies on converting the weights of the materials into moles, and that is done by dividing these weights by molecular weights. Molar concentrations were calculated using moles and volume of solvent, as shown in in Eq **(3.6)**. The materials that were used in preparing the nanoparticles were imported from Germany, and the properties of these materials are shown in ***Tables 3.5 to 3.7*** .***Tables 3.8 and 3.9*** show the results of the nanoparticle

synthesis, including the amount of oxides obtained as well as some important properties of the prepared materials.

$$\text{Mole} = \frac{Weight}{Molecular\ weight} \quad \textbf{(3.5)}$$

$$\text{Mole concentration} = \frac{Number\ of\ moles}{Volume} \quad \textbf{(3.6)}$$

The molecular weights of the reactants are as following

Copper nitrate = 241.606

Cerium nitrate = 434.22

Copper oxide = 79.5

Cerium oxide = 172.12

Table 3.5 Certificate of Analysis

Copper(II) nitrate trihydrate		
Spec. Values Batch Values		
Assay(iodometric)	≥ 99.5 %	99.8 %
Chloride (Cl)	≤ 0.0005	≤ 0.0005
Sulfate(SO_4)	≤0.005	≤0.005
Calcium(Ca)	≤0.005	≤0.005
Iron(Fe)	≤0.002	≤0.002
Potassium(K)	≤0.01	≤0.01
Sodium(Na)	≤0.01	≤0.01
Nickel(Ni)	≤0.001	≤0.001
Lead(pb)	≤0.001	≤0.001
Zinc(Zn)	≤0.001	≤0.001

Table 3.6 Certificate of Analysis

Product Name	Cerium(III) Nitrate Hex hydrate 99% trace metals	
Product Number	238538	
Batch Number	BCB27878	
Brand	Aldrich	
CAS Number	10294-41-4	
Formula	$Ce(NO_3)\ 6H_2O$	
Formula Weight	43422	
Quality Release Data	15 Jan 2019	
Test	Specification	Result
Appearance (Color)	White to Yellow	Off White
Appearance (Form)	Powder or Crystals or Powder with Chunk(S) or Crystals with Chunk(S)	Crystals
Purity Based on Trace	99% Based on Rare Earth	> 99% Based on Rare Earth
Metals Analysis	Analysis Meets Requirements	Analysis Meets Requirements
Titration (Ion Exchange)	31.1 -33.4 % CE	32.3%
Solubility (Color)	Colorless	Colorless
Solubility (Turbidity)	Clear to Slightly Hazy	Slightly Hazy
Solubility(Method)	C=5% Water	C=5% Water
Proof of Identity	X-Ray Diffraction Conforms to Structure	Conforms
Metal Trace Analysis (ICP)	≤ 15000 .0 PPM Trace Rare Earth Analysis	<15000 .0 PPM Trace Rare Earth Analysis

Table 3.7 Certificate of Analysis

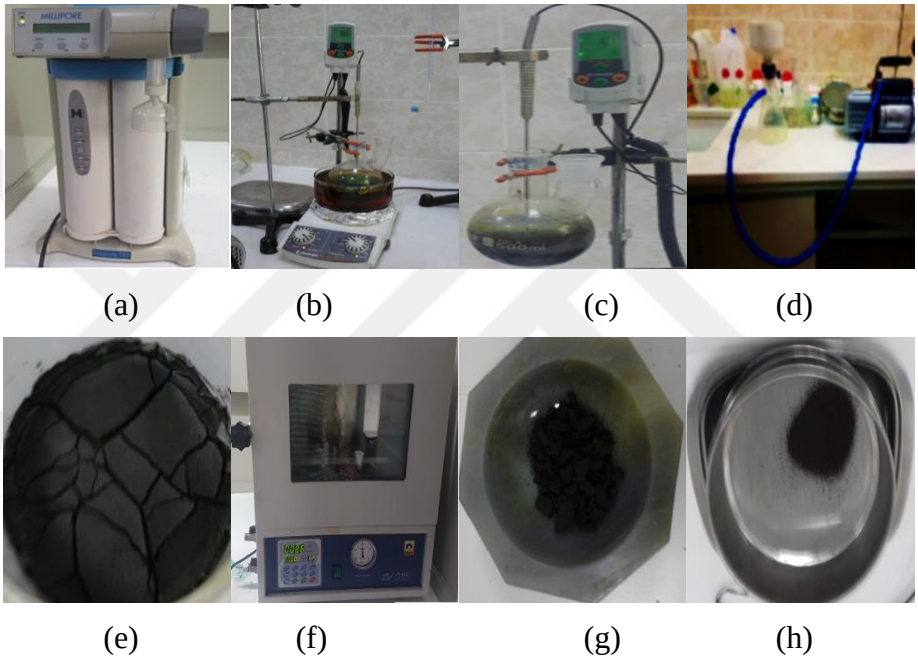
Ammonia solution 25%		
Spec. Values Batch Values		
Assay(acidimetric, NH3)	25.0-30.0 %	26.5%
Identity	Passes test	Passes test
Appearance of solution	Passes test	Passes test
Density (20/20 ∘C)	0.892-0.910	0.904
Carbonate (as Co2)	≤ 10 ppm	< 10 ppm
Chloride (Cl)	≤ 0.5 ppm	< 0.5ppm
Phosphate (PO4)	≤ 0.5 ppm	< 0.5ppm
Silicon (asSiO2)	≤10 ppm	< 1ppm
Sulfate (SO4)	≤ 2ppm	< 2 ppm
Sulphide (S)	≤ 2ppm	< 2 ppm
Pyridine and related substances	≤ 2ppm	< 2 ppm
Silver (Ag)	≤ 0.020 ppm	< 0.010 ppm
Aluminum (Al)	≤ 0.500 ppm	< 0.200 ppm
Gold (Au)	≤ 0.100 ppm	< 0.020 ppm
Barium (Ba)	≤0.050 ppm	< 0.020 ppm
Bismuth (Bi)	≤ 0.100 ppm	< 0.050 ppm
Calcium (Ca)	≤ 0.500 ppm	< 0.200 ppm
Cobalt (Co)	≤ 0.050 ppm	< 0.020 ppm
Cadmium (Cd)	≤ 0.050 ppm	< 0.020 ppm
Chromium (Cr)	≤ 0.050 ppm	< 0.020 ppm
Copper (Cu)	≤ 0.100 ppm	< 0.020 ppm
Iron (Fe)	≤ 0.100 ppm	< 0.050 ppm
Gallium (Ga)	≤ 0.020 ppm	< 0.010 ppm
Indium (In)	≤ 0.020 ppm	< 0.020 ppm
Potassium (K)	≤ 0.500 ppm	< 0.200 ppm
Lithium (Li)	≤ 0.020 ppm	< 0.010 ppm
Magnesium (Mg)	≤ 0.100 ppm	< 0.050 ppm
Manganese (Mn)	≤ 0.050 ppm	< 0.020 ppm
Molybdenum (Mo)	≤ 0.050 ppm	< 0.020 ppm
Sodium (Na)	≤ 0.500 ppm	< 0.200 ppm
Nickel (Ni)	≤ 0.050 ppm	< 0.020 ppm
Lead (pb)	≤ 0.050 ppm	< 0.020 ppm
Platinum (Pt)	≤ 0.100 ppm	< 0.020 ppm
Tin (Sn)	≤ 0.100 ppm	< 0.020 ppm
Strontium (Sr)	≤ 0.100 ppm	< 0.100 ppm
Titanium (Ti)	≤ 0.100 ppm	< 0.050 ppm
Thallium (Tl)	≤ 0.050 ppm	< 0.010 ppm
Zinc (Zn)	≤ 0.100 ppm	< 0.050 ppm
Oxidizable substances	Passes test	Passes test
Substances reducing potassium permanganate (as O)	≤ 5 ppm	< 5 ppm
Residue on ignition (as SO4)	≤ 10 ppm	< 10 ppm
Nonvolatile matter	≤ 10 ppm	< 10 ppm

Table 3.8 The results of synthesis of mixtures

No	Proportion		Molar concentration		Molar concentration of the mixtures	The Quantities (g)
	Copper oxide %	Cerium oxide %	Copper nitrate	Cerium nitrate		
1	fifty	fifty	0.20867	0.09673	0.1527	12.67
2	sixty	forty	0.250408	0.07753	0.181258	11.44
3	seventy	thirty	0.300075	0.05834	0.21530	10.97
4	forty	sixty	0.16694	0.11622	0.13651	13.07
5	thirty	seventy	0.125687	0.135569	0.13260	13.85

Table 3.9 Some properties of nanoparticles [119]

No	Nanoparticles	Mw	ρ	K	Cp
1	Copper oxide	79.55	6320	32.9	536
2	Cerium oxide	172.115	6100	11.715	352
3	50% Copper oxide +50% Cerium oxide	125.833	6210	22.31	444
4	60% Copper oxide +40% Cerium oxide	116.576	6232	24.43	462.4
5	70% Copper oxide +30% Cerium oxide	107.32	6254	26.54	480.8
6	40% Copper oxide +60% Cerium oxide	135.089	6188	20.19	425.6
7	30% Copper oxide +70% Cerium oxide	144.346	6166	18.07	407.2



(a) (b) (c) (d)

(e) (f) (g) (h)

Figure 3.24 Nanoparticles synthesis equipment of this study

3.3 Setup of Ansys Fluent Program

The refrigerating system that was worked on using R134a lacked a line for charging nanoparticles, which made this system not suitable for charging nanoparticles experimentally, as shown ***Figure 3.25*** ,and thus the Fluent program was chosen to simulate the refrigerating system to charge the nanoparticles theoretically .

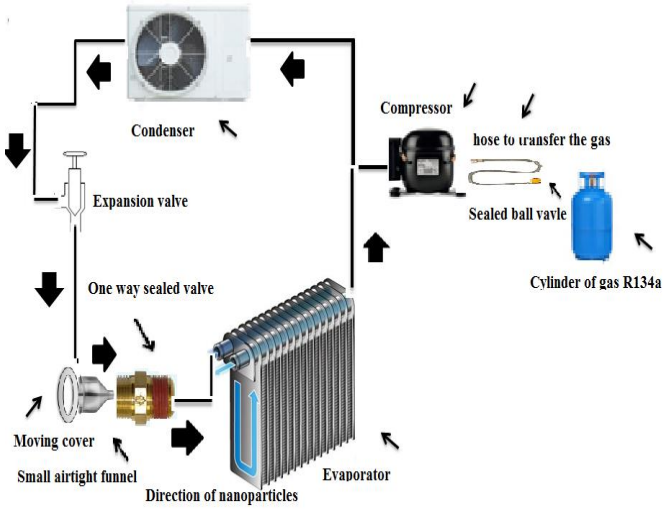


Figure 3.25 Scheme of the actual system of charging nanoparticles with refrigerant

The setup step of Ansys Fluent comes after the geometry and mesh of the refrigeration system becomes system ready to receive nanoparticles, where the solver is based on pressure, absolute velocity, steady state and -9.81 m/s^2 as gravity. Viscous models with standard k – epsilon and mixture models are chosen to deal with models that have multi-phase flow in Computational Fluid Dynamics. To achieve the multi-phase process, the materials properties are prepared according to nanofluid equations as shown below [120,102,103].

$$\text{Keff} = \text{kbf}\left(\frac{\text{kp}+2\text{kbf}+2(\text{kp}-\text{kbf})\varphi}{\text{kp}+2\text{kbf}-(\text{kp}-\text{kbf})\varphi}\right) \quad \textbf{(3.7)}$$

$$\mu_{\text{nr}} = \mu_{\text{r}}\frac{1}{(1-\emptyset)^{2.5}} \quad \textbf{(3.8)}$$

The densities and heat capacity of the nanorefrigerants are shown in Eqs (9) and (10)

$$\rho_{\text{eff}=(1-\emptyset)\ \rho_{\text{f}+}\ \emptyset\ \rho_{\text{np}}} \quad \textbf{(3.9)}$$

$$C_{pnf}=\frac{(1-\emptyset)(\rho cp)\ Bf+\emptyset(\rho cp)NP}{(1-\emptyset)\rho BF+\emptyset\ \rho\ NP} \quad \textbf{(3.10)}$$

A mixture models was used to solve the continuity, momentum, and energy equations as shown in the below equations .

$$\frac{1}{\rho_q}\left[\frac{\partial}{\partial t}\left(\alpha_q \rho_q\right) + \nabla.\left(\alpha_q \rho_q \vec{v}_q\right) = S_{\alpha_q} + \sum_{\rho=1}^{n}\left(\dot{m}_{\rho q} - \acute{m}_{qp}\right)\right. \quad \textbf{(3.11)}$$

$$\frac{\partial}{\partial t}(\rho\vec{v}) + \nabla.\left(\rho\vec{v}\,\vec{v}\right) = -\nabla\rho + \nabla.\left[\mu\left(\nabla\vec{v} + \nabla\vec{v}^{T}\right)\rho\vec{g} + \vec{F}\right. \quad \textbf{(3.12)}$$

$$\frac{\partial}{\partial t}(\rho E) + \nabla.\left(\vec{v}(\rho E + P)\right) = \nabla.\left(k_{eff}\nabla T\right) + S_h \quad \textbf{(3.13)}$$

Eq **(3.14)** is used to determine the mass fractions of nanoparticles [100,101] . 2.6 g was determined as the amount of nanoparticles and 1039 g is the quantity of R134a, which is the similarity of quantity charged in the experimental part.

$$\text{mass fraction} = \frac{m_n}{m_n + m_r} \quad \textbf{(3.14)}$$

3.4. Thermophysical Properties of R134a with Nanoparticles

There are many numerical equations for calculating the thermophysical properties of nanofluids. Recently, these equations have been chosen to determine the thermal properties of nanorefrigerants depending on the liquid phase of the refrigerants. The thermophysical properties of R134a based on 0.05 to 0.33 wt.% of nanoparticles are indicated clearly in ***Tables 3.10 to 3.13.*** The Maxwell model shown in *Eq* ***(3.7)*** was chosen to calculate thermal conductivity. The Brinkman model shown in ***Eq (3.8)*** was chosen to calculate viscosity. ***Eqs (3.9) and (3.10)*** were chosen to calculate density and heat capacity

Table 3.10 Thermal conductivities of R134a with nanoparticles

Thermal conductivities ($Wm^{-1}k^{-1}$)	mass fractions φ						
	0.05	0.09	0.1	0.2	0.24	0.28	0.33
CuO	0.09577	0.10716	0.11016	0.14431	0.16046	0.17839	0,20377
CeO_2	0.09558	0.10680	0.10976	0.14328	0.15909	0.17661	0,20136
50%CuO+50%CeO_2	0.09572	0.10706	0.11006	0.14404	0.16010	0.17792	0.20313
60%CuO+40%CeO_2	0.09573	0.10709	0.11009	0.14411	0.16020	0.17805	0.20331
70%CuO+30%CeO_2	0.09574	0.10711	0.11011	0.14417	0.16028	0.17815	0.20345
40%CuO+60%CeO_2	0.09570	0.10703	0.11002	0.14395	0.15998	0.17777	0.20293
30%CuO+70%CeO_2	0.09568	0.10699	0.10998	0.14384	0.15984	0.17758	0.20267

Table 3.11 The viscosities of R134a with nanoparticles

The viscosities (mPa.s)	mass fractions φ						
	0.05	0.09	0.1	0.2	0.24	0.28	0.33
	0.22964	0.25571	0.26287	0.35288	0.40116	0.45922	0.54975

Table 3.12 The densities of R134a with nanoparticles

The densities (kg m^{-3})	mass fractions φ						
	0.05	0.09	0.1	0.2	0.24	0.28	0.33
CuO	1546.06	1747.07	1797.32	2299.84	2500.85	2701.86	2953.12
CeO_2	1535.06	1727.27	1775.32	2255.84	2448.05	2640.26	2880.52
50%CuO+50%CeO_2	1540.56	1737.17	1786.32	2277.84	2474.45	2671.06	2916.82
60%CuO+40%CeO_2	1541.66	1739.15	1788.52	2282.24	2479.73	2677.22	2924.08
70%CuO+30%CeO_2	1542.76	1741.13	1790.72	2286.64	2485.01	2683.38	2931.34
40%CuO+60%CeO_2	1539.46	1735.19	1784.12	2273.44	2469.17	2664.90	2909.56
30%CuO+70%CeO_2	1538.36	1733.21	1781.92	2269.04	2463.89	2658.74	2902.30

Table 3.13 The specific heat of R134a with nanoparticles

Specific heat (J kg^{-1} K^{-1})	mass fractions φ						
	0.05	0.09	0.1	0.2	0.24	0.28	0.33
CuO	1.1765	1.0789	1.0579	0.8986	0.8528	0.8138	0.7725
CeO_2	1.1445	1.0267	1.0012	0.8061	0.7496	0.7018	0.6499
50%CuO+50%CeO_2	1.1602	1.0524	1.0286	0.8519	0.8007	0.7571	0.7108
60%CuO+40%CeO_2	1.1633	1.0575	1.0347	0.8609	0.8108	0.7681	0.7228
70%CuO+30%CeO_2	1.1667	1.0629	1.0406	0.8706	0.8216	0.7798	0.7355
40%CuO+60%CeO_2	1.1571	1.0473	1.0236	0.8429	0.7907	0.7461	0.6988
30%CuO+70%CeO_2	1.1538	1.0419	1.0178	0.8334	0.7800	0,7345	0.6862

CHAPTER 4

RESULTS AND DISCUSSION

The results of this research involve several parts, as follows: Part one involves the experimental and theoretical results obtained from a simple vapor compression refrigeration system. The second part involves specifications of nanoparticles .The third part involves the theoretical values from charging nanoparticles to a refrigeration system theoretically to study their effects on COP, and the last part involves thermophysical properties of R134a based on different mass fractions of nanoparticles using some numerical equations .

4.1 Comparing Experimental and Theoretical Values of a VCRS

The results obtained were included in ***Tables 4.1 to 4.2***, and were plotted as shown in ***Figure 4.1.*** These results indicated that *COP* improves significantly with an increase of the average temperatures of evaporator, and this confirms increases in mass flow rate of the refrigerant into the evaporator with an increase in the enthalpy difference, and thus the refrigerating loads of the evaporator improve and energy consumed decreases as shown in ***Figure 4.1a***. While power consumption decreases with an increase of evaporator temperatures, which causes a high mass flow rate of the refrigerant into the compressor as shown in ***Figure 4.1b.*** The results related to the effect of average condensate temperatures showed that *COP* decreased with an increase of condenser temperatures, due to a decrease in cooling capacity and an increase in energy consumed, Increase of the average temperatures of condenser leads to increase heat rejected, as a result in increasing enthalpy difference and mass flow rate of the refrigerant as shown in ***Figure 4.1c***. While power consumption increases with an increase in condenser temperatures as shown in ***Figure 4.1d***. To obtain the highest accuracy, the experiments were splited to many cases; every case involved ten experiments, where the repetition of every experiment was three times. The theoretical results that were most close to the experimental results are chosen and are plotted against the average temperatures of both the evaporator and condenser. The results

from experiments and theoretical studies were in good agreement with each other, and in agreement with previous studies that confirmed that *COP* increases with increasing temperatures of the evaporator and that it decreases with increasing temperatures of the condenser. On the other hand, the power consumed decreases with increasing temperatures of the evaporator and increases with increasing temperatures of the condenser [121].

Table 4.1 A comparison between experiment and theoretical results of evaporator

T_5 ansys (°c)	T_5(°c)	T_6 ansys (°c)	T_6 (°c)	P_5 ansys (bar)	P_5 (bar)	P_6ansys (bar)	P_6 (bar)	COP ansys	COP	Accuracy Rate %	case	Tav,cond (°c)	Tav Ansys (°c)
9.2	9.3	17.9	18.7	5.3	5.44	5.32	5.19	2.06	1.99	96.5	1	14.0	13.6
6.5	6.8	22.9	23.2	4.7	4.76	4.93	4.55	2.41	2.39	99.1	10	15.0	14.7
0.9	1.6	24.8	24.1	3.8	3.95	3.87	3.77	1.07	1.03	96.1	20	12.9	12.9
-8.8	-10.7	22.7	23.2	2.6	2.43	2.53	2.27	0.72	0.68	94,1	30	6.3	6.9
-1.2	-1.5	24.6	23.8	3.8	3.56	3.05	3.38	0.95	0.94	98.9	40	11.2	11.7
7.8	11.0	22.7	23.6	4.9	4.59	5.6	5.4	1.87	1.57	80.9	50	17.3	15.3
8.9	8.0	21.6	22.0	5.3	5.04	4.7	4.88	1.70	1.52	88.2	60	15.0	15.3
-2.5	-4.9	21.5	22.6	3.1	3.04	2.8	2.9	0.89	0.82	91.5	70	8.9	9.5
6.9	7.8	22.8	22.2	5.0	4.93	4.66	4.76	1.54	1.43	92.3	80	15.0	14.9
4.1	4.3	23.7	22.9	4.6	4.42	4.3	4.25	1.23	1.21	98.3	90	13.6	13.9
7.9	7.7	23.7	22.7	5.0	4.99	4.83	4.79	1.51	1.5	99.3	100	15.2	15.8
3.9	4.6	23.9	23.3	4.7	4.5	4.32	4.25	1.25	1.19	94.9	110	14.0	13.9
-2.5	-3.0	23.7	23.1	3.6	3.4	3.21	3.17	0.90	0.89	98.8	120	10.1	10.6
-11.7	-14.6	24.5	24.4	2.1	2.08	1.85	1.9	0.68	0.63	92.1	130	4.9	6.4
-11.6	-11.2	24.9	24.7	2.3	2.4	2.35	2.22	0.69	0.68	98.5	140	6.8	6.7
-0.7	-1.6	24.6	23.7	3.9	3.52	3.54	3.34	0.97	0.94	96.8	150	11.1	11.9
4.7	4.6	23.6	24.9	7.4	7.61	4.39	4.25	1.25	1.23	98.0	160	14.8	14.2
7.6	8.0	21.5	20.2	5.0	4.99	4.65	4.75	1.51	1.48	97.7	170	14.1	14.6
7.23	7.3	22.2	21.7	4.9	4.81	4.75	4.62	1.66	1.55	92.9	180	14.5	14.7
5.7	5.8	20.7	20.9	4.9	4.66	4.54	4.44	1.34	1.3	96.9	190	13.4	13.2
4.9	5.4	21.6	21.4	4.9	4.65	4.12	4.4	1.39	1.38	99.3	200	13.4	13.3

Table 4.2 A comparisons between experiment and theoretical results of condenser

T3 ansys (°c)	T3(°c)	T4ansys (°c)	T4 (°c)	P3 ansys (bar)	P3 (bar)	P4ansys (bar)	P4 (bar)	COP ansys	COP	Accuracy Rate %	case	Tav,cond (°c)	Tav,cond Ansys (°c)
40.2	40.8	27.7	28.2	8.9	8.9	8.8	8.8	2.24	2.21	98.6	1	34.5	33.9
45	45.7	26.6	27.4	8.2	8.2	7.9	8.0	1.49	1.45	97.2	10	36.6	35.8
47.1	46.6	26.7	27.2	8.0	8.2	7.5	8.0	1.40	1.31	93.1	20	36.9	36.9
41.1	40.1	24	23.1	7.8	7.4	7.3	7.3	1.40	1.36	97.1	30	31.6	32.6
45.1	45.5	23.8	24.3	7.9	7.7	7.9	7.6	1.15	1.12	97.3	40	34.9	34.5
38.3	38.5	26.6	24.9	7.6	7.6	7.4	7.4	1.97	1.83	92.3	50	31.7	32.5
35.7	35.0	22.8	22.0	7.1	7.1	7.3	6.9	2.28	1.89	79.4	60	28.5	29.3
35.6	35.5	21.5	22.0	7.0	7.2	7.2	7.1	2.29	1.87	77.5	70	28.8	28.6
34.9	35.4	22.8	22.3	7.2	7.0	7.6	6.9	1.63	1.53	93,5	80	28.9	28.9
41	40.1	23.7	23.0	7.4	7.3	6.9	7.1	1.38	1.36	98.5	90	31.6	32.4
40	39.4	25.5	24.2	7.5	7.5	7.3	7.3	1.36	1.24	90.3	100	31.8	32.8
43.1	42.6	23.9	24.7	7.5	7.6	7.0	7.4	1.18	1.17	99.1	110	33.7	33.5
42.2	42.5	23.7	24.3	7.1	7.5	7.5	7.4	1.34	1.29	96.1	120	33.4	33.0
45.4	44.6	24.5	23.8	7.2	7.6	7.8	7.5	1.17	1.14	97.4	130	34.2	34.9
46.5	47.8	24.9	24.4	7.5	7.7	7.8	7.6	1.15	1.04	89.4	140	36.1	35.7
46.4	46.4	24.6	24.6	7.6	7.6	7.5	7.5	1.19	1.13	94.7	150	35.5	35.5
42.4	43.5	23.4	24.9	7.8	7.6	7.9	7.5	1.34	1.23	91.1	160	34.2	32.9
42.6	43.7	27.0	27.6	8.0	8.2	7.9	8.0	1.33	1.21	90.1	170	35.7	34.8
45.7	44.3	26.2	27.4	7.9	8.0	7.7	7.8	1.26	1.14	89.5	180	35.9	36.0
40.3	40.7	24.7	24.1	7.9	7.4	6.9	7.2	1.58	1.45	91.0	190	32.4	32.5
40.3	40.4	25.6	24.0	7.4	7.4	7.3	7.3	1.75	1.46	80.1	200	32.2	32.9

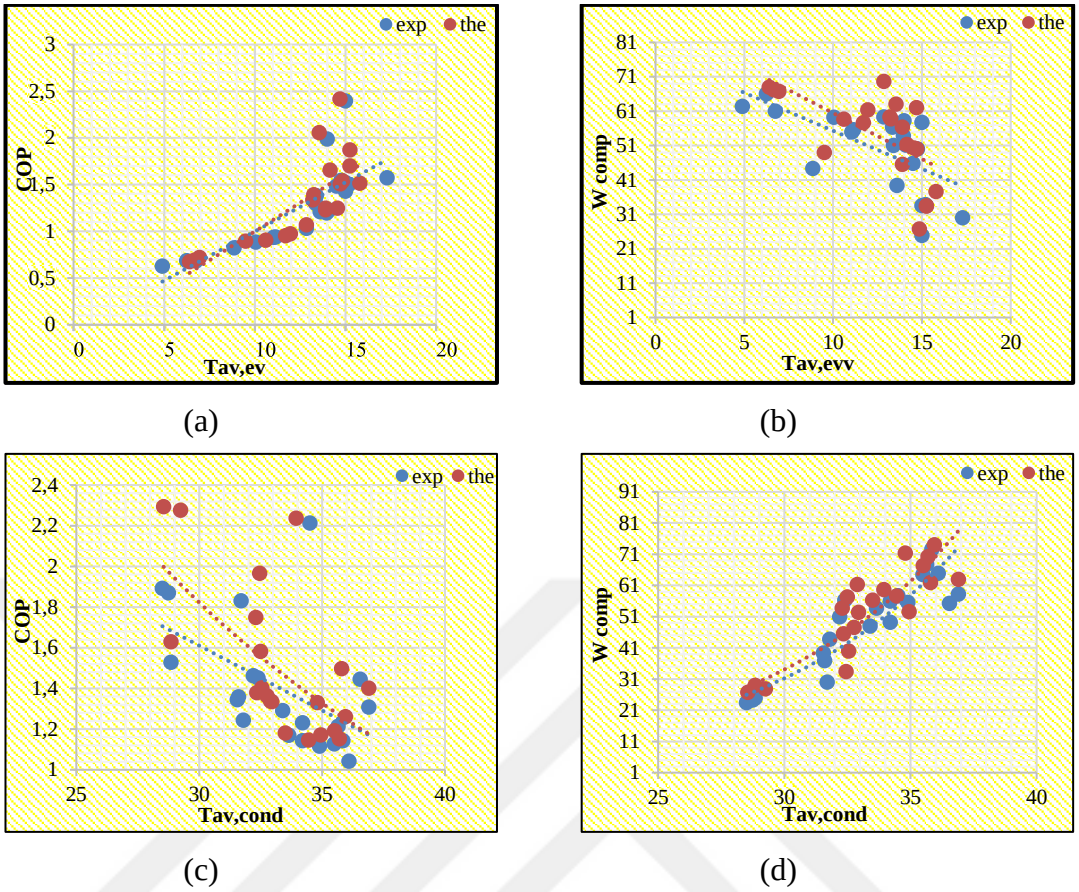


Figure 4.1 (a) *Cop* against $T_{av,\,ev}$ (b) power consumption W_{COMP} against $T_{av,\,ev}$ (c) *COP* against $T_{av,\,cond}$, and (d) power consumption W_{COMP} against $T_{av,\,cond}$ on

4.2 Specifications of Nanoparticles

The properties of the prepared nanoparticles were verified by sending samples to Huazhong University of Science and Technology in China on September 24, 2019, as shown in ***Figure 4.2,*** where XRD analysis was used and scanned from 20 deg to 80 deg to examine the samples. The results showed all of the peaks agree with the database standard (JCPDS 00-045-0937) of face- centered cubic CuO. All of the peaks agree with the database standard (JCPDS 00-004-0593) of face-centered cubic CeO_2 . SEM images showed that the samples were spherical with diameters of 78.95 nm, 79.9 nm, 44.15nm, and 63.3nm for CuO, CeO_2, fifty% CuO + fifty % CeO_2, and sixty % CuO + forty % CeO_2 respectively, as shown in ***Figure 4.3*** .The nanoparticles preparation method in succeeded in obtaining suitable diameters, and because CeO_2 has not been used before in the refrigerating system to investigate its influence on the

performance of a vapor compression refrigeration systems. This gives a significantly indication for future researchers to be interested in preparing nanoparticles as a mixture and focuses attention on CeO_2, which has not been used before within a vapor compression refrigerating system. An attempt to reveal the most important properties and its effective to enhance the efficiency of refrigerating system and whether it will be effective while it was mixed with other oxides [122-125].

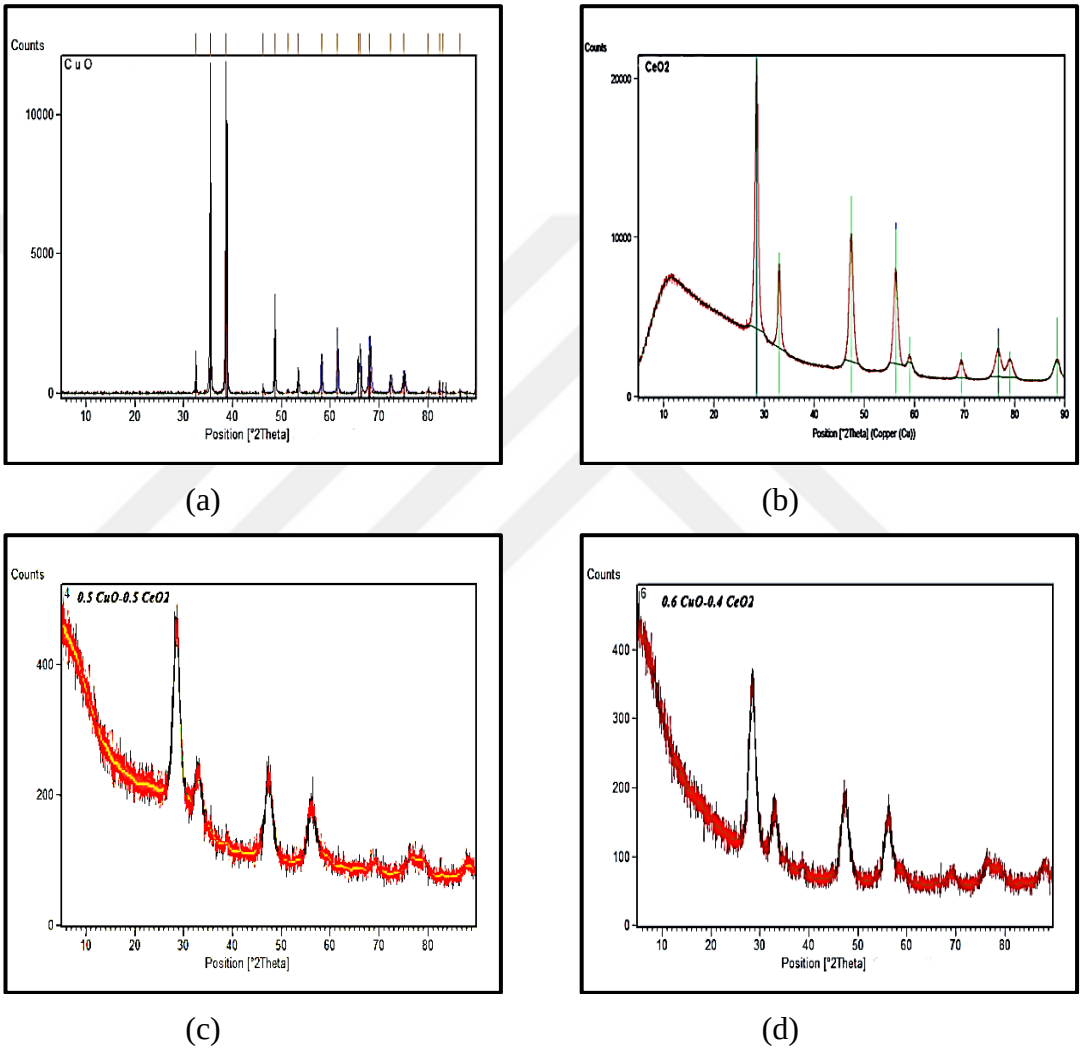


Figure 4.2 (a) X-ray diffraction for (a) CuO (b) CeO_2 (c) 50% CuO + 50% CeO_2 and (d) 60% CuO + 40 % CeO_2 Nanoparticles

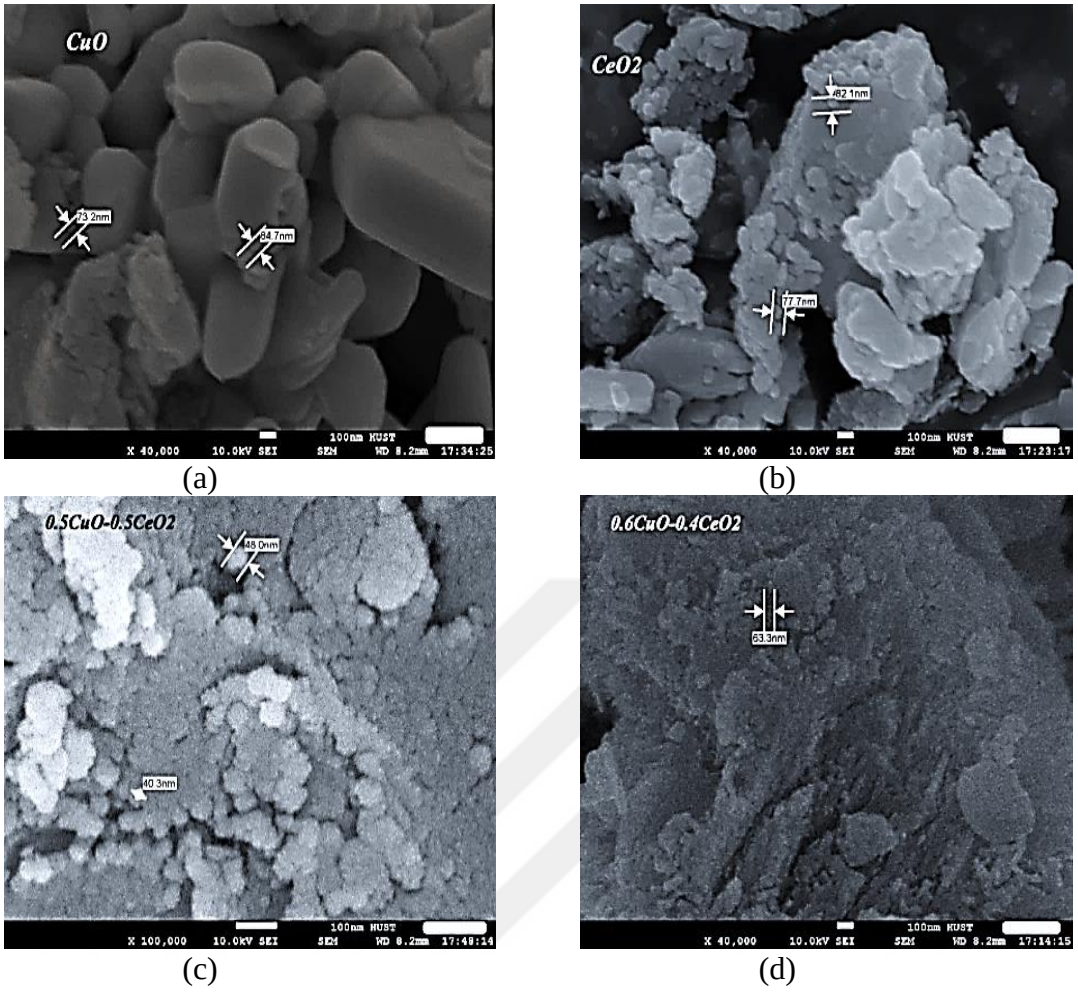


Figure 4.3 Scanning electron microscopy for (a) CuO (b) CeO_2 (c) 50% CuO+50% CeO_2 and (d) 60% CuO+40% CeO_2

4.3 Theoretical Values From Charging Nanoparticles

The evaporator was simulated when adding nanoparticles theoretically because the heat absorption processes take place in an evaporator. Therefore, adding nanoparticles that improve the thermophysical properties of the refrigerants is the most important method recently used to improve the functions of the evaporator, which is the most important component within the refrigerating system, thus the performance of the refrigerating system is enhanced. The results obtained were included in ***Tables 4.3 to 4.7*** and were plotted with the average temperatures of the evaporator as shown in ***Figure 4.4.*** The results indicated that increasing the average temperatures of the evaporator by 0.25 wt.% copper oxide improves the performance of the refrigerating

system and thus reduces power consumption. These changes are explained by improving thermophysical properties of R134a, particularly thermal conductivity, as a result of mixing it with CuO, with CuO's thermal conductivity ranging from 20 to 40 W/(m K).When adding the same amount of cerium oxide the average temperatures of the evaporator increased, which caused improvements in the performance of the refrigerating system and thus a reduction in the power consumption. These changes are explained by improving thermophysical properties of R134a, particularly thermal conductivity, as a result of mixing it with CeO2, which has a thermal conductivity of 11.7 W/(mK).

When adding the same amount of 50% CuO with 50 % CeO_2 the average temperatures of the evaporator increased, which caused improvements in the performance of the refrigerating system and thus a reduction in the power consumption. These changes are explained by improving thermophysical properties of R134a especially, thermal conductivity as a result of mixing it with nanoparticles. When adding the same amount of 60 % CuO with 40 % CeO_2 the average temperatures of the evaporator increased, which caused improvements in the performance of the refrigerating system and thus a reduction in the power consumption. These changes are explained by enhancing thermophysical properties of R134a after mixing it with nanoparticles.

As previous research showed that the improvements in the *COP* of the refrigerating systems are related to adding nanoparticles , where the deference in the type , size and method of preparing of nanoparticles is an important criteria in determining the amount of improvements in *COP* of the refrigerating systems , additionally to the average temperatures of the evaporator , so the results were plotted against them at constant mass fractions of nanoparticles The results of this research came in agreement with the study of the researcher ***M. Nagaraju et al (2018),*** who proved that mixing CuO with R134a enhanced *COP* of a simple vapor compression refrigeration system by a value close to the value achieved by this research.

Table 4.3 Comparisons between the performance of refrigerating cycle with and without CuO

T_5 ansys (°c)	T_5(°c)	T_6 ansys (°c)	T_6 (°c)	P_5 ansys (bar)	P_5 (bar)	P_6 ansys (bar)	P_6 (bar)	COP ansys	COP	case	Qev	Q ev ansys	Tev av	Tev av ansys	w comp	w comp ansys
21.5	9.3	36.0	18.7	4.1	5.4	3.8	5.2	2.48327	1.989362	1	804.6	986.3	14.0	28.7	62.0	47.0
18.5	6.8	41.2	23.2	3.6	4.8	3.3	4.6	1.813366	1.414634	10	762.0	913.5	15.0	29.9	63.0	47.4
12.3	1.6	43.2	24.1	2.9	4.0	2.8	3.8	1.397544	1.071111	20	656.9	808.3	12.9	27.8	55.3	48.6
1.8	-10.7	41.0	23.2	2.0	2.4	1.7	2.3	1.045877	0.684366	30	507.2	619.9	6.3	21.4	40.0	30.0
10.0	-1.5	43.0	23.8	2.9	3.6	2.5	3.4	1.302755	0.940711	40	576.6	695.3	11.2	26.5	55.6	46.9
19.9	11.0	41.0	23.6	3.9	4.6	3.2	5.4	1.941566	1.873016	50	489.8	595.6	17.3	30.5	30.0	27.2
21.1	8.0	39.9	22.0	4.1	5.0	3.5	4.9	2.123536	1.571429	60	397.9	474.0	15.0	30.5	23.5	22.7
8.6	-4.9	39.8	22.6	2.4	3.0	2.1	2.9	1.275862	0.821818	70	290.6	364.7	8.9	24.2	24.3	23.6
18.9	7.8	41.1	22.2	3.9	4.9	3.5	4.8	1.84982	1.541667	80	456.3	555.5	15.0	30.0	24.9	21.8
15.9	4.3	42.1	22.9	3.5	4.4	3.1	4.3	1.607218	1.231183	90	527.9	652.7	13.6	29.0	39.4	37.1
20.0	7.7	42.1	22.7	3.9	5.0	3.5	4.8	1.905592	1.513333	100	671.8	829.0	15.2	31.0	43.8	38.8
15.6	4.6	42.3	23.3	3.6	4.5	3.2	4.3	1.584379	1.245989	110	706.3	855.7	14.0	28.9	53.8	45.9
8.6	-3.0	42.1	23.1	2.8	3.4	2.4	3.2	1.256831	0.885057	120	677.0	826.5	10.1	25.3	49.2	42.9
-1.4	-14.6	42.9	24.4	1.6	2.1	1.5	1.9	0.968415	0.625641	130	546.0	668.5	4.9	20.8	48.0	42.7
-1.3	-11.2	43.3	24.7	1.8	2.4	1.7	2.2	0.970881	0.688022	140	672.8	771.8	6.8	21.0	64.5	57.2
10.6	-1.6	43.1	23.7	3.0	3.5	2.5	3.3	1.327874	0.936759	150	720.5	878.8	11.1	26.8	64.9	54.9
16.6	4.6	42.0	24.9	5.8	7.6	5.4	4.3	1.652105	1.226601	160	713.6	915.3	14.8	29.3	56.0	49.9
19.8	8.0	39.8	20.2	3.9	5.0	3.5	4.8	1.98726	1.655738	170	868.9	1044.1	14.1	29.8	74.1	59.2
19.4	7.3	40.5	21.7	3.9	4.8	3.4	4.6	1.914733	1.506944	180	819.2	1013.7	14.5	29.9	67.8	58.2
17.7	5.8	38.9	20.9	3.6	4.7	3.3	4.4	1.830943	1.384106	190	743.7	899.5	13.4	28.3	56.3	46.7
16.8	5.4	39.9	21.4	3.8	4.7	3.3	4.4	1.727155	1.3375	200	685.5	1057.5	13.4	28.3	51.0	43.8

Table 4.4 Comparisons between the performance of refrigerating cycle with and without CeO_2

T_5 ansys (°c)	T_5(°c)	T_6 ansys (°c)	T_6 (°c)	P_5 ansys (bar)	P_5 (bar)	P_6ansys (bar)	P_6 (bar)	COP ansys	COP	case	Qev	Q ev ansys	Tev av	Tev av ansys	w comp	w comp ansys
13.5	9.3	23.3	18.7	5.1	5.4	4.8	5.2	2.373347	1.989362	1	804.6	852.0	14.0	18.4	62.0	54.9
10.8	6.8	28.3	23.2	4.5	4.8	4.5	4.6	1.616087	1.414634	10	762.0	789.1	15.0	19.6	63.0	55.3
5.2	1.6	30.2	24.1	3.6	4.0	3.5	3.8	1.207751	1.071111	20	656.9	698.3	12.9	17.7	56.7	55.3
-4.5	-10.7	28.1	23.2	2.5	2.4	2.3	2.3	0.86209	0.684366	30	507.2	535.5	6.3	11.8	40.0	35.0
3.1	-1.5	30.0	23.8	3.6	3.6	7.3	3.4	1.115113	0.940711	40	576.6	600.6	11.2	16.6	55.6	54.8
12.1	11.0	28.1	23.6	4.8	4.6	5.1	5.4	1.873016	1.754835	50	489.8	514.5	17.3	20.1	31.7	30.0
13.2	8.0	27.0	22.0	5.1	5.0	4.3	4.9	1.954447	1.571429	60	397.9	409.5	15.0	20.1	26.5	23.5
1.8	-4.9	26.9	22.6	3.0	3.0	2.5	2.9	1.071628	0.821818	70	290.6	315.0	8.9	14.4	27.5	24.3
11.2	7.8	28.2	22.2	4.9	4.9	4.2	4.8	1.657663	1.541667	80	456.3	479.9	15.0	19.7	25.4	24.9
8.4	4.3	29.1	22.9	4.4	4.4	3.9	4.3	1.40521	1.231183	90	527.9	563.9	13.6	18.8	43.3	39.4
12.2	7.7	29.1	22.7	4.9	5.0	4.4	4.8	1.720614	1.513333	100	671.8	716.1	15.2	20.7	45.2	43.8
8.2	4.6	29.3	23.3	4.5	4.5	3.9	4.3	1.388074	1.245989	110	706.3	739.2	14.0	18.8	53.8	53.5
1.8	-3.0	29.1	23.1	3.5	3.4	2.9	3.2	1.065862	0.885057	120	677.0	714.0	10.1	15.5	50.0	49.2.
-7.4	-14.6	29.9	24.4	2.0	2.1	1.7	1.9	0.801768	0.625641	130	546.0	577.5	4.9	11.3	49.8	48.0
-7.3	-11.2	30.3	24.7	2.3	2.4	2.1	2.2	0.806006	0.688022	140	672.8	666.8	6.8	11.5	66.7	64.5
3.6	-1.6	30.1	23.7	3.7	3.5	3.2	3.3	1.136106	0.936759	150	720.5	759.2	11.1	16.8	64.9	64.0
9.0	4.6	29.0	24.9	7.2	7.6	4.0	4.3	1.449326	1.226601	160	713.6	790.7	14.8	19.0	58.3	56.0
11.9	8.0	26.9	20.2	4.9	5.0	4.2	4.8	1.79175	1.655738	170	868.9	902.0	14.1	19.4	74.1	69.0
11.5	7.3	27.6	21.7	4.8	4.8	4.3	4.6	1.716149	1.506944	180	819.2	875.7	14.5	19.6	67.9	67.8
10.0	5.8	26.1	20.9	4.5	4.7	4.1	4.4	1.619963	1.384106	190	743.7	777.0	13.4	18.1	56.3	54.5
9.2	5.4	27.0	21.4	4.7	4.7	3.7	4.4	1.515984	1.3375	200	685.5	913.5	13.4	18.1	51.1	51.0

Table 4.5 Comparisons between the performance of refrigerating cycle with and without 50 % CuO + 50 % CeO2

T_5 ansys (°c)	T_5(°c)	$_6$ansys (°c)	T_6 (°c)	P_5 ansys (bar)	P_5 (bar)	P_6ansys (bar)	P_6 (bar)	COP ansys	COP	case	Qev	Q ev ansys	Tev av	Tev av ansys	w comp	w comp ansys
15.1	9.3	25.8	18.7	4.5	5.4	4.8	5.2	2.411875	1.989362	1	804.6	894.6	14.0	20.4	62.0	52.1
12.1	6.8	31.0	23.2	4.0	4.8	4.2	4.6	1.638691	1.414634	10	762.0	828.5	15.0	21.6	63.0	52.6
5.9	1.6	33.0	24.1	3.2	4.0	3.5	3.8	1.217391	1.071111	20	656.9	733.2	12.9	19.5	55.3	53.8
-4.6	-10.7	30.8	23.2	2.2	2.4	2.2	2.3	0.870185	0.684366	30	507.2	562.3	6.3	13.1	40.0	33.3
3.6	-1.5	32.8	23.8	3.2	3.6	3.2	3.4	1.123161	0.940711	40	576.6	630.6	11.2	18.2	55.6	52.0
13.5	11.0	30.8	23.6	4.3	4.6	4.1	5.4	1.873016	1.778771	50	489.8	540.2	17.3	22.2	30.1	30.0
14.7	8.0	29.7	22.0	4.5	5.0	4.5	4.9	1.981308	1.571429	60	397.9	430.0	15.0	22.2	25.1	23.5
2.2	-4.9	29.6	22.6	2.7	3.0	2.7	2.9	1.080365	0.821818	70	290.6	330.8	8.9	15.9	26.2	24.3
12.5	7.8	30.9	22.2	4.3	4.9	4.4	4.8	1.677874	1.541667	80	456.3	503.8	15.0	21.7	24.9	24.1
9.5	4.3	31.9	22.9	3.9	4.4	3.9	4.3	1.424391	1.231183	90	527.9	592.0	13.6	20.7	41.1	39.4
13.6	7.7	31.9	22.7	4.3	5.0	4.4	4.8	1.743779	1.513333	100	671.8	751.9	15.2	22.7	43.8	43.0
9.2	4.6	32.1	23.3	4.0	4.5	4.0	4.3	1.401834	1.245989	110	706.3	776.2	14.0	20.6	53.8	50.8
2.2	-3.0	31.9	23.1	3.1	3.4	3.0	3.2	1.074112	0.885057	120	677.0	749.7	10.1	17.0	49.2	47.5
-7.8	-14.6	32.7	24.4	1.8	2.1	1.9	1.9	0.807526	0.625641	130	546.0	606.4	4.9	12.5	48.0	47.3
-7.7	-11.2	33.1	24.7	2.0	2.4	2.1	2.2	0.811482	0.688022	140	672.8	700.1	6.8	12.7	64.5	63.4
4.2	-1.6	32.9	23.7	3.3	3.5	3.1	3.3	1.147794	0.936759	150	720.5	797.1	11.1	18.5	64.9	60.8
10.2	4.6	31.8	24.9	6.3	7.6	6.8	4.3	1.470615	1.226601	160	713.6	830.2	14.8	21.0	56.0	55.3
13.4	8.0	29.6	20.2	4.3	5.0	4.4	4.8	1.823928	1.655738	170	868.9	947.0	14.1	21.5	74.1	65.6
13.0	7.3	30.3	21.7	4.3	4.8	4.3	4.6	1.74627	1.506944	180	819.2	919.5	14.5	21.6	67.8	64.5
11.3	5.8	28.7	20.9	4.0	4.7	4.1	4.4	1.645291	1.384106	190	743.7	815.9	13.4	20.0	56.3	51.7
10.4	5.4	29.7	21.4	4.2	4.7	4.1	4.4	1.538621	1.3375	200	685.5	959.2	13.4	20.0	51.0	48.5

Table 4.6 Comparisons between the performance of refrigerating cycle with and without 60 % CuO + 40 % CeO_2

T_5 ansys (°c)	T_5(°c)	T_6 ansys (°c)	T_6 (°c)	P_5 ansys (bar)	P_5 (bar)	P_6ansys (bar)	P_6 (bar)	COP ansys	COP	case	Qev	Q ev ansys	Tev av	Tev av ansys	w comp	w comp ansys
18.1	9.3	30.8	18.7	4.4	5.4	4.3	5.2	2.425758	1.989362	1	804.6	939.3	14.0	24.4	62.0	49.5
15.1	6.8	36.0	23.2	3.8	4.8	3.7	4.6	1.720936	1.414634	10	762.0	870.0	15.0	25.6	63.0	49.9
8.9	1.6	38.0	24.1	3.1	4.0	3.1	3.8	1.305422	1.071111	20	656.9	769.8	12.9	23.5	55.3	51.1
-1.6	-10.7	35.8	23.2	2.1	2.4	1.9	2.3	0.957259	0.684366	30	507.2	590.4	6.3	17.1	40.0	31.6
6.6	-1.5	37.8	23.8	3.1	3.6	2.8	3.4	1.211335	0.940711	40	576.6	662.2	11.2	22.2	55.6	49.4
16.5	11.0	35.8	23.6	4.1	4.6	3.6	5.4	1.873016	1.853375	50	489.8	567.2	17.3	26.2	30.0	28.6
17.7	8.0	34.7	22.0	4.4	5.0	3.9	4.9	2.042403	1.571429	60	397.9	451.5	15.0	26.2	23.9	23.3
5.2	-4.9	34.6	22.6	2.6	3.0	2.4	2.9	1.177021	0.821818	70	290.6	347.3	8.9	19.9	24.9	24.3
15.5	7.8	35.9	22.2	4.1	4.9	3.9	4.8	1.758317	1.541667	80	456.3	529.0	15.0	25.7	24.9	22.9
12.5	4.3	36.9	22.9	3.7	4.4	3.5	4.3	1.51261	1.231183	90	527.9	621.6	13.6	24.7	39.4	39.1
16.6	7.7	36.9	22.7	4.1	5.0	3.9	4.8	1.818339	1.513333	100	671.8	789.5	15.2	26.7	43.8	40.8
12.2	4.6	37.1	23.3	3.9	4.5	3.5	4.3	1.490058	1.245989	110	706.3	815.0	14.0	24.6	53.8	48.3
5.2	-3.0	36.9	23.1	3.0	3.4	2.7	3.2	1.164116	0.885057	120	677.0	787.2	10.1	21.0	49.2	45.1
-4.8	-14.6	37.7	24.4	1.7	2.1	1.6	1.9	0.887125	0.625641	130	546.0	636.7	4.9	16.5	48.0	44.9
-4.7	-11.2	38.1	24.7	1.9	2.4	1.9	2.2	0.890302	0.688022	140	672.8	735.1	6.8	16.7	64.5	60.2
7.2	-1.6	37.9	23.7	3.2	3.5	2.8	3.3	1.236112	0.936759	150	720.5	837.0	11.1	22.5	64.9	57.8
13.2	4.6	36.8	24.9	6.1	7.6	6.0	4.3	1.557814	1.226601	160	713.6	871.7	14.8	25.0	56.0	52.6
16.4	8.0	34.6	20.2	4.1	5.0	3.9	4.8	1.898161	1.655738	170	868.9	994.4	14.1	25.5	74.1	62.3
16.0	7.3	35.3	21.7	4.1	4.8	3.8	4.6	1.824146	1.506944	180	819.2	965.5	14.5	25.6	67.8	61.3
14.3	5.8	33.7	20.9	3.8	4.7	3.6	4.4	1.733111	1.384106	190	743.7	856.6	13.4	24.0	56.3	49.1
13.4	5.4	34.7	21.4	4.0	4.7	3.6	4.4	1.628934	1.3375	200	685.5	1007.1	13.4	24.0	51.0	46.1

Table 4.7 Comparing the results with and without nanoparticles theoretically

Tev, av exp	Tev, av th	Tev, av CuO	Tev, av CeO2	Tev, av 0.5CuO +0.5Ceo2	Tev, av 0.6CuO +0.4CeO2	COP exp	COP th	COPcuo	COP ceo2	COP0.5cuo+0.5ceo2	COP 0.6cuo+0.4ceo2
14.0	13.6	28.7	18.4	20.4	24.4	1.989361702	2.057471264	2.483270093	2.373346897	2.411874708	2.425758173
15.0	14.7	29.9	19.6	21.6	25.6	1.396341463	1.414634146	1.813365575	1.616086708	1.638690947	1.720935784
12.9	12.9	27.8	17.7	19.5	23.5	1.037656904	1.071111111	1.397543633	1.207750699	1.217391304	1.3054221
6.3	7.0	21.4	11.8	13.1	17.1	0.684365782	0.720634921	1.045877405	0.862090101	0.870184845	0.957259249
11.2	11.7	26.5	16.6	18.2	22.2	0.940711462	0.953488372	1.302755071	1.115113257	1.123161136	1.211335255
17.3	15.3	30.5	20.1	22.2	26.2	1.523489993	1.873015873	1.941566123	1.754834685	1.778771272	1.853374709
15.0	15.3	30.5	20.1	22.2	26.2	1.571428571	1.700787402	2.123535676	1.954446855	1.981308411	2.042402827
8.9	9.5	24.2	14.4	15.9	19.9	0.821818182	0.895833333	1.275862069	1.071627537	1.080365297	1.177021277
15.0	14.9	30.0	19.7	21.7	25.7	1.433962264	1.541666667	1.849820144	1.657662948	1.677874187	1.758317025
13.6	13.9	29.0	18.8	20.7	24.7	1.209183673	1.231182796	1.607217873	1.405209841	1.424391333	1.512610211
15.2	15.8	31.0	20.7	22.7	26.7	1.5	1.5133333	1.905592031	1.720614294	1.743779054	1.818338674
14.0	13.9	28.9	18.8	20.6	24.6	1.195	1.245989305	1.584379097	1.388073829	1.401834462	1.490058245
10.1	10.6	25.3	15.5	17.0	21.0	0.885057471	0.904580153	1.256831417	1.06586169	1.074111504	1.164115512
4.9	6.4	20.8	11.3	12.5	16.5	0.625641026	0.67679558	0.968415116	0.801768015	0.807526218	0.88712522
6.8	6.7	21.0	11.5	12.7	16.7	0.682191781	0.688022284	0.970881398	0.806005846	0.811482434	0.890302252
11.1	12.0	26.8	16.8	18.5	22.5	0.936758893	0.97235387	1.327873909	1.13610586	1.147793578	1.236112472
14.8	14.2	29.3	19.0	21.0	25.0	1.226600985	1.248677249	1.65210547	1.449326011	1.470615456	1.557814485
14.1	14.6	29.8	19.4	21.5	25.5	1.655737705	1.54676259	1.987259555	1.791749834	1.823928461	1.898160856
14.5	14.7	29.9	19.6	21.6	25.6	1.482965932	1.50694444	1.914732713	1.716149068	1.746269517	1.824146304
13.4	13.2	28.3	18.1	20.0	24.0	1.38	1.38410596	1.830942864	1.619962802	1.645290581	1.733110712
13.4	13.3	28.3	18.1	20.0	24.0	1.293413174	1.3375	1.727154612	1.515984296	1.538621047	1.628933772

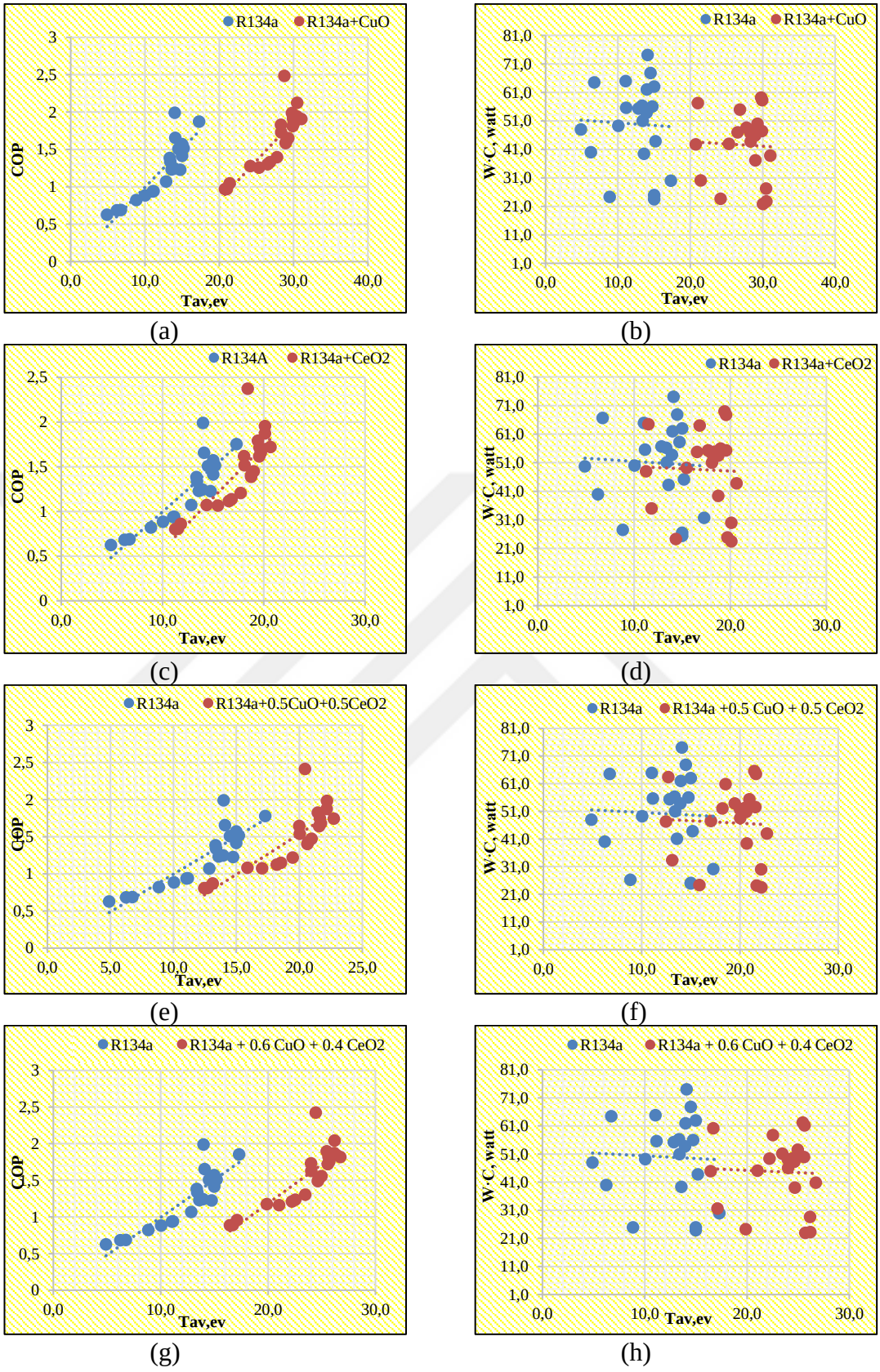
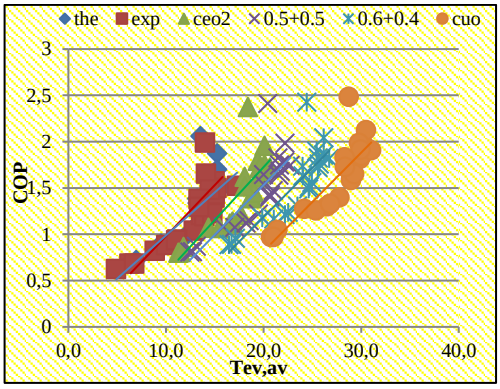


Figure 4.4 *COP* and W_{Comp} against $T_{av,\,ev}$ at constant mass fractions



(i)

Figure 4.4 (continued) *COP* and W_{Comp} against $T_{av,\,ev}$ at constant mass fractions

4.4 Thermophysical Properties of R134a Based on Numerical Equations

The results of the numerical equations that were chosen to determine the thermal properties of (R134a + CuO) , (R134a + CeO_2) , (R134a + mixture No1) , (R134a + mixture No.2) , (R134a + mixture No3) , (R134a + mixture No4), and (R134a + mixture No 5) for mass fractions of 0.05 to 0.33 wt.% , showed that all of the thermophysical properties increase linearly with nanoparticles concentration except heat capacity ,which reduces with increasing nanoparticles concentration, where CuO with R134a achieved the best results among other types of nanoparticles as shown in ***Figure 4.5*** . These results are in agreement with the results published by ***Omer A. Alawi and Nor Azwadi Che Sidik (2014)***, indicated that diffusion of CuO inside R134a with increasing its concentration enhanced the thermophysical properties of nanorefrigerants.

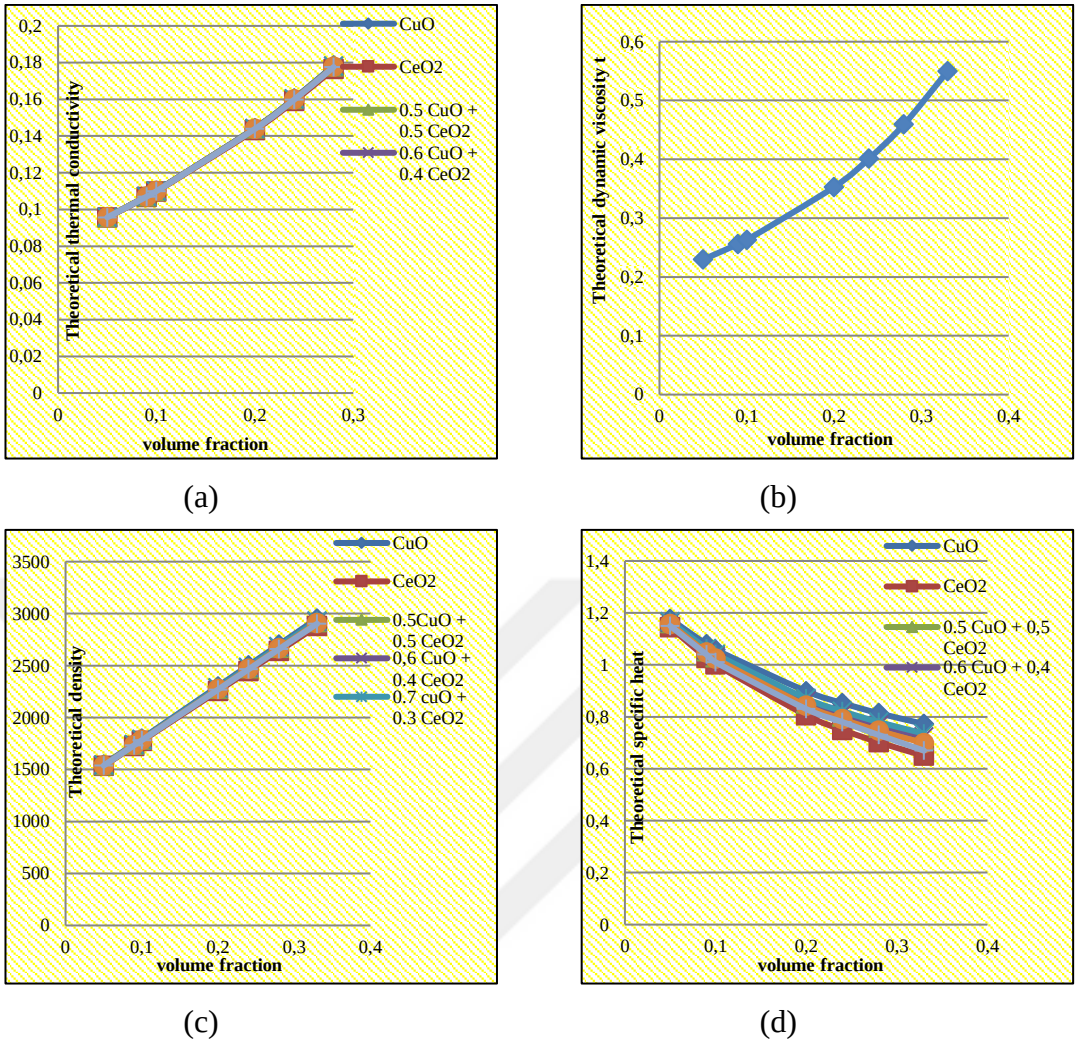


Figure 4.5 Variation of thermophysical properties of nanorefrigerants at different mass fractions

CHAPTER 5

CONCLUSIONS

The first barrier that prevents the uses of nanoparticles in many applications is the cost. This research presents a new method for preparing nanoparticles as oxides and a mixture of different oxides. The method by which nanoparticles were prepared was simple, easy, and inexpensive, and from materials available in every laboratory. Thus the cost barrier that prevented the use of nanoparticle on a large scale in refrigeration systems was broken. Moreover, the materials prepared were characterized by good thermal properties and the cost of nanoparticles rises as they have better thermal properties. This method will be succeed in producing nanoparticles with a high thermal conductivity so that the door of research remains open to answer these questions

The second barrier is to maintain a nanoparticle attached to refrigerant or lubricant for as long as possible time, as the deposition of nanoparticle is considered one of the biggest problems, and this is known as stability. Recently, the concept of using nanoparticles as a hybrid began to appear as an attempt to solve the problem of stability. Will the mixtures that were mentioned in this research succeed in achieving the best results? The mixture No.1 with fifty % copper oxide and fifty % cerium oxide was distributed inside R134a using an ultrasound machine for an hour and achieved a stable mixture for the entire day. The theoretical study that was implemented on the real refrigeration system for this research showed that a convergence between the experiments and theoretical values, with a percentage ranging from 77 to 98%, and this was encouraging to rely on it in studying the influences of nanoparticles on the *COP* of the refrigeration system theoretically. The results of the theoretical study for using CuO agreed with literature review, where 0.25 wt % of CuO succeeded in enhancing the COP by 25% and CeO_2 achieved a similar result, and the mixtures showed their effectiveness to enhance the efficiency of refrigerating systems, especially as the proportion of copper oxide within the mixture increased.

With regard to the study of the thermophysical properties, the results were in agreement with the literature review, whether these studies were experimental,

theoretical, or using numerical equations. The results of this research indicated that all the thermophysical properties of nanorefrigerants increase with an increasing proportion of nanoparticles within the mixture expect heat capacity which reduces with an increasing proportion of nanoparticles within the mixture.

RECOMMENDATIONS

Recommendations are mentioned as follows:

- Use the materials that were produced in this study with different types of refrigerants or lubricants to investigate their effects on the COP of a refigeration system
- Carry out some studies to compare the different types of refrigerants and lubricating oils, when they are mixed with the materials prepared in this study, to find out which of refrigerants or lubricants are more compatible with these materials.
- The need to conduct many experiments, which include adding nanoparticles with different concentrations, to find out the best percentage of nanoparticles to be added to the refrigerants or lubricants to get the best results.
- Verification of the behavior of CeO_2 inside the refrigeration system experimentally , especially that it was tested theoretically in this research and actually improved COP of a refigeration system
- All the mixtures that were referred to in this research are recommended to be mixed with different types of refrigerants and lubricating oils to verify their effectiveness in improving their thermophysical properties.
- It is recommended to use nanoparticles as a hybrid and compare them with the nanoparticles as a mixture that was prepared in this study to compare the stability results and which one gave better results if mixed with refrigerant or lubricants.
- It is recommended to use nanoparticles as a hybrid and compare them with the nanoparticles as a mixture that was prepared in this study to compare the thermophysical properties results and which one gave better results if mixed with refrigerant or lubricants.

- It is recommended to use nanoparticles as a hybrid and compare them with the nanoparticles as a mixture that was prepared in this study to compare the COP of the system and which one gave better results if mixed with refrigerant or lubricants.

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