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Senior Design Project Report

"Enhancing the efficiency of a Refrigeration system using nanofluids"

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Abstract

Refrigeration is the transfer of heat from one place to another one, by increasing the heat transfer we improve the performance of a refrigeration system. The project setup uses (R134a), with nanofluid inside the condenser bucket, that contain two types of nanoparticles. Each material has its properties that could enhance the cycle performance due to it's thermal conductivity. Nanofluid is a fluid containing nanometer-sized particles, each size delivers a different output. The purity of the material could be an important factor for more enhancement for the system.

The project objective is to enhance the performance of a refrigerant cycle, using nanoparticles mixed in a stationary water, in the condenser bucket. Therefore, comparing the results of reading temperatures and power input to base water. The Project focuses on two types of nanoparticles, which are aluminum oxide nanoparticle and copper nanoparticle, both nanoparticles are mixed with water individually in the condenser bucket, then calculation comes ahead of the heat transfer rate of the evaporator and condenser.

After experimenting, the result is shown improvement in the performance when using nanoparticles as a heat transfer medium, by increasing the heat transfer, also decreasing the power input to the system, which is the main goal we're trying to accomplish.

Acknowledgments

First of all, we as a group would like to thank Dr. Waqar Khan for taking us in as our advisers to help and guide us throughout the journey of the senior project. He gave us knowledge and guidance that we couldn't be more thankful for it. we would also thank our co-advisor Dr. Faizan Ahmed for Helping us each time with data and Lab instructions and, giving us valuable ideas on how to operate the experiment. A special thanks to PMU for allowing us to access the Mechanical Engineering lab and providing us a perfect atmosphere for us to work.

Finally, we would like to thank our families and friends for believing in us and encouraging us to do our best in life.

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Chapter 1: Introduction

1. Introduction

Nanofluids are used in many applications, for example, in, Solar thermal applications, automobiles, medical applications, electronic cooling. In our case increasing the heat transfer rate while also increasing the coefficient of performance using nanofluid, could be very beneficial to the industry since it could save a lot of money and operation time while using less power consumption.

Single Material nanofluids. was found by Choi, in 1995, the method considered a desirable form of nanofluids, it was experimented by many scientists, that nanofluids as a heat transfer medium are better in performance, and more effective due to their thermal conductivity, that considered much larger than base fluid. Water, for example, has less thermal conductivities, which limit its boundaries to achieve a better heat transfer rate, also reaching higher cooling performance as nanofluid.

Nanofluids are formed by dispersing solid particles of 1 to 100 nm size in the base fluid. Smaller size nanoparticles are better for heat transfer, since it means a larger surface area, so particles can flow smoothly through such channels, in our case we used stationary water. Adding metal or metal oxide particles to the base fluid expands the thermal conduction and convection, which makes nanofluids more superior as coolants than other fluids.

1.1 Problem Description

In this project, an experimental setup of a refrigeration system that contains a shell and tube heat exchanger, designed to mix the nanoparticles in the condenser bucket, which allow the nanoparticles to flow constantly in stationary water during the compressor running time. Results are compared with base fluid. The experiment uses two types of nanoparticles, which are aluminum oxide nanoparticle and copper nanoparticle, both types are to be mixed with water separately and constantly. The examination of the heat transfer rate of the condenser and evaporate has been considered and evaluated.

1.2 Project objectives

This project aims to address the performance and heat transfer rate of a refrigeration system using nanofluids. The study has the following objectives:

i. Design of an experimental setup to perform the study.

ii. Enhancing the efficiency of a refrigeration system.

iii. comparting two types of nanofluids on the performance of the refrigeration system.

iv. evaluate the results by comparing the base fluid to nanofluids.

Chapter 2: Literature Review

Over the past years, many authors and scientists have proven that nanoparticles enhance the thermal conductivity of fluids. Also increasing the heat transfer of a system. Here are some results of past experiments, that could lighten up some aspect of nanoparticle materials and their outcome. These researches has helped us to investigate more about nanofluid as heat transfer medium.

2. Literature Review

Material	**Volume Fraction (%)**	**Thermal Conductivity Enhancement (%)**	**Reference**
Fe_3O_4	7.8	23	[1]
CuO	0.4	8	[2]
MWCNT in water	0.6	38	[3]
Al_2O_3	4.3	15	[4]
Graphene in distilled water	0.05	16	[5]
Ag	0.9	69.3	[6]
TiO_2	5	30	[7]
SiO_2	0.03	7.57	[8]

NF	Outcome	Reference
Al_2O_3	Increase in heat due to presence of NP is much higher than the prediction of single phase heat transfer correlation used with nanofluid properties.	[9]
$FeCl_3$	Fe3O4 magnetic np dispersed in water cannot enhance convective heat transfer in laminar flow regime in the absence of magnetic field but particularly significant under the influence of an applied magnetic field and magnetic nanoparticle volume fraction.	[10]
Fe_3O_4	Heat transfer is enhanced by 30.96% and friction factor by 10.01% at 0.6% volume concentration.	[11]
Fe_3O_4	Increased concentration of np is disadvantage to improve the forced heat under transition region with present investigated conditions.	[12]
$CuO-H_2O$	Heat increases with the enhancement in the nanofluid concentration from 0 to 0.4 vol% and decreases with increase of nanofluid inlet temperature from 50C to 80C.	[13]
Ag-DI	Measured thermal conductance, effectiveness, and external Nu are 4.1%, 3.7%, and 4.3%, respectively with 0.005%, 0.01%, and 0.02% volume fraction.	[14]

NF	Outcome	Reference
AL_2O_3	The enhancement in heat transfer with 6mm glass beads, at Reynolds number of 500 and 3000 is respectively greater by 14.6% for 0.5% nanofluid concentration.	[15]
AL_2O_3	Maximum thermal enhancement at 4.2% with Al2O3/EG nanofluid 0.5 vol% in corrugated tube with twisted tape at twist ratio 2.	[16]
Graphene	Enhancement 10.3% for thermal conductivity and 14.2% for h at Re 1850 with 0.02 vol% in a laminar forced heat transfer inside a circular tube.	[17]
SiO_2-CuO	Electron beam physical vapor deposition (EBPVD) coating approach used to fabricate nanofluid which caused reduction of about 36% in the incipience superheat and 58% enhancement in heat transfer.	[18]
Ag & Cu	At nanofluid 1.0 vol%, heat transfer and Nu were augmented by 52% and 47.5% for Ag nanofluids, 27.6% and 24.3% for CuO nanofluids, respectively, in turbulent flow.	[19]
CNT-TiO_2	Significant enhancement of heat (about 38%) was achieved by using 0.2 wt% CNT–TiO2 hybrid NFs at 38C in laminar flow.	[20]

Chapter 3: System Design and Specification

3.1 System Block Diagram

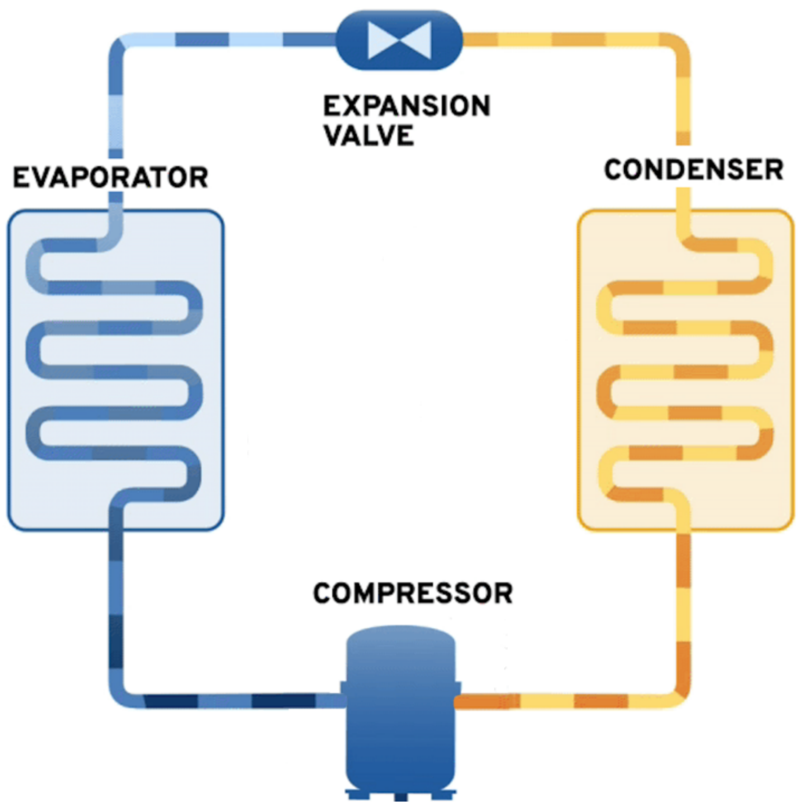

Figure 3. 1: Block diagram

3.1.1 Specifications and Standards

The System used in this project is a basic refrigeration cycle that has a condenser, evaporator, and compressor, expansion valve. All of these parts connected to run the cycle.

It's and Refrigerant R134a design that has:

- Internal helix diameter of evaporating apparatus and liquefier: 13 cm each
- Water volume of the heat reservoir: 7 liters each

- Manometer in low pressure section: Measurement range: -1 to +10 bar
- Dew point scale: -60 to +50 °C
- Manometer in high pressure part: Measuring range: -1 to +30 bar
- Dew point scale: -60 to +95 °C
- Dimensions of tubes are: 2 m x 6 mm
- Connection: 230 V, 50 Hz.
- Power consumption: approx. 130 VA
- Dimensions of the system: 70 cm x 82 cm x 50 cm
- Weight of the design: 30 kg

3.1.2 Engineering standards

Table 3.1: Engineering standard

Part	Engineering Standard
Copper Tube for Refrigeration	ASTM B280
Compressor	MA57LBEG
Pressure Gauges	ASME B40.1

3.2 Constraints and Design Methodology

In this segment, we provide our design methodology and constraint that our project has encountered.

3.2.1 Design Methodology

The Picture below shows our design and the adjustment of each part.

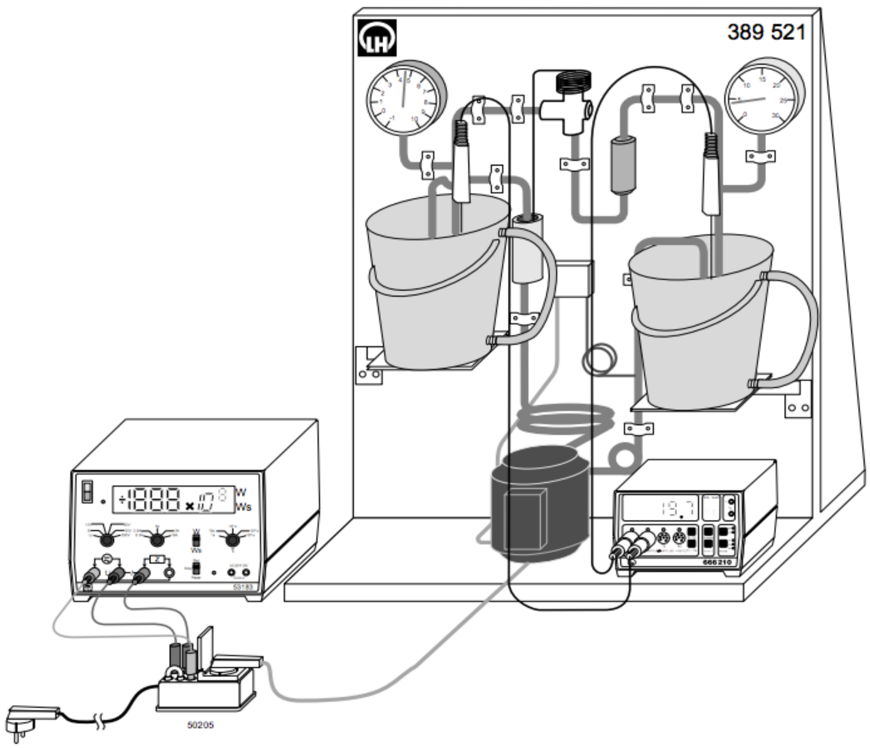

Figure 3.2: Design assembly of refrigeration system

3.2.2 Shell and coil heat exchanger

The system consists of two shell and coil heat exchangers, on the right side HEX, behave is a condenser which is our main focus, the design coils are fixed to the plate, so our studies are limited to a smaller bucket that contains 7 kg of base water to mix the nanoparticles.

3.2.3 Condenser bucket

The condenser bucket is filled with 7 liters of base water that has a room temperature 21 c°, during compressor ruining time the nanoparticles inserted and mixed manually, at the center of the heat exchanger which shaped as a hollow circle, the mixing done carefully to prevent damaging the copper coil, that behaves as a heat exchanger, this is the biggest constraint that gets in the way of the experiment.

3.2.4 Evaporator bucket

The evaporator bucket is filled with 7kg of water that has a temperature of 40 c°, to prevent ice formation, since we take readings every five minutes that 15 minutes in total. So our reference tempter is best when it's higher to avoid such a case. The evaporator bucket does not contain nanoparticles.

3.2.5 Geometrical Constraints

As mentioned earlier the parts, piping of the system is fixed to a plate, that can't be adjusted another way, so we are limited to a smaller size bucket for both condenser and evaporator.

3.2.6 Safety

A factor of safety increases the safety of people and reduces the risk of failure of a product during the experiment.

- The coolant circuit is pressurized. Do not attempt to open this circuit under any circumstances.
- Do not thermally insulate the compressor; this can cause the device overheat.
- Do not carry the apparatus by the copper tubing, danger of bending.

3.2.7 Nanoparticles

Nanomaterials that are labeled as "chemical substances" could harm the body in many ways, so it is required to use safety equipment, such as masks, safety glasses, protected gloves. Since nanoparticles are very small, it can be hardly seen by the human eye.

3.3 Parts and Shipments Standard

The table bellow provides the materials used as nanoparticles and their engineering standard:

Table 3.2: Material Engineering standard

Material	Engineering Standard
Pure Copper	CAS 7440-50-8
Aluminum Oxide	CAS 1344-28-1

3.4 Theoretical Calculations

To know the difference and the impact of nanofluid as an enhancement to the refrigeration system, we have listed these equations needed to calculate the heat transfer ate and COP.

3.4.1 The Volume fraction of nanoparticles

$$\phi = \left[\frac{(\frac{m_{nf}}{\rho_{nf}})}{\left(\frac{m_{nf}}{\rho_{nf}}+\frac{m_{bf}}{\rho_{bf}}\right)}\right]$$

Equation (3-1)

3.4.2 The density of the nanofluid

$$\boldsymbol{\rho nf} = (\mathbf{1}-\boldsymbol{\phi}) * (\boldsymbol{\rho bf}) + (\boldsymbol{\phi} * \boldsymbol{\rho np})$$

Equation (3-2)

3.4.3 The specific heat capacity of nanofluid

$$C_p nf = \frac{(1-\phi) * \rho_{bf} * C_{p-bf} + (\phi * \rho_{np} * C_{p-np})}{\rho_{nf}}$$ *Equation (3-3)*

3.4.4 The heat transferred in evaporator

$$Q_e = m_w C_p \Delta T_e$$ *Equation (3-4)*

3.4.5 The heat transferred in condenser

$$Q_c = m_{nf} C_p - nf \Delta T_c$$ *Equation (3-5)*

3.4.6 The Coefficient of Performance for refrigerator

$$COP_R = \frac{Q_e}{W}$$ *Equation (3-6)*

3.4.7 The Coefficient of Performance for heat Pump

$$COP_H = \frac{Q_c}{W}$$ *Equation (3-7)*

3.5 Product selection of Components

Copper and aluminum oxide as nanoparticles is best known for their high thermal conductivity, which is the core of enhancing the heat transfer using nanoparticles.

Selection of the materials:

- copper nanoparticles (Cu, 70 nm, 99.9% purity, metal basis).
- Aluminum Oxide nanoparticles (Al2O3, 50 nm, 99.9% purity, Hydrophilic)

3.6 Project prototype

The below pictures show our main parts of our project prototype:

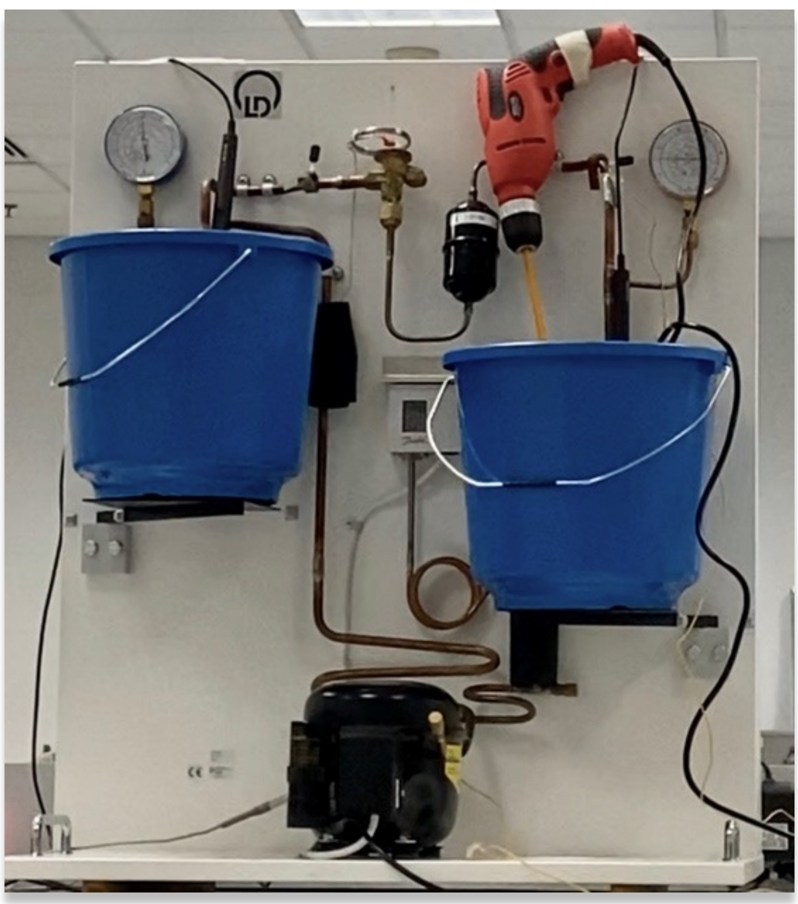

Figure 3.3: Project prototype

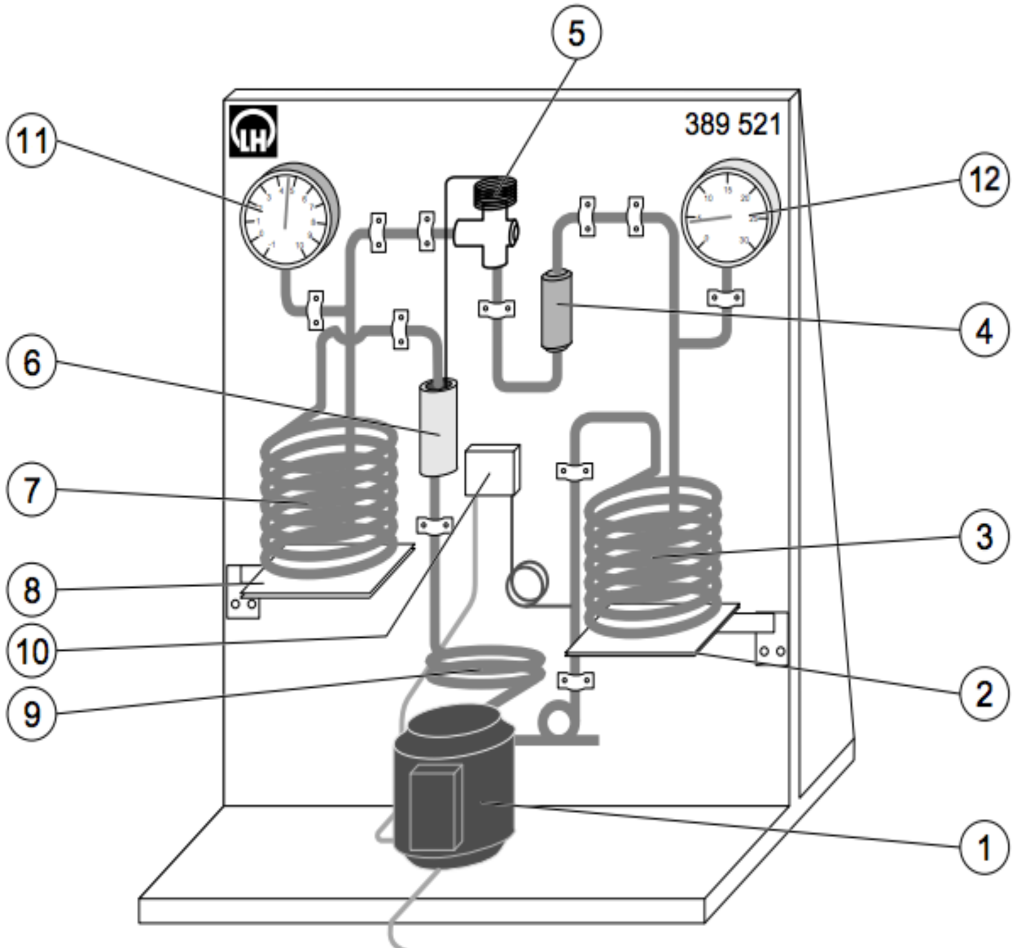

Figure 3.4: Project prototype(CAD)

1) Compressor 230 V; 50/60 Hz. Power consumption approx. 130 W at 50 Hz.

2) Hinged support for water vessel with red mark

3) Liquefier, internal diameter approx. 13 cm

4) Collector/purifier

5) Expansion valve, thermostatically controlled

6) Temperature sensor for expansion valve, thermally insulated

7) Vaporizer, internal diameter approx. 13 cm

8) Hinged support for water vessel with blue mark

9) Spiral tubing as elastic connection between compressor and heat exchanger

10) A Pressure switch

11) Manometer for the low-pressure side; inner scale for pressure measurement from -1...+10 bar, outer scale with corresponding dew-point temperature of R134a from -60 °C to +40 °C.

12) Manometer for high-pressure side; inner scale for pressure measurement from -1...+30 bar, outer scale with corresponding dew-point temperature of R134a from -60 °C to + 85°C.

Chapter 4: System Testing and Analysis

4.1 Results

The data analysis that found on the experiments and equation calculation as follows:

Table 4.1.1: Pure Water with mass of 7 kg

time	T-w-evap	T-w-cond	Win	Pevap	Pcond
min	*C*	*C*	*watts*	*bar*	*bar*
0	40	20	154	3.7	8.9
5	34	23.5	172	4.1	10.2
10	24.4	28.7	182	4.1	12
15	22	40	187	3.9	13.3

Table 4.1.2: Calculation of Pure water with mass of 7 Kg

Q-cond	0.650222222 KW
Win	0.17375 KW
Q-evap	0.5852 KW
COP-HP	3.742286171
COP-R	3.368056

Table 4.2.1: Pure copper with mass of fraction (0.02%)

time	T-w-evap	T-w-cond	Win	Pevap	Pcond
min	*C*	*C*	*watts*	*bar*	*bar*
0	40	19.4	148	3.7	6.9
5	32.4	28.2	152	4	9.5
10	23.8	37.6	172.8	4	10
15	19.9	45.7	175	3.7	12.1

Table 4.2.2: Calculations of Pure copper with mass of fraction (0.02%)

Q-cond	0.735194407 Kw
Win	0.16195 KW
Q-evap	0.653473333 KW
COP-HP	4.539638
COP-R	4.03503137

Table 4.3.1: Pure copper with mass of fraction (0.05%)

time	T-w-evap	T-w-cond	Win	Pevap	Pcond
min	*C*	*C*	*watts*	*bar*	*bar*
0	40	19	149	3.9	7.9
5	29.8	30.1	164	4	9.2
10	20.5	40.5	172	4	10.9
15	19	55	171	3.4	12.7

Table 4.3.2: Calculations of Pure copper with mass of fraction (0.05%)

Q-Cond	0.83033 KW
Win	0.164 KW
Q-Evap	0.682733333 KW
COP-HP	5.062988939
COP-R	4.16300813

Table 4.4.1: Aluminum Oxide with mass of fraction (0.02%)

time	T-w-evap	T-w-cond	Win	Pevap	Pcond
min	*C*	*C*	*watts*	*bar*	*bar*
0	39	20	148	3.6	7.5
5	31.6	27.5	150.7	3.9	8.1
10	22.6	34.2	165.5	4	9.9
15	20.2	42.9	171.2	3.7	12

Table 4.4.2: calculations: Aluminum Oxide with mass of fraction (0.02%)

Q-Cond	0.700657828 KW
Win	0.15885 KW
Q-Evap	0.611208889 KW
COP-HP	4.410814153
COP-R	3.847710979

Table 4.5.1: Aluminum Oxide with mass of fraction (0.05%)

time	T-w-evap	T-w-cond	Win	Pevap	Pcond
min	*C*	*C*	*watts*	*bar*	*bar*
0	40	20	150	3.8	9.8
5	30.6	29.9	155	4	9.1
10	23.3	38.4	169	4	10.8
15	19.6	48.5	180.1	3.8	13.1

Table 4.5.2: Calculations of Aluminum Oxide with mass of fraction (0.05%)

Q-Cond	0.800665795 KW
Win	0.163525 KW
Q-Evap	0.663226667 KW
COP-HP	4.8962
COP-R	4.0558

4.2 Graphs

In this section, we provided five charts to illustrate our calculation in the simplest form, to see the difference and impact of our study of nanoparticles. The graphs deal with different parameters such as heat transfer, COP, and power input, in the case of volume fraction (Phi) of nanoparticles used, which is (0.02, 0.05) for copper and aluminum oxide.

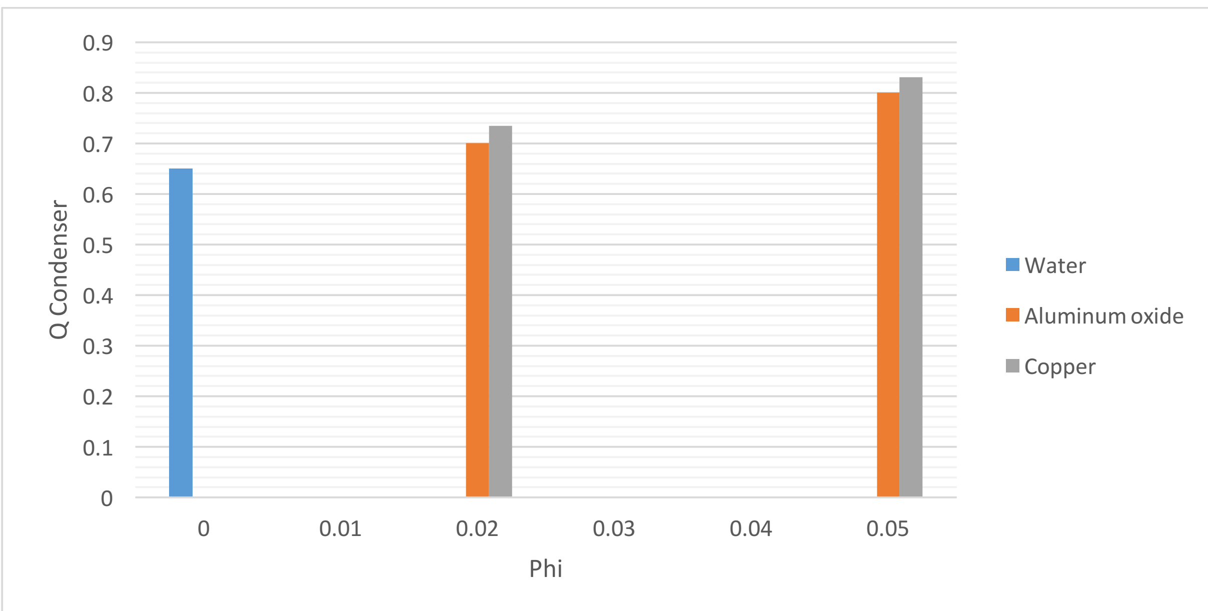

Figure 4.2.1: Q condenser V.S Phi

The graphs above show the heat transfer rate of the condenser vs the volume fraction of nanoparticles. We see an increase in heat transfer the more we add volume fraction, and copper nanofluid has a bigger number than alumina by a small difference.

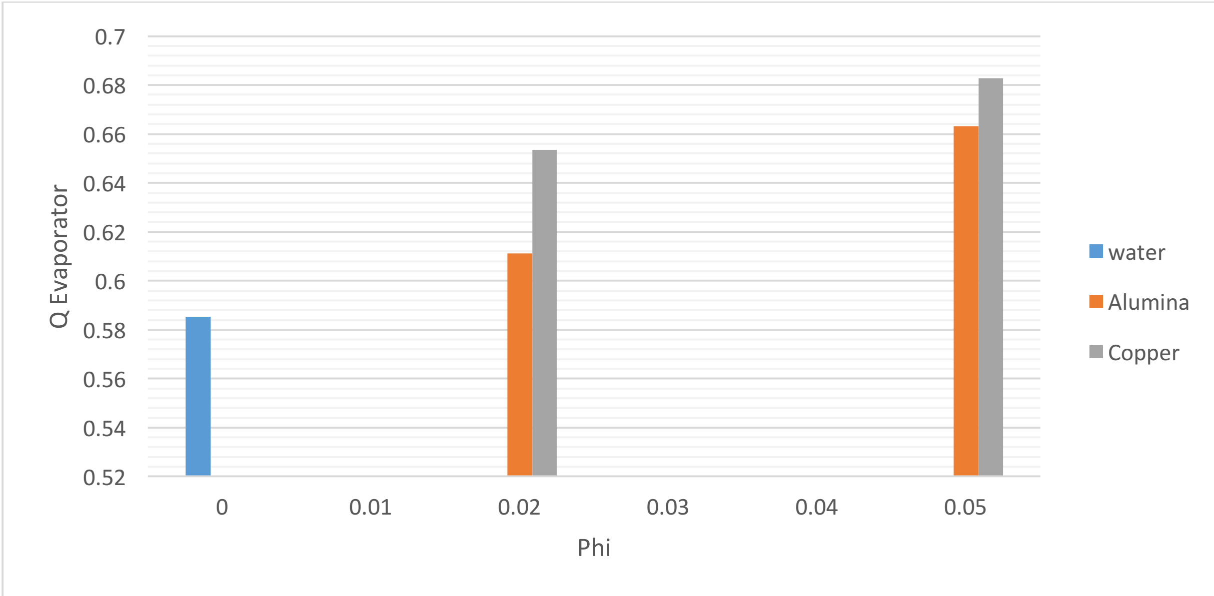

Figure 4.2.2: Q evaporator V.S Phi

The graphs above show the heat transfer rate of the evaporator VS volume fraction. It shows a bigger improvement when using copper nanofluid. However, we see a much larger improvement in the evaporator heat, since the evaporator reference temperature is 40 c.

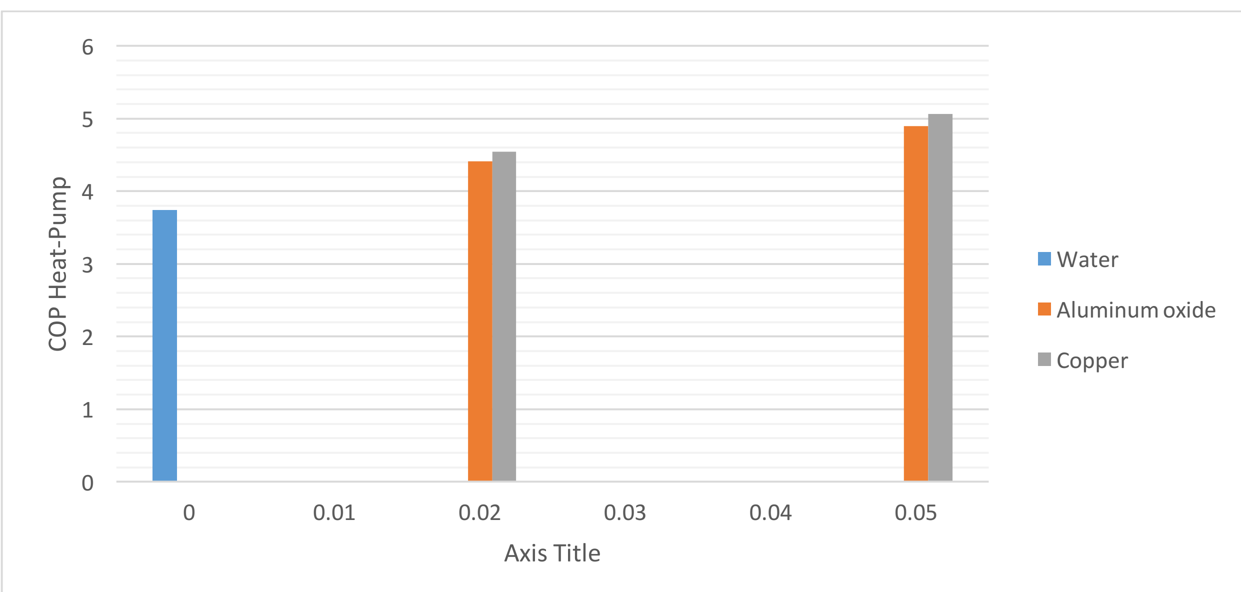

Figure 4.2.3: COP V.S Phi

For COP Heat-Pump, at 0.02 volume fraction, coefficient of performance has increased by 7.14% for Alumina and 10.28% for Copper. At 0.05 volume fraction, coefficient of performance has increased by 18.94% for alumina and 22.99% for Copper.

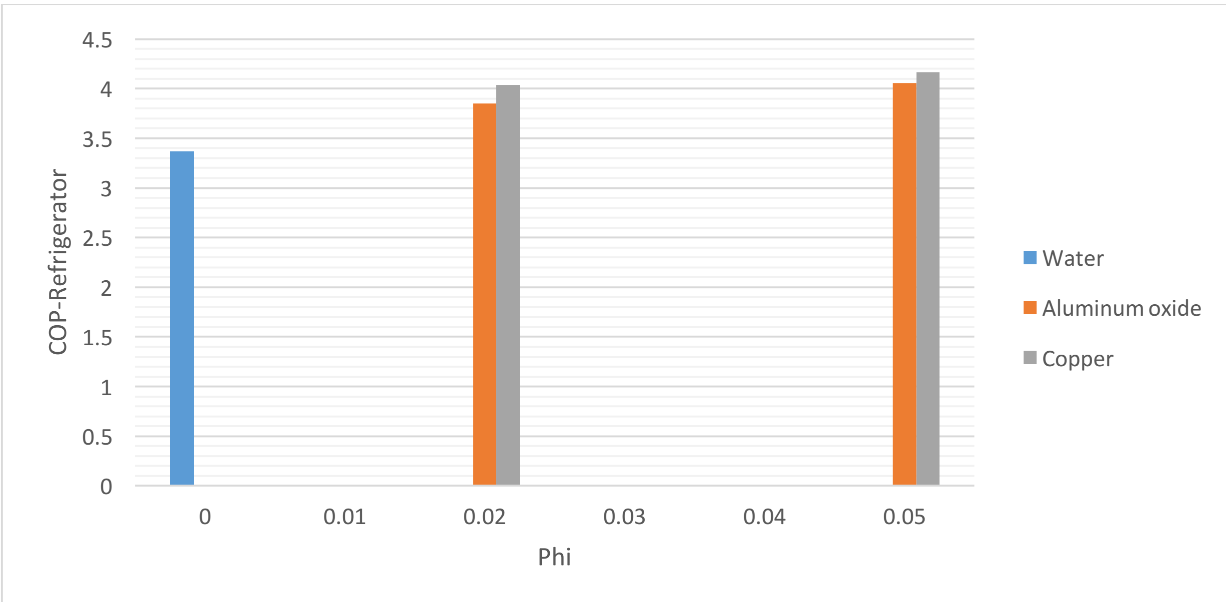

Figure 4.2.4: COP V.S Phi

For COP Refrigerator, at 0.02 volume fraction, coefficient of performance has increased by 2.819% for Alumina and 19.80% for Copper. At 0.05 volume fraction, coefficient of performance has increased by 8.38% for alumina and 23.6% for Copper. The results show improvement COP refrigerator because the reference temperature for evaporator is set to be 40 C

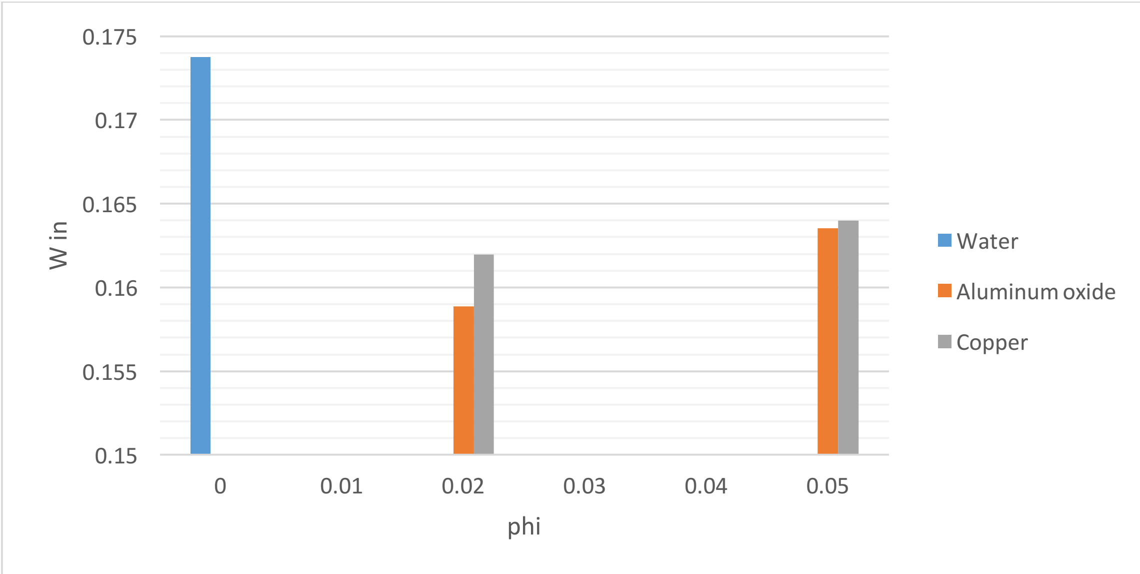

Figure 4.2.5: Win V.S Phi

The chart above shows how much power input the compressor consumes for the experiment. After adding 0.02 volume fraction of nanoparticles, the power consumption decreases by almost 54-60% compared to what base water require to operate. However, when using 0.05 volume fraction of particles the power consumption is increased a little, but still consumes less power than base water.

Chapter 5: Project Management

5.1 Project Plan

The project is planned with several tasks that have a timeline for each one, the group members have participated effectively to make it happen. Table 5.1bellow shows the tasks and time duration set at the beginning of taking the project.

Table 5.1: List of tasks with time duration of each task.

Tasks	Start Date	Days to complete
Identifying the Project	9/21/2019	5
Determine objectives	9/21/2019	5
Gathering ideas and information	9/21/2019	5
Design the cycle for machine	10/1/2019	10
Collecting prices for tools & buy them	10/15/2019	20
Ordering Nano powder	10/20/2019	5
Assembling the tools	10/21/2019	4
Make sure the adjustments correct	10/24/2019	2
Testing the machine	10/24/2019	1
1.Starting the experiment with water only	10/29/2019	1
2. Starting the experiment with copper	11/4/2019	1
3. Starting the experiment with aluminum oxide	11/4/2019	1
Take reading for flow and temperature.		1
Compare the results	11/4/2019	1
Taking notes	11/5/2019	4
Taking reading for flow of inlet.	11/5/2019	1
Measure temperature	11/5/2019	1
Compare the results	11/7/2019	1
Writing	11/8/2019	10
corrections	11/9/2019	3
presentation	10/15/2019	10
prepare for Final	11/21/2019	15
Finalize final report	11/22/2019	8

5.2 Project Execution Monitoring

weakly meetings have set to share ideas and gather information on how to improve our project. each meeting is very helpful where team members discuss a problem we face with our adviser and try to look for a solution. Below is the table for our meetings:

Table 5.2: Project Execution Monitoring Activities.

Activity	Time
Member’s meeting	two times every week
Advisor meeting	One time every week
Lab meeting	Three times every week

5.3 Challenges and Decision Making

The main challenges we faced at the beginning of the project:

- we tried to pump nanofluid from an external tank to the condenser bucket, but we have faced many problems in the way, such as water leakage, pressure drop. however, we managed to change our adjustment so we can use the experiment with stationary water.
- Another challenge we faced, nanoparticles are not available in the country and takes over a month to order it from outside.
- Theoretical Calculation

5.4 Project Budget

The table bellow shows the items used for our design and the cost of each item:

Table 5 3: Bill of Material

Material	**Cost**
Copper Nanoparticles	2500 SR
Aluminum Oxide Nanoparticles	1000 SR
2 tanks	120 SR
Mixer	150 SR
Fittings	50 SR
Total	**3820 SR**

Chapter 6: Project Analysis

6.1 Life Long Learning

This project has successfully refined our skills as students, it has a great impact on how we work and cooperate as a team. Giving us a lifelong knowledge and experience that has elevated our understanding of how to run a project.

6.1.1 Understanding The Refrigeration system

The project gave us a better understanding of the refrigeration system since we have bonded with the machine itself. We have learned the mechanism of the condenser and evaporator and how to calculate several parameters related to our project. It has helped us a lot as engineering students, to see this kind of experiment, where we apply what we have studied years ago and seen how it looks like in real life.

6.1.2 Time Management Skill

Time management is an important factor to achieve our goals since we have only three members of the group. We tried to make as much possible with our time by distributing tasks to the group members. This project has to give us another experience; unlike any group project, we did in previous years of study. It requires patience and physical effort since we have done many experiments that each experiment could take more than 4 hours in the lab.

6.1.3 Problem Solving

When you design a project, not everything will go as you planned, this is where problem-solving skill comes in handy. Problem-solving is one of the important skills needed to run our project. we have faced many problems theoretically and experimentally, but we gathered as a team with our adviser to look for answers, alternatives to calculate data and operate our system correctly.

6.2 Engineering Solution

It's necessary to understand the impact of engineering solutions on the economic, environment.

6.2.1 Environmental impact

Nanofluid is a solution that needed to be researched more, but it has already proven that it saves a lot of power consumption which could help the environment by using less electricity. Since generating electricity damages the atmosphere by releasing gasses to the air. In our project, we have seen the results of power consumption when using nanoparticles, and it satisfying.

6.2.2 Economical impact

Nanofluid as a heat transfer medium could save a lot of money and time, because of their thermal properties that could enhance the system. Nanofluid economical impact is achieved by reducing the power input which could help the industry in so many ways, so the industry can reduce operation time with desirable and effective output, while also saving money.

6.3 Conclusion

The results have shown a satisfying improvement of the heat transfer rate and the performance of a refrigeration system when using nanofluid as a heat transfer medium. The experiment has used 0.02 and 0.05 volume fraction of pure copper and pure alumina due to their higher thermal conductivity which is an important factor in this field. The coefficient of performance has increased by the increase of the heat transfer rate of the condenser and evaporator, while also decreasing the power input from 0.173 kW to 0.158 kW when adding 2% of aluminum oxide. For COP Heat-Pump, at 0.02 volume fraction, the coefficient of performance has increased by 7.14% for Alumina and 10.28% for Copper. At 0.05 volume fraction, the coefficient of performance has increased by 18.94% for alumina and 22.99% for Copper. After experimenting with three types of fluids, (water, copper nanofluid, alumina nanofluid), the results show that copper nanofluid is the best in performance. Investigation of nanofluid related to power input should be considered.

6.4 Future Recommendation

The results have shown a satisfying improvement of the heat transfer rate and the performance. As a team member, we recommend using hyper nanofluid which is mixing two or more types of nanoparticles. This could help to lower the cost of nanoparticles since we can mix expensive material such as copper with less expensive material.

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