PERFORMANCE ANALYSIS OF A NANOREFRIGERANT (HYDROCARBON+ CuO) BASED REFRIGERATION SYSTEM

Thesis submitted in partial fulfillment of the requirements for the award of the degree of

MASTER OF ENGINEERING

In

THERMAL ENGINEERING

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DECLARATION

I hereby declare that the work which is being presented in the dissertation entitled, **"Performance Analysis of a Nanorefrigerant (Hydrocarbon+Cuo) Based Refrigeration System"** in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Mechanical Engineering with specialization in **THERMAL ENGINEERING** submitted in **Mechanical Engineering Department** of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of Mr. Kundan Lal. The work refers other researchers' works which are duly listed in the references section.

The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

(Rajneesh Kaushik)

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ABSTRACT

Refrigeration and air conditioning plays a crucial role in order to fulfill the day today human needs and industrial requirements. The performance of any such system largely depends upon the performance of its integral subsystems like; evaporator, compressor, condenser, expansion valve and the thermal performance of the type of the refrigerant being used. The performance of these conventional refrigeration systems depends on the inherited poor thermal properties of the refrigerant. In the presented work, an attempt has been made to review the performance of such system by replacing the conventional refrigerant (R134a) with nanorefrigerant (hydrocarbon+CuO). The experimental work was done on the standardized experimental set up which was fabricated and made to function in the department lab. It has been found that the refrigerant's characteristics can be enhanced by mixing nano particles to the base refrigerant. The nano particles improve its heat transfer performance, which is desirable to increase refrigeration effect & coefficient of performance of the system. In the experimental set up, hydrocarbon refrigerant along with CuO nano particles has been used. Hydrocarbon refrigerant is more eco friendly than the conventional refrigerants such as R134a. CuO nano particles are introduced in vapour compression system with the help of charging line & small straw. Different tests are carried out & reading of temperature, pressure, energy consumed was taken at different points & under different conditions. COP, Cooling speed, condenser temperature drop & evaporator temperature gains are calculated. The results showed that there is improvement in COP (4.7-11%) and also in cooling speed (8.4~18.6%) with increase of nanoparticles concentration. This is due to better thermo physical properties of the nano refrigerants. The experiments also showed that nanorefrigerant work normally in vapour compression systems. Thus, CuO nano particles can be used in refrigeration systems for efficient working.

Keywords: Copper oxide nanoparticles, nano-refrigerant, thermal conductivity, cooling speed, COP, power consumption

CONTENTS

LIST OF FIGURES

List of Tables

CHAPTER 1

INTRODUCTION

1.1 Nanofluids:

It is quite evident now that industrialization is on its peak & demand for the power is increasing with very fast pace. This industrialization has brought us on very delicate juncture. As the power requirement is increasing, the supply is also increasing. Either we are fulfilling our demands by producing power from fossil fuels or some other resources. Due to enormous use of fossil fuels, the pollution level is increasing & we are facing global warming, extreme erratic variations in the weather. This situation is enforcing the world to make new methods for the power generation, which should be eco friendly & the new systems should be more compact & efficient. The nano refrigerant exhibits more desirable properties, which makes it suitable for refrigeration purpose. Nano particles are the particles of the either metals or metal oxides, metal ceramics of nano scale sizes. Recently, technology has made it possible to make the particles of nano size. The conventional particles are broken to the scale of nano size, which shows a complete different behavior compared to their original mother particles. The refrigerators & air conditioners use the refrigerant, which affects the environment to certain degree. But the nano refrigerant gives an alternate, which is more efficient & nature compatible. When the metals nano sized particles are added to refrigerant, we get nano refrigerant. The nano refrigerants show a reasonable enhancement in the certain properties, such as thermal conductivity & it improves the performance of the system. To get different nano refrigerants, the amount of nano particles is changed. Even a minor change in the amount of particles changes the performance significantly. The nano fluids have better properties compared to solid liquid suspension such as better heat transfer due to better surface area & have better diffusion stability. They also consume less power due to better HT characteristics. Nano particles are mixed in various sizes varying from 1nm~100nm to the base fluids to form the nano fluid. These nano fluids exhibit properties with very good thermal characteristics. The nano science is of great importance to study the science of nano particles.

1.2 Properties of Nano fluids

Nano fluids behave differently than their original mother particle. There properties vary with various parameters. These parameters are nano particles size, particles shape, surface to volume concentration, particles material etc. These particles are of the size 10^{-9}m.These particles are quite stable, but its stability depends on the above parameters. The nano particles differ from the micro particles. Micro particles have size of 10^{-6}m.These particles has main problem of settling in the base fluid. Also there is a great problem of clogging in the pipes. This makes them unsuitable for the applications which use small diameter pipes. Most of the refrigeration applications use the expansion pipe, which have small diameter. So the micrometer particles can't be used in such applications. These micro particles don't stabilize properly in the base fluid. They have lesser surface to volume ratio, so the heat transfer is also not very good. All these problems of stability, heat transfer & clogging can be solved by the use of the nano particles. The nano particles can stabilize easily so the possibility of clogging can be reduced significantly. They have very good surface to volume ratio, when compared with micro particles, so it makes them desirable for the heat exchange applications. This is due to better heat conductance properties. The nano fluids can reduce the energy consumption significantly. The factors which affect the nano particles behavior are nano particles shape, material, concentration, pH value & temperature. To understand better, in the following table 1.1 the particles are compared on the basis of their particle size.

	Micro particles (10^{-6}m)	**Nano particles(10^{-9}m)**
Stability	Settles down in the base fluid	Most of the time, remains in suspended mode.
Surface/volume ratio	Very less	Higher compared to micro particles
Thermal conductivity	Less	More
Clogging	Get clogged	Less chances of clogging
Energy consumption	High	Less

Table 1.1 Comparison of Micro particles & Nano particles.

The table 1.1 shows that stability, surface/volume ratio, thermal conductivity is better for nano particles compared to micro particles. Due to very small sizes, nano particles keep in suspension mode so they shows better stability compared to micro particles which settles down due to its large size. Due to this they have better surface to volume ratio, which makes lesser prone to clogging or chocking. The nano particles have good thermal conductivity, which makes them conducive for the heat transfer applications. The nano particles have better contact with its base fluid. As these particles have good thermal conductivity so they make nano fluid a better conductive material. All these properties lead them a preferable fluid for various applications.

1.2.1 Nano fluids thermal conductivity

Thermal conductivity is the main property which is very important for the nano particles. Various studies & researches have been done to find the thermal conductivity. A main selection criterion for the nano fluid is its thermal conductivity. The nano fluids have better thermal conductivity than the base fluid. The nano particles size & shape also play an important role in the thermal conductivity. If the surface area is more, the better could be its thermal conductivity.

1.2.2 Material of the particle

Another important parameter which is also very critical to decide the nanofluid is the material of nano particles. It is because the thermal conductivity is directly related to material of the nano particle. As the CuO has better thermal conductivity than Al_2O_3. So the CuO nano particles have good thermal conductivity than Al_2O_3.As the CNT has good thermal conductivity so they have better thermal conductivity when it is compared to the base fluid.

1.2.3 Particle size

The particles size of nano particles also affects its properties. The main properties which change with the size are thermal conductivity & viscosity. It is because of the decrement in size, its surface to volume ratio increases, which makes a better contact between the nano particles & base fluid & which leads to increase in the thermal conductivity. If the size is more then it increases the viscosity.

1.2.4 Particle shape

Another parameter which affects the properties of nano fluids is their shape. Mostly the nano particles are both spherical and cylindrical shapes. The cylindrical particles have higher thermal conductivity than others because of high aspect ratio. It has been found experimentally. It is because the heat flow occurs along the wall of the particles in cylindrical nano particles, but requires higher power.

1.2.5 Base fluid

The base fluid is very important parameter, which affects the thermo physical properties of the nano refrigerant. According to theory, thermal conductivity of the base fluid is less more is the thermal conductivity ratio with nano particles. The desirable properties of the base fluids should be like that they have capacity to carry the nano particles without clogging.

1.3 Nanoparticles materials

Nano particles are prepared from different materials..They can be prepared in different sizes varying from 0~500nm.These materials have different properties & they vary from the conventional bulk solids significantly. The different materials nano particles have varying properties .Few of the materials which are used to make the nano particles are as follows:

- Metal – Al, Cu
- Metal Oxide – Al_2O_3, CuO
- Metal carbide – SiC
- Nitrides – AlN, SiN
- Nonmetals – Graphite, carbon nanotubes

1.4 Base fluids

Base fluids are the fluids in which nano particles are mixed .The combination of nano particles & base fluid makes a nano fluid. Some of the base fluids such as ethylene glycol, which has less thermal conductivity than other fluids, show higher conductivity with nano particles addition. It is true for certain fluids & doesn't hold the same for many fluids.The base fluids which is commonly used are as follows:

- Water

- Ethylene glycol
- Refrigerant
- Lubricating oils
- Bio gradable fluids

1.5 Vapor compression refrigeration system based on nano refrigerants

1.5.1 Nanorefrigerant

Recent research shows that there is lot of testing is on in refrigeration system with nano refrigerants. This is due to the enhanced thermo physical properties of the nano refrigerants. The concept of dispersing particles in fluids was brought by Maxwell to enhance the properties of the refrigerants. He used either millimeter particles or micro sized particles, which used to clog down or settle down. Introduction to nano particles brought new kind of materials in which all the convention liquid solid suspensions problems were removed. Nano particles showed improved thermo physical properties & it also removed the wearing problems. Lot of work has been published on the nano refrigerants in various applications. Bi et al. (2007) performed the experiment with R-134a refrigerant & TiO_2 nano particles in the lubricating oil. They found that there is great enhancement in energy savings & freezing capacity. This was due to better thermal conductivity of the nano refrigerant, which has improved power consumption. R. Reji Kumar et al. performed with various refrigerants like R12, R22, R600a & 134a mixed with Al_2O_3 nano particles, based on Indian standard testing conditions. There was a remarkable improvement in the parameters such as power consumption, freezing capacity & reduction in the energy consumption. This was again due to better & enhanced thermo physical properties of the nano refrigerants.COP increased by 19.6% & power consumption reduced by 11.5%. Jwo et al. (2009) experimented with hydrocarbon refrigerant & Al_2O_3 nano particles based mineral lubricant oil. The addition of Al_2O_3 Nanoparticle with lubricating oil was for the enhancement in heat transfer & better lubrication in the system. There was reduction in power consumption by 2.4% & Improvement in COP by 4.4%. Dongsoo Jung et al. (2009) experimentally performed with refrigerant R430A in refrigeration system of domestic water purifiers to replace R134a. He concluded that due to the small internal volume of the refrigeration system in water purifiers, the system performance was greatly influenced by the amount of charge. Test results showed that power consumption is increased by approximately 13.4% with charging quantity of 21–22 g, when compared with R134a.The pull down temperatures obtained with R430A were also almost comparable with the R134a .Test results obtained during the simulation showed that the coefficient of performance (COP) of R430A would be 19.1% higher than that of HFC134a. The compressor discharge and condenser temperatures of R430A were similar to those of HFC134a.

1.5.2 Vapour compression refrigeration system

In the present scenario, the need of better & efficient refrigeration systems are required. Due to rapid growth, the requirement of power is at the peak. Also with the global warming & extreme weather condition, the requirement of controlling the environment is very necessary. This purpose can be solved with vapour compression system. This is the basic cycle of refrigeration systems. In the vapour compression, there are four basic parts like compressor, evaporator, condenser & expansion valve. The refrigerant flows in the system producing refrigeration effect in the evaporator & this extra heat is dissipated through condenser. To meet the energy requirement, we need more effective systems. Nano technology is finding a way out to make the more efficient systems. In India, most of the domestic refrigerators are using R134a refrigerant. Some of the manufacturers are also using R600a refrigerant. So nano particles can be used to enhance the working fluid properties and energy efficiency of these refrigerating systems. Lot of research has been done in this field. Sheng et al. (2008) examined the performance of the fridge using R134a and POE oil with two types of nano particles of TiO_2 and Al_2O_3 & done the comparative study with R134a, without nano particles & found significant improvement in various parameters.

CHAPTER 2

LITERATURE SURVEY

Mao-Gang He et al. (2005) performed the test with a mixture of refrigerants of (HFC152a/ HFC125) in the domestic refrigerator to replace refrigerant CFC12. The refrigerant (HFC152a/ HFC125) which was mixed in different proportions has optimum value with 85/15 wt%. The refrigerant has eco friendly characteristics. They found that mixture of hydrocarbons is having comparable performance on the domestic refrigerators. With 97 g of charging quantity, power consumption was obtained 1.156kW/h/day. The storage temperature was found with little difference, but could be corrected by system redesign.

Jung-In Yoon et al. (2005) experimentally performed on different hydrocarbon refrigerants (R-1270, R-290 and R-600a) & conventional refrigerant R-22 to find heat transfer coefficient & pressure gradient for the heat exchangers in two diameter pipes. The study was carried to improve the heat transfer properties. They found that with hydrocarbon refrigerants ,for the smaller pipe of internal diameter of 9.52mm improved heat transfer characteristics by 31% to conventional refrigerant R22.The heat transfer characteristics also improved with mass flow rate .The rate was observed higher in hydrocarbon than R-22 refrigerant. But the pressure drop observed was 50% higher for hydrocarbon than R22.

Jose M. Corberan et al. (2007) cited in study for the requirement of certain safety measures during the design, repairing & servicing with the use of flammable nature of hydrocarbon refrigerants. Author mentioned about the favorable characteristics of hydrocarbons. But, cautioned for the requirement of safety measures, when charging quantity is more. It was also concluded that hydrocarbon can be used for the small appliances such as domestic refrigerators, where charging quantity is less than 150g with certain safety amendments.

Bi et al. (2007) performed the experiment with R-134a refrigerant & TiO2 nano particles in the lubricating oil. During their comparison with R134a & POE oil, it was found that this system worked so efficiently that it saved maximum 21.2% of energy consumption. In Year 2008,Bi et al found that it has remarkable increment in freezing capacity. They cited that this performance enhancement is due to better thermo physical properties of nano particles & lubricating oil.

R. Reji Kumar et al. (2007) found the nano lubricating oil effect on the COP & freezing capacity of the system. The system tested on various refrigerants like R12, R22, R600a & 134a based on Indian standard testing conditions. It was found that with nano particles, the thermo physical properties of the system enhances, resulting the improvement in COP of the system. There was significant increase in the COP by 19.6%.The freezing capacity was found increased by the use of mineral oil with Al_2O_3 nano particles & reducing of power consumption by 11.5%.

Jwo et al.(2009) experimented with mixture of mineral lubricant oil & Al_2O_3 nano particles with hydrocarbon refrigerant. The addition of Al_2O_3 Nanoparticle with lubricating oil was for the enhancement in heat transfer & better lubrication in the system. They concluded that 0.1%Al_2O_3 had best performance with reduced power consumption by 2.4% & Increase in COP by 4.4%.

Dongsoo Jung et al. (2009) experimentally performed with refrigerant R430A in refrigeration system of domestic water purifiers to replace R134a. He concluded that due to the small internal volume of the refrigeration system in water purifiers, the system performance was greatly influenced by the amount of charge. Test results showed that power consumption is increased by approximately 13.4% with charging quantity of 21–22 g, when compared with R134a.The pull down temperatures obtained with R430A were also almost comparable with the R134a .Test results obtained during the simulation showed that the coefficient of performance (COP) of R430A would be 19.1% higher than that of HFC134a. The compressor discharge and condenser temperatures of R430A were similar to those of HFC134a.

Henderson et al. (2010) performed experiments with R134a refrigerant & nano fluid in horizontal tube. They analyzed for the flow heat transfer coefficient. They got excellent results

& achieved the heat transfer rise up to 100% with copper oxide Nanoparticle based R134a refrigerant & POE oil.

Peng et al. (2011) experimented on nucleate pool boiling heat transfer with R113 refrigerant .The lubricating oil used was VG68 with diamond nano particles. They discovered that nucleate pool boiling heat transfer coefficient was better for it than R113 & oil mixture. Also they experimented with Cu nano particles of different sizes, Aluminum & Alumina nano particles & Copper oxide nano particles. Two different nano refrigerants R113,R141b & n-pentane with varying of lubricating oil from 0~10% .with heat flux variation from 10~100kWm2. The results found were that during pool boiling, migration ratio of nano particles increases with decrement of nano particles size, density & dynamic viscosity. They also found that migration velocity increases with increment of liquid phase density.

Bi et al. (2011) performed & studied the experimental study of R600a refrigerant & TiO_2 on the vapour compression based refrigerator. They found that Nanorefrigerant based system works very efficiently & effectively. The system saved energy up to 9.6%. They also found that system freezing capacity is also enhanced significantly. So during their experiments, they found that R600a based nano refrigerants are workable & are very good.

Wang and Xie (2011) experimented with R134a Refrigerant & TiO_2 nano particles & they found that they works as a good additive & enhances the solubility of refrigerant & mineral oil. They found improvement in the performance by using nano particles. They concluded that this improvement is due to injecting more oil back to the compressor. They also found that the results have almost same trend when compared with the polyester & R134a based system. Here they studied various combinations & compared their performance. In the one they analyzed the performance of vapour compression based refrigerator with R600a & Al_2O_3 nano particles. Also they performed the tests of energy consumption test & freezing capacity test with R134a & CuO nano particles. They gave the basic data & found the results better than plane refrigerants.

Kyung Hee University et al.(2012) found the value of thermal conductivity of the Al_2O_3 nano particles based fluids like DI water & pure ethanol with the method of transient hot-wires.

There were some doubts in the repititions during the experiments & were approximately 1.95% for DI water & 1.34% for pure methanol. The experiments concluded that dispersion of nano particles increases the thermal conductivity of the nano fluid. The results showed that for the concentration of 0.1% of Al2O3 & 40% of methanol, the thermal conductivity increased by 6.3%.The other effects such as Tindal effect & visualization was studied to find the stability of nano particles.

M.S. Hatamipour et al. (2012) experimented with refrigerant R436 on the domestic refrigerator to replace refrigerant R 134a.He performed on 238 L refrigerator with single evaporator. It was found that charging quantity of 55 g of R436 is optimum quantity which was 48% reduction for the same system with R134a refrigerant. Results also showed that compressor on time is reduced by 13% & power consumption is reduced by 5.3%.

Mahbubul I.M. et al. (2013) done the analysis to study thermophysical properties and their consequence on COP of R141b refrigerant mixed with 5% volume of Al_2O_3 nanaoparticles at temperature of 283-308 K. it was found that thermal conductivity of the nano refrigerant increased with the increase of nanoparticle volume. The density and viscosity of nano refrigerant increased by 13.68% and by 11% with the temperature rise. So this improvement in thermal conductivity, density and viscosity results the increase of the COP.

Qusay R. Al-Amir et al. (2014) performed experiments on two residential air conditioners(1TR & 2TR) with R22 and alternatives R290, R407C, R410A.During analysis, various parameters such as COP, cooling capacity, power consumption, pressure ratio, power per ton of refrigeration were determined under varying temperature of outside. Outside temperature was raised from 35^0C to 55^0C with the increment of 5^0C in each test while internal temperature of air was set constant. Their results showed that R290 is the better refrigerant to replace R22 under high ambient air temperatures with best coefficient of performance. R407C has the best matching performance to R22, which is followed by R410A.

Giovanni A. Longo et al. (2015) done the comparative performance analysis of the low GWP refrigerants HFO1234yf, HFO1234ze (E) and HC600a inside a commercial roll-bond evaporator for household refrigerators & compared with regular refrigerant HFC134a .They used 16 thermocouples on the various points of evaporator & vaporization performances were evaluated at two evaporation temperatures, of 15^0C and 20^0C with different refrigerant mass flow rates. The results showed that refrigerant capacity is a linear function of the refrigerant mass flow rate ratio. The refrigerant heat transfer coefficient increases with the specific heat flux. Refrigerants HFO1234yf, HFO1234ze (E), and HC600a exhibit vaporization performance similar to HFC134a .But refrigerant HFO1234yf exhibits vaporization performance similar to HFC134a at similar mass flow rate, so it could be best replacement with refrigerant R134a with few required changes in the compressor.

Reference	**Refrigerant+ Nanoparticles**	**Size**	**%volume concentration**	**Parameters finding**
Alsaas M.A. et al. (1997)	LPG refrigerant (24.4% propane+ 56.4% butane +17.2% isobutene	-	-	Coefficient of performance of 3.4 achieved. Evaporator temp of -15^0C achieved
Tashtoush B et al(2001)	Mixture of propane/butane/R134a			COP decreases by 5.4%, but improves volumetric efficiency. Lubrication is also improved.
Park et al. 2007	R123,R134a+ CNT	20nm	1.00%	Coefficient of Heat transfer increased to the level of 36.6%.
Hao et al. 2009	R113 + CuO	40nm	0.15–1.5%	Maximum enhancement of heat transfer coefficient, 29.7%
Kedzierski et al. 2009	R134a + CuO	30nm	0.50%	Heat transfer coefficient risen by 50 % to by 275%
Jin et al. 2010	NH_3/H_2O+ Al_2O_3/CNT	–	0.06%/0.08 %	Increase of Heat transfer rate by 20%

Subramani et al. 2010	R134a + Al_2O_3	50nm	0.06%	Cooling speed increase by 28%, Energy consumption reduction by 28% ,COP enhancement up to 33% by nano lubricant
Mahbubul et al. 2011	R123 + TiO_2	-	0.05-1%	Sharp enhancement in pressure gradient with volume concentrations increase.
Hafez et al. 2011	R134a + CuO	15-70nm	0.1-1%	Heat Transfer Coefficient increases directly with the increase of heat flux up to 0.55% CuO up to size 25nm & then reduces with size.
Kumar et al. 2013	R600a + TiO_2	50nm	0.1-0.5g/L	Energy consumption decreases by 5.94% for rate 0.1 g/L and decreases by 9.6% for rate 0.5g/L

Table 2.1: Literature survey

CHAPTER 3

GAPS IN STUDY AND OBJECTIVES

Although very useful and tremendous work has been reported the field of nanofluids, but still more is needed to be discovered. There is a lot of work going on the various parameters of nanofluid's which are effecting their performance such as; the nanofluid thermal conductivity, particle volume fraction, particle material, base fluid, particle size, and particle shape etc. Also, a lot of work has been done in refrigeration systems with many refrigerants such as R12, R22, R600, R600a and 134a. But, with global warming, the need of the hour is having a refrigerant, which should have low ODP & GWP. In this field, very minimal work has been reported with nanoparticles. Also the work, which has been already done is not standardized enough & carry a very limited significance in domestic refrigerators. Vapour refrigeration cycle can be studied with a nanorefrigerant which should be eco friendly and parameters like COP, power consumption, temperature drop etc can be taken to investigate the performance of the system

Objectives: To study the performance of a nano-refrigerant (Hydrocarbon+ CuO) based vapour compression refrigeration system. Following are the parameters, which are set as study objectives for the experimentation:

1) COP
2) Power consumption
3) Evaporator cooling capacity
4) Temperatures at Condenser, Evaporator, Compressor inlet and outlet
5) Performance at varying flux to the evaporators
6) Performance under varying concentration of nanoparticles

CHAPTER 4

EXPERIMENTAL SET UP

4.1 Details of experimental set up: This chapter gives the information of the experimental set up, which has been prepared in refrigeration & Air conditioning laboratory of Thapar University, Patiala. This system works on the vapour compression cycle. Earlier, this system was not working. It has been not in use. But after modification, this set up is used for the performance checking of the vapour compression based refrigeration system. In this chapter, we have also discussed about the use of nano particles & its induction in the system. Figure 4.1 shows the experimental set up in the laboratory.

Fig: 4.1

In this system, refrigerant used is pure hydrocarbon & copper oxide nano particles are mixed with it for the performance checking.

4.2 List of Components

S. No.	Component	Qty.	Specification	Purpose
1	Reciprocating Compressor	1	410 Btu/hr.	For the compression of refrigerant
2	Condenser	1	Open ,Wire type	Working as Heat exchanger
3	Expansion Device	1	Manual, flow control valve	To maintain low pressure
4	Evaporator	1	Tube type	To take the heat load
5	Filter	1	Sieve type	For obstruction of impurity
6	Heater	1	230W	For proving heating load
7	Refrigerant	57 gm.	99.9% pure R134a	Medium used for taking out heat
8	Pressure Gauge	4	low & high pressure	For taking pressure at various points
9	Ampere Meter	1	0-15Amp.	To Check supply current
10	Volt Meter	1	0-300 Volt	To Check supply voltage
11	Energy meter	2	KWH	To measure power consumption
12	Temperature Gauge	5	(-10 ^{0}C – 110 ^{0}C) Hg type	For measuring temperature at various points
13	Hand Shut Valve	4	For ¼ inch pipe	For charging or vacuuming the system
14	Charging Line	5		For charging the system.
15	Vacuum Pump	1	2 bar	To make vacuum before charging in the system
16	Rota meter	1		To measure the mass flow of the refrigerant.

Table 4.1: Components of Experimental Setup

4.2.1 Refrigeration Compressor

It is the main part of the refrigeration system. The importance of the compressor to the system is same like the heart to human body. The primary function of the compressor is to raise the pressure & temperature of refrigerant, which carries the heat load from evaporator & supplies it into the suction side of the compressor. Compressors are distinguished by their method of pumping. They are of different types such as reciprocating compressor, rotary compressor, screw compressor, centrifugal compressor & scroll compressor. In the present set up, a reciprocating compressor has been used. It is RSCR type. The manufacturer of the compressor is Godrej Boyce.

Fig 4.2: Reciprocating Compressor

Compressor Specifications	
Manufacturer	Godrej & Boyce Mfg. Co. Ltd.
Model	Power cool
Dimensions (m*m*m)	0.201*0.164*0.175
Capacity (Btu/hr)	410
Motor Input (W)	107
EER(Btu/W hr)	3.83.
Displacement (CC)	4.6
Voltage Range (V)	150-260
Type	OLP protected & Capacitor type
Net Weight (Kg)	7.8

Table 4.2 Compressor Specifications

4.2.2 Condenser

The condenser is another vital part of the vapour compression based refrigeration systems. In the condenser part, the high temperature & pressurized refrigerant rejects the heat by changing the phase of refrigerant. The three main types of condensers depending upon the cooling medium are as follows:

1) Air cooled condenser 2) Water cooled condenser 3) Evaporative condenser

Generally, in the industry, tube type steel condensers are used due to good heat transfer characteristics & optimized cost. In the experimental set, we have used air cooled, tube type condenser. In recent times, these types of condenser are used only in low income segments. In the bigger capacity (i.e) 230lts above in the refrigerator, the condensers are covered under the cabinet with the help of conductive Aluminum tape. The following characteristics makes any condenser desirable to buyer are:

Good heat transfer characteristics.

Easy to manufacture & less cost.

The heat transfer can be changed or affected by the following parameters:

(1) Temperature difference (Refrigerant and the Cooling medium).More the difference is desirable for better heat conduction.

(2) The flow rate of the cooling medium & flow rate of the flowing refrigerant.

Another type of classification of condensers based on their making is as follows:

(1) Fin type static condenser

(2) Fin type forced convection condenser

(3)Wire type static condenser

(4)Plate type static condenser

Fig 4.3 Finned static condenser

Condenser Specifications	
Type	Tube type (Static)
Diameter of pipe(m)	0.00635
Length of pipe(m)	13.8
Material of pipe	Copper

Table 4.3: Condenser Specifications

4.2.3 Expansion Device

An expansion device is another key component of the vapour compression system. It is fixed between the condenser outlet & evaporator inlet. The main function of any expansion device is to drop the pressure of refrigerant & due to that temperature also drops accordingly. Another main function is to send the refrigerant in liquid form in the evaporator. It is desirable as phase change should occur by taking heat in the evaporator, hence maximizing the heat carrying capacity of the evaporator. In the present experimental set up, we have used an expansion valve instead of capillary tube. In India's refrigerators, capillary tube is being used for expansion purpose. We are checking the performance of vapour compression system with nano refrigerant. To avoid any chance of chocking in the system due to presence of nano particles, capillary tube is replaced by manual expansion device. In the experiment, this device was controlled manually for the flow of refrigerant & kept on same position during the steady state.

Expansion devices are of different types. The main types are as follows:

(1) Capillary tube

(2) Automatic expansion valve

(3)Thermostatic expansion valve

(4)Manual expansion valve

Fig 4.4: Hand Operated Expansion Valve

4.2.4 Evaporator

This is another important component of vapour compression system. It is fixed in the system between the expansion valve outlet & inlet of compressor. The main function of the evaporator is to the heat load from the system. In this, liquid refrigerant which is at low pressure, takes heat from the external things & refrigerant converts in to vapour phase. Thus taking the heat of vaporization from the external matter & cooling that part of the system. In the experimental set up, the heating load is given to the water by heater. This heater is put in water container, where evaporator coil & heating coil are immersed. The container is properly insulated from all sides. This container contained 10.5 liters of water, which is being stirred with the help of agitator. The requirement of agitator is to uniformly heat up the water.

Evaporator Specifications	
Type	Coil Type (Emerged in water)
Diameter of pipe (m)	0.00635
Length of pipe (m)	7.65
Material of pipe	Copper

Table 4.4: Evaporator Specifications

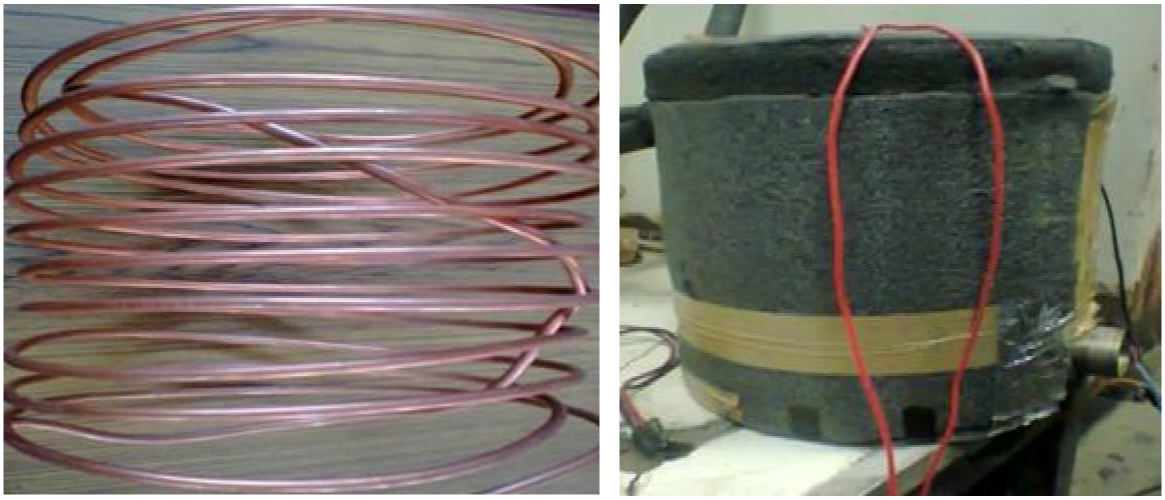

Fig 4.5: Coil Evaporator

4.2.5 Filter

The filter is used to remove the impurities, such as dust or other fine particles from the system. Filter is fixed between the condenser outlet & expansion inlet. Generally filters has 2~3 types of sieves & fine round particles of silica gel. The sieve is used to block the impurities & silica gel is to absorb the moisture of the system. Both particles & moisture can affect the performance of the system & may chock or damage the system. The size of mesh varies from (5-5000) micrometers. This mesh cannot block the nano particles. In the experimental set up, we have used the filter without silica gel, as the nano particles may stick to these particles.

Fig 4.6: Filter

4.2.6 Heater

It is the part of evaporator. Heater is having one heating element, which has very high resistance. When the electricity is passed through this element, due to high resistance, the current is being converted into heat. In the experimental set up, heater is used in the evaporator to provide heating flux to water. This heating flux defines the load of the system. This heating load is being taken by evaporator. Hence in this way, we can supply constant heating flux to the refrigeration system for certain duration.

Heater Specifications	
Specifications	230V,50Hz A/C

Table 4.5 Heater Specifications

Fig 4.7: Heating Element

4.2.7 Refrigerant and Nanoparticles:

It is the heat carrying medium in the refrigeration system. Its properties are very crucial from the point of design, manufacturing & safety. In most of the domestic refrigerators in India, we are using R134a, R600a because of suitable properties. In experimental setup, Hydrocarbon refrigerant has been used. This refrigerant is a mixture of 50% propane and 50% butane. It thermodynamic properties are comparable to refrigerant R134a.It has certain advantage on R134a of having negligible GWP.

Refrigerant Specifications	
Name	Hydrocarbon Refrigerant
Weight	170gm
O.D.P.	Zero
Contents	50% Propane and 50% Butane

Table 4.6: Refrigerant Specifications

Fig 4.8: Hydrocarbon Refrigerant

Nano Particles Specification: CuO of size 40 nano meter

4.2.8 Pressure Gauge

Pressure gauge is used to measure the pressure of the Hydrocarbon Refrigerant at various points. The pressure gauge, which is used in the experiment, is Bourdon tube type. The working principle of the bourdon gauge is the expansion or contraction of bourdon tube, when pressure varies. As the tube tries to straighten or contraction, the signal is generated, which reflects on the indicator on the gauge. In the experiment, four pressure gauges have been used at compressor inlet, compressor outlet, and expansion valve inlet & expansion valve outlet.

Pressure Gauge Specifications	
High Pressure	0-300 Psi
Low Pressure	(-50)-150 Psi

Table 4.7: Pressure gauge Specifications

Fig 4.9: Pressure Gauge

4.2.9 Ammeter:

It is an device used to measure supply current in the circuit. In the experimental set up it is digital type & made by Prototyron.

Fig 4.10 Ammeter

Ammeter Specifications	
Range	0-15 A

Table 4.8 Ammeter Specifications

4.2.10 Voltmeter

It is a device, which is used the measure the voltage supply. The voltmeter in the present set up manufactured by ESS VEE Electricals & is of analog type

Voltage Specifications	
Range	0-500 V

Table 4.9: Voltmeter Specifications

Fig 4.11: Voltmeter

4.2.11 Energy-meter

It is a device used to measure the power consumption .Most of Indian houses, this type of energy meters are used to check the energy consumed for the electricity bills. In the present set up, we used two energy meters. First was for the measurement of compressor power consumption & second for the electric heater power consumption

Fig 4.12 Energy meter

Energy-meter Specifications	
Specs	220V,50Hz

Table 4.10 Energy-meter Specifications

4.2.12 Thermometers

Thermometers are used to measure the temperature at various points. They are of Hg type. In the present set up, five thermometers are used at evaporator inlet & outlet , at the condenser inlet & outlet and at the ambient temperature .

Fig 4.13 Thermometers

4.2.13 Manual Shut off Valve

It is the valve, which is being used to control the flow of refrigerant in the system. In the present set up; there are four manually controlled valves. One is used for the charging of the system, two are used for the flow through rotameter & one is being used as the expansion device .During experiment, these two were used only to check the mass flow rate. Then they were bypassed throughout the experiment.

Fig 4.14 Manual Shut off Valve

4.2.14 Charging Line

It is used for charging the refrigerant into the system. This charging line one end is attached to main refrigerant cylinder & other end is attached to charging port with the help of manual shut off valve.

Fig 4.15 Charging line

4.2.15 Vacuum Compressor

Vacuuming is an important process in vapour compression system. It is being done before the charging of refrigerant. This process is being done with the help of vacuum compressor.

Fig 4.16 Vacuum Compressor

4.2.16 Rota meter

It is a device which is used to measure the mass flow rate of the refrigerant in the system. It is made of glass tube, having a float (shaped weight) which is pushed up by the drag force of the flow and pulled down by gravitational force. In the experimental set, we have used the same Rota meter & its range is 2-40LPH.

Fig 4.17: Rotameter

CHAPTER 5

METHODOLOGY

The main purpose of this experimental set up was to check the actual performance analysis for the hydrocarbon refrigerant with Copper oxide nano particles. The whole set up was made on the basis of vapour compression cycle. The testing condition was 30+/- 2 ^{0}C.This condition is very close to Indian standards of the testing. The main parameters to be measured during the experiments were temperature & pressure at various points. These points were compressor inlet, compressor outlet, and expansion valve inlet, expansion valve outlet. All these parameters are required to measure the system performance such as COP, Energy consumption & cooling speed .In this experiment, four thermometers & four pressure gauges are fixed at above said points. Firstly, test was performed with pure hydrocarbon refrigerant & then same test was repeated with Hydrocarbon nano refrigerant with same conditions & procedures. This test is done with three different concentrations of nano particles.

5.1 Testing Procedure:

The test is being performed at the set up in RAC lab of Thapar University. This test rig has all basic components of vapor compression cycle with some additional components for the proper working of the system & some recording instruments for recording of the data. The additional key components required for the proper working are dryer, manual control valves, heater, agitator, & vacuum pump. The recording instruments are thermometers, pressure gauges, voltmeter, ammeter, energy meter, rotameter & weighing balance. There are three basic tests, which are performed to analyze the system behavior by finding out cooling speed test, COP of the system Power consumption of the system. These all tests are performed four times. Firstly it is checked for the pure hydrocarbon refrigerant & it is repeated for the three different concentrations of CuO nano particles with hydrocarbon refrigerant.

5.1.1Procedure for charging of the system:

Firstly, all components are joined together by different methods. After completion of this, charging is done in the system. To do charging, ensure that there is no air & moisture present in the system. To remove it, the vacuum pump is fixed with charging port of the compressor. After noting the negative pressure in whole system, close the manual valve & remove the vacuum pump from the system. After this charging of the refrigerant is being done. After measuring the weight of refrigerant cylinder on weighing balance, it is connected to charging port of compressor with the help of charging line. Initially, the supply is disconnected by the manual valve. After opening the manual valve, the refrigerant is passed into the running system. After getting the cooling effect, shut off the valve & disconnect the charging lines .Measure the weight of cylinder. The difference in the weight of the cylinder shows the refrigerant charged into the system.

5.1.2 Test procedure for cooling speed:

The basic purpose of the test is to get the desired refrigeration in quick time. This test is done at standard atmospheric conditions of 30^0C+/-2^0C.Connect the supply of the system to main power point. After this, the system will on & it will start functioning & will continue, till the system reaches its steady state. Once the system reaches steady state, the heater is started & keeps it on, till the temperature of the water in evaporator reaches 40^0C.Switch off the heater. Note the energy meter reading of compressor, heater, all thermometers & pressure gauges at respective points at 40^0C of evaporator. All these readings with time are noted for every degree of cooling till the temperature of evaporator reaches at 25^0C.

5.1.3 Test procedure for constant flux test:

This test's basic purpose is to check the COP of the system at various constant heat loads. This test is done at standard atmospheric conditions of 30^0C+/-2^0C.Connect the supply of the system to main power point. After this, the system will on & it will start functioning & will continue, till the system reaches its steady state. Once the system reaches steady state, set the heater load at the desired testing temperature.(e.g, in the present test set up, it is checked for two different heater load at 25^0C~26^0C & 35^0C~36^0C.) After that, for every 1 degree load & cooling of that load, continue noting the respective data for three hrs.

All these three tests are repeated four times. Firstly it is for pure hydrocarbon refrigerant, secondly it is with hydrocarbon refrigerant mixed with 0.2g of CuO nano particles, thirdly it is with hydrocarbon refrigerant mixed with 0.3g of CuO nano particles & lastly it is with hydrocarbon refrigerant mixed with 0.4g of CuO nano particles. For testing with nano refrigerant, nano particles has to be added in to the system with the existing system & small straw fixed between the manual charging port & charging line.

CHAPTER 6

RESULTS AND DISCUSSION

During the experimentation, pressure, temperature & time readings are taken to find the COP, power consumption & cooling speed. The experiments were performed on various concentrations of nano particles such as 0.2g CuO, 0.3g CuO & 0.4g CuO. The volume flow rate was kept 3.8 LPH and the readings were taken at different conditions. To find the cooling speed, the reading is noted after under steady state conditions which are generally obtained after 2 hours of running of the system. After that the heater is switched on on, till the temperature of the evaporator rises above 40^0C.Then the heater is switched off, & the time & other reading are recorded for every drop in 1 degree of temperature. This process is continued till the temperature of the evaporator falls up to 25 degree C. For the COP calculation & energy consumption, the test is done at different flux load. Firstly the temperature range is kept between $35{\sim}36^0$ C. During this test, the heating load is provided from 35^0C to 36^0C. Then it is automatically off & keeping the compressor on this time. All the parameters are recorded to keep the temperature at 35^0 C. Same test is repeated for the flux range of $25{\sim}26^0$ C. All the parameters are summarized in the table below.

Refrigerant	Evaporator Temperature load at (25-26 ^{0}C)									
	C.O.P.	P1 (kg/cm^2)	P2 (kg/cm^2)	P3 (kg/cm^2)	P4 (kg/cm^2)	T1 (^{0}C)	T2 (^{0}C)	T3 (^{0}C)	T4 (^{0}C)	T_{atm}
Pure Hydrocarbon	1.25	20.85	30.26	243.65	232.92	-1.24	26.82	83.5	58.5	30.8
Hydrocarbon + 0.2g CuO	1.33	20.16	26.79	239.09	228.70	-1.77	28.02	86.5	58.32	31.5
Hydrocarbon + 0.30g CuO	1.38	20.11	27.5	241.5	229.5	-1.82	28.5	87.8	58.5	31.6
Hydrocarbon +0.4gm CuO	1.41	20.05	28.3	242.1	231	-1.92	28.6	88.8	58.6	31.6

Table 6.1: Detailed Data with constant volume flow rate of 3.8 LPH at 25-26 ^{0}C

Refrigerant	Evaporator Temperature load at (35-36 ^{0}C)									
	C.O.P.	P1 (kg/cm^2)	P2 (kg/cm^2)	P3 (kg/cm^2)	P4 (kg/cm^2)	T1 (^{0}C)	T2 (^{0}C)	T3 (^{0}C)	T4 (^{0}C)	T_{atm}
Pure Hydrocarbon	1.34	21.34	29.27	245.42	234.77	-0.27	36.99	89.05	58.2	30.6
Hydrocarbon + 0.2g CuO	1.37	20.37	26.97	239.42	228.42	-0.46	40.65	92.5	58.8	31.6
Hydrocarbon + 0.3g CuO	1.4	20.69	27.8	242.3	230.8	-0.5	41.2	93.5	59.02	31.7
Hydrocarbon + 0.4g CuO	1.44	20.81	28.43	244.7	232.5	-0.6	41.6	96.2	59.2	31.8

Table 6.2 – Detailed Data with constant volume flow rate of 3.8 LPH at 35-36 ^{0}C

6.1 Temperature drop in Condenser:

The condenser is the main heat exchanger, which is used to dissipate the heat of high temperature & pressured refrigerant, which comes out from the compressor. The condenser consists of helix of pipes in which the elevated pressure and risen temperature vapour refrigerant is reduced and cooled at steady pressure. There are two thermometers & two pressure gauges are fixed at the inlet & outlet of condenser. This helped us to find the temperature drop & pressure drop occurred in the condenser. To find the temperature drop, it can be found by subtracting the temperature outlet from the temperature inlet. If the temperature drop along the condenser is more, then the condenser is very effective. We have used the condenser, which is air cooled. The refrigerant vapour is converted in to liquid at saturation pressure. In the experimental set up, the condenser temperature drop is measured for pure hydrocarbon refrigerant & for different concentrations of the nano particles at two heat fluxes .The different concentrations are 0.2g, 0.3g & 0.4g of CuO.

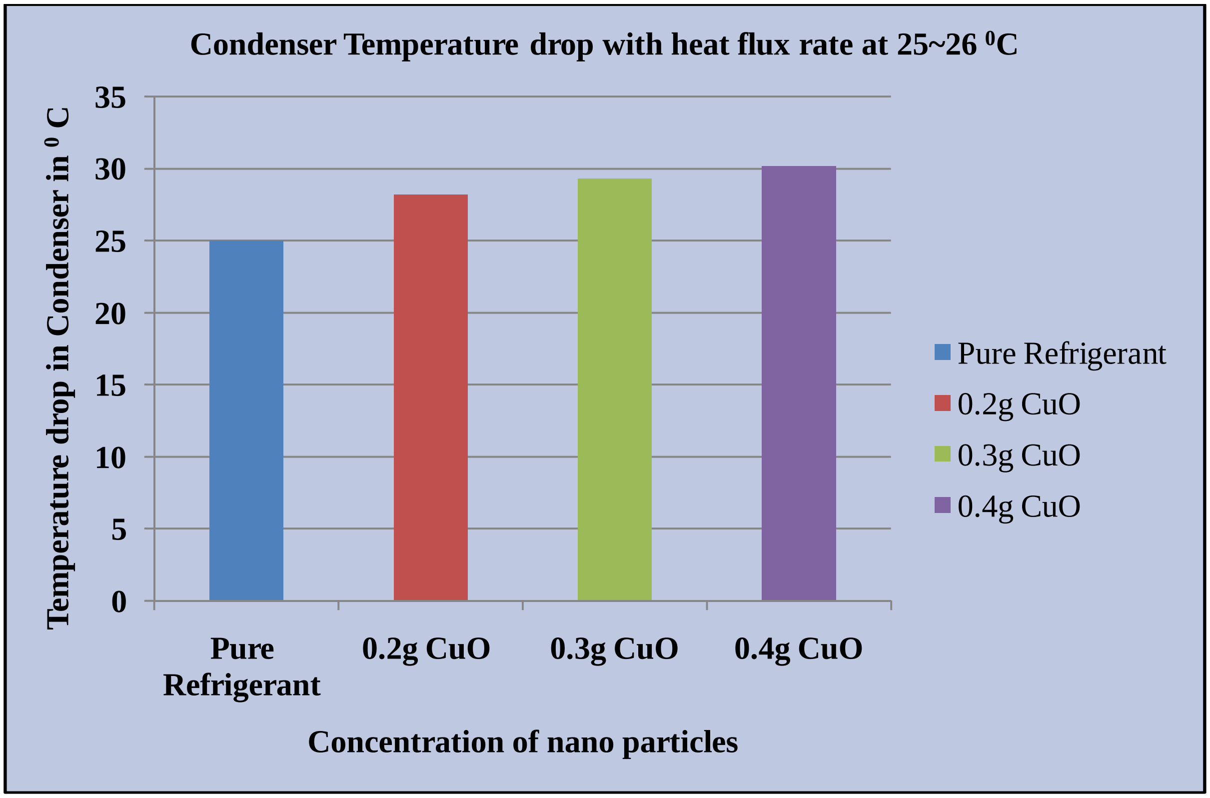

Fig. 6.1: Temperature drop in condenser for different concentrations

Above Fig.6.1 shows the condenser temperature drop for 3.8 LPH volume flow rate of nano refrigerant during the steady heat load of 25-26 ^{0}C and at surrounding temperature of 30^{0}C±2^{0}C. For pure hydrocarbon refrigerant, which is taken as reference for the comparison, the drop is 25 ^{0}C. With the nano particles concentration, this drop has been increased. The condenser temperature drop with the nano particles concentration is 28.1^{0}C for 02.g of CuO, 29.3^{0}C for 0.3g of CuO & 30.2^{0}C for the concentration of 0.4gCuO. So there is a significant enhancement in condenser temperature drop with addition of nano particles in the hydrocarbon refrigerant. So, there is a minimum 12.72% increase in condenser temperature drop for concentration of 0.2g of CuO & maximum increase 20.8% for concentration of 0.4g of CuO. This increase is important in such a way that it affects the overall performance of the system.

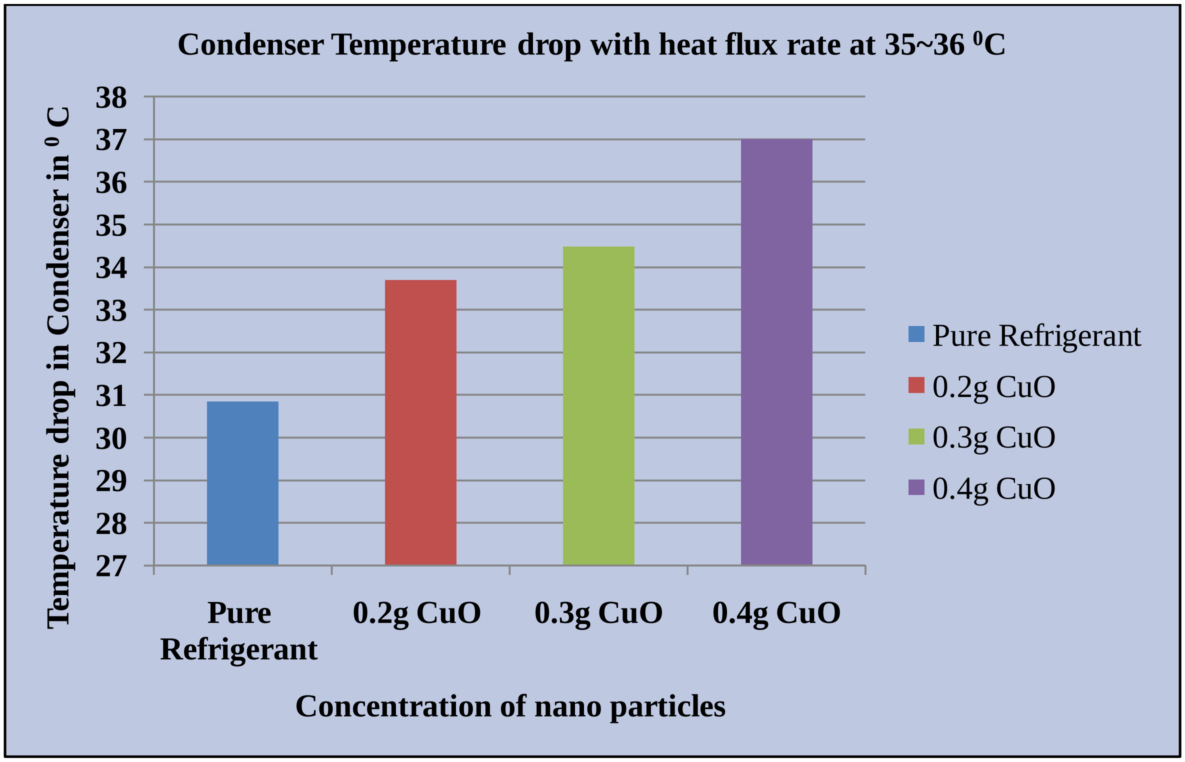

Fig. 6.2: Temperature drop in condenser for different concentrations

Above fig 6.2 is showing the condenser temperature drop in the condenser at steady heat load of 35~36^{0}C. The results showed the same inclination, which is observed in the 25~26^{0}C heat load. The testing condition was 30^{0}C ± 2^{0}C. Again in this test, the reference test was done with pure hydrocarbon refrigerant. Then the same test was repeated for checking the performance of the system with nano particles concentration of 0.2g of CuO, 0.3g of CuO & 0.4g of CuO in the hydrocarbon refrigerant. The temperature drop in condenser for pure hydrocarbon refrigerant is taken as reference. For pure hydrocarbon refrigerant temperature reduction in condenser temperature is 30.8^{0}C. With nano refrigerant, the condenser temperature drop is found increased by 9.2% with 0.2g CuO, 11.8% with concentration of 0.3g CuO & 19.9% with concentration of 0.4g CuO. So the data is showing a certain trend in condenser temperature drop. It means, the thermo physical properties of hydrocarbon based CuO nano refrigerant enhances. This is the reason in improvement of heat transfer characteristics of nano refrigerant used in the experiment.

6.2 Temperature gain in the evaporator

Evaporator is another heat exchanger, which is used between the expansion outlet & compressor inlet. This is the main part in refrigeration cycle, where cooling is obtained by absorbing the latent heat of vaporization. In the evaporator, the refrigerant enters at very low pressure in liquid form & absorbs the heat from the evaporator, results the vaporization of the refrigerant. This causes the cooling in that zone. This heat exchange occurs at constant temperature & pressure. In the experimental set up, the heat load is given by the heater to water. On the reverse of it, the refrigerant, which is at low temperature & low pressure, takes this heat from water. Hence the refrigerant carries the heat along with it. So the net cooling effect is observed in the evaporator area. We have tried to find the temperature gain by the evaporator. The temperature gain is the difference in temperature between evaporator outlet & evaporator inlet. If the difference is large then the carried will be large & the performance of the system would be better.

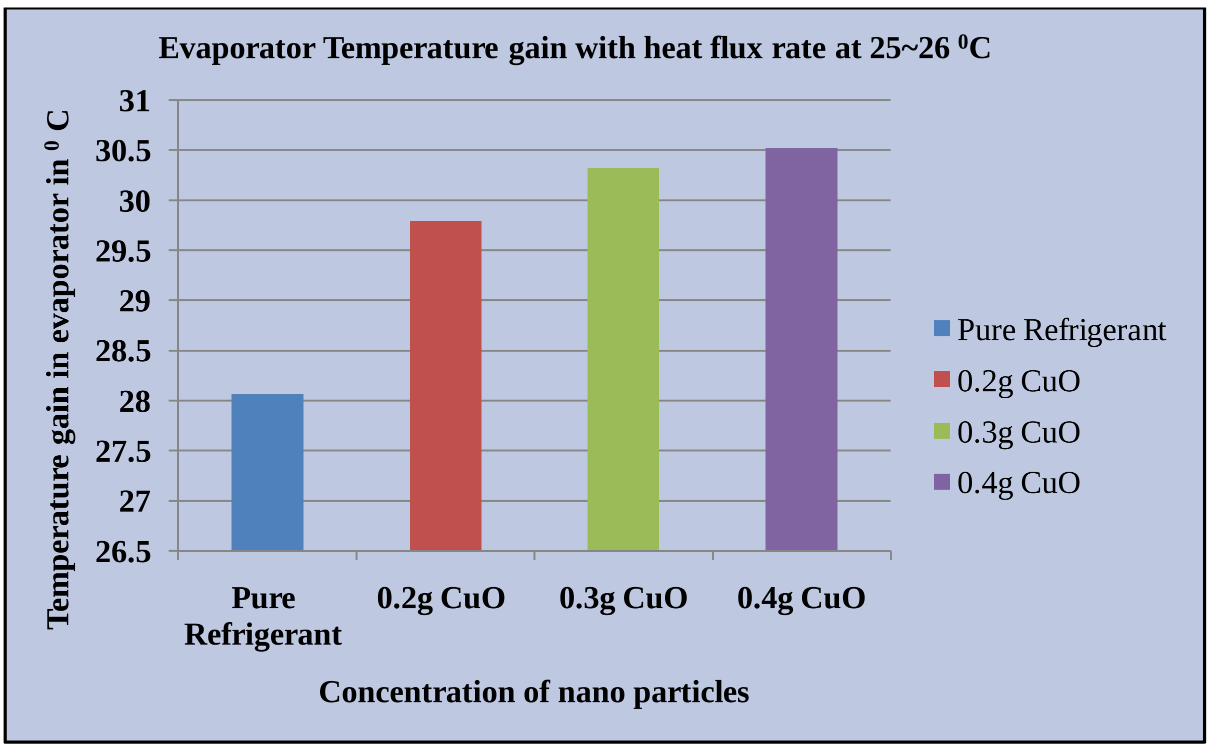

Fig 6.3: Temperature gain in evaporator for different concentrations

The above Fig.6.3 illustrates the evaporator temperature gain with constant flow rate of 3.8LPH at constant heat load at 25-26 ^{0}C .The ambient conditions may little vary & we consider it $30^0C \pm 2^0C$ of temperature. The higher will be the temperature gain in the evaporator, better will be the system performance. To analyze the same, vapour compression system on hydrocarbon refrigerant base is checked for evaporator gain at constant heat load .Then on the same conditions; this test is repeated for the nano hydrocarbon refrigerant with concentration of nano particles of 0.2g CuO, 0.3g CuO & 0.4g CuO. The reference is taken with pure hydrocarbon & the evaporator temperature gain for the pure hydrocarbon refrigerant is obtained as 28.1^0C.With nano particles based refrigerant, the results obtained were on the better side. There is a evaporator temperature gain from 6.1% to 8.7% with different nano particles concentrations when compared with pure hydrocarbon refrigerant

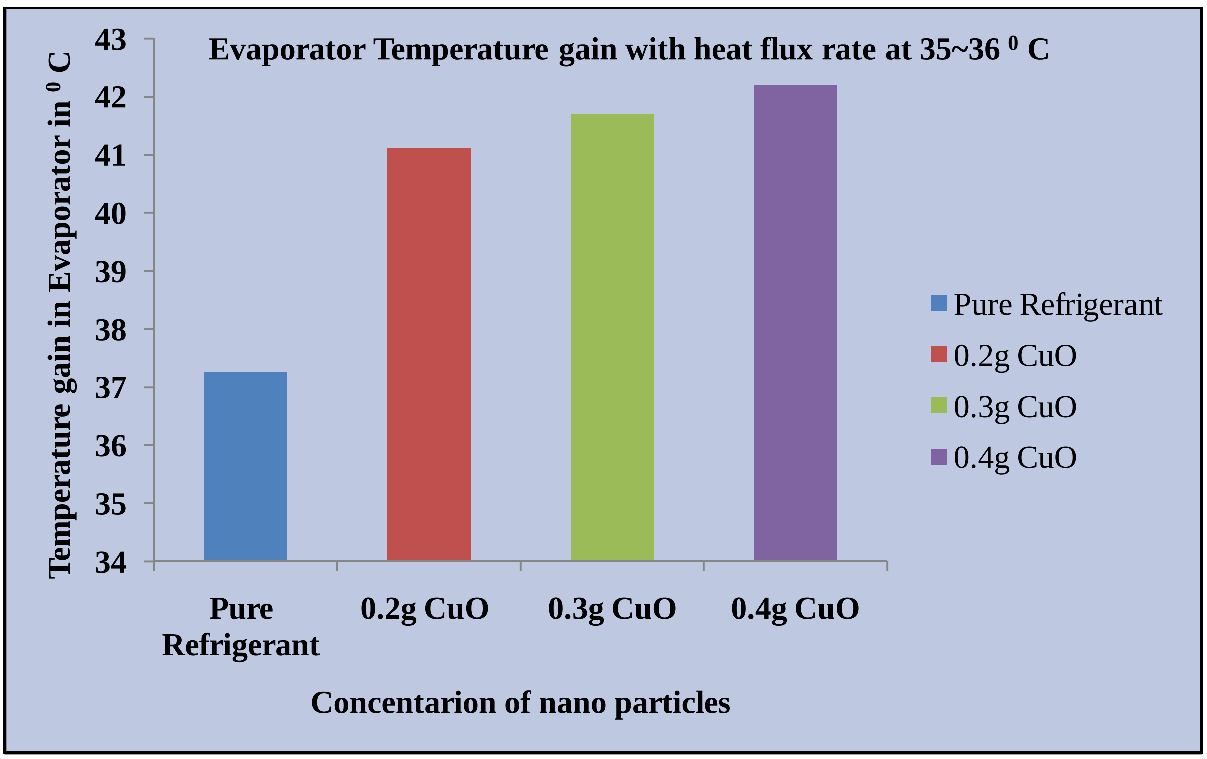

Fig 6.4: Temperature gain in evaporator for different concentrations

Above fig 6.4 is showing the evaporator temperature gain at constant mass flow rate & at constant heat load of $35\sim36^0C$.The conditions are kept same as the previous test except the heat load temperature. In this test, firstly the parameters are checked with pure hydrocarbon refrigerant & then it is being repeated with different concentrations of nano particles of CuO mixed with hydrocarbon refrigerant. The different concentrations are 0.2g CuO, 0.3g CuO, 0.4g CuO. It has been found in the experiments that there is a significant evaporator temperature gain with nano refrigerant. The gain is between 10.3%~13.2%, when it is compared with pure hydrocarbon refrigerant. This gain suggests the better refrigerant effect, which is desirable from the customer & manufacturer point of view. So all these results of temperature drop in condenser & temperature gain in evaporator is indicating performance enhancement with the use of nano refrigerants.

6.3 COP

It is the most important parameter which should be checked for refrigeration systems. Higher COP of the system is always desirable. It can be defined as the ratio of refrigeration effect to the power supplied to the system.COP depends on the ambient working conditions .In the experimental set up, refrigerant effect is obtained by the heating load. It is being measured by one of the energy meter. The power supply of the compressor is input supply & which is recorded by the second energy meter. In all of the experiments, the flow rate is kept constant at 3.8LPH. The COP is evaluated for different concentrations at steady heating load of 25~26^{0}C & 35~36^{0}C.

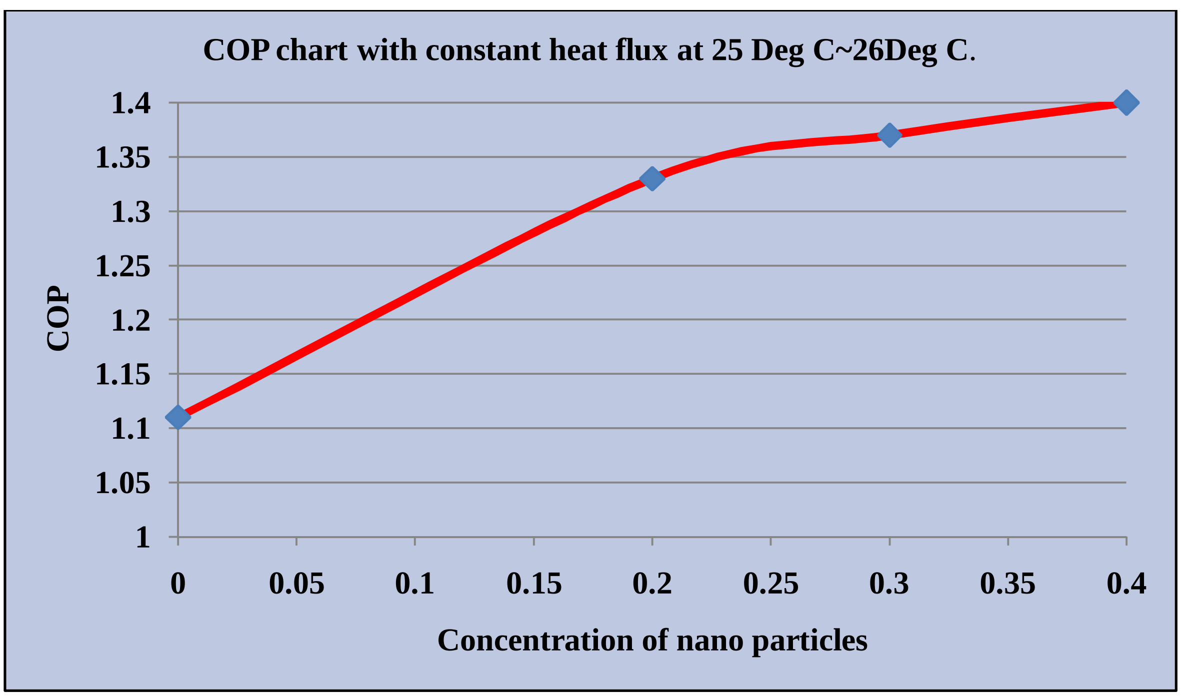

Fig 6.5: C.O.P. comparison for different concentrations

For the 25~26^{0}C heat load, the COP of the system is increased with the increase of CuO nano particle in the hydrocarbon refrigerant. The trend was increasing sharply for 0.2g of CuO. It continued to increase with subsequent concentrations of nano particles of CuO of 0.3g & 0.4g, but the rate is fallen. The detailed graph is shown in above fig 6.5. The COP found with pure refrigerant is 1.25, which is increased with the presence of Copper Oxide nano particles. The increase of the COP is in the range of 4.7%~11% when compared with pure hydrocarbon refrigerant. The highest COP is obtained for the concentration of 0.4g of CuO mixed in the hydrocarbon refrigerant.

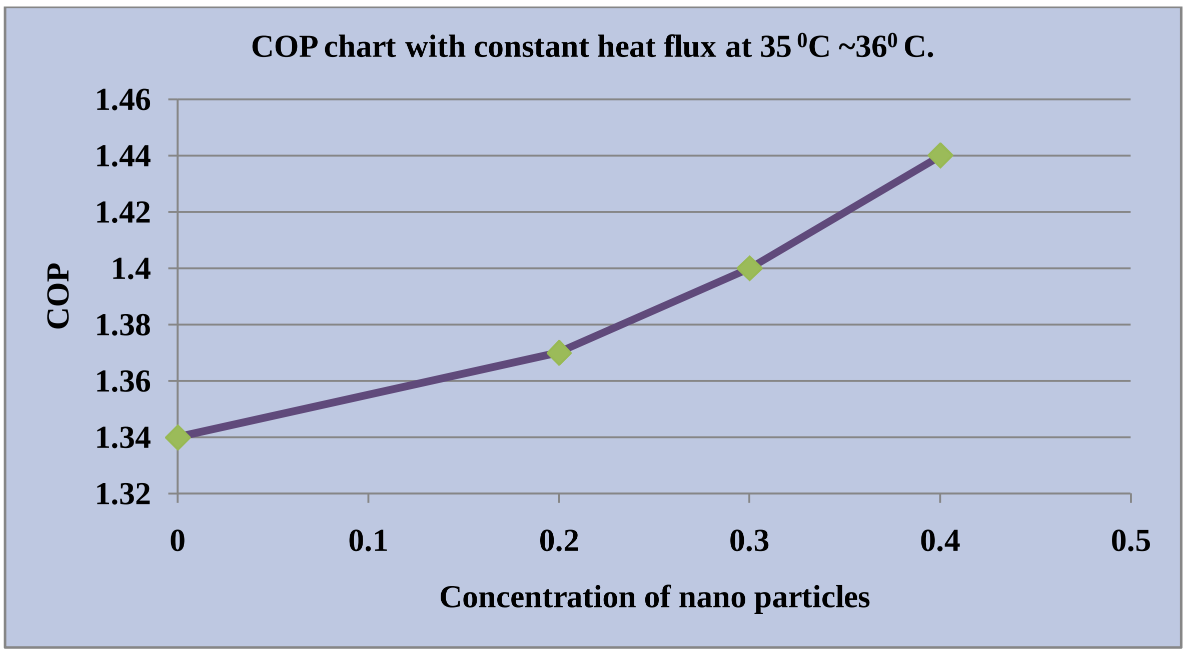

Fig 6.6: C.O.P. comparison for different concentrations

The same test is performed with constant volume flow rate to obtain the COP at heat load of 35~36^{0}C. In this test, the reference has been taken with pure hydrocarbon refrigerant. All the COP with different concentration of CuO nano particles are compared with reference .Form the experiments, almost same trend is observed of improvement of COP with concentration of nano particles. This is because of the better thermo physical properties of nano refrigerants. It is quite useful for the industry & customer point of view. The results show that there is rise in COP of the range of 2.2%~7.4% with addition of nano particles.

6.4 Cooling speed

It is defined as a rate of removal of heat with respect to time. As per the Indian standards for the domestic refrigerator, it is time taken to cool the freezer compartment from 32^0C to 5^0C & in the fresh food compartment, from 32^0C to 15^0C..It is a very significant parameter. If the rate is higher, the system would be rated as a better appliance. In the present experimental set up, the cooling speed is found between 40^0C to 25^0C temperature in the freezer compartment.

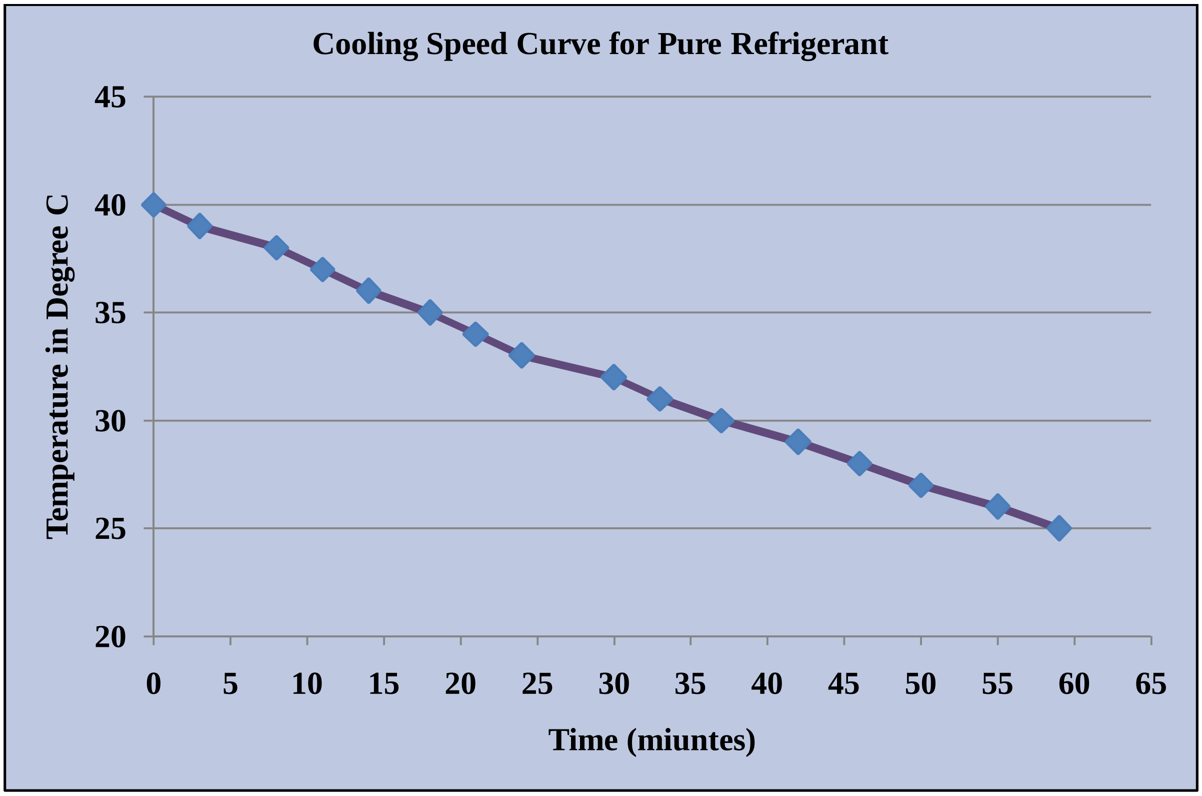

Fig 6.7: Temperature-Time graph for Pure Hydrocarbon

In the above Fig 6.7 is showing the cooling speed for pure hydrocarbon refrigerant. This is taken as reference for the comparison of cooling speed with different concentration of nano particles. The ambient temperature & mass flow is taken same as in the previous tests. It has been found that the cooling speed for pure refrigerant is 59 minutes for 15 degree of temperature drop from 40^0C to 15^0C.

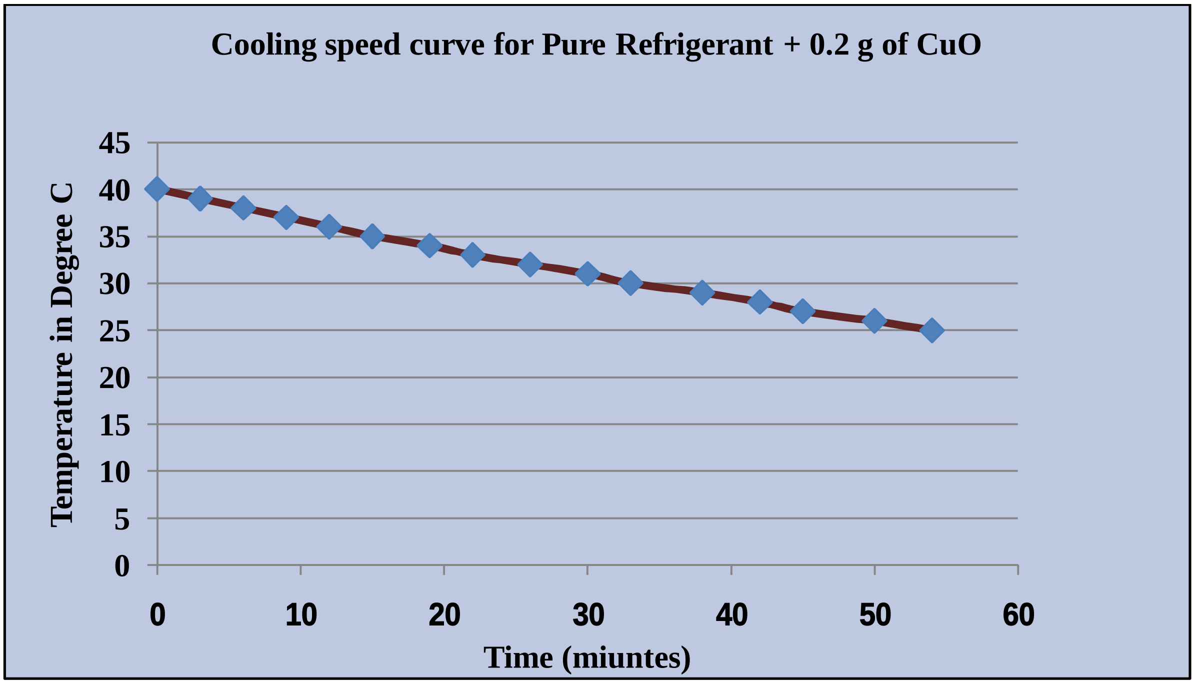

Fig 6.8: Temperature-Time graph for Hydrocarbon+0.20gm CuO

Above Fig is showing cooling speed curve for the hydrocarbon with 0.20gm CuO refrigerant at same flow rate & ambient conditions as in the reference test for the cooling speed. The cooling speed obtained in this case is 54 minutes. It means there is an improvement of 5 minutes with 0.2CuO nano particles in hydrocarbon based refrigerant.

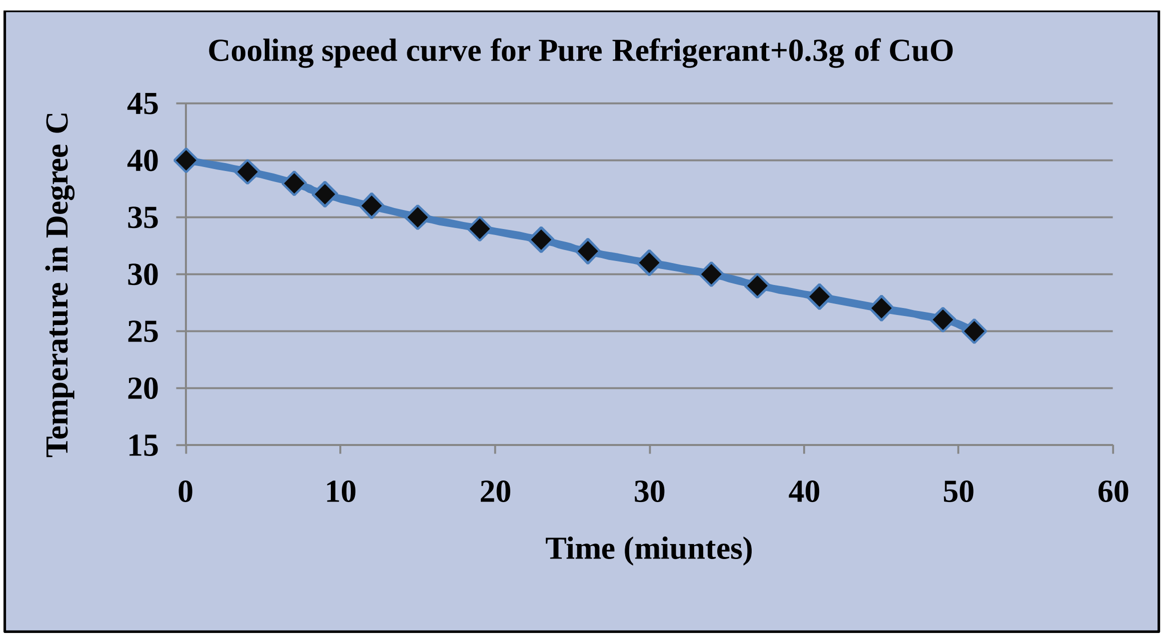

Fig 6.9: Temperature-Time graph for Hydrocarbon+0.30gm CuO

Above fig 6.9 is showing the cooling speed with 0.3g CuO mixed in hydrocarbon refrigerant. All the testing parameters were kept same except the concentration of nano particles. The cooling speed obtained in this case is 51 minutes. The net gain in the speed is by 9 minutes.

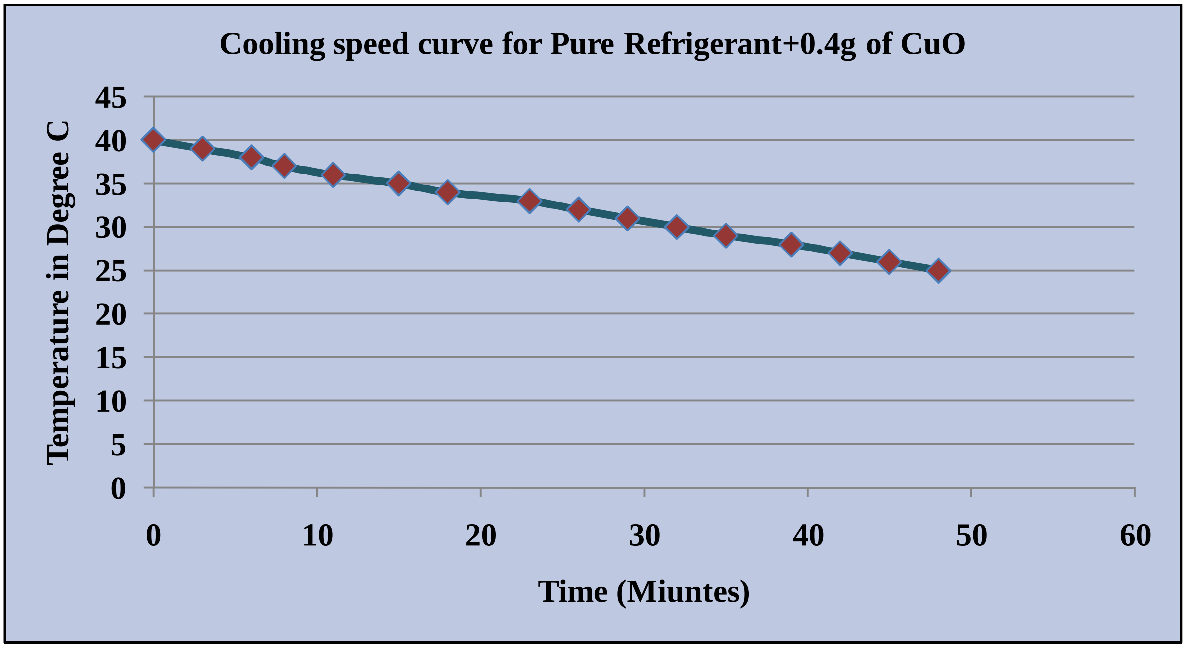

Fig 6.10: Temperature-Time graph for Hydrocarbon+0.40gm CuO

Above fig 6.10 is showing the cooling speed with 0.4g CuO mixed in hydrocarbon refrigerant. All the testing parameters were kept same except the concentration of nano particles. The cooling speed obtained in this case is 51 minutes. The net gain in the speed is by 11 minutes.

6.5 Cooling speed detailed Analysis

Following fig 6.11 is showing the detailed cooling speed curve for all the concentrations together to get the comparative study. It can be concluded form the graph that cooling speed is improved up to 18% by the addition of 0.4g of CuO nano particles in hydrocarbon based refrigerant.

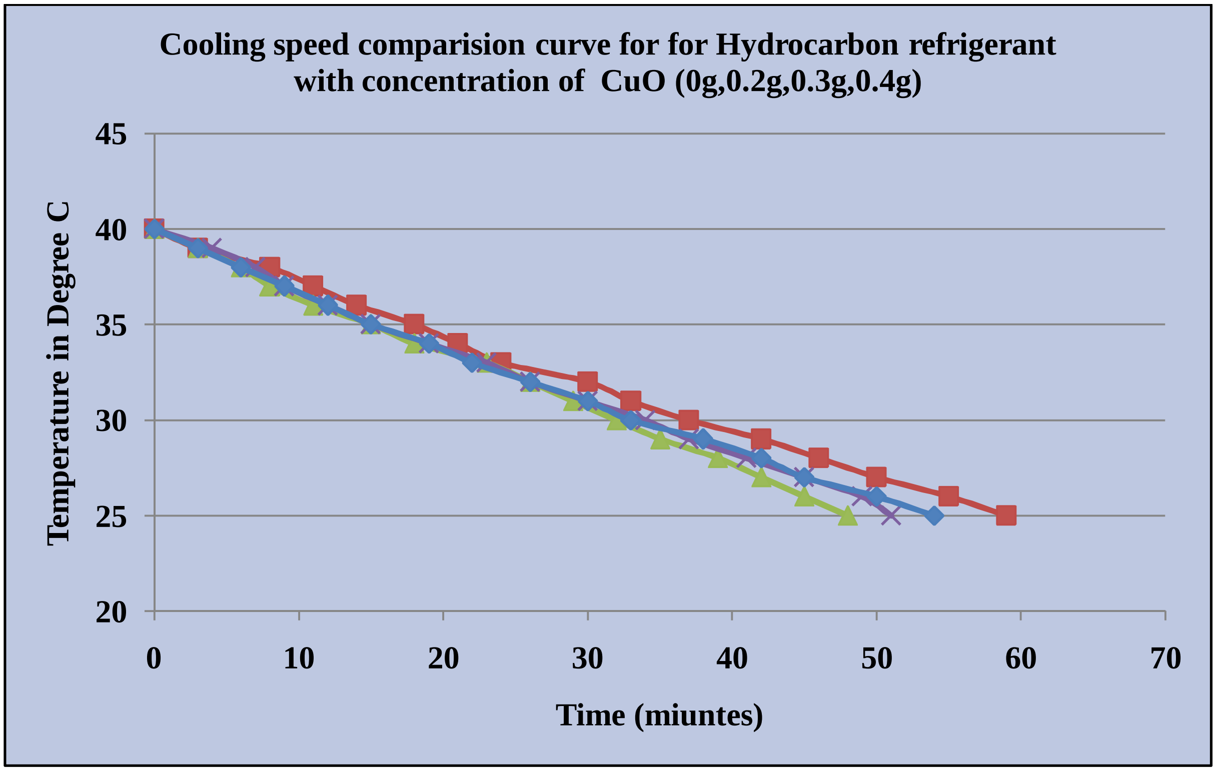

Fig 6.11: Detailed cooling curve for various nano particles concentrations.

6.6 Energy consumption:

This is another very important parameter, which is very crucial from the cost point of view. If the system is efficient, its energy consumption will be low & it can be rated as higher star rating. In the present set up, power consumption is measured for the compressor for cooling the evaporator from 40^0C to 25^0C. This test is repeated with all concentration of nano particles to get the comparative data of power consumption. Here the result shows that there is significant fall in power consumption as the concentration of the nano particles increases. Following fig 6.12 is showing the comparative graph of energy consumption with pure hydrocarbon refrigerant, Hydrocarbon with 0.2g of CuO, Hydrocarbon with 0.3g of CuO & Hydrocarbon with 0.4g of CuO.

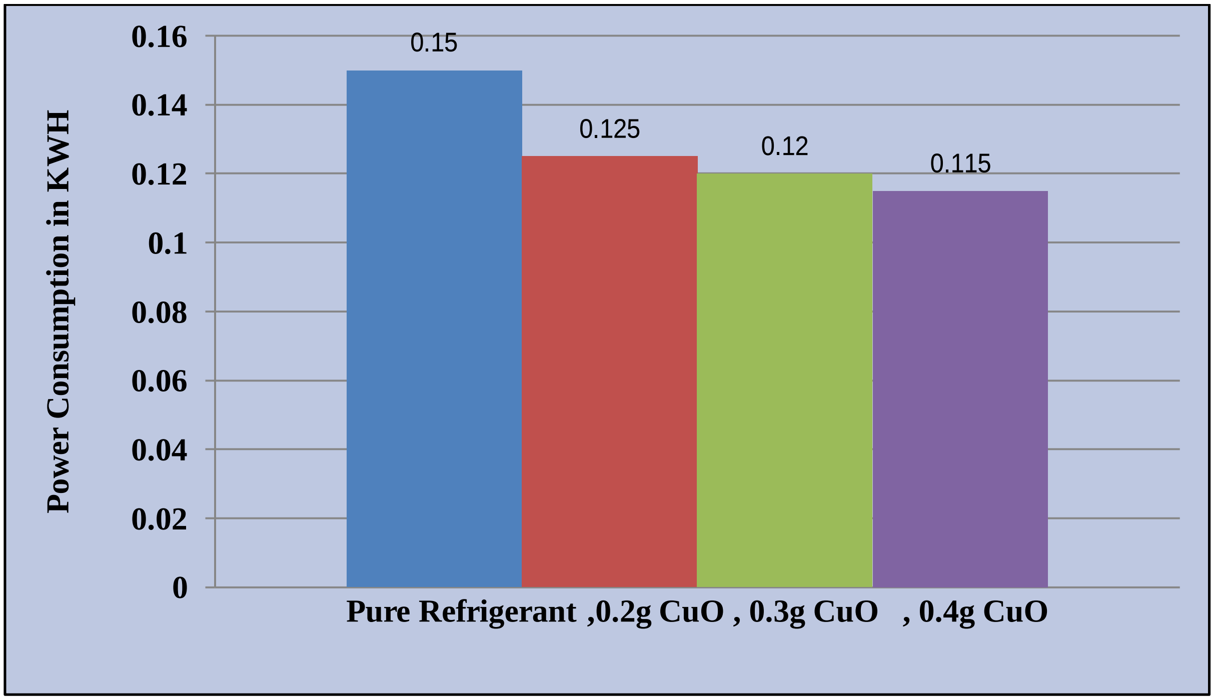

Fig 6.12: Power consumption by various concentrations of nano refrigerants

Fig 6.12 shows power consumption for 40^{0}C to 25^{0}C temperature drop at steady volume flow rate with ambient condition 30^{0}C$\pm$2^{0}C. Results showed that pure hydrocarbon consumed power 0.15 KWh power to drop in temperature from during the cooling from 40^{0}C to 25^{0}C, whereas hydrocarbon + 0.20gm CuO nano refrigerant consumed 0.125 KWh power, hydrocarbon + 0.30gm CuO nano refrigerant consumes 0.12 KWh power and hydrocarbon + 0.40gm CuO nano refrigerant consumes 0.115 KWh power. So there is significant power drop of 16.6% by hydrocarbon + 0.20gm CuO as compared to pure hydrocarbon refrigerant. Reduction in power consumption for hydrocarbon + 0.30gm CuO and hydrocarbon + 0.40gm CuO nano refrigerant is found to be 20% and 23.3%. Do it can be concluded that with increase in concentration of nano particles, the power consumption decreases.

CHAPTER-7

CONCLUSION AND FUTURE SCOPE

7.1 Conclusions

The present research work entitled "Nano refrigerants Based Vapour Compression System" was aimed at, to use Copper Oxide nano particles in combination with Hydrocarbon refrigerant. The CuO nanoparticles of 40 nanometer size have been used. Various concentrations of nano particles were mixed with hydrocarbon refrigerant to explore the performance of a vapour compression system.

(i) The system was charged with nano refrigerant Hydrocarbon + CuO, 0.20 g mass, 0.30 g mass and 0.40 g mass of nano particles.

(ii) All readings were observed at constant volume flow rate of 3.8LPH for cooling speed of the system & energy consumption of the system at ambient condition (30^0C± 2^0C).

(iii)For COP calculation, readings are noted for two heat loads in evaporator at temperature 25–26 ^{0}C and 35–36 ^{0}C.

(iv) Temperature drop in condenser, temperature gain in evaporator, COP for the system and cooling speed graph were studied for pure hydrocarbon refrigerant and nano refrigerant at all concentrations.

(v) The experimental results showed that thermo physical properties & HT characteristics enhances with adding of CuO nano particles to the hydrocarbon refrigerant.

(vi) It was observed that there is more temperature drop across the condenser for the nano refrigerant (12.7% – 20.8%) compared to pure hydrocarbon refrigerant. Similarly, a gain of (6.1%- 8.7%) was obtained for evaporator temperature. An improvement in COP was also observed during the investigations (4.7% – 11%). This was achieved under evaporator constant load at 25-26^0C

(vii) The results were also observed when refrigeration system is operated at heat load 35–36^0C evaporator temperature.

(viii) Results found reduction in the power consumption (16.6% to 23.3%) during temperature drop (from 40^0C – 25^0C) with the use of nano refrigerants.

(ix) The system works normally same as any conventional refrigeration system

(x) Refrigerating effect enhances with the addition of nanoparticles (0.20gm to 0.40gm) in refrigerant.

7.2 Future scope

The present research work was aimed at only one type of refrigerant, three concentrations of nano particles of CuO only. But there could be number of other parameters which can be varied to get the system performance.

(i) Nanoparticles with different concentrations can be used

(ii) There are number of refrigerants other than refrigerant hydrocarbon which can be used to investigate the performance

(iii) The performance may be evaluated with different mass flow rates, different size of nano particles, different heat loads & different working conditions.

(iv) The system can be evaluated at more controlled environment condition such as in testing chambers to get more accurate results

(v) The evaporator load can be replaced with actual load.

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ANNEXTURE-I

Constant Heat Flux (Constant Temperature of Evaporator): (35-36°C)

Mass flow rate: 3.8 LPH

1.Temperature drop in condenser and evaporator

Heat Flux Constant	(35-36°C)	**Temperature drop in Condenser**		
Mass flow rate	3.8LPH			
	Concentration	**Temp inlet Condenser**	**Temp outlet Condenser**	**Concentration**
Pure Hydrocarbon	0	89.05	58.2	30.85
Hydrocarbon +CuO(0.2g)	0.2	92.5	58.8	33.7
Hydrocarbon +CuO(0.3g)	0.3	93.5	59.02	34.48
Hydrocarbon +CuO(0.4g)	0.4	96.2	59.2	37

Heat Flux Constant	(35-36°C)	**Temperature drop gain in Evaporator**		
Mass flow rate	3.8LPH			
	Concentration	**Temp. outlet Evaporator**	**Temp. inlet Evaporator**	**ΔT in Evaporator**
Pure Hydrocarbon	0	-0.27	36.99	37.26
Hydrocarbon +CuO(0.2g)	0.2	-0.46	40.65	41.11
Hydrocarbon +CuO(0.3g)	0.3	-0.5	41.2	41.7
Hydrocarbon +CuO(0.4g)	0.4	-0.6	41.6	42.2

2.Pressure drop in Condenser and Evaporator

Heat Flux Constant	(35-36°C)	Pressure drop in Condenser		
Mass flow rate	3.8 LPH			
	Concentration	Pr inlet Condenser	Pr outlet Condenser	ΔPr in Condenser
Pure Hydrocarbon	0	245.42	234.77	10.65
Hydrocarbon +CuO(0.2g)	0.2	239.42	228.42	11.00
Hydrocarbon +CuO(0.3g)	0.3	243.5	231.8	11.7
Hydrocarbon +CuO(0.4g)	0.4	245.8	233.0	12.8

Heat Flux Constant	(35-36°C)	Pressure drop in Evaporator		
Mass flow rate	3.8 LPH			
	Concentration	Pr inlet Evaporator	Pr outlet Evaporator	ΔPr in Evaporator
Pure Hydrocarbon	0	21.34	29.27	7.93
Hydrocarbon +CuO(0.2g)	0.2	20.37	26.97	6.60
Hydrocarbon +CuO(0.3g)	0.3	20.21	26.41	6.20
Hydrocarbon +CuO(0.4g)	0.4	19.9	26.02	6.12

ANNEXTURE-II

Constant Heat Flux (Constant Temperature of Evaporator): at (25-26°C)

Mass flow rate: 3.8 LHP

1-Temperature drop in Condenser and Evaporator

Heat Flux Constant	**(25-26°C)**	**Temperature drop in Condenser**		
Mass flow rate	**3.8LPH**			
	Concentration	**Temp inlet Condenser**	**Temp outlet Condenser**	**Concentration**
Pure Hydrocarbon	0	83.5	58.5	25
Hydrocarbon +CuO(0.2g)	0.2	86.5	58.32	28.18
Hydrocarbon +CuO(0.3g)	0.3	87.8	58.5	29.3
Hydrocarbon +CuO(0.4g)	0.4	88.8	58.6	30.2

Heat Flux Constant	**(25-26°C)**	**Temperature drop gain in Evaporator**		
Mass flow rate	**3.8LPH**			
	Concentration	**Temp. outlet Evaporator**	**Temp. inlet Evaporator**	**ΔT in Evaporator**
Pure Hydrocarbon	0	-1.24	26.82	28.06
Hydrocarbon +CuO(0.2g)	0.2	-1.77	28.02	29.79
Hydrocarbon +CuO(0.3g)	0.3	-1.82	28.5	30.32
Hydrocarbon +CuO(0.4g)	0.4	-1.92	28.6	30.52

2. Pressure drop in Condenser and Evaporator

Heat Flux Constant	**(25-26°C)**	**Pressure drop in Condenser**		
Mass flow rate	**3.8 LPH**			
	Concentration	**Pr inlet Condenser**	**Pr outlet Condenser**	**ΔPr in Condenser**
Pure Hydrocarbon	0	243.65	232.92	10.73
Hydrocarbon +CuO(0.2g)	0.2	240.1	228.7	11.4
Hydrocarbon +CuO(0.3g)	0.3	238.4	225.9	12.5
Hydrocarbon +CuO(0.4g)	0.4	237.34	224.4	12.94

Heat Flux Constant	**(25-26°C)**	**Pressure drop in Evaporator**		
Mass flow rate	**3.8 LPH**			
	Concentration	**Pr inlet Evaporator**	**Pr outlet Evaporator**	**ΔPr in Evaporator**
Pure Hydrocarbon	0	20.85	30.26	9.42
Hydrocarbon +CuO(0.2g)	0.2	20.16	26.79	6.63
Hydrocarbon +CuO(0.3g)	0.3	20.05	26.78	6.73
Hydrocarbon +CuO(0.4g)	0.4	19.89	26.1	6.21

ANNEXTURE-III

Heat Flux varied range (40-25°C) varied Temperature of Evaporator): 40-25°C

Mass flow rate: 3.8 LPH

Temperatures drop in evaporator w.r.t. time.

Temperature drop(^{0}C)	40	39	38	37	36	35	34	33
Pure Hydrocarbon time taken (minutes)	0	3	8	11	14	18	21	24
Hydrocarbon +CuO(0.2g) time taken (minutes)	0	3	6	9	12	15	19	22
Hydrocarbon +CuO(0.3g) time taken (minutes)	0	4	7	9	12	15	19	23
Hydrocarbon +CuO(0.4g) time taken (minutes)	0	3	6	8	11	15	18	23
Temperature drop(^{0}C)	32	31	30	29	28	27	26	25
Pure Hydrocarbon time taken (minutes)	30	33	37	42	46	50	55	59
Hydrocarbon +CuO(0.2g) time taken (minutes)	26	30	33	38	42	45	50	54
Hydrocarbon +CuO(0.3g) time taken (minutes)	26	30	34	37	41	45	49	51
Hydrocarbon +CuO(0.4g) time taken (minutes)	26	29	32	35	39	42	45	48

2- Total time required for all concentration CuO.

Time Taken (minutes)	Total time
Pure Hydrocarbon	59
Hydrocarbon +CuO(0.2g)	54
Hydrocarbon +CuO(0.3g)	51
Hydrocarbon +CuO(0.4g)	48

3- Power consumption by compressor for all Concentration CuO for cooling from flux (40-25°C)

Mass flow rate	3.8 LPH			
Nano particle concentration	0.0	0.2	0.3	0.4
Power Consumption(KWh)	0.15	0.125	0.12	0.115