

# **PERFORMANCE EVALUATION OF A NANOREFRIGERANT BASED VAPOR COMPRESSION REFRIGERATION SYSTEM**

*Thesis submitted towards the partial fulfillment of the requirements for the award of degree of*

## **MASTER OF ENGINEERING IN THERMAL ENGINEERING**

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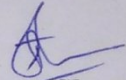
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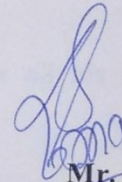


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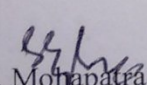
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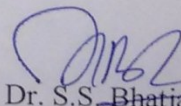


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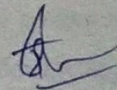
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## ABSTRACT

In the era of technological advancements in various fields, refrigeration systems play a vital role to fulfill the human comfort and industrial needs. The various researches are being carried out by researchers in order to improve the performance of these systems. In the presented work, an attempt has been made to improve the performance of such systems. Our, present study, on experimental investigations into the performance of a nanorefrigerant (hydrocarbon+Al<sub>2</sub>O<sub>3</sub>) based refrigeration system, is conducted at the Mechanical Engineering Department, Thapar University, Patiala. A standard experimental setup was build up and made to function under varying load conditions. The performance of the refrigeration system depends upon the various factors like; individual component's performance, nature and properties of the refrigerant being used, environmental conditions etc. Experiments have been conducted to investigate the effect of nanoparticles on the performance of the refrigeration system. After deliberations & discussion it has been decided to use hydrocarbon as a base refrigerant which is alternative for R134a refrigerant, reason being its ODP and GWP threats if it continued in use for long time. Hydrocarbon R290/R600a refrigerant can be used as a replacement of R134a due to its almost similar properties (thermodynamic and physical properties) and eco-friendly nature. But, it has been found that its heat transfer capacity is limited and it also consumes more power when taken to refrigeration cycle, which is like as that of conventional refrigerants. In addition to this, choice of a particular refrigerant also affects the temperature across condenser and evaporator of the refrigeration system, time taken to reach a particular temperature in the evaporator or freezing capacity. In order to make an enhancement in its performance, an experimental study has been conducted by using nanorefrigerant rather than the conventional refrigerant. Nanoparticles are injected along with the R290/R600a to increase the heat transfer capacity, to reduce the power consumption and thereby to increase the performance of the system.

Aluminium oxide (Al<sub>2</sub>O<sub>3</sub>) nanoparticles of size (20-30) nm have been used in the refrigeration system with its three different concentrations (0.20, 0.30 and 0.40 gm). Data is collected for 3.4 LPH volume flow rate and for two heat fluxes in evaporator supplied at 25–26 °C and 35–36 °C. It has been found that addition of aluminium oxide (Al<sub>2</sub>O<sub>3</sub>) nanoparticles to the refrigerant result in an improvement in the thermo physical properties

and heat transfer characteristics of the refrigeration system. There is more temperature drop across the condenser for the nanorefrigerant (14.4% – 20%) compared to pure R290/R600a hydrocarbon refrigerant. Similarly, a gain in the evaporator temperature (2.33% – 5.55%) has been observed. An improvement in COP (3.68% – 11.05%) is also observed during the investigations. This is achieved under 25–26 °C evaporator temperature load conditions. Similar improvements are also observed when refrigeration system is operated at 35–36 °C evaporator temperature load conditions. A reduction in the power consumption (13.6% - 30.04%) along with faster cooling (from 40°C – 25°C) is also achieved when nanorefrigerant is used. The experimental studies indicate that the refrigeration system with nanorefrigerant works normal like any conventional refrigeration system. Thus, aluminium oxide ( $\text{Al}_2\text{O}_3$ ) nanoparticles can be used to improve the performance of a hydrocarbon based refrigeration system under investigated conditions.

**Keywords:**

Aluminum oxide nanoparticles, nanorefrigerant, hydrocarbon, thermal conductivity, cooling capacity, COP, energy consumption

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## NOMENCLATURE

COP	=	Coefficient of performance
Nm	=	Nanometer
CNT	=	Carbon nanotubes
LPH	=	Liter per hour
SEM	=	Scanning Electron Microscope
KW	=	Kilowatt
EG	=	Ethylene Glycol
POE	=	Polyolester
Psi	=	Pound square inch
Ppm	=	Parts per million
amp.	=	Ampere
V	=	Volts
Kg	=	Kilogram
CC	=	Centimeter cube
PAG	=	Polyalkylene glycol
Hz	=	Frequency
Cp	=	Specific heat
K	=	Temperature in Kelvin
km/hr	=	Kilometer per hour
kWh	=	Kilowatt hour energy consumed
Kw	=	Power consumption
m <sup>3</sup> /kg	=	Specific volume
kg/m <sup>3</sup>	=	Density
wt%	=	Concentration by weight
vol%	=	Concentration by volume

## INTRODUCTION

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### 1.1 Introduction to Vapor Compression Refrigeration System

Demand for the refrigeration and air conditioning has been increasing day by day. Industry as well as in the homes there is need for the comfort environment for human as well as for manmade products. This is achieving by the refrigeration and air conditioning. Vapor compression refrigeration is the system among all most used for this purpose. In this system, refrigerant is used as the working fluid which is the crucial part of the system. Its working involves four main processes i.e. compression, condensation, throttling and evaporation. The low pressure and low temperature vapor refrigerant enters into the compressor through inlet valve and discharges to high pressure and high temperature refrigerant. Then it enters into the condenser in which phase change of refrigerant occurs at constant pressure and temperature, where it rejects heat to the environment, now the refrigerant is throttled through throttle valve in which refrigerant temperature becomes low and it enters into evaporator through which it absorbs heat and the cycle continues. The main measuring parameter to check the performance of the system is COP which is defined as the ratio of cooling effect produced and work input. Technology improves time by time and made the amendments in the refrigeration system all around the world. Various researches held to increase the performance of the system.

#### 1.1.1 Refrigerant

Refrigerant is the fluid which is used in refrigeration and air conditioning systems for heat transfer purposes. The performance of the system mainly depends upon the properties of the refrigerant. There are different types of refrigerants available like HFC, HC, azeotropes etc. HFC refrigerants are mostly used due to their high performance characteristics. But now trend is changing and HFC refrigerants usage is limited upto some extent due to their effect on environment and ozone layer. Now days ecofriendly refrigerants are introducing for refrigeration and air conditioning systems and hydrocarbon refrigerants are the best alternative due to low ODP and GWP. Recently

various researches are going on for the replacement of HFC refrigerant with the HC refrigerants. It has been observed that hydrocarbon refrigerant of 60% propane mass proportion shows improvement over R134a in domestic refrigerator at same working conditions (Fatouh M. et al. (2006)). Jwo Ching Song (2009) used R290/R600a refrigerant in place of R134 and get positive results by reduction in energy consumption upto 4.4%. Therefore there are number of HC refrigerants which can replace CFC refrigerants.

### **1.1.2 Nanorefrigerant**

Recently to improve the heat transfer characteristics some studies on the nanoparticles in refrigeration systems have been conducted. Nanoparticles used with refrigerant as a fluid are called nanorefrigerants. There is scope of using nanoparticles in the vapor compression refrigeration cycle. Nanoparticles can be either mixed with refrigerant or it can also be used as a nanolubricant in which nanoparticles mixed with lubricating oil. Results show that there is improvement in the system with the use of nanotechnology in the refrigeration system.

Sheng-shan et al (2007) investigated the performance of the refrigerator using R134a and POE oil as the base and then compared using R134a and mineral oil with nanoparticles of  $\text{TiO}_2$  which results in reduction in energy consumption. Jwo et al. (2009) studied the mixing of mineral lubricant with  $\text{Al}_2\text{O}_3$  nanoparticles to improve the lubrication and heat-transfer performance. This analysis showed that R-134a and 0.1 wt %  $\text{Al}_2\text{O}_3$  nanoparticles were optimal for better performance. Bi et al. (2011) used a domestic refrigerator with reciprocating compressor for experimental study in which  $\text{TiO}_2$ -R600a nanorefrigerant was used as working fluid. This investigation also showed positive impact on performance.

## **1.2 Introduction to Nanofluids**

In cooling as well as heating applications, thermo–physical properties of matter play an important role. It has been observed that the system performance mainly depends on thermal conductivity, viscosity, specific heat and density of gases and liquids which are used in system.

Conventional fluids have poor heat transfer properties and low thermal conductivity which limits its performance. Due to this, there is always a need to develop effective & efficient fluids which able to meet with high heat transfer rate. Small solid additives usually in micrometer size are good option to enhance the thermal properties of fluids, but it has been found that these small solid additives also possess various problems like particle sedimentation, particle clogging, large pressure drop in the system, corrosion of components, etc (Maxwell et al., 1873). Investigations show that scattering of nanoparticles in conventional fluids is a good option and it also reduces the number of other problems because at nanometer the material behaves like colloidal solutions. It is possible to break down the limits of conventional solid particle suspensions by adopting the concept of nanoparticle-fluid suspensions. These nanoparticle-fluid suspensions are termed as nanofluids which is obtained by mixing nanometer sized particles in a base fluid like water, oil etc. In other words solid particles with size less than 100nm suspended in a fluid is known as nanofluid. Nanoparticles such as metallic oxides ( $\text{Al}_2\text{O}_3$ ,  $\text{CuO}$ ,  $\text{SiO}_2$ ), semiconductors ( $\text{TiO}_2$ ,  $\text{SiC}$ ), nitride ceramics ( $\text{AlN}$ ,  $\text{SiN}$ ), carbide ceramics ( $\text{SiC}$ ,  $\text{TiC}$ ), metals ( $\text{Cu}$ ,  $\text{Ag}$ ), single, double or multi walled carbon nanotubes are used. Even at very low concentrations the nanofluid shows a good enhancement in the performance and thermal conductivity (Choi et al., 2001). With increase in temperature and concentration they show large improvement (Wang et al., 1999).

### **1.2.1 Properties of Nanofluid**

Like Conventional fluids, nanofluids have also number of properties which determine its behavior like particle size, particle shape, material, thermal conductivity etc. and also the stability of particles in base fluid, which is a major concern. The main reason which helps nanoparticles to make stable suspension is their high surface to volume ratio .As the thermal conductivity of nanoparticles is higher than that of base fluids therefore overall thermal conductivity of mixture increases. Due to the very small dimensions, the nanoparticles disperse easily in base fluids and behave like a suspended base fluid molecule, which helps to reduce problems like particle clogging, sedimentation, corrosion etc. Viscosity of nanofluids is also an major concern. If concentration of

nanoparticles in base fluid increases beyond certain limit (5%) then viscosity also increases this limits its performance & suitability for particular application.

### **1.2.2 Particle volume fraction**

Particle volume fraction determines the amount of nanoparticles in the base fluid. It plays an important role in the formation of base fluid. It affects the properties like thermal conductivity and viscosity of base fluid. There are many researches that have been performed to see the effect of particle volume fraction on the thermal conductivity and viscosity of nanofluids. For a volume fraction of about 4.3% of  $\text{Al}_2\text{O}_3$  nanoparticles there is a 32.4% improvement in thermal conductivity of nanofluid (Masuda et al., 1993). Xing et al (2015) analyses the thermal conductivity of nanofluid by mixing it with three different types of CNT at 0.48% vol. fraction which results in 8.1%, 16.2% and 5% enhancement in thermal conductivity for single walled nanotubes, long walled nanotubes and multi walled nanotubes. Xiaoke (2015) studied the rheological behavior of ethylene glycol (EG) with SiC nanoparticles of 1.0 % vol. in which they found 16.21% enhancement in thermal conductivity.

### **1.2.3 Nanofluids Thermal Conductivity**

The effect of nanoparticle depends mainly on the basis of improved value of thermal conductivity. There are various theoretical and practical models to explain the rise in the thermal conductivity of nanofluids. But researches are still going on to find the best way to explain the increased value of thermal conductivity. The improved value of thermal conductivity totally depends upon the concentration of nanoparticles in the base fluid which shows superior results over base fluid. Shape, size, surface area all these factors plays a vital role in the enhancement of thermal conductivity. Higher the surface area more enhanced thermal conductivity. Also phenomenon like boiling and convection are being studied by many researchers to find the coefficient of heat transfer so that improvement can be made.

#### **1.2.4 Particle material**

Another property which decides the thermal conductivity of nanofluids is the particle material like CuO has higher thermal conductivity than  $Al_2O_3$  due to the reason Cu is more conducting than Al. Rudyak (2014) determines the dependency of particle material on viscosity of nanofluid. He added aluminium and lithium nanoparticles into lithium argon fluid and shows dependency. Huminic et al (2015) also shows higher thermal conductivity in base fluid water due to addition of FeC nanoparticles and found out that thermal conductivity and viscosity of nanofluid increases with the weight concentration of nanoparticles in nanofluid.

#### **1.2.5 Base Fluid**

It is simply a fluid which can be used for various purposes like heat transfer, lubrication, cooling etc. Maxwell (1873) determines that the less is the thermal conductivity of base fluid, more is the thermal conductivity ratio when nanoparticles will mixed into it. Since ethylene glycol (EG) has less thermal conductivity than water and engine based fluids therefore EG based nanofluids show high thermal conductivity ratio as compared to others and engine oil shows somewhat lower thermal conductivity ratio than ethylene glycol. Compatibility of the nanoparticles with the base fluid is also an important factor, it should carry nanoparticles without sedimentation. Some nanoparticles are not compatible with the base fluid so selection of base fluid and nanoparticles is an important factor for investigation.

#### **1.2.6 Particle shape**

Nanoparticles have different shapes like cylindrical, spherical, rectangular etc. Also the thermal conductivity varies with their shapes. Jeong et al. (2013) investigated ZnO nanofluids with nanoparticles of rectangular and spherical shape. The results show that viscosity and thermal conductivity of rectangular nanoparticles was dominant over spherical nanoparticles. Mare et al. (2015) also found out there is sharp rise in thermal conductivity by using CNT in water. CNT shows higher thermal conductivity due to heat transfer along the tube length but it also creates a menace of high pumping power due to increased value of viscosity.

### **1.2.7 Particle size**

The thermophysical properties of the nanofluid also depend upon the particle size of nanoparticles. Thermal conductivity and viscosity of nanofluids are the main properties which vary with the particle size. Smaller size particles have more surface area therefore causes more contact with base fluid and hence improved heat transfer rate. Larger the size of the nanoparticles more is the viscosity. It has been found that the effective thermal conductivity of a nanofluid increases with decreasing nanoparticle size. But in some cases it is not true, conflicting results also have been reported.

### LITERATURE REVIEW

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**Alsaas M.A. et al. (1997)** investigated the performance of refrigerator by replacing the refrigerant CFC 12 with the LPG refrigerant containing 24.4% propane, 56.4% butane and 17.2% isobutene. The result shows that C.O.P. value reached to 3.4 and the evaporator temperature reached to  $-15^{\circ}\text{C}$  with ambient condition  $20^{\circ}\text{C}$  and condenser temperature  $27^{\circ}\text{C}$ . Therefore use of propane/butane gives improvement in system over the use of CFC 12 refrigerant.

**Fatouh M. et al. (2006)** has experimented on domestic refrigerator by replacing R134a with the hydrocarbon refrigerant over a wide range of evaporator temperature ( $-35$  to  $-10^{\circ}\text{C}$ ) and condenser temperature ( $40$  to  $60^{\circ}\text{C}$ ) with different proportions of propane in propane/buane/isobutene mixture of refrigerant. The analysis shows that hydrocarbon refrigerant with 60% propane mass proportion is most efficient and it improves the C.O.P. over the use of R134a and also reduces pressure drop by 11.1% as compared to R134a.

**Somchai Wongwises et al. (2005)** tested the performance of auto-motive air conditioners by replacing HFC-134a refrigerant with hydrocarbon refrigerant. They done study on four different ratios of hydrocarbon mixtures and found out that the mixture propane/butane/isobutane (50%/40%/10%) is the most appropriate mixture to replace HFC-134a and having best performance regarding C.O.P., the refrigeration capacity and the compressor power consumed.

**Somchai Wongwises et al. (2004)** works on the application of hydrocarbon refrigerant in place of HFC134a refrigerant in a domestic refrigerator. Hydrocarbons used are propane, butane and isobutene. In this system they used energy consumption test (ECT) method in which the temperature of the refrigerator compartment was noted down after every 1 min for 24 hours then energy consumption is measured in KWh. They also measured compressor work and recorded temperature and pressure at salient points. This procedure

was adopted with three different refrigerant mixtures i.e. three hydrocarbon mixtures, two hydrocarbon mixtures and two hydrocarbon and HFC134a mixture. All experiments were conducted at 25<sup>0</sup>C ambient temperature. On investigating all three mixture refrigerant with HFC134a refrigerant experimentally the results shows that there is 0.69% reduction in energy consumption as compared to HFC134a and results also shows that propane 60% and butane 40% mixture is the best alternative of HFC134a.

**Hammad M.A. et al. (1998)** investigated the performance of domestic refrigerator by using four proportions of propane, butane and isobutane to find the optimal alternative for R12 refrigerant. Different proportions of hydrocarbons are 75% propane 19.1% butane 5.9% isobutane, 50% propane 38.3% butane 11.7% isobutane and 25% propane 57.5% butane 17.5% 100% propane isobutane. The C.O.P. and cooling load were evaluated by using these proportions and compared with R12. The result shows that propane 100% gives highest C.O.P. but 50% propane mixture is the best alternative to R12 on the basis of COP.

**Jwo Ching Song et al. (2009)** investigated the performance of home refrigerators by replacing R134a refrigerant with the R-290/R-600a hydrocarbon refrigerant. In this experiment they used 50% of each proportion of R-290 and R-600a with varied mass and evaluated the results compared to R134a. They found out that the R-290/R-600a hydrocarbon refrigerant with 90g mass has better performance as compared to 150g R-134a which is reduced to 40%. They also found out that change in refrigerator temperature is also enhanced with faster cooling rate as compared to R-134a and the consumption in energy is also reduced by 4.4%.

**Rasti M. et al. (2012)** has presented an experimentation on substitution of R134a refrigerant with the R436A (a mixture of 56% R290 and 44% R600a) in a 238L domestic refrigerator. They charged different amounts of R436a refrigerant and measured power consumption and temperature at various sections of the system. The various graphs were plotted to compare the effects of R436 with the R134a. The result shows that in comparison to R134a the charged amount is reduced to 48% and the evaporator

temperature is also reduced by 3.5<sup>0</sup>C. Furthermore the energy consumption is reduced by 13.6% and Energy Efficiency Index is improved from E to D.

**Joudi et al. (2014)** has done an investigation on the performance of split air conditioners by using four alternative refrigerants to R22. They used two split air conditioner systems of capacity 1TR and 2TR in which they measured C.O.P., power consumption and condenser heat rejection. In this the compartment air is maintained at constant temperature but the ambient condition was varied. They proposed a methodology to increase ambient temperature from 35<sup>0</sup>C to 55<sup>0</sup>C with 5<sup>0</sup>C increment. The experimental results showed that refrigerant R410 has highest power consumption and cooling capacity moreover it also has highest heat rejection in condenser. R290 has the better COP as compared to other refrigerants and it is also a best alternative to R22 whereas R407 has a highest compression ratio.

**Rasti Mehdi et al. (2013)** studied the influence of two hydrocarbon refrigerants in place of R134a refrigerant in domestic refrigerator. They done parameter analysis by using two types of compressor one is HFC compressor and other is HC compressor in the refrigerator. They found out that in compared to 105g R134a charge in refrigerator the R436a and R600a charged 60g and 55g while using HFC compressor moreover result also shows that energy consumption was reduced by 14% and 7%. In case of HC type compressor the charged amount of R436a and R600a is reduced to 50g only and the power consumption also reduced by 14.6% and 18.7%.

**Bi Shengshan et al. (2011)** used TiO<sub>2</sub>-R600a based nanorefrigerant in domestic refrigerator in which two concentrations of nanoparticles were used. They optimized the performance of refrigerator at 0.1 and 0.5 g/L concentrations of TiO<sub>2</sub>-R600a and found out that at 0.1 g/L concentration the energy consumption reduced by 5.64% and at 0.5 g/L concentration it reduced by 9.60%. Moreover, the freezing velocity of TiO<sub>2</sub>-R600a is also fast as compared to R600a pure refrigerant.

**Subramani N et al. (2011)** studies indicated that the refrigeration system with nanorefrigerant works normally and give better results. It was found that the freezing

capacity improves and the power consumption reduces by 25% when POE oil is replaced by a mixture of mineral oil and alumina nanoparticles. Result also showed that enhancement factor in the evaporator is 1.53 when nanorefrigerants were used instead of pure refrigerant.

**Kumar S.D et al. (2012)** did experimental work on nanorefrigerant by using  $\text{Al}_2\text{O}_3$ -PAG oil in R134a vapor compression refrigeration system. The system performance was investigated on the basis of energy consumption test and freeze capacity test. It was found out that  $\text{Al}_2\text{O}_3$  nanorefrigerant works normally and safely in the refrigeration system. It was investigated that performance of refrigeration system was better than pure lubricant with R134a working fluid, a 10.32% less energy was consumed when 0.2% volume of the concentration used in the system. Furthermore heat transfer coefficient increases with the usage of nanoparticle  $\text{Al}_2\text{O}_3$ . Thus, using  $\text{Al}_2\text{O}_3$  nanorefrigerant in refrigeration system enhances the performance of the system.

**Mahbubul I.M. et al. (2015)** analyzed the thermo-physical properties and their effect on COP. 5% volume of  $\text{Al}_2\text{O}_3$  nanoparticles are added at temperature of 283-308 K. The results indicate that the thermal conductivity of nanorefrigerant  $\text{Al}_2\text{O}_3$  increases on increasing temperature i.e. 8.12% to 28.58% for 208K to 308K. The density and viscosity of nanorefrigerant also increased by 13.68% and 11% for the same temperature rise. The variation in thermal conductivity, density and viscosity also increases the COP by 15%, 3.2% and 2.6%.

**Mahbubul I.M et al. (2012)** investigated the volumetric and temperature effects over viscosity of R123- $\text{TiO}_2$  nanorefrigerants for 5°C to 20°C temperatures up to 2 % volume concentration of nanoparticles. Moreover effect of pressure drop with the increase in viscosity has also been studied. Based on the investigation it was found that viscosity of nanorefrigerant increases accordingly with the increase of nanoparticle volume concentrations and decreases with the rise in temperature and also pressure drop increases significantly with the intensification of volume concentrations. Therefore it is suggested to use low concentration nanoparticles for better performance.

**Bi Shengshan et al. (2007)** have experimented with R134a as refrigerant and a mixture of mineral oil and TiO<sub>2</sub> as the lubricant in a domestic refrigerator. It was found that the refrigeration system with the above combination works normally and efficiently and also the energy consumption reduces by 21.2% as compared with R134a/POE oil system.

**Kumar R.R et al. (2013)** investigated the effect of Al<sub>2</sub>O<sub>3</sub> based nano-lubricant on the COP of the system and freezing capacity of the system. In the experimental setup R12, R22, R600, R600a and R134a were used as a refrigerant. The performance of the system depends upon the thermo-physical properties of the refrigerant therefore the addition of nanoparticles to the refrigerant results in improvement in the thermo- physical properties. Although improving the performance of the refrigeration system. The experimental studies indicate that the refrigeration system with nanorefrigerant works normally and efficiently in same working condition. The COP of the system increases by 19.6 % and it was found that there is an increase in freezing capacity and reduction in power consumption by 11.5 % as compared to polyester.

**Jwo C.S et al. (2009)** had used mineral lubricant with Al<sub>2</sub>O<sub>3</sub> nanoparticles to improve the lubrication and heat-transfer performance. This study showed that R134a + 0.1 wt % Al<sub>2</sub>O<sub>3</sub> nanoparticles were optimal for best performance and results in reduced power consumption by about 2.4%. COP was increased by 4.4%.

**Peng H et al. (2011)** investigated the influence of refrigerant-based nanofluids composition and heating condition on the migration of nanoparticles during pool boiling. The nanoparticles include Cu (average diameters of 20, 50 and 80 nm), Al and Al<sub>2</sub>O<sub>3</sub> (average diameters of 20 nm), and CuO (average diameter of 40 nm) and the refrigerants include R113, R141b and n-pentane. The mass fraction of lubricating oil RB68EP is from 0 to 10 wt%, the heat flux is from (10 to 100) kW/m<sup>2</sup> and the initial liquid-level height was from 1.3 to 3.4 cm. The results showed that a migration ratio of nanoparticles during the pool boiling of refrigerant-based nanofluid increases with the decrease of nanoparticle density, nanoparticles size, dynamic viscosity of refrigerant, mass fraction of lubricating

oil or heat flux; while increases with the increase of liquid-phase density of refrigerant or initial liquid-level height.

**Hafez E.A et al. (2011)** used CuO-R134a in the vapor compression system and evaporating heat transfer coefficient was experimentally investigated. Measurements were taken for heat flux ranged from 10 to 40 kW/m<sup>2</sup>, using CuO nanoparticles of size 15 to 70 nm with different concentrations (0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.55, 0.6, 0.8 and 1%). There is upto 0.55% increase in heat transfer coefficient in the investigated concentration range and then decreases for remaining values of heat flux. Moreover the heat transfer coefficient increases up to particle size of 25nm then it decreases with the increase in particle size.

**Mahbubul I.M. et al. (2013)** studied the volumetric effects on thermal conductivity, density and viscosity of nanorefrigerant Al<sub>2</sub>O<sub>3</sub>-R141b. The experiments were done for different temperature ranges. The experimental results show that thermal conductivity increases with the volume concentrations and temperature. The viscosity and density also increases with the volume concentration but decrease with the increase in temperature. Therefore an optimal volume concentration can enhance the performance of the system.

**Tashtoush B et al. (2001)** studied the replacement of R12 with the mixture refrigerant of propane/butane/R134a in domestic refrigerator. The tests were performed in a range of evaporator duty from 100W to 350W. The refrigerator with this mixed refrigerant can work normally and efficiently without any change in mineral oil and condenser. The study shows that COP of mixed refrigerant at 100W evaporator duty is 5.4% less and 0.8% less at 350W evaporator duty. But the volumetric efficiency of mixed refrigerant is better than R12 and mixed refrigerant also improves the lubricity and miscibility of lubricating oil.

**Mohanraj M. (2013)** investigated the energy performance of domestic refrigerator by replacing R134a refrigerant with the R430a. The investigations were done for three different condensing temperature 40, 50 and 60<sup>0</sup>C, the evaporator temperature also ranges

from  $-30^{\circ}\text{C}$  to  $0^{\circ}\text{C}$ . They found out that COP of the refrigerator with R430a is higher than R134a by 2.6%, 4.3% and 7.5% at condensing temperatures of 40, 50 and  $60^{\circ}\text{C}$ . the energy consumption was also reduced by 1–7.7%, 1.2–8.2%, and 2.5–9.8% at condensation temperatures 40, 50 and  $60^{\circ}\text{C}$ . However it is also found out that discharge temperature of compressor is slightly more with R430a refrigerant which affects compressor life.

### GAPS IN STUDY AND OBJECTIVES

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Literature review shows that lots of research work is being reported on the nanofluid's thermal conductivity, its properties, effect of particle volume fraction, particle material, base fluid, particle size, particle Shape etc. Also work has been done on refrigeration and air conditioning using HFC refrigerant like R134a, R12, R22 etc. with nanoparticles. Use of nanoparticles with HC refrigerant is also an emerging field where lot of investigation is required.

#### 3.1 Gaps in study

Following are the points which helped me to take my thesis work on nanorefrigerants based refrigeration system are as under:

- (i) A limited work has been reported on use of HC refrigerant in vapor compression refrigeration system.
- (ii) The effect of HFC refrigerant on environment
- (iii) There are various HC refrigerants which can replace HFC refrigerants.
- (iv) Use of HC refrigerant in same refrigeration system without any much modification in system using HFC refrigerant.
- (v) A limited work has been reported on use of HC refrigerant with nanoparticles.
- (vi) Through the hydrocarbon based nanorefrigerant power consumption and performance of system are the key factors to investigate.

### **3.2 Study objectives**

After an extensive literature survey it has been decided to investigate the performance of  $\text{Al}_2\text{O}_3$  based nanorefrigerant in the vapor compression cycle. Following are the parameters which are set as thesis's objectives and undertaken for investigation.

- (i) COP of refrigeration system
- (ii) Power consumption
- (iii) Effect of volumetric concentration of nanoparticles
- (iv) Time required to achieving a desired temperature/freezing capacity of the system
- (vi) Temperature drop across the condenser, temperature gain across the evaporator
- (vii) Pressure drop across evaporator & condenser
- (viii) Effect of mixed nanoparticles

**EXPERIMENTAL SETUP AND METHODOLOGY**

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This section provides a detailed description of the components and their working for experimentation in this system. The charging and evacuation of nanoparticles also discussed there.



**Fig 4.1: Experimental Setup**

Above fig. is the actual vapor compression refrigeration system (domestic) where experimentation of pure hydrocarbon refrigerant along with nanoparticles is performed.

## 4.2 COMPONENTS OF SETUP

S. NO.	COMPONENTS	QTY.	SPECIFICATIONS
1	Compressor	1	165 litre
2	Expansion Device	1	Manual
3	Condenser	1	Finned type
4	Evaporator	1	Coiled Type
5	Filter	1	Without Silica Gel
6	Pressure Guage	4	R134a low and high pressure
7	Heating Element	1	230 W
8	Rotameter	1	2-40 LPH
9	Refrigerant	170 gms	Pure Hydrocarbon
10	Voltmeter	1	0-300 volt
11	Ampmeter	1	0-15 Amp.
12	Energymeter	2	
13	Digital Temperature Controller	1	
14	Hand Shut Valve	4	For ¼ inch pipe
15	Temperature Gauge	4	Mercury glass thermometer (-10 °C – 110 °C)
16	Flexible Charging Line	1	
17	Vacuum Pump	1	

**Table 4.1: Components of Experimental Setup**

### 4.2.1 Refrigeration Compressor

Compressor is an integral and important part of any refrigeration system. Its main work is to raise the pressure and temperature of the refrigerant across the pipe by giving some

pumping power. There are different types of compressors like; reciprocating compressors, rotary screw compressors, centrifugal compressors, scroll compressors and hermetically sealed compressor which are commonly used in refrigeration systems depending upon the requirements.

In this setup hermetically sealed compressor of 165L capacity has been used. Normally in hermetic and mainly semi-hermetic compressors the compressor and motor driving the compressor are integral part of compressor, and run inside the refrigerant system.



**Fig 4.2: Compressor of the Experimental Setup**

Compressor Specifications	
Manufacturer	Godrej & Boyce Mfg. Co. Ltd.
Model	Power cool comp R134a G1-1+CAPCT
Dimensions	0.201*0.164*0.175 m <sup>3</sup>
Capacity	410 Btu/hr.
Motor Input	107 Watts
EER	3.83 Btu/Whr.
Displacement	4.6 CC
Voltage Range	150-260 V
Oil Charge	300 CC
Net Weight	7.8 kg

**Table 4.2: Compressor Specifications**

### 4.2.2 Refrigerant Flow Device

An expansion valve is a component in vapour compression refrigeration system which controls the quantity of refrigerant flow into the evaporator. It maintains the required pressure & temperature in the evaporator. There are different types of expansion devices which are commonly used. They are as follows:-

- (i) Capillary tube
- (ii) Automatic expansion valve
- (iii) Thermostatic expansion valve
- (iv) Manual expansion valve

In this setup flow control device used is hand operated manual expansion valve to control the flow of refrigerant. The valve needle remains open during steady state operation. The size of the opening or the position of the needle is related to the pressure and temperature of the evaporator where smaller is the opening lower is the pressure and temperature after expansion device.



**Fig 4.3: Hand Operated Expansion Valve**

### 4.2.3 Condenser

A condenser is a device used to condense a fluid from its gaseous state to its liquid state. In vapor compression refrigeration system condenser is used to condense refrigerant from vapor phase into liquid phase. It rejects heat to the environment and its inlet is outlet of the compressor from which high temperature and pressure refrigerant enters. It rejects

heat to the environment through the surface which is either air cooled or water cooled.

The heat rejection capacity of a condenser depends mainly on following factors:

- (i) The temperature difference between the refrigerant and the cooling media
- (ii) The flow rate of the cooling media through the condenser
- (iii) The flow rate of the refrigerant through the condenser

Types of condensers are

- (i) Finned-static condenser
- (ii) Finned-forced convection condenser
- (iii) Wire-static condenser
- (iv) Plate-static condenser

In this system finned-static condenser has been used.



**Fig 4.4: Finned static condenser**

<b>Condenser Specifications</b>	
Type	Natural Draught
Diameter of pipe	0.00635m
Length of pipe	13.7 m
Area of condenser	0.2732 m <sup>2</sup>
Material of pipe	Copper

**Table 4.4: Condenser Specifications**

#### 4.2.4 Evaporator

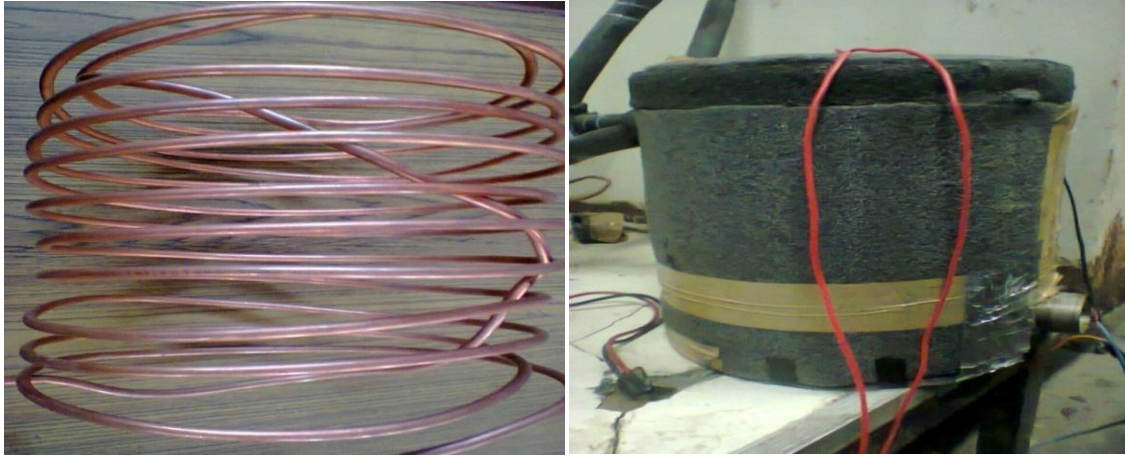
The liquid refrigerant enters the evaporator from the refrigerant flow control device is under low pressure and low temperature. Evaporator makes contact with the water and the medium from which heat has to be removed. Here liquid refrigerant changes phase to vapor phase.

In this set up emersion coil type evaporator is used. Evaporator is dipped in 10.5 litre of water. Water is stirred with help of the agitator to ensure uniform heat transfer. The heat exchange rate within an evaporator is influenced by these factors:

- (i) The temperature difference between the refrigerant and the water being cooled
- (ii) The flow rate of the water through the evaporator
- (iii) The flow rate of the refrigerant through the evaporator

Evaporator Specifications	
Type	Emersion Coil Type
Diameter of pipe	0.0635m
Length of pipe	7.62 m
Area of condenser	0.152 m <sup>2</sup>
Material of pipe	Copper

**Table 4.5: Evaporator Specifications**



**Fig 4.5: Emersion Coil Type Evaporator**

#### **4.2.5 Heating Element**

A heating element is a component which converts electricity into heat through the process of resistivity or Joule heating. Refrigerant takes the heat from the water present in evaporator which is added by heating element to the water at constant rate in evaporator. It is used to add heating load or to maintain the required flux or temperature in the evaporator. In this setup metal heating element is used.

<b>Heating Element Specifications</b>	
Power	230W
Specifications	230V,50Hz A/C

**Table 4.6 Heater Specifications**



**Fig 4.6: Heating Element**

### **5.2.6 Filter**

Impurities present in the vapor compression refrigeration system can damage number of components of the system like compressor and expansion device can damage due to impurities. To obstruct any impurity present in the system and to avoid any kind of choking filter has been used in experimental setup at condenser outlet. Mesh size of filter varies from (5-5000) micrometers. Nanoparticles can pass through this filter easily.



**Fig 4.7: Filter**

### **4.2.7 Pressure Gauge**

It is used to measure pressure of the hydrocarbon Refrigerant at respective points. Four pressure gauges are used in which one gauge is at compressor inlet, and other at outlet, one gauge after expansion device and other after evaporator outlet. Bourdon tube type refrigeration pressure gauges are used to measure the pressure. The bourdon pressure

gauge works on the principle that a flattened tube tends to straighten or regain its original form in cross-section when pressurized. In this set up two types of gauges are used high pressure gauge and low pressure gauge.

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

**Table 4.6: Pressure gauge Specifications**



**Fig 4.7: Pressure Gauge**

#### 4.2.8 Refrigerant

Refrigerant plays an important role in the vapor compression refrigeration system. Its properties decide the design of the system. In this experimental setup R290/R600a hydrocarbon refrigerant has been used. Hydrocarbon refrigerant is a mixture of propane and butane in which 50% is propane and 50% is butane with thermodynamic properties similar to refrigerant R134a but with zero ozone depletion potential and negligible global warming potential.



**Fig 4.9: Hydrocarbon Refrigerant Can**

Refrigerant Specifications	
Name	Hydrocarbon Refrigerant
Weight	170gm
G.W.P.	Zero
Gas Content	50% R-290 and 50% R600a (LPG)
Charged mass	50gm

**Table 4.7: Refrigerant Specifications**

#### 4.2.9 Rotameter

A rotameter consists of glass tube, with a float actually a shaped weight which is pushed up by the drag force of the flow and pulled down by gravity. For the flow rate of refrigerant glass tube rotameter has been used. Its position is vertical and its range is 2-40LPH. The liquid refrigerant coming from the condenser passes through the rotameter and in this way moving element gives reading. The rotameter is manufactured by Zest engineering Delhi.



**Fig 4.10: Rotameter**

#### 4.2.10 Voltmeter

A voltmeter is a device used to calculate electrical potential difference between two points in an electric circuit. Analog voltmeters move a pointer across a scale in proportion to the voltage of the circuit whereas digital voltmeter shows the voltage digitally. It draws only a smallest amount of current to operate.

Voltage Specifications	
Manufacturer	ESS VEE Electricals
Range	0-300 V

**Table 4.8: Voltage Specifications**



**Fig 4.11: Voltmeter**

#### **4.2.11 Ammeter**

An ammeter is a measuring device used to measure the electric current in an electrical circuit. Electric currents are measured in amperes (A). In this set up digital ammeter has been used.



**Fig 4.12 Ammeter**

Ammeter Specifications	
Manufacturer	Pyrotron
Range	0-15 A
Type	Digital

**Table 4.9 Ammeter Specifications**

#### 4.2.12 Energy-meter

An Energy meter is an instrument that measures the amount of electric energy consumed by an electrically powered machine. There are two energy meters used in the system in which one is used to measure the power consumed by the compressor and other to measure the power consumed by the heater. The unit to measure energy is kilowatt hour (kWh). The energy input for both the devices is used to calculate the coefficient of performance of the system.



**Fig 4.13 Energy meter**

Energy-meter Specifications	
Manufacturer	Jaipur Metals and Electricals
Range	0-20 KWh
Type	AC, 1 Phase, 2 wire, 50Hz
Rev/KWh	600

**Table 4.10 Energy-meter Specifications**

### 4.2.13 Digital Temperature Controller

Temperature controller is a device used to measure variation in temperature of space and can be adjusted to achieve a desired temperature. Digital temperature controller is used to cut off the heater supply when the temperature exceeds a particular set value in the evaporator. It is connected to a Relay device which is connected to heating element in which it sends signal to the relay switch which cuts off the supply as well as on the supply of the heating element. There is a sensing element which always dipped in the water in evaporator. With the help of digital temperature controller constant heat flux in the evaporator can be maintained.



Fig 4.14 Digital Temperature Controller

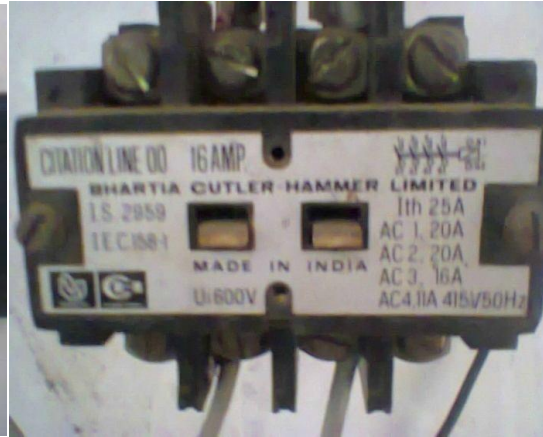


Fig 4.15 Relay Switch

Digital Temperature Controller Specifications	
Manufacturer	ACR Inst & Valve Pvt. Ltd
Range	$(-40)^{\circ}\text{C} - 50^{\circ}\text{C}$
Type	Digital

Table 4.11 Digital Temperature Controller Specifications

### 4.2.14 Hand Shut off Valve

A valve is a device that regulates, directs or controls the flow of a fluid by opening, closing or partially obstructing various passageways. Hand shut off valves are used to control the flow in the line. It is also used to divert the flow towards rotameter. Four valves of this type are used in which one valve is fitted at charging line inlet, two valves

are used at each end of rotameter. If there is need to bypass the flow then parallel valve to the rotameter is opened.



**Fig 4.16 Hand Shut off Valve**

#### **4.2.15 Temperature Gauge (Thermometers)**

Mercury glass thermometers are used to measure temperature at relative points. The thermometers are fitted at evaporator inlet and outlet, before expansion valve and condenser inlet. These temperature values are used to calculate temperature gain in evaporator and temperature drop in condenser. One is also installed to measure ambient temperature.



**Fig 4.17 Mercury Glass Thermometers**

#### **4.2.16 Flexible Charging Line**

Flexible line is used to charge the refrigerant into the system through compressor charging line. Line is connected to the gas cylinder and then connected to the valve from where refrigerant goes in the vapor compression system.



**Fig 4.18 Flexible Charging line**

#### **4.2.17 Vacuum Compressor**

Vacuum compressor is a compressor similar to the compressor used in the vapor compression refrigeration system. It can be used to check for any leakage and is also used to do charging of the system with the air. Also before charging refrigerant the vacuum is produced in the system to remove moisture or any air.



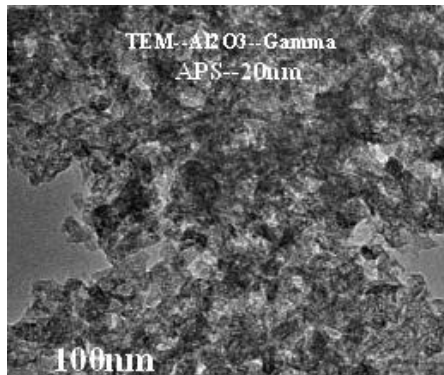
**Fig 4.19 Vacuum Compressor**

#### 4.2.18 Nanoparticles

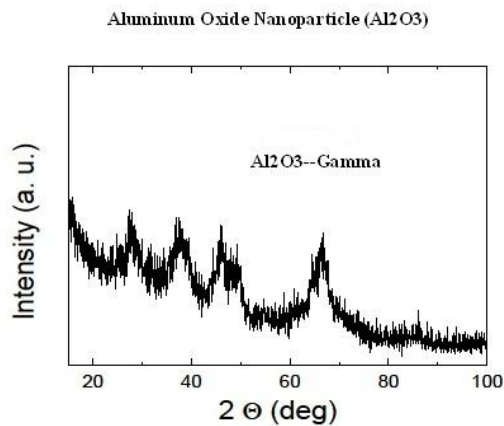
For better performance it is necessary to determine the suitable nanoparticles which can easily suspend into nanofluid. Nanoparticle shape and size are other factors which are necessary for investigation purposes. In this experimental setup  $\text{Al}_2\text{O}_3$  nanoparticles of size 20 to 30 nm is used.

Nanoparticle Specifications	
Nanoparticle	$\text{Al}_2\text{O}_3$
Crystal form	Gamma
Size	20-30 nm
Colour	White
$\text{Al}_2\text{O}_3$ Content	99.99%

**Table 4.12:  $\text{Al}_2\text{O}_3$  Nanoparticle Specifications**



**Fig 4.20:  $\text{Al}_2\text{O}_3$  (SEM)**



**Fig 4.21: XRD of  $\text{Al}_2\text{O}_3$  Nanoparticle**

### **4.3 METHODOLOGY**

In this experiment, the performance of the pure hydrocarbon refrigerant is compared with the nano refrigerant in which different concentrations of  $\text{Al}_2\text{O}_3$  nanoparticles are mixed with hydrocarbon refrigerant in vapor compression refrigeration system. The temperature of the refrigerant at inlet and outlet of each component of the system should be measured with thermometer. Similarly pressure measurements are also taken across each component of system with the pressure gauges fitted at the inlet and outlet of the compressor and evaporator. These measurements are necessary to evaluate the performance of the system. The readings of power meter and energy meter also be taken to find the power consumption and energy consumption of the system. Firstly the performance is investigated with the pure hydrocarbon refrigerant. Then weighted  $\text{Al}_2\text{O}_3$  nanoparticles are injected into the system and performance is evaluated. The key parameter which varied during experiment is the concentration of the nanoparticles in the system.

#### **4.3.1 Test Procedure**

The setup is placed in a constant room temperature with proper insulation. The fluctuation in ambient temperature and room air velocity in room is found to be  $\pm 2\%$  and 0.1 m/s. Evaporator of the system is dipped in 10.5 liter water and maintained at constant temperatures ( $25\text{-}26^\circ\text{C}$ ) and ( $35\text{-}36^\circ\text{C}$ ). All readings were taken at constant volume flow rate i.e. 3.4 LPH. Firstly data is collected for pure hydrocarbon refrigerant and then nanoparticles are introduced having three different weights 0.20gm, 0.30gm and 0.40gm. The charged mass of the gas is 50gm. Experiments were carried out with 20-30 nm nanoparticles size. Tests are performed to study C.O.P., power consumption, time taken for temperature drop from  $40^\circ\text{C}$  to  $25^\circ\text{C}$ , temperature drop in condenser, temperature gain in evaporator and temperature at all salient points. The temperature at inlet and outlet of each component of the system is measured with the mercury thermometer which was already calibrated with standard fluid.

Firstly the system is evacuated to remove moisture, as if moisture combine with refrigerant may affect the thermo physical properties. Moreover it produces highly

corrosive compound which produce pitting and damage to valves and compressor cylinder walls. It also causes choking of expansion which leads to improper expansion of flow. Therefore to remove the moisture, system is evacuated with the help of external air compressor. After evacuation system is charged with hydrocarbon refrigerant (50 gm) through charging line. Now the system is switched on and allowed to reach into steady state which was found to be achieved after 1:30 hrs. After steady state temperature and pressure readings at compressor inlet and outlet, condenser outlet and after expansion were taken within interval of 15 minutes. The ambient temperature is also noted down in this interval. At the start and at the end of the experiment readings for energy meters and heater should be also be taken. Same procedure is adopted for nanorefrigerant Hydrocarbon+Al<sub>2</sub>O<sub>3</sub> (20-30 nm) for 0.20gm, 0.30gm and 0.40gm mass of Al<sub>2</sub>O<sub>3</sub>. Data is collected to find C.O.P., temperature drop in condenser, temperature gain in evaporator and time taken to achieve temperature drop from 40<sup>0</sup>C to 25<sup>0</sup>C and hence in this way performance of the system is evaluated.

#### **4.3.2 Charging of Nanoparticles**

After removing air from the system measured quantity of Al<sub>2</sub>O<sub>3</sub> nanoparticles is injected into it. The nanoparticles are placed in charging line, before opening the charging valve the line is purged to remove any extra air in the charging line. Now the hydrocarbon refrigerant is made to charge the system through the charging line which carries the nanoparticles through it. Thus with this technique the system is charged with nanoparticles and which have nanorefrigerant as working medium instead of pure hydrocarbon.

RESULTS AND DISCUSSION

After conducting experiments with pure R290/R600a hydrocarbon refrigerant, nanorefrigerant with different concentration of Al<sub>2</sub>O<sub>3</sub> in R290/R600a refrigerant, readings have been taken for pressure, temperature, energy consumption at 3.4 LPH flow rate at two types of fluxes supplied to the evaporator at different temperature. Graphs are drawn under steady state for coefficient of performance (COP) of refrigeration system, temperature drop in condenser, temperature gain in evaporator and time taken for drop in temperature from 40<sup>0</sup>C to 25<sup>0</sup>C. All the parameters are summarized in the table below.

Refrigerant	Evaporator Temperature load at (25-26 <sup>0</sup> C)									
	C.O.P.	P1 (kg/ cm <sup>2</sup> )	P2 (kg/ cm <sup>2</sup> )	P3 (kg/ cm <sup>2</sup> )	P4 (kg/ cm <sup>2</sup> )	T1 ( <sup>0</sup> C)	T2 ( <sup>0</sup> C)	T3 ( <sup>0</sup> C)	T4 ( <sup>0</sup> C)	T <sub>atm</sub>
Pure R290/R600a	1.19	20.38	249.46	239.3	27.29	26.61	73.96	49.8	-0.75	29.3
R290/R600a + 0.20gm Al <sub>2</sub> O <sub>3</sub>	1.2	20.21	260	246.2	26.76	27	78.37	50.73	-1	30.38
R290/R600a + 0.30gm Al <sub>2</sub> O <sub>3</sub>	1.22	19.97	257	242.4	26.28	26.6	76.82	48.5	-1.75	30
R290/R600a + 0.40gm Al <sub>2</sub> O <sub>3</sub>	1.25	19.74	254	238.7	25.8	26.38	75.27	46.27	-2.5	29.60

**Table 5.1: C.O.P., pressure and temperature for R290/R600a refrigerant and nanorefrigerants for flow rate 3.4 LPH and at heat flux 25-26 <sup>0</sup>C**

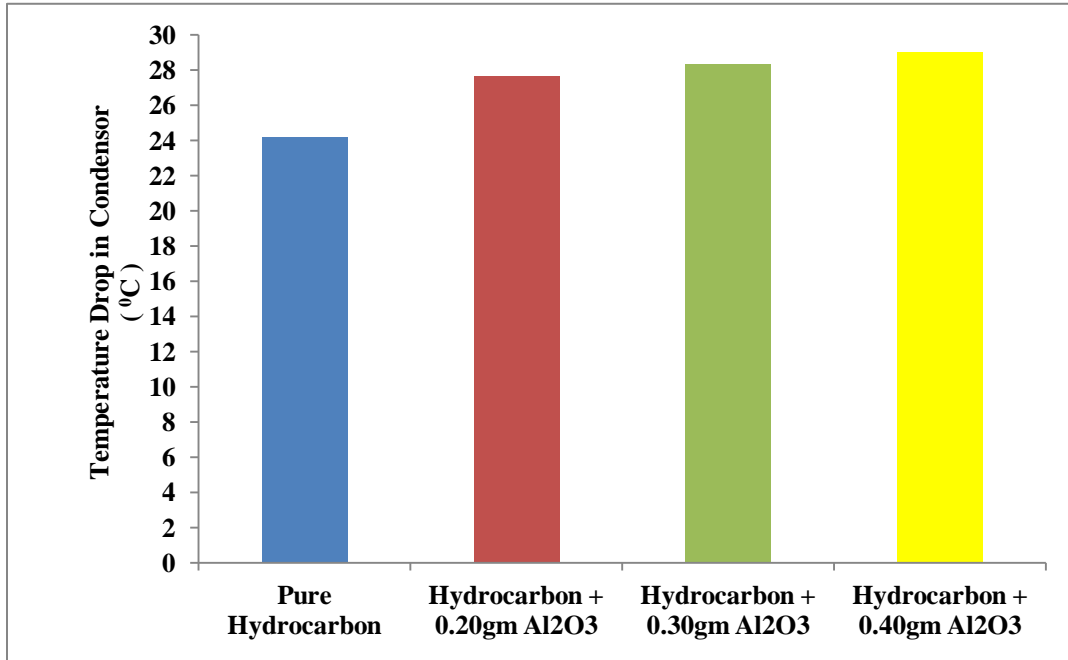
Refrigerant	Evaporator Temperature load at (35-36 °C)									
	C.O.P	P1 (kg/ cm <sup>2</sup> )	P2 (kg/ cm <sup>2</sup> )	P3 (kg/ cm <sup>2</sup> )	P4 (kg/ cm <sup>2</sup> )	T1 (°C)	T2 (°C)	T3 (°C)	T4 (°C)	T <sub>atm</sub>
Pure R290/R600a	1.9	20.38	244.76	234.15	26.69	34.19	81.96	49.15	-1	28.27
R290/R600a + 0.20gm Al <sub>2</sub> O <sub>3</sub>	1.97	20.38	256.92	246.92	26.38	34	84.65	47.8	-1.25	29.69
R290/R600a + 0.30gm Al <sub>2</sub> O <sub>3</sub>	2.13	20.69	258.62	248.3	27.29	34.55	85.48	47.56	-2.12	30
R290/R600a + 0.40gm Al <sub>2</sub> O <sub>3</sub>	2.3	21	260.32	249.68	28.2	35.1	86.32	47.32	-3	30.31

**Table 5.2- C.O.P., pressure and temperature of pure R290/R600a and nanorefrigerant for 3.4 LPH flow rate and at heat flux 35-36 °C.**

### **5.1 TEMPERATURE DROP IN CONDENSER**

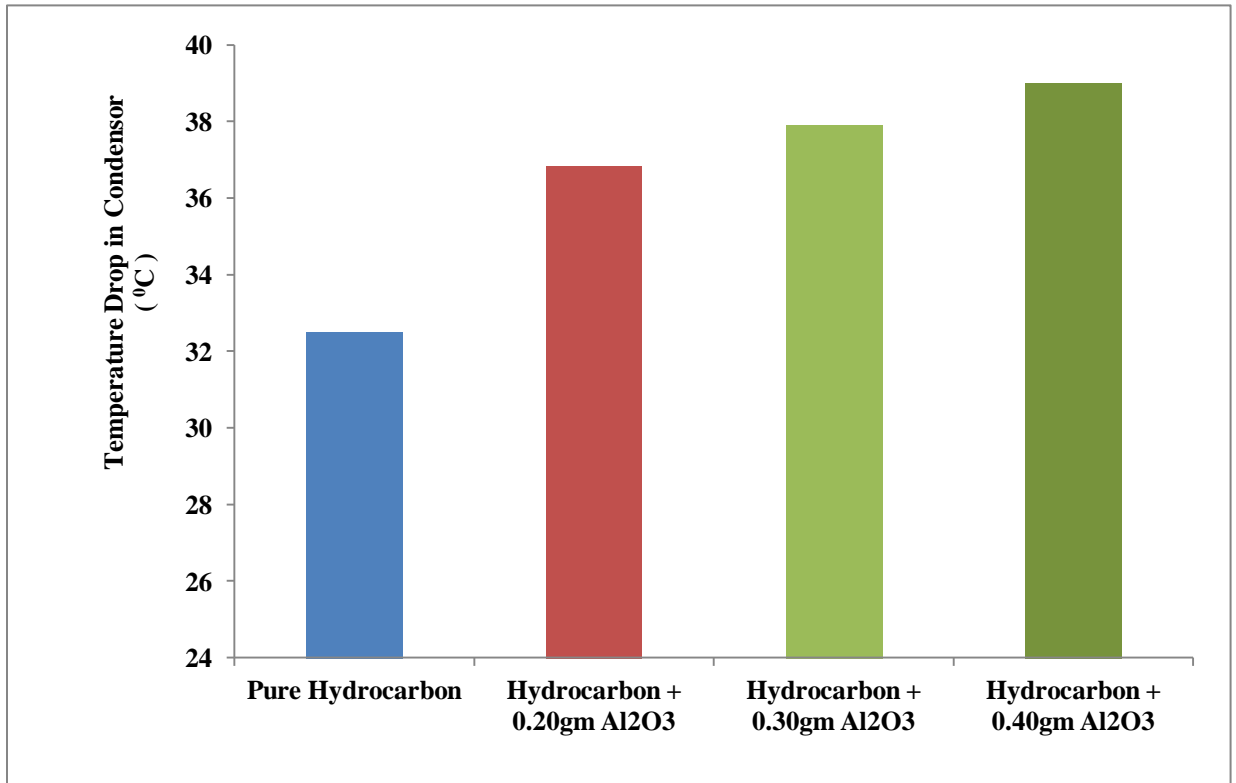
The condenser consist of coil of pipes in which the high pressure and high temperature vapor refrigerant is condensed and cooled at constant pressure. Temperature drop is the difference between the temperature of refrigerant at inlet of condenser and at outlet of condenser. Higher the temperature drop in condenser more is the heat rejected to the environment and higher the refrigeration effect. The heat is first transferred to the walls of the condenser tubes and then to the cooling medium. In this experimental test-rig the cooling medium is ambient air and the mode of heat transfer is natural convection. Sometimes, after condensation process refrigerant is cooled below saturation temperature before expansion, such process is called subcooling of the refrigerant. The resulting effect

of subcooling is to increase the value of coefficient of performance. In following study temperature drop for refrigerant across the condenser has been studied.



**Fig. 5.1: Temperature drop in condenser for nanorefrigerant at 3.4 LPH volume flow rate and at evaporator heat flux 25-26 °C**

Fig.3.1 shows a temperature drop in condenser for 3.4 LPH volume flow rate of nanorefrigerant when a constant evaporator heat load is maintained at 25-26 °C and at ambient temperature of 30°C±2°C. For R290/R600a hydrocarbon refrigerant temperature reduction in condenser is 24.16 °C, whereas with nanorefrigerant R290/R600a+0.20gm Al<sub>2</sub>O<sub>3</sub>, R290/R600a+0.30gm Al<sub>2</sub>O<sub>3</sub> and R290/R600a+0.40gm Al<sub>2</sub>O<sub>3</sub> temperature drop found to be 27.64 °C, 28.32 °C and 29 °C respectively. Therefore, a 14.4% more temperature drop with refrigerant R290/R600a+0.20gm Al<sub>2</sub>O<sub>3</sub> and 17.21% more temperature drop with refrigerant R290/R600a+0.30gm Al<sub>2</sub>O<sub>3</sub> and 20% more temperature drop with refrigerant R290/R600a+0.40gm Al<sub>2</sub>O<sub>3</sub>, has been observed compared to temperature drop in case of pure R290/R600a refrigerant and hence more improvement as compared to pure R290/R600a refrigerant.



**Fig. 5.2: Temperature drop in condenser for nanorefrigerant at 3.4 LPH volume flow rate and at evaporator heat flux 35-36 °C**

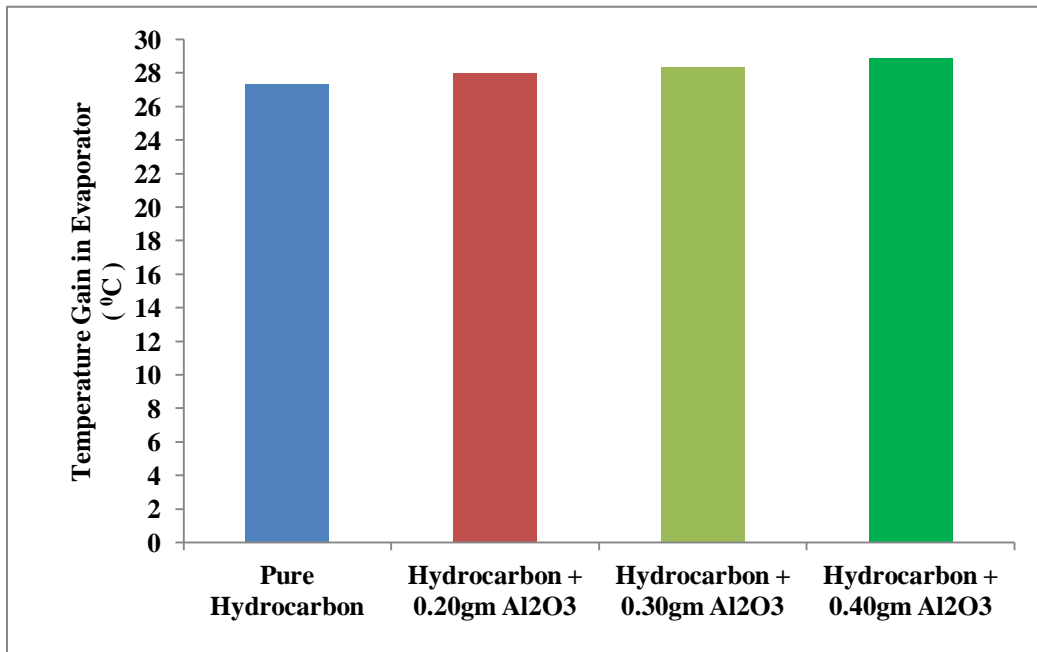
Same trend has been observed with 35-36 °C evaporator heat load and at ambient temperature of 30°C±2°C. For R290/R600a hydrocarbon refrigerant temperature reduction in condenser temperature is 32.5 °C, whereas with refrigerant R290/R600a+0.20gm Al<sub>2</sub>O<sub>3</sub>, R290/R600a+0.30gm Al<sub>2</sub>O<sub>3</sub> and R290/R600a+0.40gm Al<sub>2</sub>O<sub>3</sub> temperature drop is 36.85 °C, 37.92 °C and 39 °C respectively. Fig. 3.2 Shows a 13.38% more temperature drop with refrigerant R290/R600a+0.20gm Al<sub>2</sub>O<sub>3</sub> and 16.67% increase in temperature drop with refrigerant R290/R600a+0.30gm Al<sub>2</sub>O<sub>3</sub> and 20% more temperature drop with refrigerant R290/R600a+0.40gm Al<sub>2</sub>O<sub>3</sub> as compared to pure hydrocarbon refrigerant.

Therefore results shows that there is more temperature drop in condenser in case of nanorefrigerant used in refrigeration system i.e. improved heat transfer by rejecting more heat in condenser which enhances the refrigeration in the system. Investigating of Al<sub>2</sub>O<sub>3</sub>

based refrigerant shows more heat transfer as compared to pure refrigerant at all concentrations. This is due to the higher thermal conductivity of  $\text{Al}_2\text{O}_3$ . So it is concluded that the effects of above mentioned nanorefrigerant is to increase the heat rejection in condenser in the refrigeration system.

## 5.2 TEMPERATURE GAIN IN EVAPORATOR

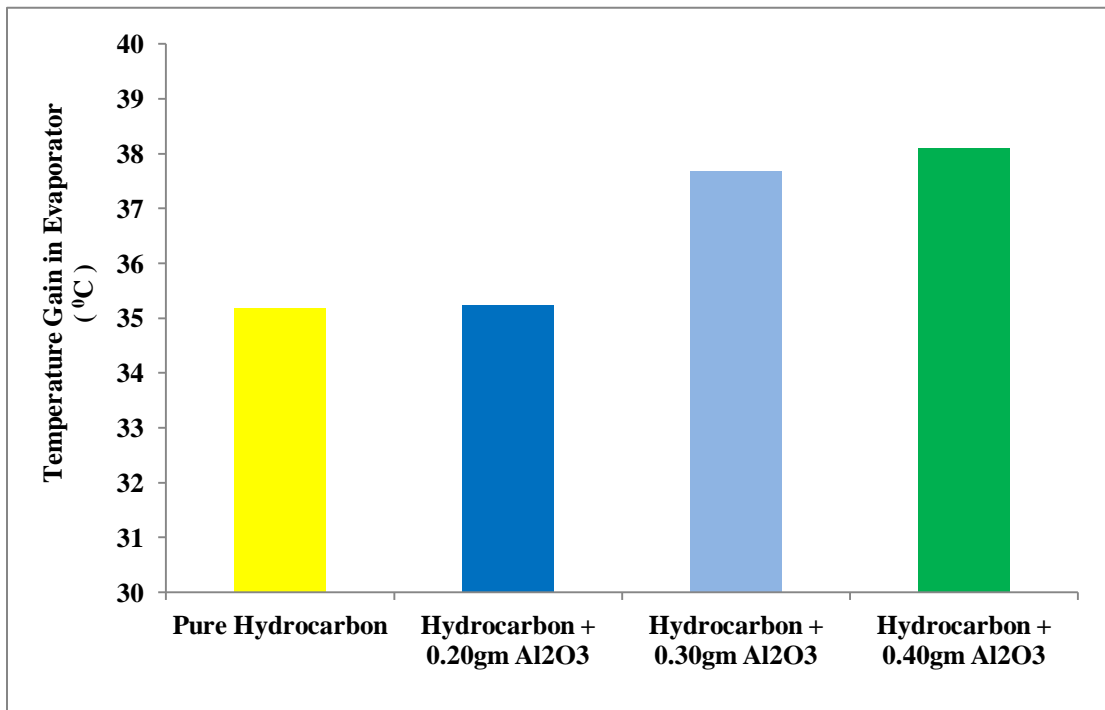
After expansion, low pressure and temperature liquid-vapour mixture enters into the evaporator, where it evaporates at constant pressure and temperature. In evaporation process refrigerant absorbs its latent heat of vaporization from the medium to be cooled as water in this experiment. Temperature gain in evaporator is the difference of evaporator outlet temperature and inlet temperature. Higher the gain in the evaporator temperature higher is the heat carried by the refrigerant hence better is the performance of evaporator.



**Fig 5.3: Temperature gain in evaporator for nanorefrigerants at 3.4 LPH volume flow rate and at 25-26 °C heat flux**

Fig.3.3 shows temperature gain in evaporator for 3.4 LPH volume flow rate of the refrigerant where evaporator is maintained at constant heat load at 25-26 °C & at ambient temperature of  $30^{\circ}\text{C}\pm 2^{\circ}\text{C}$ . For pure R290/R600a hydrocarbon refrigerant temperature

gain in evaporator is  $27.36\text{ }^{\circ}\text{C}$ , whereas with refrigerant R290/R600a+0.20gm  $\text{Al}_2\text{O}_3$ , hydrocarbon+0.30gm  $\text{Al}_2\text{O}_3$  and R290/R600a+0.40gm  $\text{Al}_2\text{O}_3$  the temperature gain is  $28\text{ }^{\circ}\text{C}$ ,  $28.35\text{ }^{\circ}\text{C}$  and  $28.88\text{ }^{\circ}\text{C}$  respectively. So a 2.33% more gain in temperature with refrigerant R290/R600a+0.20gm  $\text{Al}_2\text{O}_3$ , 3.61% more gain in temperature with refrigerant R290/R600a+0.30gm  $\text{Al}_2\text{O}_3$  and 5.55% more gain in temperature with refrigerant R290/R600a+0.40gm  $\text{Al}_2\text{O}_3$  in evaporator has been observed compared to temperature gain for a pure R290/R600a refrigerant.



**Fig 5.4: Temperature gain in evaporator for nanorefrigerants at 3.4 LPH volume flow rate and at  $35\text{-}36\text{ }^{\circ}\text{C}$  heat flux**

Same trend has been observed when evaporator heat flux is maintained at  $35\text{-}36\text{ }^{\circ}\text{C}$ . Fig.3.4 shows temperature gain in evaporator for 3.4 LPH volume flow rate of the refrigerant where evaporator is maintained at constant heat load at  $35\text{-}36\text{ }^{\circ}\text{C}$  & at ambient temperature of  $30^{\circ}\text{C}\pm 2^{\circ}\text{C}$ . For pure R290/R600a hydrocarbon refrigerant temperature gain in evaporator is  $35.19\text{ }^{\circ}\text{C}$ , whereas with refrigerant R290/R600a+0.20gm  $\text{Al}_2\text{O}_3$ , R290/R600a+0.30gm  $\text{Al}_2\text{O}_3$  and R290/R600a+0.40gm  $\text{Al}_2\text{O}_3$  the temperature gain is

35.25 °C, 37.675 °C and 38.1 °C respectively. So a 0.17% more gain in temperature with refrigerant R290/R600a+0.20gm Al<sub>2</sub>O<sub>3</sub>, 7.06% more gain in temperature with refrigerant R290/R600a+0.30gm Al<sub>2</sub>O<sub>3</sub> and 8.26% more gain in temperature with refrigerant R290/R600a+0.40gm Al<sub>2</sub>O<sub>3</sub> in evaporator has been observed compared to temperature gain for a pure hydrocarbon refrigerant.

Therefore from above it is concluded that use of nanorefrigerant enhance the heat transfer rate and hence improve the temperature gain in evaporator.

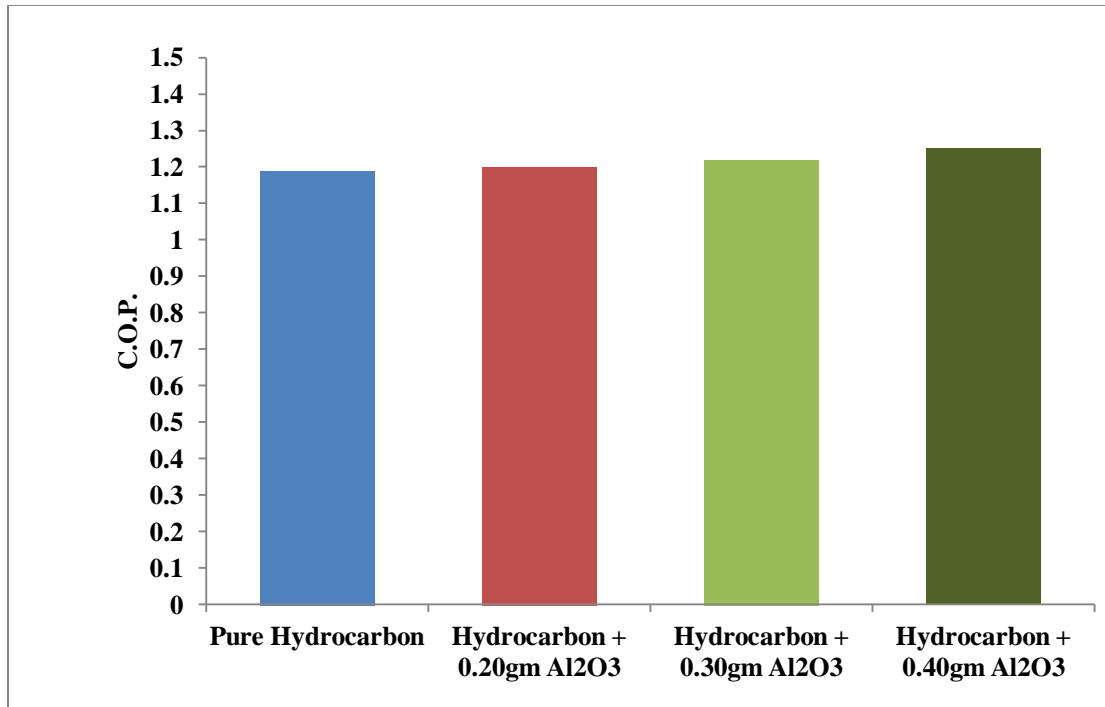
### **5.3 COEFFICIENT OF PERFORMANCE (C.O.P.)**

C.O.P. is defined as the ratio of refrigeration effect and work supply to the system. In this case C.O.P. is the ratio of power required by heater submerged in water and power consumed by the compressor.

$$\text{C.O.P.} = \frac{\text{Refrigeration Effect}}{\text{Power Input}}$$

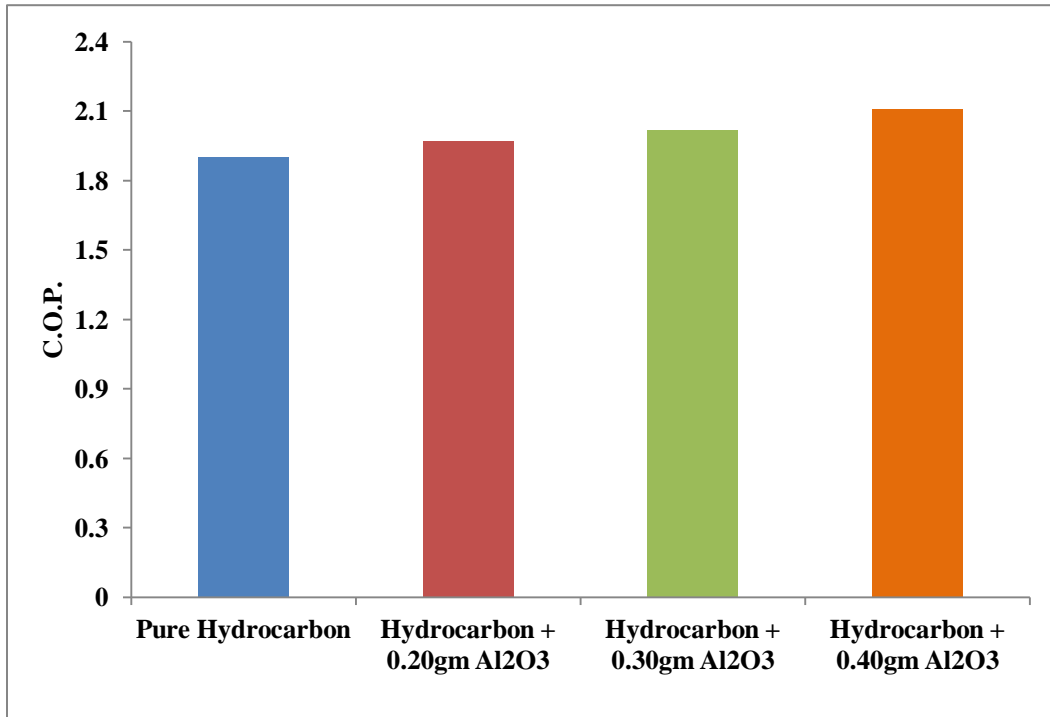
C.O.P. is highly influenced by the operating conditions, mainly ambient temperature and source and sink temperatures of the system. Here in his experimental setup actual COP of the system has been investigated.

In present study, C.O.P. of pure R290/R600a refrigerant and nanorefrigerant of the system has been studied. First readings are taken for pure R290/R600a refrigerant at volume flow rate 3.4 LPH and at heat flux 25-26 °C at ambient temperature 30°C±2°C and then readings are taken for nanorefrigerants R290/R600a+0.20gm Al<sub>2</sub>O<sub>3</sub>, R290/R600a+0.30gm Al<sub>2</sub>O<sub>3</sub> and R290/R600a+0.40gm Al<sub>2</sub>O<sub>3</sub>. Similarly readings are taken at heat flux 35-36 °C at same flow rate. Hence performance will be evaluated.



**Fig 5.5: C.O.P. comparison for nanorefrigerants at 3.4 volume flow rate and heat flux at 25-26 °C**

Fig 3.5 shows that C.O.P. of pure R290/R600a hydrocarbon refrigerant is found to be 1.19 whereas C.O.P. of nanorefrigerants R290/R600a+0.20gm Al<sub>2</sub>O<sub>3</sub>, R290/R600a+0.30gm Al<sub>2</sub>O<sub>3</sub> and R290/R600a+0.40gm Al<sub>2</sub>O<sub>3</sub> is found to be 1.2, 1.22 and 1.25. So there is a 0.84% improvement in C.O.P. for refrigerant R290/R600a+0.20gm Al<sub>2</sub>O<sub>3</sub>, 2.52% improvement in C.O.P. for refrigerant R290/R600a+0.30gm Al<sub>2</sub>O<sub>3</sub> and 5.04% improvement in C.O.P. for refrigerant R290/R600a+0.40gm Al<sub>2</sub>O<sub>3</sub> as compared to pure R290/R600a refrigerant.



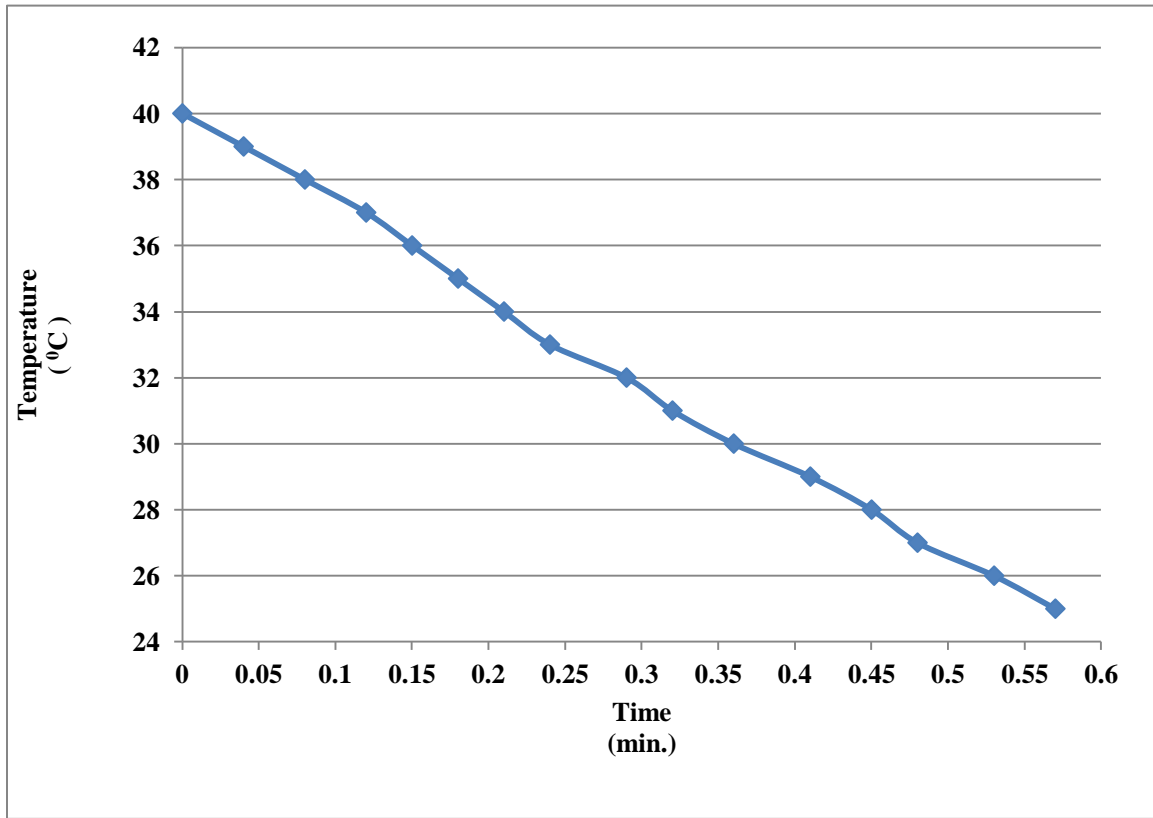
**Fig 5.6: C.O.P. comparison for nanorefrigerants at 3.4 volume flow rate and heat flux at 35-36 °C**

Same study has been performed at 3.4 LPH volume flow rate and at heat flux 35-36 °C and ambient temperature 30°C±2°C. As shown in fig. 6.6, the C.O.P. of the pure R290/R600a hydrocarbon is 1.9 whereas C.O.P. of nanorefrigerants R290/R600a+0.20gm Al<sub>2</sub>O<sub>3</sub>, R290/R600a+0.30gm Al<sub>2</sub>O<sub>3</sub> and R290/R600a+0.40gm Al<sub>2</sub>O<sub>3</sub> is found to be 1.97, 2.02 and 2.11. So there is 3.68% improvement in C.O.P. for refrigerant R290/R600a+0.20gm Al<sub>2</sub>O<sub>3</sub>, 6.3% improvement in C.O.P. for refrigerant R290/R600a+0.30gm Al<sub>2</sub>O<sub>3</sub> and 11.05% improvement in C.O.P. for refrigerant R290/R600a+0.40gm Al<sub>2</sub>O<sub>3</sub> as compared to pure R290/R600a hydrocarbon refrigerant. Hence there is increase in C.O.P. of the system with the use of nanoparticles.

#### **5.4 TEMPERATURE-TIME GRAPH**

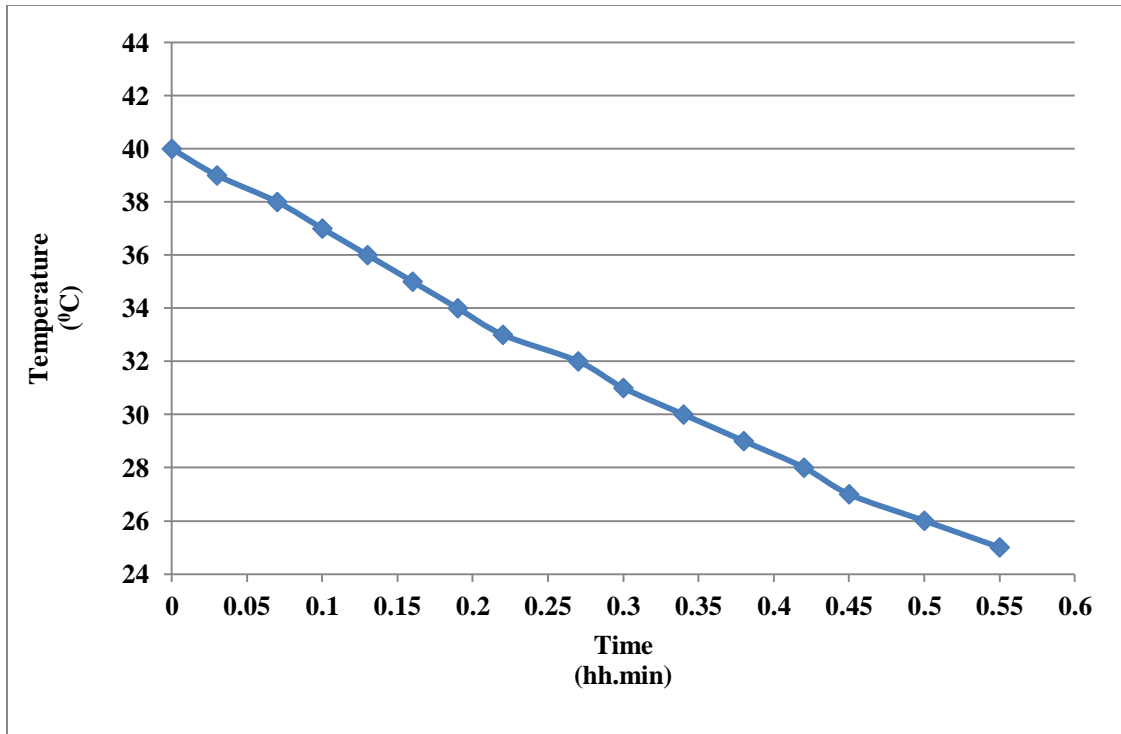
An experimental study has been done to estimate the cooling capacity of the refrigeration system. Firstly the temperature of the water in the evaporator is increased to 40°C with the help of heater after that heater is disconnected so that temperature of water can start drop to 25°C. The time will be noted down with every single drop in °C temperature. And

performance will be evaluated for pure R290/R600a refrigerant and nanorefrigerants. Lesser the time taken by system more efficient is the system.



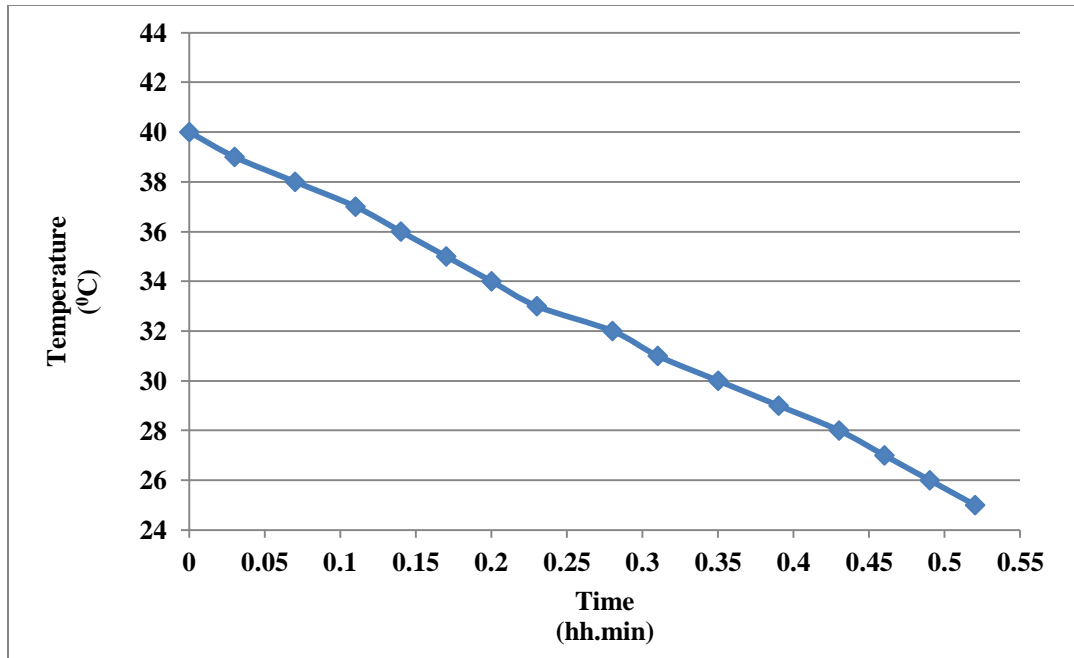
**Fig 5.7: Temperature-Time graph for Pure R290/R600a Hydrocarbon at 3.4 LPH Volume Flow Rate**

Fig 3.7 shows the temperature-time analysis for pure R290/R600a hydrocarbon refrigerant at 3.4 LPH volume flow rate at  $30^{\circ}\text{C}\pm 2^{\circ}\text{C}$  ambient temperature. In this study it is found that pure hydrocarbon refrigerant takes 57 min to drop temperature from  $40^{\circ}\text{C}$  to  $25^{\circ}\text{C}$ .



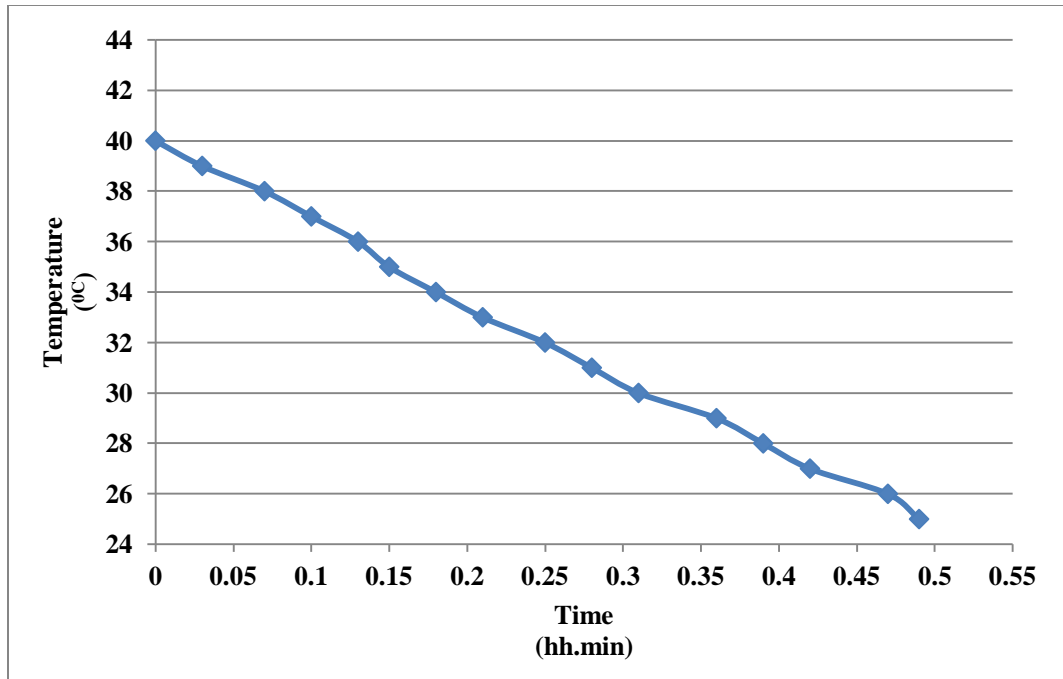
**Fig 5.8: Temperature-Time graph for R290/R600a+0.20gm Al<sub>2</sub>O<sub>3</sub> at 3.4 LPH volume flow rate**

Fig 3.8 shows the temperature-time analysis for R290/R600a+0.20gm Al<sub>2</sub>O<sub>3</sub> refrigerant at 3.4 LPH volume flow rate at 30<sup>0</sup>C±2<sup>0</sup>C ambient temperature. In this study it is found that this nanorefrigerant takes 55 min to drop temperature from 40<sup>0</sup>C to 25<sup>0</sup>C.



**Fig 5.9: Temperature-Time graph for R290/R600a+0.30gm Al<sub>2</sub>O<sub>3</sub> at 3.4 LPH volume flow rate**

Fig 3.9 shows the temperature-time analysis for R290/R600a+0.30gm Al<sub>2</sub>O<sub>3</sub> refrigerant at 3.4 LPH volume flow rate at 30<sup>0</sup>C±2<sup>0</sup>C ambient temperature. In this study it is found that this nanorefrigerant takes 52 min to drop temperature from 40<sup>0</sup>C to 25<sup>0</sup>C.

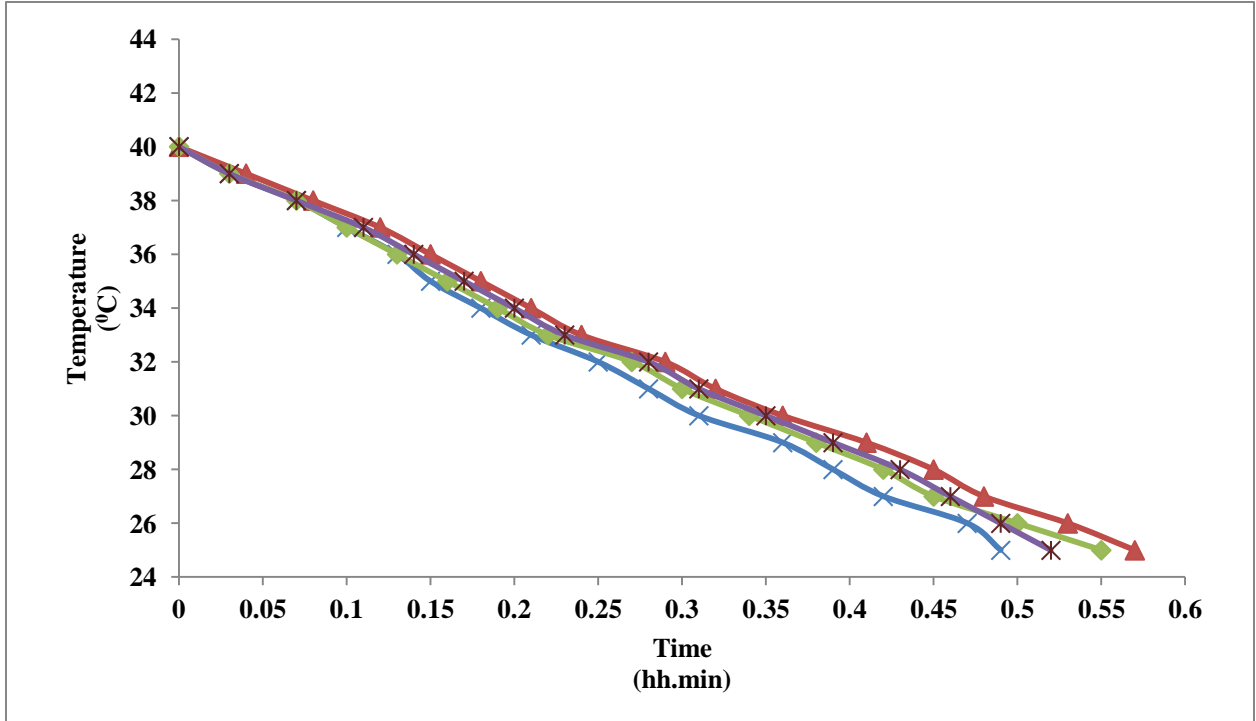


**Fig. 5.10: Temperature-Time graph for R290/R600a+0.40gm Al<sub>2</sub>O<sub>3</sub> at 3.4 LPH volume flow rate**

Fig. 3.10 shows the temperature-time analysis for R290/R600a+0.40gm Al<sub>2</sub>O<sub>3</sub> refrigerant at 3.4 LPH volume flow rate at 30°C±2°C ambient temperature. In this study it is found that this nanorefrigerant takes 49 min to drop temperature from 40°C to 25°C.

### 5.5 Overall cooling load temperature-time analysis for pure refrigerant and Al<sub>2</sub>O<sub>3</sub> based nanorefrigerant

In this section the time analysis of the system with different nanorefrigerants has been compared in a single graph. The result shows that as the concentration of nanoparticles increase in refrigerant the time taken to achieve desired temperature is also reduced.

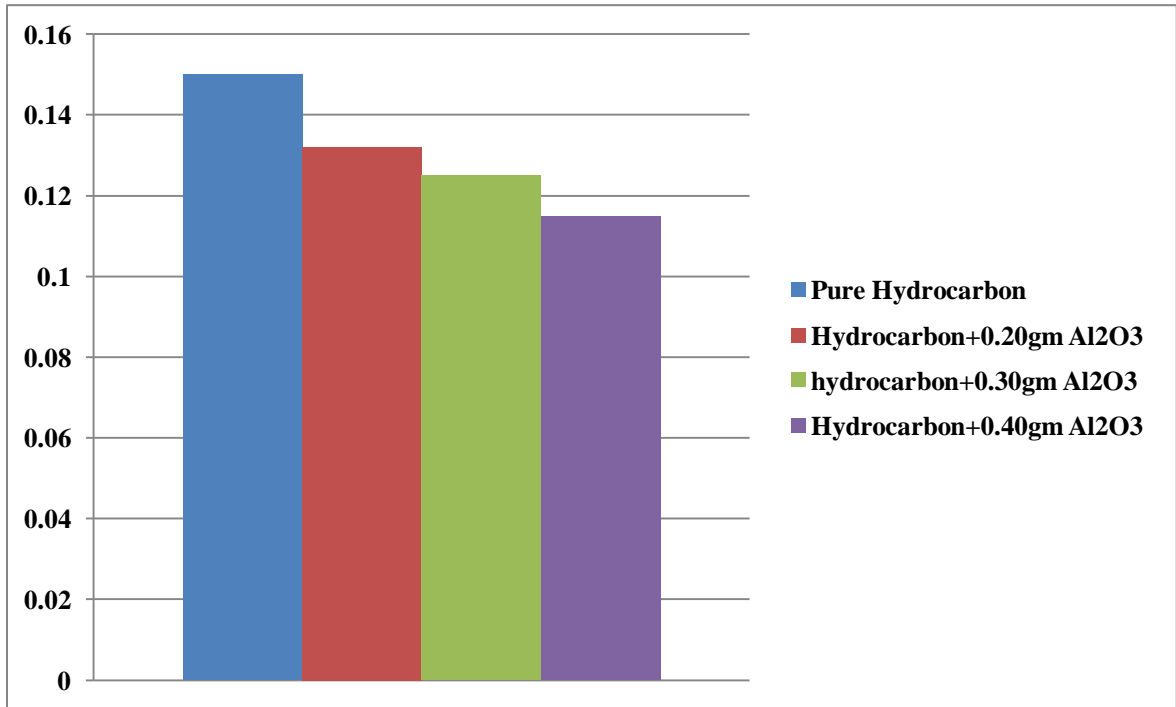


**Fig 5.11: Overall cooling load temperature-time graph for pure refrigerant and nanorefrigerant at 3.4 LPH volume flow rate**

Fig 5.11 shows the difference of time for pure refrigerant and nanorefrigerants at 3.4 LPH volume flow rate. Therefore it has proven that as the concentration of nanoparticle increases the time taken to temperature drop decreases.

## 5.6 Power consumption for temperature-time analysis

Since power consumption by the system is main concerned for a system to evaluate the C.O.P. of system. In this section power consumed by compressor to drop temperature from 40<sup>0</sup>C to 25<sup>0</sup>C has been observed for pure R290/R600a hydrocarbon refrigerant, R290/R600a+0.20gm Al<sub>2</sub>O<sub>3</sub>, R290/R600a+0.30gm Al<sub>2</sub>O<sub>3</sub> and R290/R600a+0.40gm Al<sub>2</sub>O<sub>3</sub> nanorefrigerant.



**Fig 5.12: Power consumption by pure R290/R600a hydrocarbon refrigerant and nanorefrigerants for temperature drop from 40<sup>0</sup>C to 25<sup>0</sup>C**

Fig 3.10 shows power consumption for 40<sup>0</sup>C to 25<sup>0</sup>C temperature drop at 3.4 LPH volume flow rate with ambient condition 30<sup>0</sup>C±2<sup>0</sup>C. In this it is found that pure R290/R600a hydrocarbon consumes 0.150KWh power to drop in temperature from 40<sup>0</sup>C to 25<sup>0</sup>C whereas R290/R600a+0.20gm Al<sub>2</sub>O<sub>3</sub> nanorefrigerant consumes 0.132 KWh power, R290/R600a+0.30gm Al<sub>2</sub>O<sub>3</sub> nanorefrigerant consumes 0.125 KWh power and R290/R600a+0.40gm Al<sub>2</sub>O<sub>3</sub> nanorefrigerant consumes 0.112 KWh power. So there is 13.6% reduction in power consumption by R290/R600a+0.20gm Al<sub>2</sub>O<sub>3</sub> nanorefrigerant as compared to pure R290/R600a hydrocarbon refrigerant. Reduction in power consumption for R290/R600a+0.30gm Al<sub>2</sub>O<sub>3</sub> and R290/R600a+0.40gm Al<sub>2</sub>O<sub>3</sub> nanorefrigerant is found to be 20% and 30.4%. it has been observed that the increase

concentration of  $\text{Al}_2\text{O}_3$  nanoparticles in refrigerant has result in decrease power consumption of the system.

**CONCLUSION AND FUTURE SCOPE**

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**6.1 Conclusions**

The present research work entitled “An Experimental Investigation into the Performance of a Nanorefrigerant (R290/R600a+Al<sub>2</sub>O<sub>3</sub>) Based Refrigeration System” was aimed at, to use nanoparticles in conjunction with hydrocarbon refrigerant. It has been decided to use nanoparticles Al<sub>2</sub>O<sub>3</sub> of size 20-30 nm size. Different concentrations of nanoparticles were taken to investigate the performance of a refrigeration system.

- (i) The system was charged with nanorefrigerant R290/R600a+Al<sub>2</sub>O<sub>3</sub> 0.20 gm mass, 0.30gm mass and 0.40 gm mass of nanoparticles
- (ii) Readings were taken at 3.4LPH volume flow rate and for two heat fluxes in evaporator at temperature 25–26 °C and 35–36 °C
- (iii) Temperature drop in condenser, temperature gain in evaporator, COP for the system and temperature-time chart were studied for pure refrigerant and nanorefrigerant at all concentrations.
- (iv) It was found that addition of Al<sub>2</sub>O<sub>3</sub> nanoparticles to the refrigerant results in improvement in the thermo physical properties and heat transfer properties of the refrigeration system
- (v) It was observed that there is more temperature drop across the condenser for the nanorefrigerant (14.4% – 20%) compared to refrigerant R290/R600a. Similarly, a gain of (2.33%- 5.55%) was obtained for evaporator temperature. An improvement in COP was also observed during the investigations (3.68% – 11.05%). This was achieved under evaporator constant load at 25-26<sup>0</sup>C
- (vi) Similar results were also observed when refrigeration system is operated at heat load 35–36<sup>0</sup>C evaporator temperature.
- (vii) A reduction in the power consumption (13.6% to 30.4%) along with temperature drop (from 40<sup>0</sup>C – 25<sup>0</sup>C) is also achieved when nanorefrigerants are used

- (viii) The experimental studies indicated that refrigeration system doesn't suffer with nanorefrigerant and works normal like any conventional refrigeration system
- (ix) Refrigerating effect increase with the increase in concentration (0.20gm to 0.40gm) of nanoparticles in refrigerant.

## **6.2 Future scope**

The present research work was aimed at only one type of nanoparticle, three concentrations and single refrigerant. But there are number of other parameters are also exist which can be varied and system performance can be evaluated.

- (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) By using digital temperature and pressure gauges and other Sensors to make the system more accurate.
- (iv) System can be investigated with different flow rates, different evaporator loads, at different environment conditions with different amount of refrigerants.
- (v) Nanoparticles can be used in the evaporator water or in evaporator loading system
- (vi) System can also be made to work with nanoparticles in lubricant oil.

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## APPENDIX

Temp (°C)	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25
Time (min)	0	4	8	12	15	18	21	24	29	32	36	41	45	48	53	57
P1	21	21	21	21	21	21	21	20.5	21	21	21	21	20.5	20	20	20
P2	235	234	235	235	235	235	236	236	237	240	241	236	236	234	235	235
P3	225	224	225	225	225	225	226	226	226	230	230	225	226	224	225	225
P4	28	28	28	28	27.5	27.5	27.5	27.5	28	28	28	27.5	27.5	27	26	26
T1	37	37	36	35	34.5	34	33	32.5	31.5	30.5	30	29	28.5	27.5	27	26
T2	76	76	77	77	77.5	77.5	77.5	32.5	78.5	78.5	78.5	78.5	78.5	78	78	78
T3	49	48	48.5	48.5	48.5	48.5	48	77.5	49	49.5	49.5	48.5	48.5	48	48	48
T4	0	0	0	0	-0.5	-0.5	-0.5	-1	-1	-0.5	-0.5	-1	-1	-1	-1.5	-1.5
Tatm	28	28	28	28	28	28	28.5	28.5	28.5	28.5	28.5	28.5	29	29	29	29
Ecom p	101.8															101.95

**Table A1: Temperature drop from 40°C to 25°C for pure R290/R600a refrigerant**

Temp (°C)	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25
Time (min)	0	3	7	10	13	16	19	22	27	30	34	38	42	45	50	55
P1	21	21	21	21	21	21	21	20.5	21	21	21	20.5	20.5	20.5	20.5	20.5
P2	264	265	265	265	265	264	259	256	260	262	260	259	257	255	257	258
P3	255	252	253	255	252	251	248	244	250	250	248	245	245	245	245	246
P4	28	28	28	28	28	28	28	27.5	28	28	28	27.5	27.5	27.5	27	27
T1	27	27	26	28.5	28.5	27	28	26.5	28.5	27	27.5	27	27	27	26	26
T2	82.5	83	83	83	83	82.5	83	82	83.5	83	82.5	83	83	83	81.5	81.5
T3	50	49.5	49.5	49.5	49.5	49	48.5	48	48.5	49	48.5	48.5	48.5	47.5	48	48
T4	-1	-1	-1	-1	-1	-1	-1	-1.5	-1	-1	-1	-1.5	-1.5	-1.5	-1.5	-1.5
Tatm	30	30	30	30	30	30	30.5	30.5	30.5	30.5	30.5	30	31	31	31	31
Ecom p	103. 52															103. 652

**Table A2: Temperature drop from 40<sup>0</sup>C to 25<sup>0</sup>C for refrigerant R290/R600a + 0.20gm Al<sub>2</sub>O<sub>3</sub>**

Temp (°C)	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25
Time (min)	0	3	7	10	13	16	19	22	26	29	33	36	40	43	48	52
P1	21	21	21	21	21	21	20.5	20.5	21	21	21	20.5	21	21	20.5	20.5
P2	266	267	267	267	267	266	261	258	262	264	262	261	259	257	259	260
P3	257	255	256	256	254	253	250	246	252	252	250	248	248	247	247	247
P4	28	28	28	28	28	28	27.5	27.5	28	27.5	28	27.5	28	27.5	27.5	27
T1	27	26.5	26	27.5	27.5	26.5	26.5	26.5	27	27	27.5	26.5	27	27	26	26
T2	82.5	83	83	83	83	82.5	81	80.5	81	81.5	82.5	82	81.5	81	82	82.5
T3	48	48.5	48.5	48.5	48.5	48	47.5	47	47.5	48	47.5	47.5	47.5	46.5	47	47
T4	-1	-1	-1	-1	-1	-1	-1	-1.5	-1.5	-1.5	-1	-1.5	-1.5	-1.5	-1.5	-1.5
Tatm	29	29.5	29.5	29.5	29.5	29.5	30	30	30	30	30	30	30.5	30.5	30.5	30.5
Ecom p	103. 82															103. 945

**Table A3: Temperature drop from 40<sup>0</sup>C to 25<sup>0</sup>C for refrigerant R290/R600a + 0.30gm Al<sub>2</sub>O<sub>3</sub>**

Temp (°C)	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25
Time (min)	0	3	7	10	13	15	18	21	25	28	31	36	39	42	47	50
P1	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
P2	269	269	268	270	270	270	271	272	270	271	270	269	273	270	270	270
P3	258	258	257	259	259	259	259	260	259	260	259	258	262	259	259	259
P4	28	28	28	28	28	28	28	27.5	28	28	28	27.5	27.5	27.5	27	27
T1	36.5	36.5	36	35	34.5	33.5	33	32	31.5	30.5	30	29	28	27.5	26	25.5
T2	82	82.5	82.5	82.5	82.5	83	83.5	84	83.5	83.5	83.5	83.5	83.5	83.5	83.5	83.5
T3	46	45.5	46.5	46	46	46	46	46.5	45.5	45.5	45.5	45.5	46	46	46	46
T4	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-2	-2	-1.5	-1.5	-1.5	-1.5	-1.5
Tatm	28.5	28.5	28.5	28.5	28.5	29	29	29	29	29	29	29.5	29.5	29.5	29.5	29.5
Ecomp	104.96															105.07

**Table A4: Temperature drop from 40°C to 25°C for refrigerant R290/R600a + 0.40gm Al<sub>2</sub>O<sub>3</sub>**