Experimental Investigation on the Performance of Domestic Vapour Compression Refrigeration Systems with the Usage of Nanorefrigerants.

Dissertation-II

Submitted in partial fulfillment of the requirement for the award of degree

Of

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THERMAL ENGINEERING

By

Mohd Waheed Bhat

(11617047)

Under the guidance of

Gaurav Vyas

UID 17703

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LOVELY PROFESSIONAL UNIVERSITY
PUNJAB

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SR.NO.	NAME OF STUDENT	REGISTRATION NO	BATCH	SECTION	CONTACT NUMBER
1	Mohd Waheed Bhat	11617047	2016	M1673	7696517012

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DAA Nominee Name: Kamal Hassan	UID: 17469	Recommended (Y/N): NA

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CERTIFICATE

I hereby certify that the work being presented in the dissertation entitled "***Experimental Investigation on the Performance of Domestic Vapour Compression Refrigeration Systems with the Usage of Nanorefrigerants*** " in partial fulfillment of the requirement of the award of the Degree of master of technology and submitted to the Department of Mechanical Engineering of Lovely Professional University, Phagwara, is an authentic record of my own work carried out under the supervision of (Gaurav Vyas, Assistant Professor) Department of Mechanical Engineering, Lovely Professional University. The matter embodied in this dissertation has not been submitted in part or full to any other University or Institute for the award of any degree.

(23 November 2017)

(Mohd Waheed Bhat)
11617047

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

(23 November 2017)

(Gaurav Vyas)
(17703)

COD (ME)

The external viva-voce examination of the student was held on successfully ________________

Signature of Examiner

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Mohd Waheed Bhat

(11617047)

ABSTRACT

The demand for energy is increasing dramatically, therefore energy conservation and reduction of emissions become compulsory for sustainable development. However, the enormous development in technology has led to energy shortage and environmental global warming. Domestic refrigerators have been identified as huge emission contributor globally due to usage of high Ozone Depleting and Global Warming Potential Chlorine or Fluorine based refrigerants. Globally about 12% of total energy budget is consumed to run domestic refrigerators working on R134a refrigerant. In India R134a refrigerant is used in 90% of the refrigeration systems such as refrigerators, deep freezers. Among the refrigeration systems, Vapour Compression Refrigeration Systems find wide applications in domestic and Industrial needs. From literature survey, it has been found that usage of Hydrocarbon refrigerants such as R290, R600a etc. have proved to be energy efficient and ecofriendly to the environment. Also, usage of nanoparticles in refrigerants enhances thermophysical properties such as density, thermal conductivity, viscosity and specific heat, therefore increases the performance of refrigeration systems. In this study, the calculation of thermophysical properties of mixed nanorefrigerants have been carried out using NIST database standard 4 (SUPERTRAP®) versions 3.2.1. Obtained results are used to calculate pressure drop and heat transfer characteristics to estimate compressor and evaporator performance. Experimentation and its validation will be done in near future.

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1 Introduction

Due to the massive developments in technology, the demand for energy is increasing dramatically, however energy conservation and reduction of emissions these days became compulsory for sustainable development in terms of energy shortage and environmental global warming protection [1]. Montreal and Kyoto Protocols [2] recognized Domestic refrigerators as an enormous emission contributor globally due to usage of high Ozone Depleting and Global Warming Potential Chlorine or Fluorine based refrigerants [3]. Globally about 12% of total energy budget is consumed to run domestic refrigerators working on R134a refrigerant [4]. In India R134a refrigerant is used in 90% of the refrigeration systems such as refrigerators, deep freezers [5-6]. Among the refrigeration systems, Vapour Compression Refrigeration Systems find wide applications in domestic and Industrial needs. Refrigeration systems are those devices which are used to either cool or maintain a body at a temperature lowers than that of the surroundings. In order to function, heat must flow from a body at low temperature to the surroundings at a temperature higher than that of body and to execute this function, work must be applied externally. So, refrigeration systems are work consuming plants. The examples of work consuming plants includes Domestic Refrigerators, Cold Storage Plants, Central and room air conditioning systems, food freezing plants, air Liquefaction Plants etc.

1.1 Vapour Compression Refrigeration Systems

Vapour Compression Refrigeration Systems is the most commonly used refrigeration system and find wide range of applications in Domestic as well as in Industrial needs. The working fluid in VCRS is known as Refrigerant which undergoes a change in its phase during evaporation and condensation processes.

The refrigerant extracts heat from the body to be maintained at lowers temperature that that of its surroundings from the evaporator part of refrigeration system and throws out to ambient atmosphere in the Condenser part of refrigeration system.

The refrigerant leaving the evaporator is in low pressure vapour form which is compressed to high pressure vapour form by passing through Compressor. The high pressure vapour is then admitted into the condenser where it rejects latent heat of condensation to ambient atmosphere.

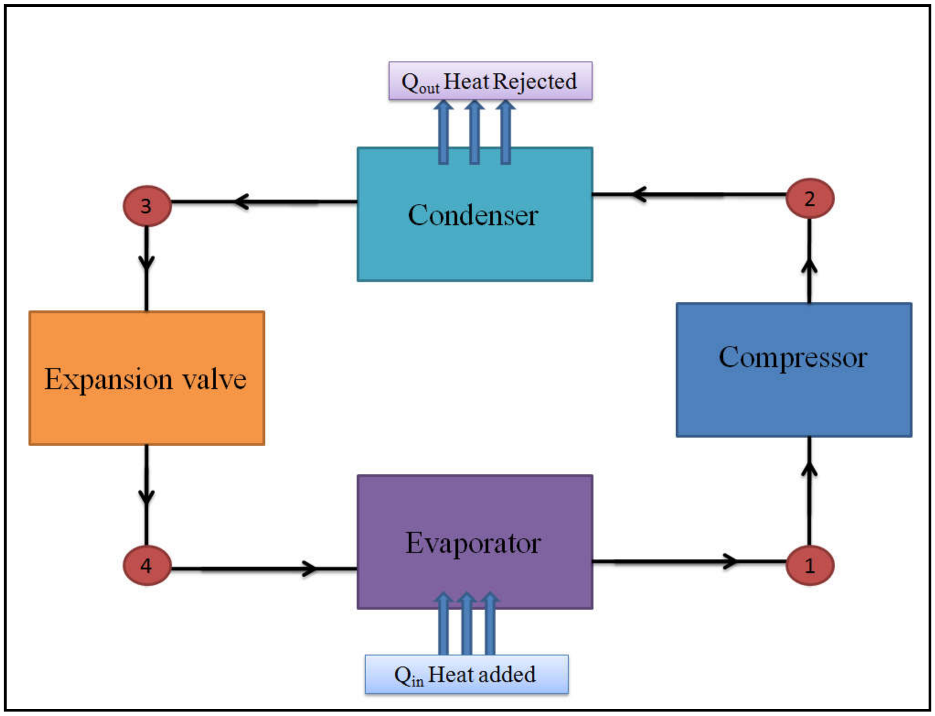

Figure 1 Schematic diagram of VCRS

1.2 Main Components of VCRS

The following are the main Components of VCRS:

- ✓ Evaporator
- ✓ Compressor
- ✓ Condenser
- ✓ Expansion Valve

1.2.1 Evaporator

In this the refrigerant extracts latent heat of vaporization from the body to be maintained at lower temperature than the surroundings and gets converted into vapour phase. The state of refrigerant leaving the evaporator is low temperature, low pressure vapour. The evaporator ideally works on isobaric heat addition process. The evaporation process is shown as 4-1 in figure 1.

Figure 2 Evaporator

1.2.2 Compressor

Before admitting the refrigerant to reject heat to surroundings in condenser, the pressure and temperature of the refrigerant is increased isentropically in the Compressor. During isentropic compression, the volume of the refrigerant gets reduced. The process is carried out with the help of external work given to Compressor. The compression process is shown as 1-2 in figure 1.

Figure 3 Compressor

1.2.3 Condenser

In this, the refrigerant rejects latent heat of condensation to the surroundings and gets converted into high pressure, high temperature liquid. The condensation process takes place at isobaric condition. The refrigerant dissipates heat to outside environment by flowing through condenser tubing. The condensation process is shown as 2-3 in figure 1.

Figure 4 Condenser

1.2.4 Expansion Valve

Process 3-4 in figure 1 represents irreversible adiabatic expansion of saturated refrigerants. The pressure and temperature gets reduced as the refrigerant is passed through the expansion valve. The state of refrigerant leaving the expansion valve is low temperature, low pressure liquid.

Figure 5 Expansion Valve

1.3 Refrigerants

A refrigerant is a substance that absorbs heat through vaporization and losses it through condensation in a refrigeration System. Refrigerants are classified into primary and secondary refrigerants. Examples include R134a, R290, R717, R600a etc.

1.4 Desirable Properties of Refrigerants

The selection of refrigerant for a particular application depends upon satisfying its essential requirements which are classified into Thermodynamic, Physical and Chemical requirements [7].

1.4.1 Thermodynamic Requirements

a) Normal Boiling Temperature

The boiling temperature of the refrigerant should be low at atmospheric pressure. The high boiling temperature reduces the capacity and operating cost of the system.

b) Freezing Point

The freezing point of the refrigerant must be lower than system temperature.

Table 1 Normal Boiling Temperature and Freezing Point of few commonly refrigerants [7]

S. no	Refrigerant	Normal Boiling Temperature (°C)	Freezing Point (°C)
1	R11	23.71	-111
2	R12	-29.8	-136
3	R152a	-24.02	-117
4	R134a	-26.074	-96.6
5	R290	-42.1	187.1
6	R600a	-11.67	159.6

c) Critical Temperature and Pressure

For high COP, Critical Temperature should be very high so that Condenser temperature line on P-h diagram is far removed from the Critical point. The critical pressure should be low so as to result in low condensing pressure.

d) Volume of Suction Vapour

It is an indication of the size of compressor. Reciprocating Compressors are used with refrigerants with high pressures and small volumes of the suction vapor. Centrifugal or Turbo Compressors are used with refrigerants with low pressures and large volumes of the suction vapor.

e) Isentropic Discharge Temperature

It is the temperature of the refrigerant leaving the compressor. The hydrocarbons such as R600a (Isobutane) and R290 (Propane) have lowest discharge temperature among all refrigerants and are therefore suitable for domestic applications.

Table 2 Isentropic Discharge Temperature of few commonly refrigerants [7]

S. no	Refrigerant	Isentropic Discharge Temperature (°C)
1	R11	43
2	R12	38
3	R152a	46.7
4	R134a	37
5	R290	36
6	R600a	30

1.4.2 Chemical Requirements

a) Flammability

None of CFCs are explosive or flammable. Except R134a, all HCFs are flammable. HCs such as Methane, Ethane, Propane and Butane are highly explosive and flammable.

b) Toxicity

Refrigerants have been divided into six groups on the basis on toxicity. First group is most toxic such as SO_2 where as Six group includes Compounds with very low degree of toxicity.

c) Reaction with Oil

Refrigerants such as R12, R152a, and R290and R600a are completely miscible with oil. Refrigerants like ammonia or CO_2 are not miscible with oil. Most fluorocarbons such as R22 are partially miscible with oil in all temperatures and concentrations. R134a is not miscible in mineral oil, accordingly is miscible in polyol-ester (POE).

d) Construction materials

Ammonia attacks copper, however Iron and Aluminum find suitable for use. The recommended material for use in Halocarbons is Copper.

1.4.3 Physical Requirements

a) Dielectric Strength

It is primarily important in hermetically sealed units in which motor is exposed to the refrigerant as the windings are cooled by the suction vapor. Most Fluorocarbons are good insulators.

Table 3 Dielectric Strength of few refrigerants [7]

S.no	Refrigerant	Dielectric Strength
1	R22	1.31
2	NH_3	0.88
3	CO_2	0.82

b) Leak Detection

The leak detection of refrigerant should be easy. Ammonia refrigerant is easily detected by its pungent odour while as fluorocarbons are odourless due to which there is complete loss of refrigerant without being detected. Also the leak tendency of refrigerants should be nil.

1.4.4 Thermophysical Requirements

a) Thermal conductivity

In order to have higher heat transfer coefficient, the thermal conductivity of the refrigerant should be high.

b) Viscosity

For better heat transfer coefficient, the desirable viscosity of the refrigerant should be low.

c) Specific heat

The specific heat of refrigerant should be lower when it is in liquid phase so that there is no further change in entropy while it passes through expansion valve, however the specific heat at vapour state should be high in order to prevent compressor from mechanical breakdown [8].

1.4.5 Environmental Considerations

a) Ozone Depletion

In the stratosphere region of atmosphere, ozone gases are present preventing [9] the harmful ultraviolet rays to reach the earth's surface by absorbing them. Halogenated refrigerants such as HCFC's, CFC's contain free chlorine radicals [10] which remove ozone from atmosphere and convert it to oxygen. Ozone layer Depletion is the presence of chlorine or bromine in the stratospheric part due to chlorine containing substances.

b) Global Warming Potential

It is relative measure of a greenhouse gas heat entrapment in the atmosphere to the heat entrapment of CO_2 at same conditions over a time horizon [10]. Greenhouse gases act as heat trapping substances thereby rise the temperature of earth. Thus both ODP and GWP these days became important criteria for selecting new alternate refrigerants for domestic refrigerators.

Table 4 Different Refrigerant Specification [2, 10]

S.no	Refrigerant Class	Examples	Critical Pressure (MPa)	Critical Temperature (K)	ODP	GWP	Atmospheric lifetime (Years)	Flammability
1	CFC's	R32 R22	5.78 4.99	351.26 369.3	0.6-1	675 1810	45-1700	Non-flammable
2	HCFC's	R11 R12	4.41 4.14	470.26 384.27	0.02-0.11	4750 10900	1-20	Non-flammable
3	HFC's	R134a R152a	4.06 4.52	374.21 386.41	0	1430 124	1-300	Non-flammable
4	HC's	R290 R600a	4.25 3.63	369.9 407.81	0	3 4	Few Days	Flammable
5	HC blend	R436a	4.27	389.04	0	3	Few Days	Flammable

1.5 Nanoparticles

Nanoparticles are nano-metre sized particles having dimension less than 100 nm. These particles are widely used in heat transfer applications because of their superior thermophysical properties [11-25] such as Thermal conductivity, Specific Heat etc. Nanoparticles consist of three layers

[26] i.e. (I) The Surface Layer, (II) The Shell Layer and (III) The Core. The surface layer consists of metal ions which can be functionalized by surfactants. Both the Shell layer and the Core are made of chemically different composite materials.

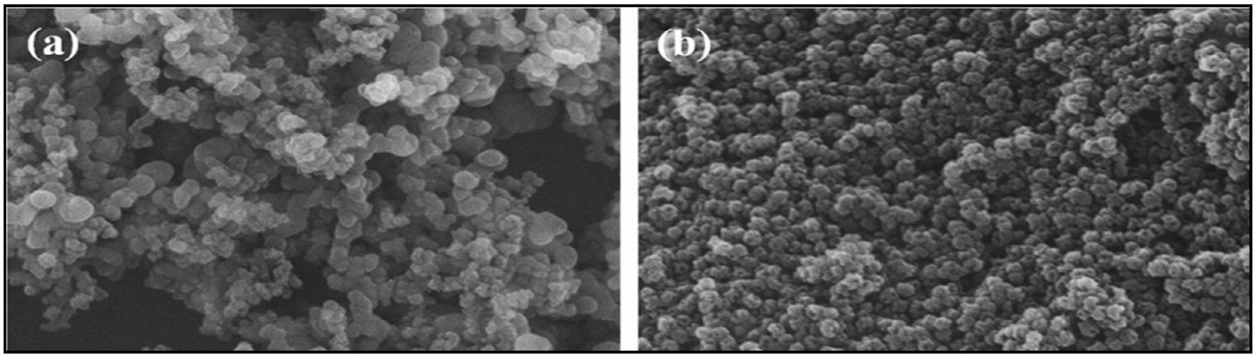

Figure 6 SEM Image SiO_2 [27]

Nanoparticles are classified into various categories on the basis of their size, morphology and Chemical Properties.

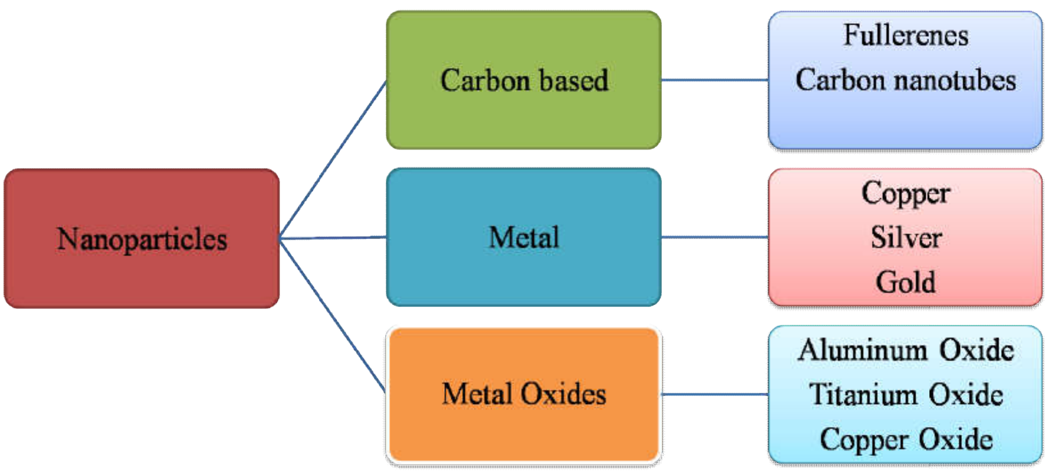

Figure 7 Classification of nanoparticles

1.6 Nanorefrigerants

These are new class of refrigerants synthesized by mixing conventional refrigerants with nanoparticles for better heat transfer applications such as in domestic refrigerators [28-29] due to their enhanced thermophysical properties. Adding Nanoparticles in the refrigerant (I) increases solubility between refrigerant and lubricating oil [30] which reduces power consumption. (II) Enhancement of heat transfer which increases COP reduces freezing Capacity, decreases pull down time in evaporator, decreases pressure ratio. (III) The energy consumption reduces due to decrease in wear and tear, friction losses get minimized.

2 Scope of the Study

The scope of the research is as follows

a) The scope of the study is to find out the new composition of mixed Nano-refrigerant which can enhance the thermo physical properties such as
   - ✓ Thermal conductivity
   - ✓ Viscosity
   - ✓ Density
   - ✓ Specific heat

b) These above significant enhancement in the Thermophysical properties of refrigerants has the ability to deliver better efficiency and to be applicable in
   - ✓ Domestic refrigeration systems
   - ✓ Water chillers
   - ✓ Heat exchangers
   - ✓ Air conditioning systems

c) The comparison of Nano-refrigerants will guide to a conclusion of the feasibility and applicability of these refrigerants at different pressure range, mass flow rate and different heat fluxes.

d) Furthermore, the study compares the performance of convention refrigerants with the Nano-refrigerants on the same platform of VCRS.

3 Objectives of the Study

- ✓ To estimate the Thermal conductivity of mixed Nano-refrigerants at various volume concentrations of different nanoparticles.
- ✓ To estimate the Viscosity of mixed Nano-refrigerants at various volume concentrations of different nanoparticles.
- ✓ To estimate the Density mixed Nano-refrigerants at various volume concentrations of different nanoparticles.
- ✓ To estimate the Specific heat of mixed Nano-refrigerants at various volume concentrations of different nanoparticles.
- ✓ To investigate the performance of domestic refrigerators using optimum mixed nanorefrigerants.

4 Review of Literature

Mani et al., 2007 [31]. In this experimental study, the performance of VCRS using R290/R600a replacing R12 and R134a respectively. The results showed that R290/R600a had better refrigeration capacity. R12 and R290/R600a were having slightly same discharge pressure and discharge temperature and were lower than R134a. The COP of the system enhances using R290/R600a.

Mohanraj et al., 2007 [32]. The effect of varied mass concentration of R290/R600a was studied experimentally as a drop in substitute to R134a in domestic refrigerators using synthetic oil as lubricant. They also calculated performance characteristics and were compared with R134a. The experimental results that R290/R600a has better performance characteristics and miscibility.

B. Palm, 2007 [33]. Experimentally compared and performed the usage of HC's as refrigerants by replacing conventional refrigerants due to global environmental considerations. It was found that HC's are having COP closely equal to similar HFC's. The only problem associated with usage of HC's is its flammability and therefore safety considerations need to be added.

Zhou et al., 2008 [34]. They measured the specific heat capacity of water based Al_2O_3 nanofluid. The effective heat flow curve of nanofluid is moved down as the nanoparticles volume fraction increases. For large nanoparticles volume fraction; this result implies that low heat energy is needed to obtain the same temperature increment. The specific heat of nanofluid decreases with increasing nanoparticles volume fraction. The thermal equilibrium model predicts good agreement with specific heat of nanofluid as compared to simple mixing model.

Tavman et al., 2008 [35]. They investigated experimentally viscosity and thermal conductivity of suspensions containing Nano sized ceramic particles. The results showed that the thermal conductivity of SiO_2-water and Al_20_3-waternanofliuds are lower than Hamilton-Crosser model at different concentrations. The relative thermal conductivity of Al_2O_3nanofluid is found to be independent of temperature increase. The viscosity of SiO_2 and Al_2O_3 nanofluids dramatically increase with increase in particle concentration and Einstein model of viscosity is unable to predict it.

Chandrasekar et al., 2009 [36]. They experimentally investigated and theoretically determined the thermal conductivity and viscosity of Al_2O_3/water nanofluid. The results obtained were both thermal conductivity and viscosity of nanoparticles increases with increase in nanoparticles concentration. Viscosity increase is substainally higher than thermal conductivity. Viscosity increase up to 2% Volume concentration is linear but above 2%, nonlinear relationship is obtained due to hydrodynamic interactions between particles. Al_2O_3/water nanofluid shows Newtonian behaviour.

Godson et al., 2010 [37]. They experimentally investigated the thermal conductivity and viscosity of Silver Deionized water nanofluid. The results obtained revealed that The thermal conductivity of nanofliud is observed to increase with an increase in temperature and particle volume concentration. The viscosity of the nanofluid increases with an increase in particle volume concentration and decreases with an increase in the temperature. For same volume concentration, thermal conductivity enhancement ratio is higher than the viscosity enhancement ratio. For metallic particle, at higher temperature the thermophoretic effect is one of the important mechanisms with the use of nanofluids as compared to Brownian motion.

Bi et al., 2010 [38]. In this experimental work, the investigation of R600a-TiO_2 nanorefrigerant on domestic refrigerator was studied without any further modifications of experimental set up. The performance was calculated on the basis of energy consumption and freezing capacity of the system. Using 0.5 g/l R600a-TiO_2 refrigerant, the energy consumption reduced to 9.6%. The suction and discharge pressure of the compressor reduces, thus performance of R600a-TiO_2 is better than R600a system.

Duangthongsuk et al., 2013 [39]. They experimentally measured temperature dependent thermal conductivity and viscosity of TiO_2/water nanofluids. The outcomes obtained were that the thermal conductivity of nanofluid significantly increases with increase in nanofluid temperature and particle volume concentration. The Viscosity of nanofluids significantly increases with decreasing nanofluid temperature and also increases with increasing particle volume concentration.

Jalal et al., 2013 [40]. They investigated the Nanofluid Viscosity, density and Pressure Drop in Circular Channel. They concluded that The added concentration enhances the density of nanofluid, whereas temperature rise reduces the density of nanofluids. Temperature rise reduces the viscosity of nanofluids, whereas increased weight fraction increases the viscosity of nanofluid. The enhancement of pressure drop for nanofluid is lower under turbulent flow in a circular pipe, but higher under laminar flow condition.

Mahbubul et al., 2014 [41]. They studied the rheological behaviour of R141/Al_2O_3 nanorefrigerant at varied volume concentrations (.005-0.15) with varying temperature range (277-289K). From the experimental work it was concluded that nanorefrigerants show non-Newtonian behaviour. However at high shear rate, this behavior comes close to Newtonian behaviour. The viscosity of nanorefrigerant enhances with increase in shear rate but reduces with increase in temperature.

Senthilkumar et al., **2015 [42].** They experimentally determined the reliability and performance of nanorefrigerant as a working fluid. The performance calculation includes cooling capacity, energy efficiency ratio. The cooling capacity of refrigerator increases by 10-20% using R600a-CuO nanorefrigerant. The experimental results also bare that both the compressor discharge and suction pressure of the R600a-CuO system reduced relative to pure R600a.The energy consumption of 0.1 g/l and 0.5 g/l R600a-CuO were 11.83% and 17.88% less than pure R600a respectively.

Behabadi et al., 2015 [43]. They experimentally carried out work on the heat transfer characteristics of a nanorefrigerant flow during condensation inside a smooth horizontal tube. Three different working fluids such as pure refrigerant (R600a), refrigerant lubricant (R600a/oil) and nanorefrigerant (R600a/oil/CuO) were experimentally used. The results showed significant heat transfer enhancement is achieved by adding up Nanoparticles to the baseline mixture and pure refrigerant. The most heat transfer augmentation was observed for nano-refrigerant with 1.5% mass fraction; 83% higher heat transfer rate compared to pure-refrigerant fluid flow at the identical experimental conditions.

Kumar et al., 2016 [44]. In this study the effect of ZnO Nanoparticles in R290/R600a (50/50) mixed refrigerant added via lubricant oil on compressor suction and discharge characteristics is experimentally investigated. The addition of ZnO Nanoparticles in refrigerant reduces both the suction and discharge pressure due to increase in viscosity and density of the refrigerant. The addition of ZnO Nanoparticles in refrigerant reduces both the suction and discharge temperature due to enhancement of heat transfer coefficient of lubricant/refrigerant oil mixture in evaporator and condenser. The energy consumption of compressor gets reduced due to decrease in frictional losses because of increase in viscosity of Nano-refrigerant. The COP enhances due to the presence of Nanoparticles in refrigeration which increases pool boiling heat transfer coefficient of refrigerant/lubricant mixture.

Adelekan et al., 2016 [45]. They experimentally calculated the performance of LPG refrigerant charges with varied concentration of TiO_2 nanolubricants in a domestic refrigerator. With the increase in nanolubricant concentration, the evaporator air temperature increases but reduces with respect to increase in time. The increase in evaporator air temperature is independent on charges of LPG. The power consumption of all varied nanolubricant concentration is less and power input given to compressor is slightly lower than pure mineral oil. The COP of the system gets enhanced and cooling capacity increases.

Haque et al., 2016 [46]. They experimentally investigated the energy consumption and freezing capacity performance of Vapour Compression Refrigeration System using POE oil with Nanoparticles. They use different sizes of Al_2O_3 and TiO_2 Nanoparticles in two different volume concentrations (.05 and 1% Vol. %). The results revealed that addition of 0.05% and 0.1 % vol. Al_2O_3 Nanoparticles increases COP by 19% and 22% respectively. Also the addition of Al_2O_3 and TiO2 in 0.05 and 0.1 % vol. reduces energy consumption by 27.73% and 14.19% respectively as compared to Pure POE oil. Thus the addition of Nanoparticles proves to be an effective and safe in domestic refrigeration.

D. Senthilkumar 2017 [47]. In this experimental study the Influence of Silicon Carbide Nanopowder in R134a Refrigerant used in Vapour compression refrigeration system is investigated. The COP of the system shows significant development due to enhanced thermophysical properties and heat transfer capabilities of nanorefrigerant. Due to increase in thermal conductivity of SiC Nanoparticles, the power consumption is less. Hence running cost reduces. The freezing capacity of the system increases with the enhancement in rate of cooling. The use of nanorefrigerants decreases global warming potential due to reduction in total mass fraction of refrigerant. Both suction and delivery pressure rises with the addition of Nanoparticles in refrigeration.

5 Research Methodology

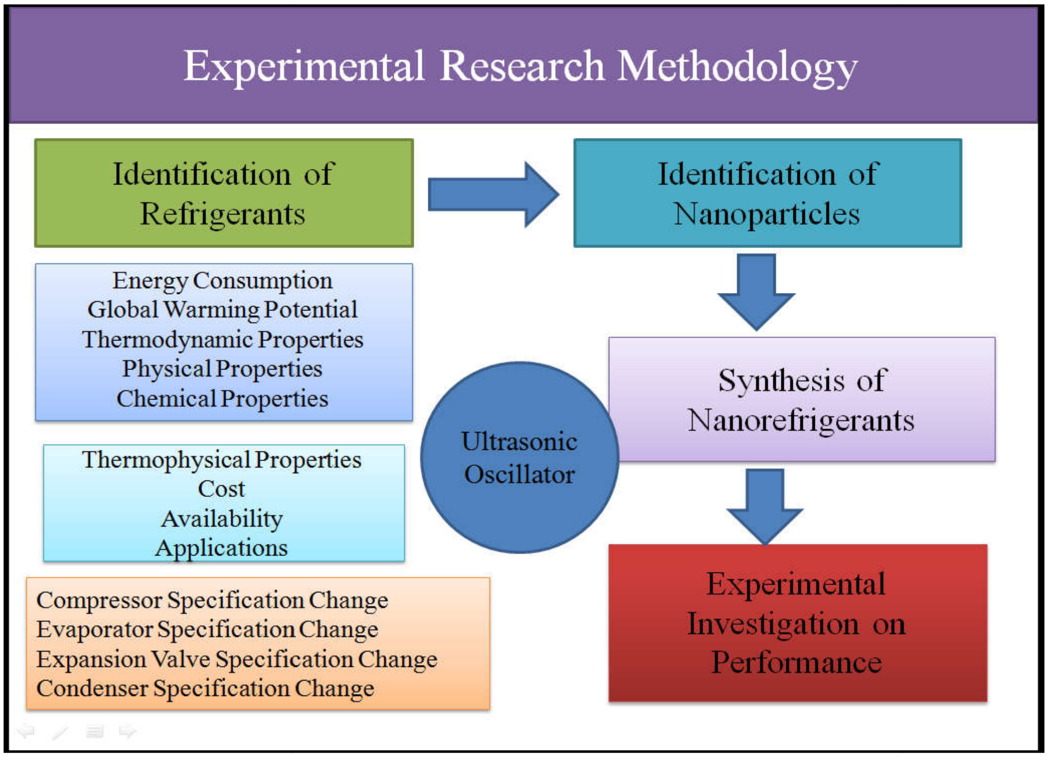

Figure 8 Experimental Research Methodology

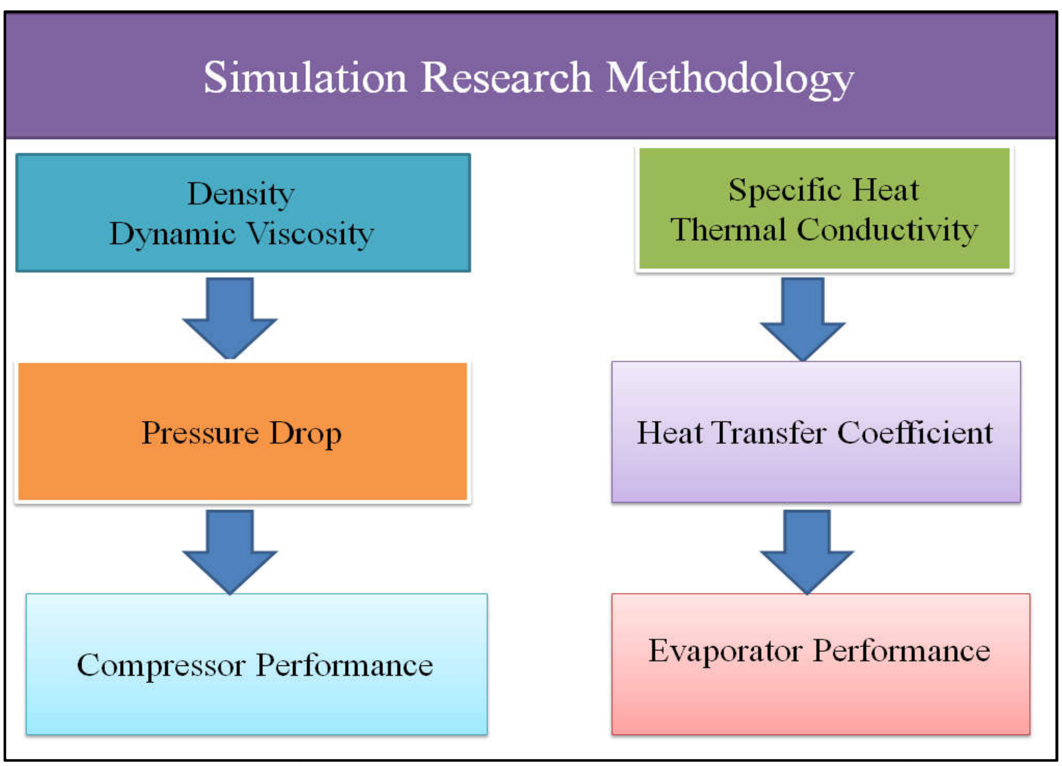

Figure 9 Simulation Research Methodology

- **Identification of Refrigerants**
  - The foremost step in this research work is to identify refrigerants which are compatible with VCRS.
  - Further on comes most crucial part which is to identify refrigerants which can be mixed together.
  - In this research work mixed refrigerant Propane (R-290) and Iso-butane (R-600a) are found to be suitable to be mixed and used in VCRS.
  - Environmental impacts such as ODP and GWP and energy considerations were also taken into account while selecting refrigerant to be used for experimental analysis.

- **Identification of Nanoparticles**
  - The second step in this research work is to identify Nanoparticles among the three dominant categories such as metals (Cu, Al), metal oxides (CuO, Al_2O_3, ZnO) and Carbides or Carbon Nanotubes.
  - In this research work Nanoparticles of Al_2O_3 were selected and found to be well suited for above mentioned mixed refrigerant.
- **Synthesis of Nano-refrigerants**
  - The synthesis of Nano-refrigerant can be done by to methods such as direct injection method and ultrasonic mixing.
  - In this research we adopted the method of direct injection method due to high vapour pressure of the mixed refrigerant.
- **Study on Nano-refrigerants**
  - The thermophysical properties such as Thermal conductivity, Density, Specific Heat and Viscosity of Nano-refrigerant with keeping in view the variation mass flow rate and heat fluxes.
  - The thermophysical properties such as Thermal conductivity, Density, Specific Heat and Viscosity of Nano-refrigerant with the variation of Volume concentration of Al_2O_3 nanoparticles.

6 Proposed Work Plan with Timelines

The project work started in January 2017 and was successfully completed by December 2017. Unparallel dedication, good literature survey, proper time management and better supervision were the corner stone of the project.

The below figure shows the various activities undertaken during the course of the project.

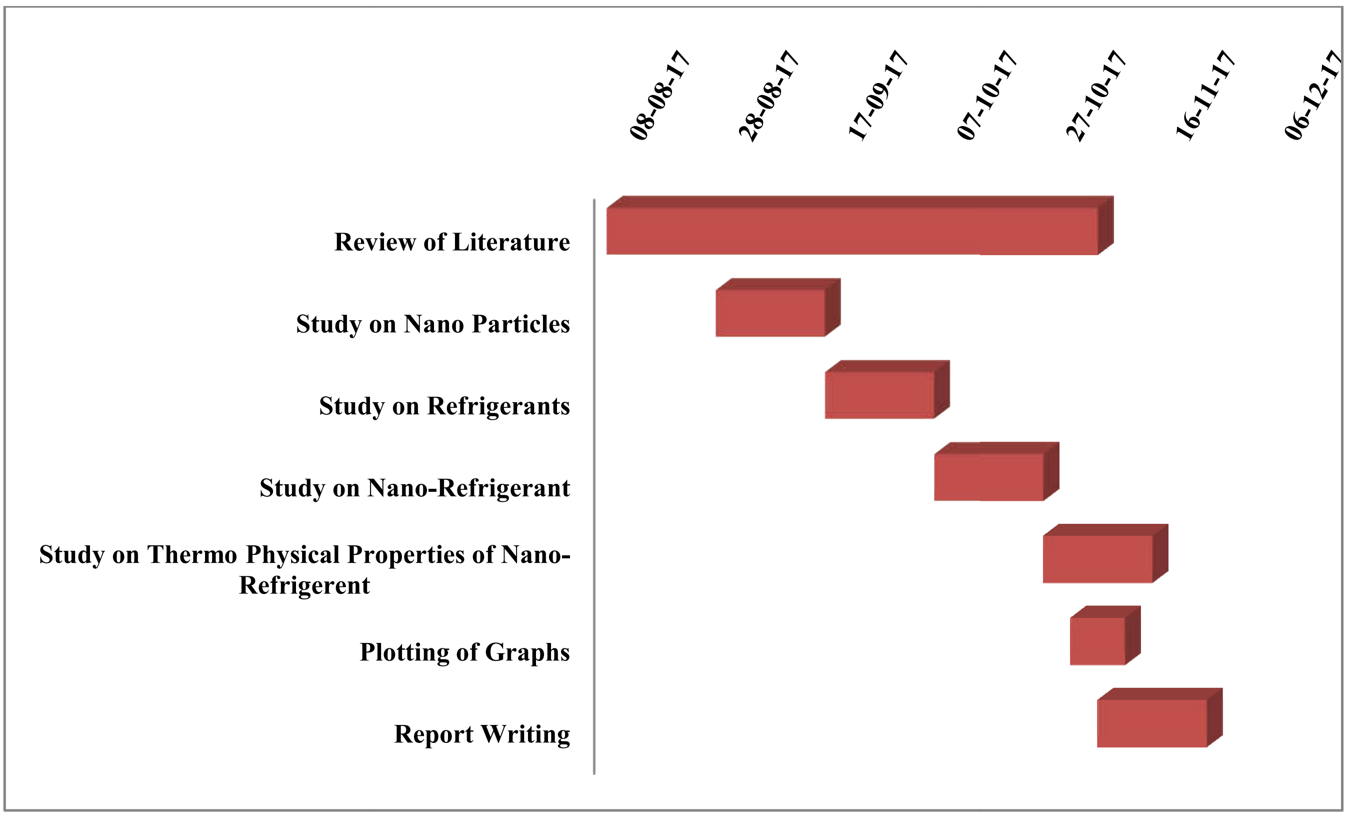

Figure 10 Proposed Work Plan with Timeline

7 Results and Discussions

In the present research work calculation of thermophysical properties such as Thermal conductivity, Density, Viscosity and Specific Heat is carried out on mixed nanorefrigerants. Three different nanoparticles Al_2O_3, Cu and SiC were chosen. The operating conditions were taken to be 3 MPa Pressure and 300 K temperature respectively. For each nanoparticle, calculation of thermophysical properties was carried separately with different volume concentrations (1-5%) respectively.

7.1 R290/R600a-Al_2O_3 nanorefrigerant at 3 MPa Pressure, 300 K Temperature

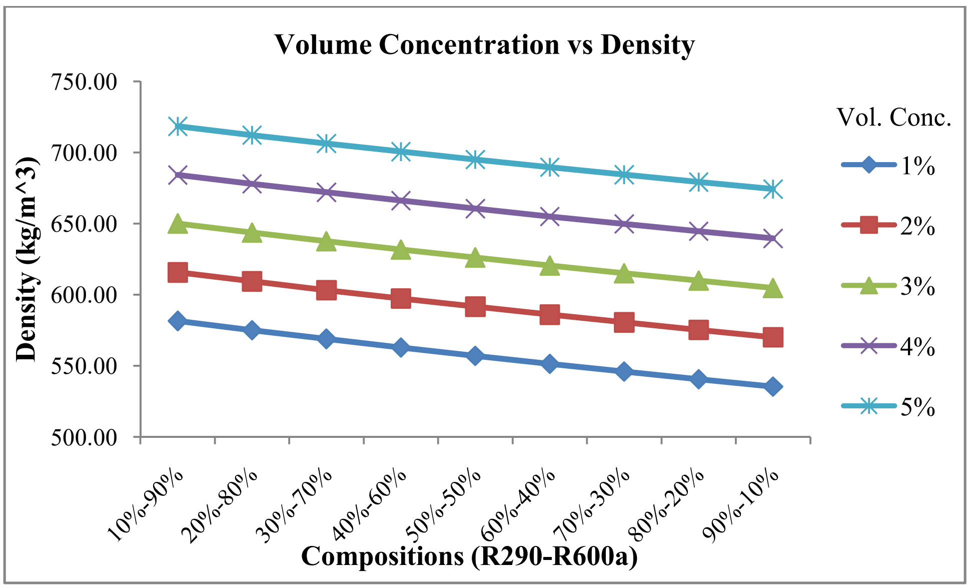

Figure 11 density as a function of Composition

Figure 11 represents density as a function of Composition. As the volumetric concentration of Al_2O_3 nanoparticles increases, the density of mixed nanorefrigerant increases. It is observed that as the concentration of R600a decreases, density decreases.

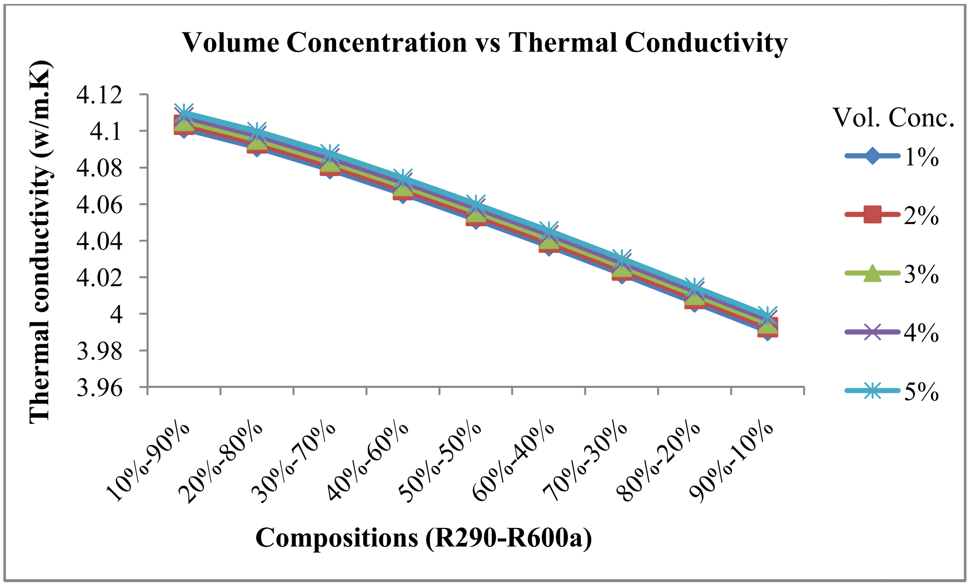

Figure 12 Thermal conductivity as a function of Composition

Figure 12 represents Thermal conductivity as a function of Composition. As the volumetric concentration of Al_2O_3 nanoparticles increases, the Thermal conductivity of mixed nanorefrigerant increases. It is observed that as the concentration of R600a decreases, Thermal conductivity decreases.

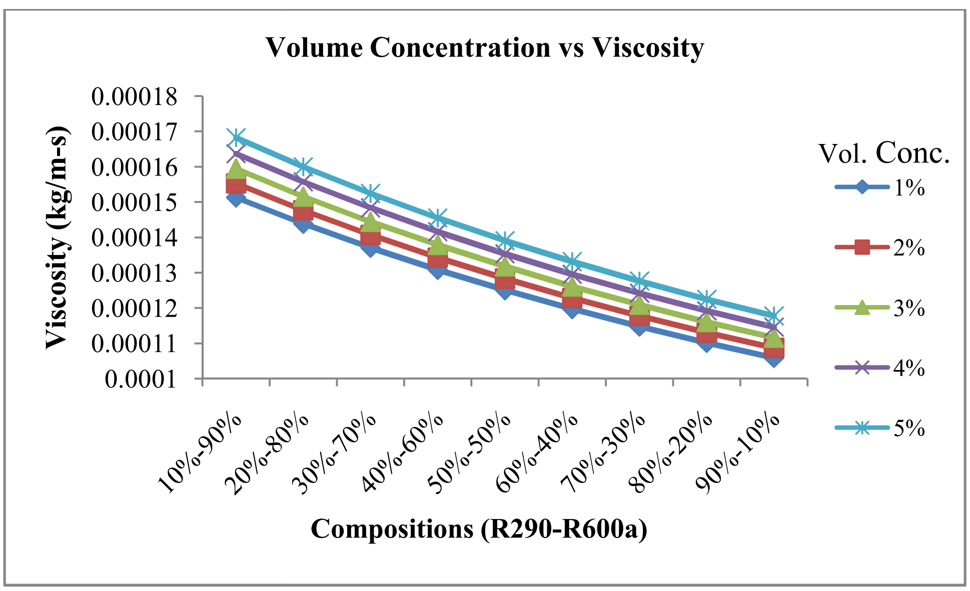

Figure 13 Viscosity as a function of Composition

Figure 13 represents Viscosity as a function of Composition. As the volumetric concentration of Al_2O_3 nanoparticles increases, the Viscosity of mixed nanorefrigerant increases. It is observed that as the concentration of R290 increases, Viscosity decreases.

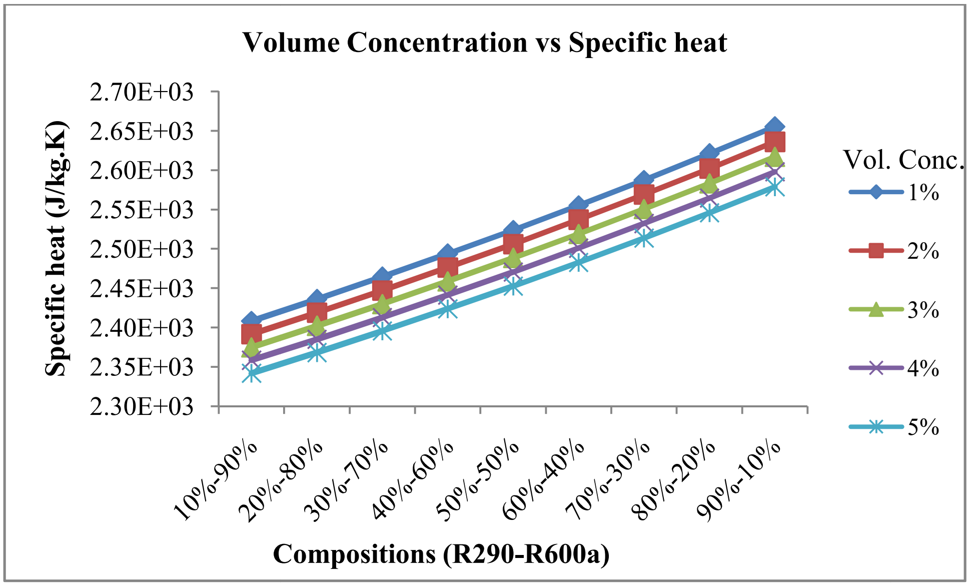

Figure 12 Specific heat as a function of Composition

Figure 14 represents Specific heat as a function of Composition. As the volumetric concentration of Al_2O_3 nanoparticles increases, the Specific heat of mixed nanorefrigerant increases. It was observed that as the concentration of R290 increases, Specific heat increases.

7.2 R290/R600a-Cu nanorefrigerant at 3 MPa Pressure, 300 K Temperature

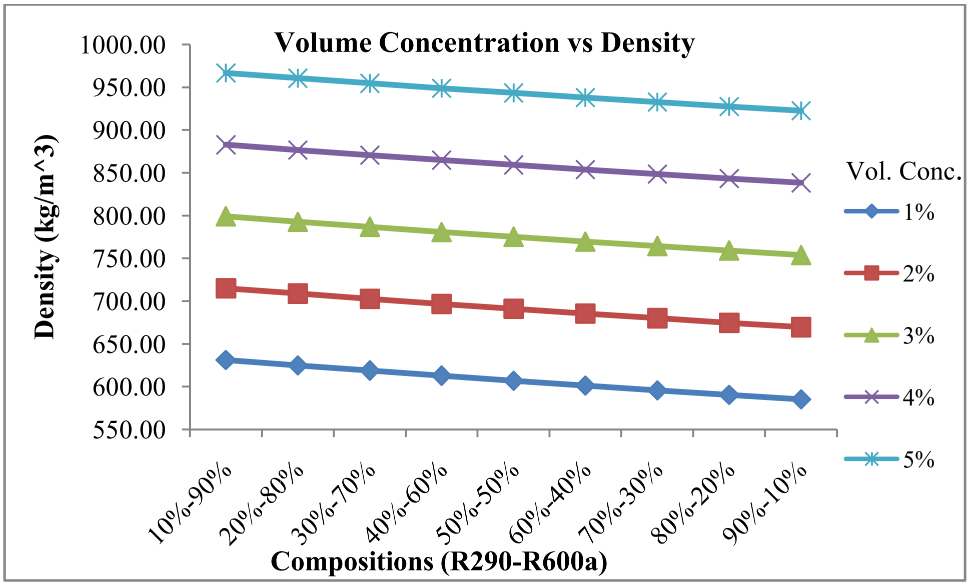

Figure 13 Density as a function of Composition

Figure 15 represents density as a function of Composition. As the volumetric concentration of Cu nanoparticles increases, the density of mixed nanorefrigerant increases. This is due to increase concentration of solid Cu nanoparticles. It is observed that as the concentration of R600a decreases, density decreases.

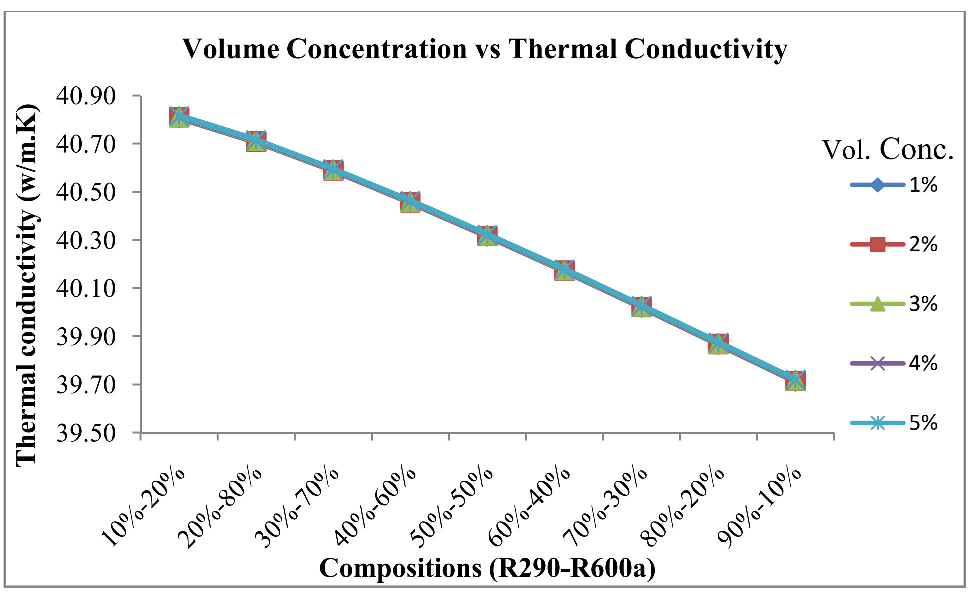

Figure 14 Thermal conductivity as a function of Composition

Figure 17 represents Thermal conductivity as a function of Composition. As the volumetric concentration of Cu nanoparticles increases, the Thermal conductivity of mixed nanorefrigerant increases. It was observed that as the concentration of R600a decreases, Thermal conductivity decreases.

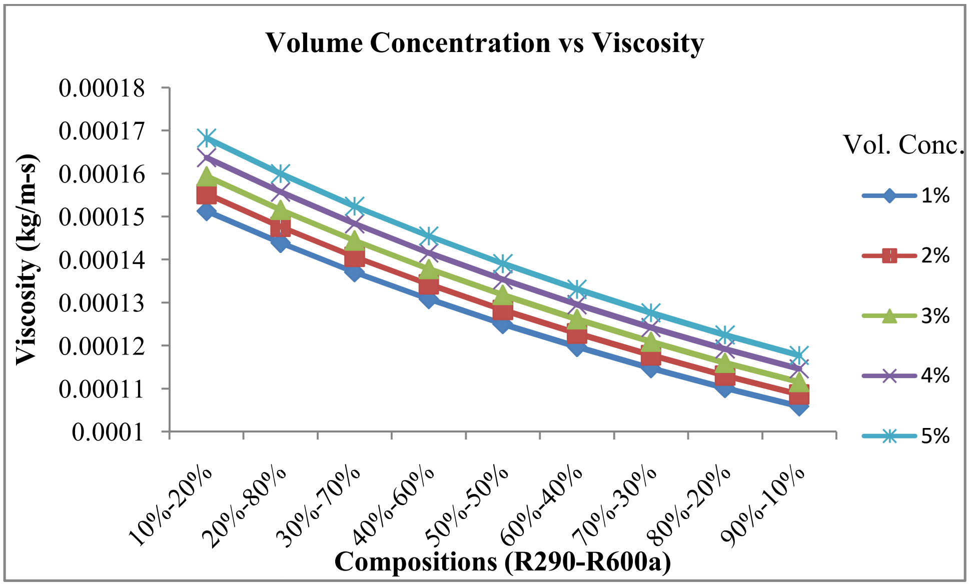

Figure 15 Viscosity as a function of Composition

Figure 18 represents Viscosity as a function of Composition. As the volumetric concentration of Cu nanoparticles increases, the Viscosity of mixed nanorefrigerant increases. It was observed that as the concentration of R290 increases, Viscosity decreases.

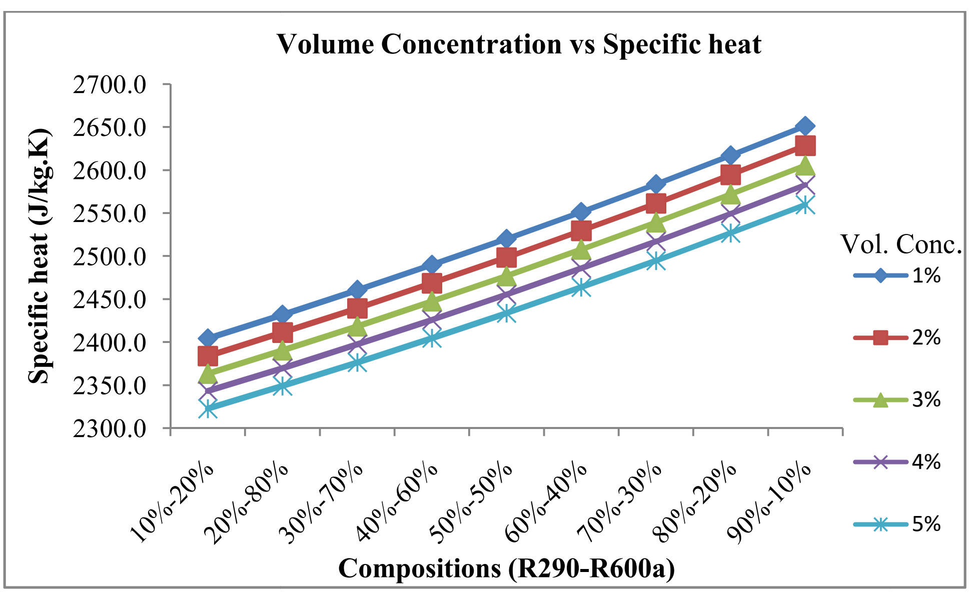

Figure 16 Specific heat as a function of Composition

Figure 19 represents Specific heat as a function of Composition. As the volumetric concentration of Cu nanoparticles increases, the Specific heat of mixed nanorefrigerant increases. Also as the concentration of R290 increases, Specific heat increases.

7.3 R290/R600a-SiC nanorefrigerant at 3 MPa Pressure, 300 K Temperature

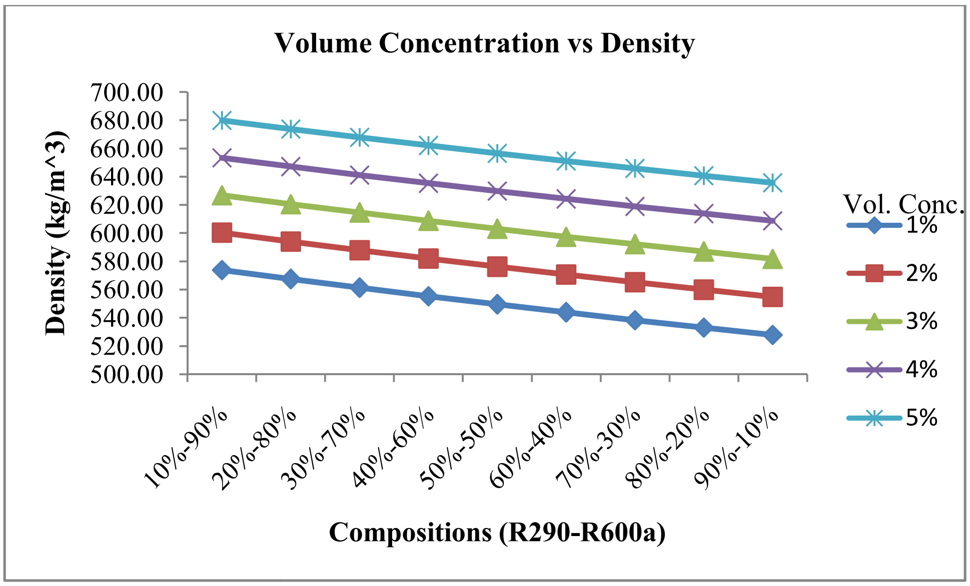

Figure 17 Density as a function of Composition

Figure 20 represents density as a function of Composition. As the volumetric concentration of SiC nanoparticles increases, the density of mixed nanorefrigerant increases. It was observed that as the concentration of R600a decreases, density decreases.

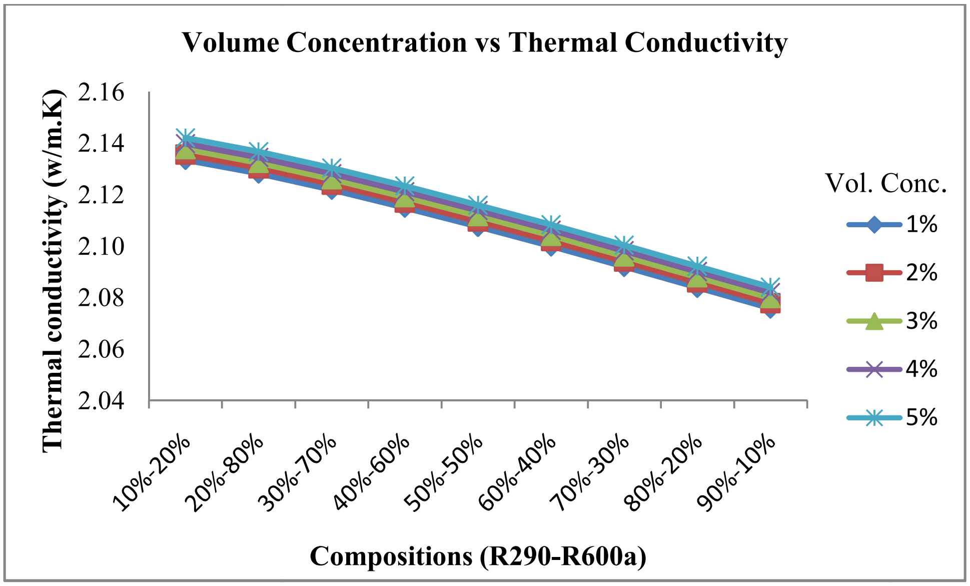

Figure 18 Thermal conductivity as a function of Composition

Figure 21 represents Thermal conductivity as a function of Composition. As the volumetric concentration of SiC nanoparticles increases, the Thermal conductivity of mixed nanorefrigerant increases. It was observed that as the concentration of R600a decreases, Thermal conductivity decreases.

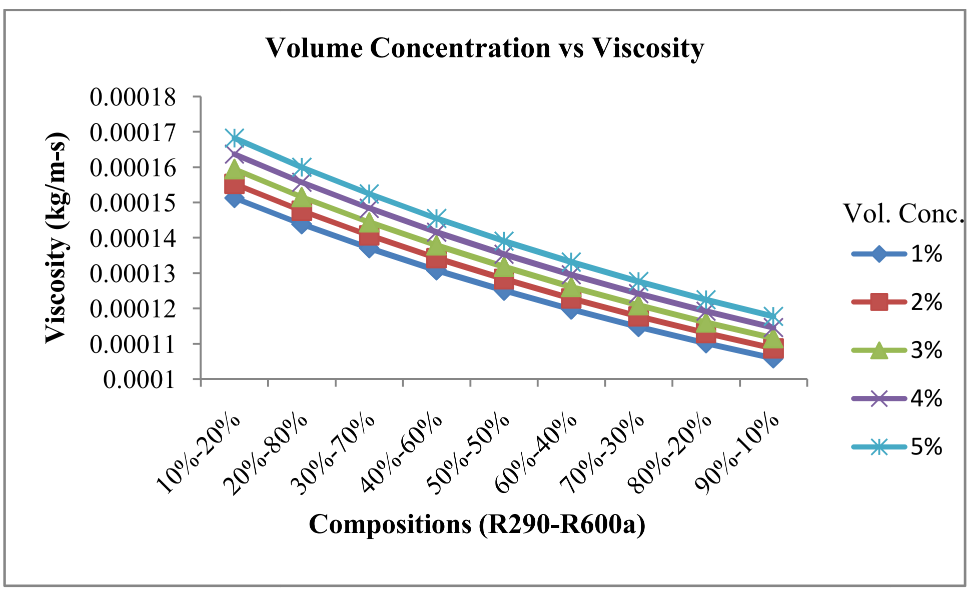

Figure 19 Viscosity as a function of Composition

Figure 22 represents Viscosity as a function of Composition. As the volumetric concentration of SiC nanoparticles increases, the Viscosity of mixed nanorefrigerant increases. It was observed as the as the concentration of R290 increases, Viscosity decreases.

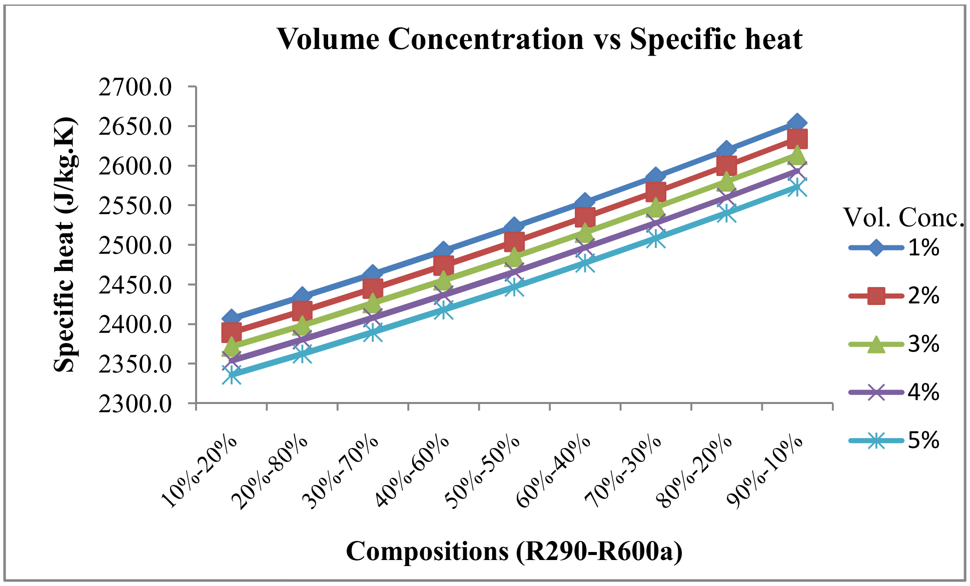

Figure 20 Specific heat as a function of Composition

Figure 23 represents Specific heat as a function of Composition. As the volumetric concentration of SiC nanoparticles increases, the Specific heat of mixed nanorefrigerant increases. It was observed as the concentration of R290 increases, Specific heat increases.

8 Expected Outcomes

In the present research work, refrigerant mixture of R290 and R600a with three different nanoparticles such as Al_2O_3, Cu and SiC are used to find the thermophysical properties. In the present work, varied concentration of three different nanoparticles at a Pressure of 3MPa and 300 K Temperature respectively are used for analysis.

The following outcomes are as follows

- ✓ Density of mixed nanorefrigerant increases with increase in volume concentration of nanoparticles. It was also observed that as concentration of R600a decreases, density decreases.
- ✓ Thermal conductivity of mixed nanorefrigerant increases with increase in volume concentration of nanoparticles. It was also observed that as concentration of R600a decreases, thermal conductivity decreases.
- ✓ Viscosity of mixed nanorefrigerant increases with increase in volume concentration of nanoparticles. It was also observed that as concentration of R290 increases, Viscosity decreases.
- ✓ Specific heat of mixed nanorefrigerant decreases with increase in volume concentration of nanoparticles. It was also observed that as concentration of R290 increases, Specific heat decreases.

9 Summary and Conclusions

The Purpose of this research was carried out for inspecting thermophysical properties of mixed nanorefrigerants. Three different nanoparticles (Al_2O_3, Cu and SiC) and mixed refrigerant of R290/R600a were synthesized individually to form mixed nanorefrigerant. The operating conditions were 3Mpa Pressure and 300 K Temperature respectively. Results are calculated for density, thermal conductivity, viscosity and specific heat of mixed nanorefrigerant.

From the results, we conclude following points

- ✓ Density of mixed nanorefrigerant increases with increase in volume concentration of nanoparticles.
- ✓ Thermal conductivity of mixed nanorefrigerant increases with increase in volume concentration of nanoparticles.
- ✓ Viscosity of mixed nanorefrigerant increases with increase in volume concentration of nanoparticles.
- ✓ Specific heat of mixed nanorefrigerant decreases with increase in volume concentration of nanoparticles.

10 List of References

[1] T. Jia, R. Wang, and R. Xu, ScienceDirect "Performance of $MoFe_2O_4$e NiFe2O4 / Fullerene-added nano-oil applied in the domestic refrigerator compressors," *Int. J. Refrig.*, vol. 45, pp. 120–127, 2014.

[2] D. S. Adelekan *et al.*, "Case Studies in Thermal Engineering Experimental performance of LPG refrigerant charges with varied concentration of TiO 2 nano-lubricants in a domestic refrigerator," *Case Stud. Therm. Eng.*, vol. 9, no. October 2016, pp. 55–61, 2017.

[3] J. M. Calm, "The next generation of refrigerants - Historical review, considerations, and outlook," *Int. J. Refrig.*, vol. 31, no. 7, pp. 1123–1133, 2008.

[4] M. Fatouh and M. El Kafafy, "Experimental evaluation of a domestic refrigerator working with LPG," vol. 26, pp. 1593–1603, 2006.

[5] D. S. Kumar and R. Elansezhian, "ZnO nanorefrigerant in R152a refrigeration system for energy conservation and green environment," 2014.

[6] Z. Yang, Y. Li, Q. Zhu, and X. Li, "Research on non-flammable criteria on refrigerants," *Appl. Therm. Eng.*, vol. 20, no. 14, pp. 1315–1320, 2000.

[8] G. Venkatarathnam and S. S. Murthy, "Refrigerants for Vapour Compression Refrigeration Systems," no. February, pp. 139–162, 2012.

[7] C. Arora, *Refrigeration and Air Conditioning*, vol. 3, no. 1. 1982. [9] M. Engineering, vol. 10, no. 1, pp. 1778–1791, 2016.

[10] K. Harby, "Hydrocarbons and their mixtures as alternatives to environmental unfriendly halogenated refrigerants: An updated overview," *Renew. Sustain. Energy Rev.*, vol. 73, no. February, pp. 1247–1264, 2017.

[11] R. K. Sabareesh, N. Gobinath, V. Sajith, S. Das, and C. B. Sobhan, "Application of TiO 2 nanoparticles as a lubricant-additive for vapor compression refrigeration systems e An experimental investigation Application des nanoparticules de TiO 2 en tant que lubrifiant ´ mes frigorifiques a ` compression de et additif dans le," *Int. J. Refrig.*, vol. 35, no. 7, pp. 1989–1996, 2012.

[12] M. Chandrasekar, S. Suresh, and A. Chandra Bose, "Experimental investigations and theoretical determination of thermal conductivity and viscosity of Al2O3/water nanofluid," *Exp. Therm. Fluid Sci.*, vol. 34, no. 2, pp. 210–216, 2010.

[13] F. S. Javadi and R. Saidur, "Energetic , economic and environmental impacts of using nanorefrigerant in domestic refrigerators in Malaysia," *Energy Convers. Manag.*, vol. 73, pp. 335–339, 2013.

[14] S. Bi, K. Guo, Z. Liu, and J. Wu, "Performance of a domestic refrigerator using TiO 2 - R600a nano-refrigerant as working fluid," *Energy Convers. Manag.*, vol. 52, no. 1, pp. 733–737, 2011.

[15] W. Duangthongsuk and S. Wongwises, "Measurement of temperature-dependent thermal conductivity and viscosity of TiO2-water nanofluids," *Exp. Therm. Fluid Sci.*, vol. 33, no. 4, pp. 706–714, 2009.

[16] S. Bobbo, L. Fedele, M. Fabrizio, S. Barison, S. Battiston, and C. Pagura, "Influence of nanoparticles dispersion in POE oils on lubricity and R134a solubility Influence de la dispersion des nanoparticules dans les huiles ´ et la solubilite," *Int. J. Refrig.*, vol. 33, no. 6, pp. 1180–1186, 2010.

[17] I. M. Mahbubul, R. Saidur, and M. A. Amalina, "In fl uence of particle concentration and temperature on thermal conductivity and viscosity of Al 2 O 3 / R141b nanorefrigerant ☆," *Int. Commun. Heat Mass Transf.*, vol. 43, pp. 100–104, 2013.

[18] Y. Chiba, A. Smaili, and O. Sari, "Enhancements of thermal performances of an active magnetic refrigeration device based on nanofluids," *Mechanika*, vol. 23, no. 1, pp. 31–38, 2017.

[19] O. A. Alawi, N. Azwadi, C. Sidik, and H. A. Mohammed, "A comprehensive review of fundamentals , preparation and applications of nanorefrigerants ☆," *Int. Commun. Heat Mass Transf.*, vol. 54, pp. 81–95, 2014.

[20] T. Jia, R. Wang, and R. Xu, "ScienceDirect Performance of MoFe 2 O 4 e NiFe 2 O 4 / Fullerene-added nano-oil applied in the domestic refrigerator compressors Performance de nano-huile avec ajout de MoFe 2 O 4 e NiFe 2 O 4 / ne dans les compresseurs pour r e frig e rateurs Fuller e do," *Int. J. Refrig.*, vol. 45, pp. 120–127, 2014.

[21] M. Jalal, H. Meisami, and M. Pouyagohar, "Investigation of titania/water nanofluid viscousity, density and pressure drop in circular channel," *World Appl. Sci. J.*, vol. 27, no. 8, pp. 1037–1041, 2013.

[22] S.-Q. Zhou and R. Ni, "Measurement of the specific heat capacity of water-based Al2O3 nanofluid," *Appl. Phys. Lett.*, vol. 92, no. 9, p. 93123, 2008.

[23] I. Tavman and a Turgut, "Experimental investigation of viscosity and thermal conductivity of suspensions containing nanosized ceramic particles," *Arch. Mater. ...*, vol. 34, no. 2, pp. 99–104, 2008.

[24] A. J. Jaffri, M. W. Bhat, G. Vyas, A. Kumar, and R. S. Dondapati, "A review on the recent development in enhancing the thermal conductivity in nanofluids," *Int. J. Mech. Eng. Technol.*, vol. 8, no. 7, pp. 1540–1545, 2017.

[25] M. W. Bhat, A. J. Jaffri, G. Vyas, A. Kumar, and R. S. Dondapati, "Experimental investigation on flow behavior and heat transfer characteristics of CUO based nanoparticles with water in composite pipe," *Int. J. Mech. Eng. Technol.*, vol. 8, no. 7, pp. 1500–1507, 2017.

[26] I. Khan, K. Saeed, and I. Khan, "Nanoparticles : Properties , applications and toxicities," *Arab. J. Chem.*, 2017.

[27] J. I. E. U. N. Lee, N. Lee, T. Kim, J. Kim, and T. Hyeon, "Multifunctional Mesoporous Silica Nanocomposite Nanoparticles for Theranostic Applications," vol. 44, no. 10, pp. 893–902, 2011.

[28] B. Sun and D. Yang, "Experimental study on the heat transfer characteristics of nanorefrigerants in an internal thread copper tube," *Int. J. Heat Mass Transf.*, vol. 64, pp. 559–566, 2013.

[29] A. Celen, Ç. Alican, M. Aktas, and O. Mahian, "ScienceDirect A review of nanorefrigerants : Flow characteristics and applications nes : caract e ristiques Un passage en revue des nanofrigorig e coulement et applications d â€™ e," vol. 4, 2014.

[30] R. Kumar and J. Singh, "Effect of ZnO nanoparticles in R290 / R600a (50 / 50) based vapour compression refrigeration system added via lubricant oil on compressor suction and discharge characteristics," *Heat Mass Transf.*, vol. 53, no. 5, pp. 1579–1587, 2017.

[31] K. Mani and V. Selladurai, "Experimental analysis of a new refrigerant mixture as drop-in replacement for CFC12 and HFC134a," *Int. J. Therm. Sci.*, vol. 47, no. 11, pp. 1490–1495, 2008.

[32] M. Mohanraj, S. Jayaraj, and C. Muraleedharan, "Improved energy efficiency for HFC134a domestic refrigerator retrofitted with hydrocarbon mixture (HC290/HC600a) as drop-in substitute," *Energy Sustain. Dev.*, vol. 11, no. 4, pp. 29–33, 2007.

[33] B. Palm, "Hydrocarbons as refrigerants in small heat pump and refrigeration systems - A review," *Int. J. Refrig.*, vol. 31, no. 4, pp. 552–563, 2008.

[34] S.-Q. Zhou and R. Ni, "Measurement of the specific heat capacity of water-based Al2O3 nanofluid," *Appl. Phys. Lett.*, vol. 92, no. 9, p. 93123, 2008.

[35] I. Tavman and a Turgut, "Experimental investigation of viscosity and thermal conductivity of suspensions containing nanosized ceramic particles," *Arch. Mater. ...*, vol. 34, no. 2, pp. 99–104, 2008.

[36] M. Chandrasekar, S. Suresh, and A. Chandra Bose, "Experimental investigations and theoretical determination of thermal conductivity and viscosity of Al2O3/water nanofluid," *Exp. Therm. Fluid Sci.*, vol. 34, no. 2, pp. 210–216, 2010.

[37] L. Godson, B. Raja, D. M. Lal, and S. Wongwises, “Experimental Heat Transfer : A Journal of Thermal Energy Generation , Transport , Storage , and Conversion Experimental Investigation on the Thermal conductivity and Viscosity of Silver-Deionized Water Nanofluid,” no. April 2013, pp. 37–41, 2010.

[38] S. Bi, K. Guo, Z. Liu, and J. Wu, “Performance of a domestic refrigerator using TiO 2 - R600a nano-refrigerant as working fluid,” *Energy Convers. Manag.*, vol. 52, no. 1, pp. 733–737, 2011.

[39] W. Duangthongsuk and S. Wongwises, “Measurement of temperature-dependent thermal conductivity and viscosity of TiO2-water nanofluids,” *Exp. Therm. Fluid Sci.*, vol. 33, no. 4, pp. 706–714, 2009.

[40] M. Jalal, H. Meisami, and M. Pouyagohar, “Investigation of titania/water nanofluid viscousity, density and pressure drop in circular channel,” *World Appl. Sci. J.*, vol. 27, no. 8, pp. 1037–1041, 2013.

[41] I. M. Mahbubul, S. S. Khaleduzzaman, R. Saidur, and M. A. Amalina, “Rheological behavior of Al2O3/R141b nanorefrigerant,” *Int. J. Heat Mass Transf.*, vol. 73, pp. 118–123, 2014.

[42] I. Conference, O. N. Recent, A. Engineering, and M. Engineering, “PERFORMANCE ANALYSIS OF A DOMESTIC REFRIGERATOR USING CUO – R600A NANO – REFRIGERANT AS WORKING FLUID,” no. 9, pp. 30–33, 2015.

[43] M. A. Akhavan-Behabadi, M. K. Sadoughi, M. Darzi, and M. Fakoor-Pakdaman, “Experimental study on heat transfer characteristics of R600a/POE/CuO nano-refrigerant flow condensation,” *Exp. Therm. Fluid Sci.*, vol. 66, pp. 46–52, 2015.

[44] R. Kumar and J. Singh, “Effect of ZnO nanoparticles in R290 / R600a (50 / 50) based vapour compression refrigeration system added via lubricant oil on compressor suction and discharge characteristics,” *Heat Mass Transf.*, vol. 53, no. 5, pp. 1579–1587, 2017.

[45] D. S. Adelekan *et al.*, “Case Studies in Thermal Engineering Experimental performance of LPG refrigerant charges with varied concentration of TiO 2 nano-lubricants in a domestic refrigerator,” *Case Stud. Therm. Eng.*, vol. 9, no. October 2016, pp. 55–61, 2017.

[46] M. E. Haque, R. A. Bakar, K. Kadirgama, M. M. Noor, and M. Shakaib, “Performance of a domestic refrigerator using nanoparticles-based polyolester oil lubricant,” *J. Mech. Eng. Sci.*, vol. 10, no. 1, pp. 1778–1791, 2016.

[47] D. Senthilkumar, “Influence of Silicon Carbide Nanopowder in R134a Refrigerant Used in Vapor Compression Refrigeration System,” vol. 25, no. 1, pp. 1–10, 2017.