A Comparative Investigation on Thermo-hydraulic Performance of Mixed Nano-Refrigerant with Conventional Refrigerant

Dissertaion-2

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Abstract

Over the past few decades, the energy consumption as has seek an increment in the usage of refrigeration systems and air conditioning systems. However, to overcome the energy crisis globally the need of highly efficient application becomes a necessity at the same time keeping the environment unaffected by this technology leap becomes a challenge. In view with the environmental impacts of technologies Montreal Protocol Treaty established in 1987 to restrict the use of substances damaging the ozone layer and was enforced from January 1989. Whereas, Kyoto Protocol Treaty was signed in 1997 to restrict usage of high GWP substances and was enforced from February 2005 onwards. Therefore, using low ODP and low GWP valued refrigerant becomes an effective substitute, such as R-600a, R-290, etc.

1 Introduction

Over the past few decades, the energy consumption has increased at an expeditious rate. The rate of energy consumption has increased by numerous folds after refrigerators and air conditioning systems were adopted domestically and it is predicted to multiply even more in coming future. As the rate of energy production is unable to race the rate of energy consumption, therefore the consuming of energy efficiently becomes key and foremost priority. The second concern turns out to be global warming and ozone layer damage due to CO_2 and CFC gases. These CFC gases such as R-11 (Trichlorofluoromethane) and R-12 (Dichlorodifluoromethane) being conventional refrigerants for refrigeration and air conditioning system has proven to be supreme cause for ozone layer depletion with highest ozone depletion potential (ODP) resulting in global warming. [5]

1.1 Vapour Compression Refrigeration System

Vapour compression refrigeration system (VCRS) are most widely used in domestic refrigeration system. This system associates in the category of vapour compression cycles, where the refrigerant goes through phase change at low pressure and high pressure as well. The refrigeration effect is obtained at the evaporator where the refrigerant in liquid state acquires heat and experiences a phase change at low pressure. There are four major components in a VCRS.

Figure 1. Experimental setup of Vapour Compression Refrigeration System

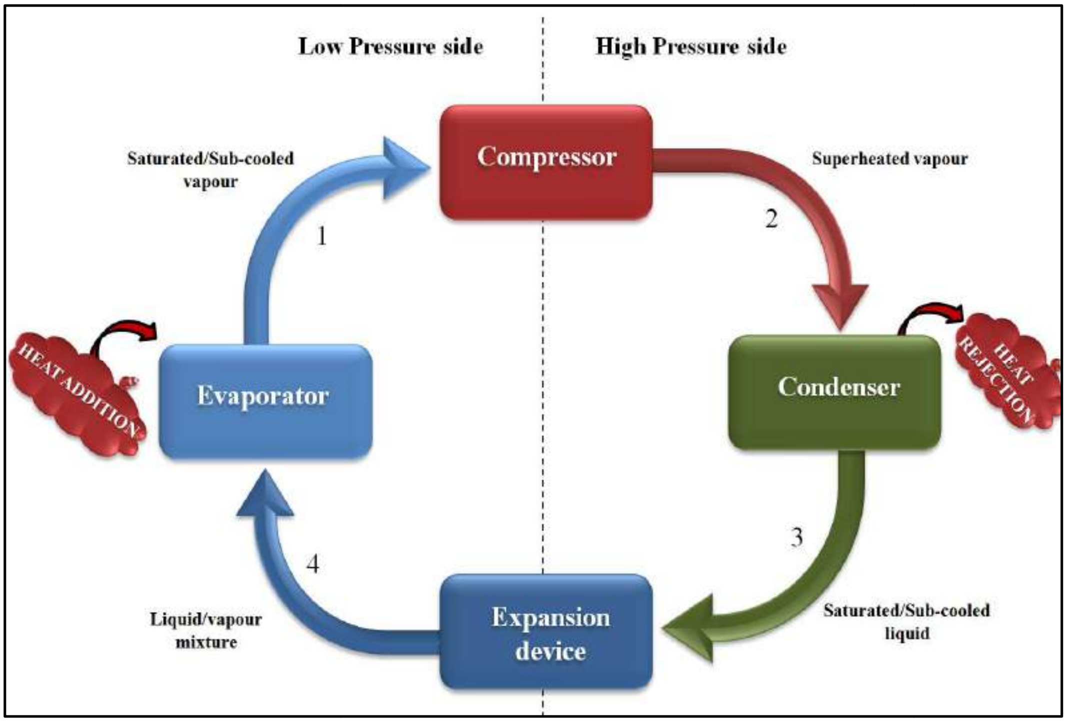

Figure 2. Vapour Compression Refrigeration Cycle

Process 1-2: Isentropic compression of saturated vapour in compressor
Process 2-3: Isobaric heat rejection in condenser
Process 3-4: Isenthalpic expansion of saturated liquid in expansion device
Process 4-1: Isobaric heat extraction in the evaporator

1.1.1 Compressors

The basic concept of compressor in a VCRS is to step-up the pressure of the low pressure dry gas from the evaporator and to displace it into the condenser. There are basically two categories of compressors, positive displacement and dynamic. The positive displacement compresses the volume of low pressure gas and reduces the volume of the gas physically by increasing the pressure, however in case of dynamic the increase in the velocity of the low pressure gas and this results increase in pressure.


Figure 3. Convection Compressor compatible with R-134a

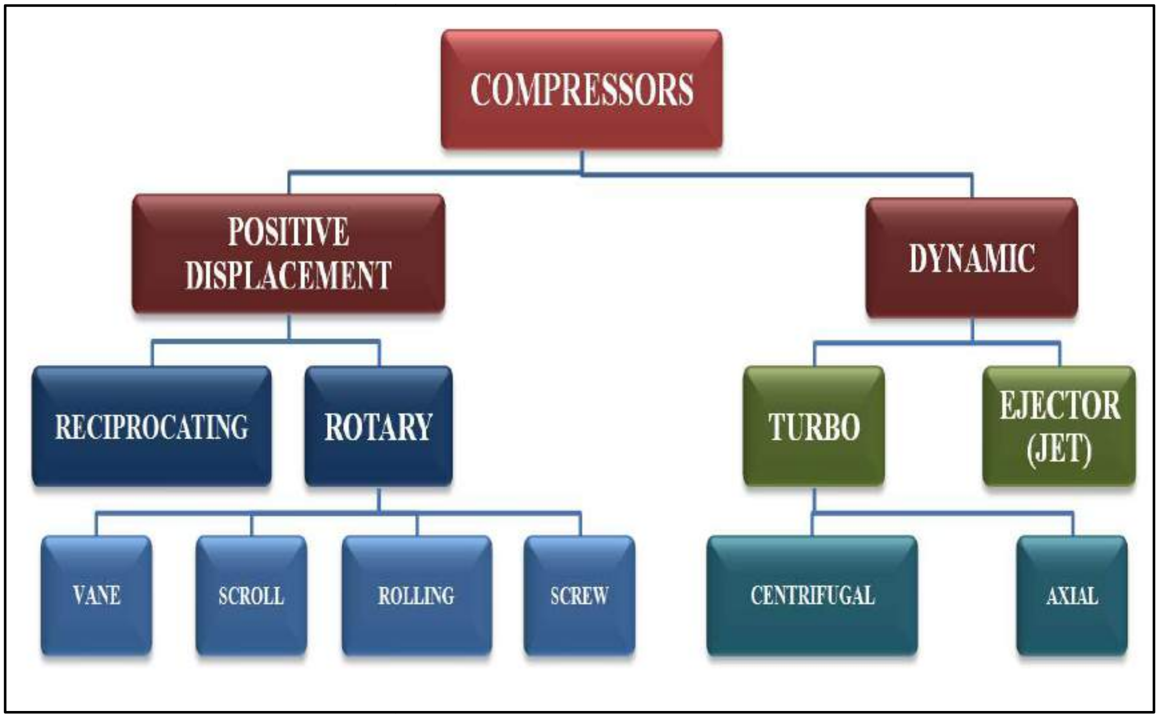

Figure 4. Classification of types of Compressors

1.1.2 Condenser

The basic purpose of the condenser in a VCRS is to reject the acquired heat into the environment from the hot gas passed over from the compressor by withholding the pressure constant. This cooling of gas results in condensation and removing the latent heat and converting the high pressure gas into liquid state. This may usually lead to slightly sub-cooled liquid.

Figure 5. Condenser

1.1.3 Expansion Valve

The basic concept of the expansion valve is to have a control over the flow of refrigerant from sub-cooled, high pressure condensing side to the low pressure evaporator. The pressure of refrigerant after passing through the expansion valve drops down drastically and passed over to the evaporator.

Figure 6. Expansion Valve

1.1.4 Evaporator

The main purpose of the evaporator in the VCRS is to accept low pressure, low temperature liquid refrigerant (partially gas) from the expansion device and to come in a proximate contact with the thermal load. This results in refrigerant taking up heat and it experiences an increase in latent heat from the thermal load and leaving the evaporator as refrigerant in a dry gaseous state.

Figure 7. Evaporator

1.2 Refrigerant

A refrigerant in general is a fluid used in pumping heat and in refrigeration system that can extort heat. A refrigerant can be a substance or a mixture too which are low in Ozone Depletion Potential (ODP) and low in Global Warming Potential (GWP). In the era of 1980's the high ODP refrigerants were taken in consideration as highly destructive refrigerants for ozone layer, whereas high GWP refrigerants were considered in early 1990's as being dominant cause for global warming.[5]

Table 1. History of Refrigerants usage [5]

Period	Refrigerants
1800–1900	Ethyl alcohol, methyl amine, ethyl amine, methyl chloride, ethyl chloride, sulphur dioxide, carbon dioxide, ammonia
1900–1930	Ethyl bromide, carbon tetrachloride, water, propane, isobutene, gasoline, methylene chloride
1931–1990	Chlorofluorocarbons, hydrochlorofluorocarbons, ammonia, water
1990–2010	Hydrofluorocarbons, ammonia, isobutene, propane, carbon dioxide, water
Recent future	Hydrofluorooelifins, hydrofluorocarbons, hydrocarbons, carbon dioxide, water

1.2.1 Ozone Depletion

Stratosphere is the layer sandwiched between two atmospheric layers named troposphere and mesosphere. Troposphere being the lowermost layer and mesosphere being the uppermost layer [5]. In the Stratosphere, the ozone gases are present, preventing the earth's surface from sun's ultraviolet rays. There are three oxygen atoms in a molecule of oxygen and these atoms are unstable as compared to O_2. Depletion of the ozone layer takes place due to the presence of gases such as Chlorine and Bromine.This depletion takes place when the free Chlorine atom reacts with O_3 and the product is O_2 as shown in the figure below. It has been predicted that a single Chlorine atom has the ability to destroy almost hundred thousand O_3 molecules. In view of depletion of ozone layer, an international treaty known as Montreal Protocol was signed which restricted the use of substances responsible for depletion of ozone layer [5].

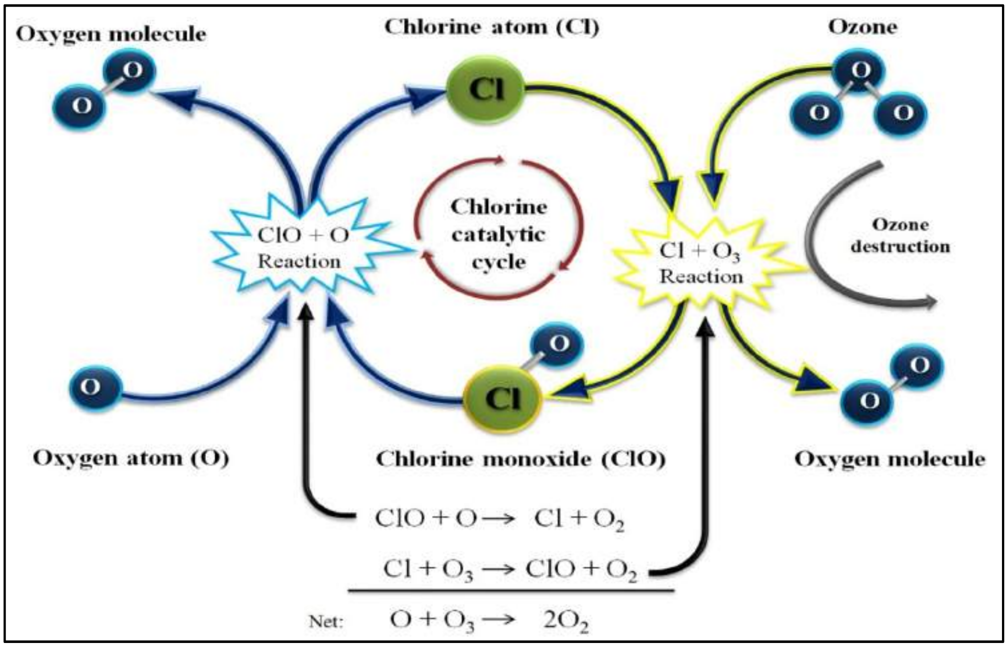

Figure 8. Shows the reaction between Chlorine and Ozone

1.2.2 Global Warming

Since the mid 20th-century earth is experiencing an enhancement of warming of the climate in every next decade unambiguously [1]. The dominant cause being the release of greenhouse gases (GHG) such as Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Ozone (O_3), Chlorofluorocarbons (CFCs) and Hydrofluorocarbons (HFCs) including HCFCs. [2] These gases have high global warming potential (GWP) and potential reason for warming earth's atmosphere. The GWP of gases are measured on factors such as absorption of infrared radiation, atmospheric lifetime and spectral absorbing wavelength. CFCs, HCFCs and HFCs having abilities and potential of high rated refrigerants (Conventional Refrigerants), however, they also have high GWP therefore, they are not safe for the environment and there is a need of alternate refrigerants essentially.

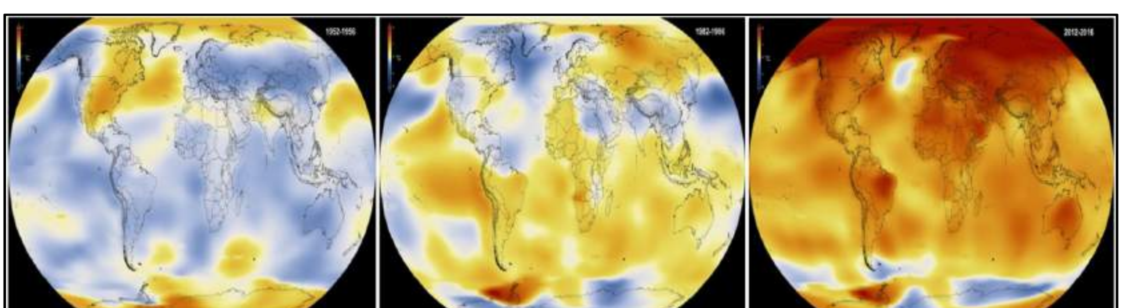

Figure 9. Variation of colours shows changes in earth's temperature from the mid 20th century.[4]

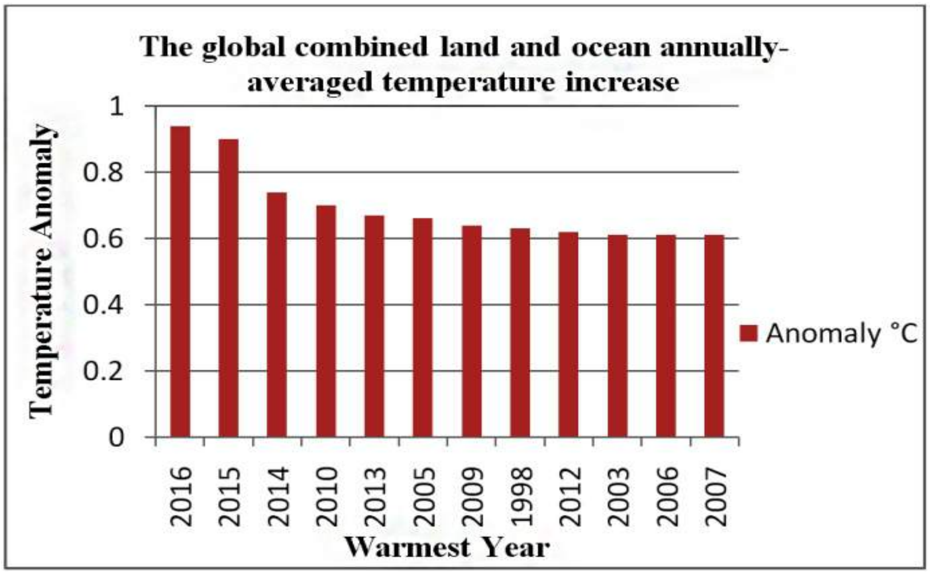

Figure 10. the global combined land and ocean annually-averaged temperature ranks. [4]

The above figure 10 shows the ranking of years with highest annual-average of anomaly temperature and the period of record ranging between years 1880-2016

Table 2. Refrigerant information sorted by environmental impact. [3]

Type	Product R-Number	ODP	Impact	GWP	Impact
Natural	717	0	Zero	0	Low
	744	0	Zero	1	Low
	1270	0	Zero	2	Low
	290	0	Zero	3	Low
	600a	0	Zero	3	Low
	1150	0	Zero	4	Low
HFO	1234yf	0	Zero	4	Low
	1234ze	0	Zero	6	Low
Natural	170	0	Zero	6	Low
HFC	32	0	Zero	675	Medium
	134a	0	Zero	1430	Medium
	407C	0	Zero	1774	Medium
	437A	0	Zero	1805	Medium
	407F	0	Zero	1825	Medium
	442A	0	Zero	1888	Medium
	410A	0	Zero	2088	Medium
	407A	0	Zero	2107	Medium
	427A	0	Zero	2138	Medium
	438A	0	Zero	2265	Medium
	423A	0	Zero	2280	Medium
	417A	0	Zero	2346	Medium
	424A	0	Zero	2440	Medium
	422D	0	Zero	2729	High
	422A	0	Zero	3143	High
	434A	0	Zero	3245	High
	428A	0	Zero	3607	High
	MO89	0	Zero	3805	High
	404A	0	Zero	3922	High
	507A	0	Zero	3985	High
	508B	0	Zero	13396	High
	23	0	Zero	14800	High
HCFC	123	0.06	Medium	77	Low
	402B	0.03	Medium	2416	Medium
	401A	0.033	Medium	1182	Medium
	401B	0.036	Medium	1288	Medium
	409A	0.046	Medium	1909	Medium
	22	0.055	Medium	1810	Medium
	402A	0.019	Medium	2788	High
	408A	0.024	Medium	3152	High
CFC	502	0.33	High	4657	High
	12	1	High	10900	High

1.2.3 Desirable Thermodynamic, Thermophysical and Chemical properties

a) **Thermal Conductivity-** For faster heat transfer during condensation and evaporation process the thermal conductivity of a refrigerant should be high.

b) **Vapour Density-** To enhance the efficiency of refrigeration system the usage of smaller compressor is essential, therefore the vapour density of the refrigerant need to be low.

c) **Latent Heat of Vaporization-** Heat absorption should be maximum therefore; the latent heat of vaporization should be high of the refrigerant.

d) **Viscosity-** It is required for a refrigerant to exhibit low viscosity to reduce pressure drop in case of both liquid and vapour state.

e) **Critical Temperature-** It is very essential for a refrigerant to have a high critical temperature in order to widen the range of isothermal energy transfer.

f) **Specific Heat-**It is required for a refrigerant in liquid state to exhibit minimum change in its entropy during the throttling process; therefore the specific heat should be low, whereas in vapour state it is required to have high specific heat in order to overcome vapour superheat during the suction stage. [5]

g) **Chemical Requirements-** The refrigerant needs to be non-toxic and inflammable especially for the application in air-conditioning and food preservation. Its rating of GWP and ODP should be very low.

Table 3. Required properties for Refrigerants

Properties		Requirements
Thermo-physical	Normal Boiling Temperature	**Low**
	Freezing Point	**Lower than system**
	Thermal Conductivity	**High**
	Vapour Density	**Low**
	Latent Heat of Vaporization	**High**
	Critical Temperature	**High**
	Critical Pressure	**Low**
	Specific Heat	**Low**
Chemical	Toxicity	**Non-toxic**
	Global Warming Potential	**Low GWP** (Zero)
	Ozone Depletion Potential	**Low ODP** (Zero)
	Flammability	**Inflammable**
	Reaction with Oil	**Low miscibility**
Cost		**Economical**
Availability		**Easy**

1.2.4 Crystal Structure of Refrigerants

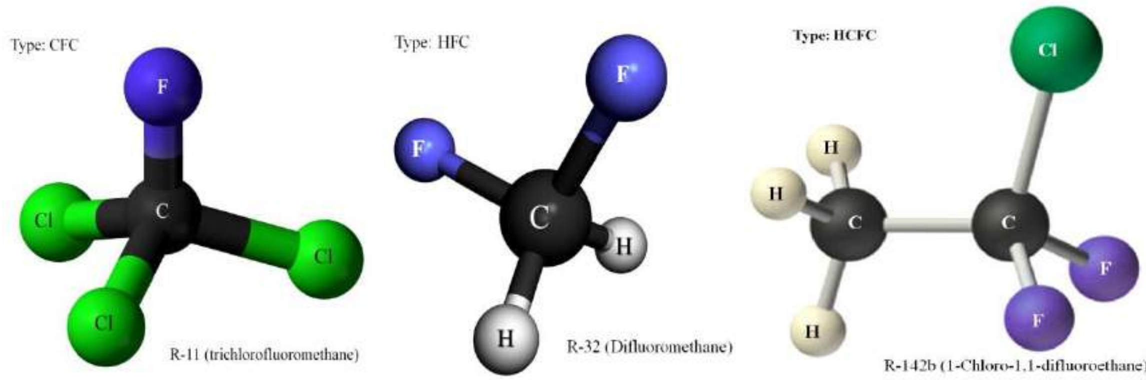

Figure 11. The above figure shows crystal structure of CFC, HFC and HCFC refrigerant

1.3 Nanoparticles

Nanotechnology made its mark in the late 1950's, making it one of the highly potential dimensions for research and developments. Therefore, researchers and scientist began an extensive work towards this new dimension of technology claiming it to be the renaissance in the field of applied technology.

Nanoparticles are bits or fragments sized one billionth times smaller than a metre making it a microscopically visible. On the basis of size, they can be categorised into ultrafine particles (1 to 100nm) [6], fine particles (100 to 2500nm) and coarse particles (2500 to 10,000nm).[25-26]

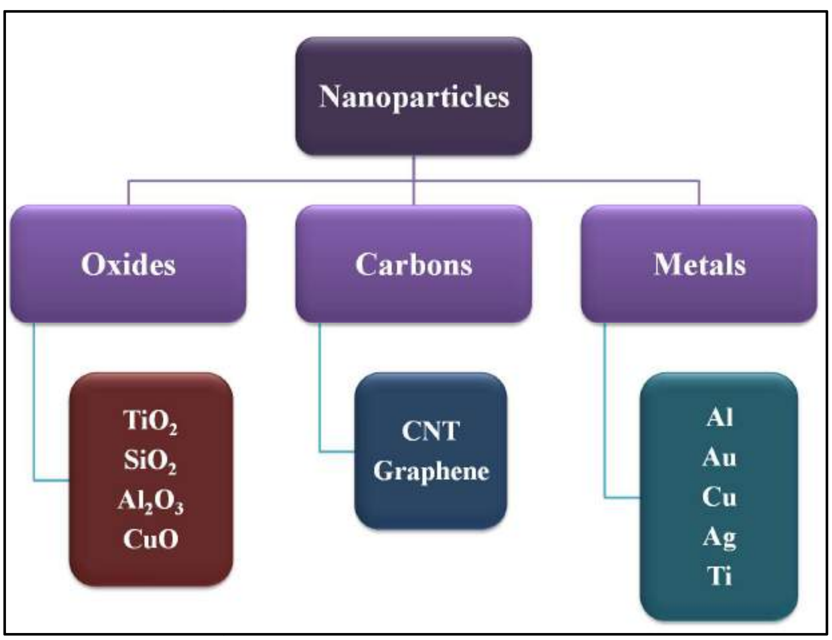

Figure 12. Classification of Nanoparticles

1.4 Mixed Nano-Refrigerants

Nano-Refrigerant, a new generation of efficient refrigerants exhibiting superior thermophysical properties as compared to conventional refrigerants. These refrigerants are of varied composition wherein, suspension of Nanoparticles in two heterogeneous refrigerants mixture in equal or unequal proportions. This new generation of refrigerants are low ODP and GWP value refrigerants. [27-28]

1.4.1 Correlations for Thermophysical Properties

Table 4. Commonly used correlation for metals and metal oxides

Thermophysical properties	Reference	Correlations	Relevant information
Thermal Conductivity	Maxwell [8] 1881	— 6] 6] 3 9 4 / 6] 9 3 9 4	Liquid and solid suspension
	Hamilton and Crosser [7] 1962	— 6 3 9 [4 6 3 9 [4 3 9 4 / 6 3 9 [4 9 3 9 4 = 6] =] 6 [	— [Œ
	Devis 1986 [8]	— [6 3 9 [4 / 3 9] 4 9 3 9 [4 6 3 4 6	3 4] = [C 3 4 C=
Specific heat	Pak and Cho 1998	6 3[9 4	Spherical and non-spherical particles
Density	Pak and Cho 1998	6 3[9 4	Spherical and non-spherical particles
Viscosity	Pak and Cho 1998	— [6] = 6 ǂ	Modified Einstein model
	Einstein 1906	— 3[6] = 4	

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 Nano-refrigerants at various volume fractions of different Nanoparticles.
- To estimate the Viscosity of Nano-refrigerants at various volume fraction of different Nanoparticles.
- To estimate the Density of Nano-refrigerants at various volume fraction of different Nanoparticles.
- To estimate the Specific heat of Nano-refrigerants at various volume fraction of different Nanoparticles.
- To investigate thermo-hydraulic performance of domestic refrigerators using mixed Nano-Refrigerants.

4 Review of Literature

Prasad Mangalkar et al., 2017 [9] - As in the present scenario the CPUs are being designed with focus on performance, therefore it requires higher voltage supply comparatively. This supply of high voltage generates more heat which degrades the performance. Thus cooling of electronics and its components becomes necessary. Prasad Mangalkar et al. [ ] worked on cooling of microprocessor of CPU with the use of Al_2O_3-H_2O NF which resulted in enhancement of 18% in performance.

M. M. Sarafraz et al., 2017 [10] - The performance of liquid gallium is compared with CuO-H_2O nF and H_2O. The CuO-H_2O nF were used at weight concentration of 0.1%, 0.2% and 0.3% of which 0.3% concentration performed the best among the nF and water. Whereas liquid gallium performed was anomalous when considering all the coolants at different CPU state.

K. Wongcharee et al., 2017 [11] - A combination of swirling impinging jet (SIJ) and TiO_2-H_2O nF where used to achieve greater Nusselt number than the conventional fluid. It has been reported that concentration of 0.5%, 1%, 1.5% and 2% shows an enhancement while 2.5% concentration exhibits negative results. Thus, the maximum enhancement was achieved at 2% volume concentration.

Ravinder Kumar et al., 2017 [12] – The author worked on VCRS with the usage of mixed refrigerants. The mixed refrigerant used in composition R-290/R-600a and mineral oil with ZnO. It was observed that the suction pressure is reduced by approximately 21% with the usage of 0.2-1% weight percentage of nPs. It was also observed that the suction and discharge temperature reduced and the energy consumption by the compressor was reduced by 7.48% than the conventional refrigerant usage system. Compression ratio dropped by about 5.76% and viscosity increased in the mineral oil after the addition of nPs.

M. E. Haque et al., 2016 [13] – The authors investigated on the enhancement in heat transfer by the usage of nPs in evaporator. It was observed that the freezing ability of VCRS has also enhanced and consumption of power of the compressor reduced by 27.73% using 0.1% Alumina nPs whereas, in case of TiO_2 Nano-lubricant it has reduced by 14.19%. The COP of the system has enhanced by about 19% and 22% when two different compositions of Al_2O_3 Nano-lubricant are used.

N. Ahammed et al., 2016 [14] - Investigated cooling of electronics (COE) using nFs at volume% 0.1% and 0.2% of Al_2O_3-H_2O nFs. It was observed that enhancement of 40% in COP for 0.2% volume concentration it was also observed that 9.15% decline in thermo-electric temperature. The researchers concludes by making a statement that pressure drop is directly propositional to flow rate and volume concentration, and volume concentration is directly proportional to thermal effectiveness.

S.S. Khaleduzzaman et al., 2015 [15] - The analysis shows that the nFs are stable physically. It is observed from the research that even at higher volume concentration the sedimentation is very mediocre. And there were no obstacles for nFs to pass through mini channels. Thus, the nPs could pass seamlessly through the channels without any sedimentation.

S.S. Khaleduzzaman et al., 2014 [16] - The researcher made a statement that the energy efficiency is directly proportional to volume fraction of nFs. Furthermore, the frictional factor is inversely proportional to flow rate and volume fraction of nPs of Al_2O_3.

Assel Sakanova et al., 2014 [17] - The use of double layer and double side MCHS (micro channel heat sink) has been observed. The volume concentration of nF plays an important role in increment of cooling capability of cooling system, therefore it has been stated by the researcher that as the volume concentration increases the cooling effect is increasing. The researcher used nFs of 1% and 5% volume concentration of Al_2O_3-H_2O which resulted in 10.6% and 17.3% enhancement in cooling effect.

S.S. Khaleduzzaman et al., 2014 [18] - Three different nFs were used CuO-H_2O, Al_2O_3-H_2O and SiC-H_2O. The highest k enhancement was exhibited by SiC-H_2O nF of 12.45%. Whereas CuO-H_2O exhibited highest enhancement of heat flux of 8.51% as when compared with the result of H_2O as a coolant.

T. Yousefi et al., 2013 [19] - Experimentally investigated the COE (CPU) with the use of Al_2O_3-H_2O nFs. This nF application results in decrement in thermal resistance by 15% and 22% when 10W and 25W heat is generated respectively.

Manu Mital, 2013 [20] - The researcher semi-analytically investigated on base fluid and nF. The observation shows that despite nF reduces the heat resistance but on the other hand pumping power is to be increased.

Ali Ijam et.al., 2012 [21] - Used SiC and TiO_2 NPs with water at 4% volume concentration which resulted in enhancement in k of 12.44% and 9.99% respectively. Further investigation shows that there is an increment in cooling performance of approximately 7.25%-12.43% in SiC-H_2O and 7.63%-12.77% in TiO_2-H_2O nFs.

W. Escher et al., 2011 [22] - At volume concentration of 0%, 5%, 16% and 31% of silica nFs. It was reported that none of the nFs exhibits anomalous enhancement in heat transfer rate. Furthermore, reported that the *k* doesn't impact the performance of micro channels.

N.A. Roberts et al., 2010 [23] - has worked on Al_2O_3-H_2O and DI-H_2O (Deionised water). Apparently the researchers used nPs of sized between 20-30nm and this nF resulted in 18% enhancement h_c (convective heat transfer coefficient) than DI-H_2O. The researchers mentioned that this nF doesn't require very high pumping power which is a merit whereas it can be more maintenance as it tends to settle.

M. Mohanraj et al., 2007 [24] - The researcher worked on refrigeration system keeping in view the application of domestic refrigerator with the usage of mixed refrigerants HC290-HC600a of composition 45%-55% respectively. The experimental work was done with 50 g, 70 g and 90 g which enhanced the COP of the system by 6.4%, 11.4% and 12.7%. It was also observed that discharge temperature of mixed refrigerant being lower than HFC134a by approximately 7^{o}C, 12 ^{o}C and 18 ^{o}C for 90 g, 70 g and 50g respectively. The lowest power consumption was reported by 50 g. The statement made by authors stated that 70 g mixture proved to be suitable alternative for HFC134a.

5 Research Methodology

Steps to be followed

➢ 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.

➢ 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 Nanotube.
- In this research work Nanoparticles of CuO were selected and found to be well suited for above mentioned mixed refrigerant.

➢ Synthesis of Nano-refrigerants

- The synthesization 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 of Nano-refrigerant with keeping in view the variation mass flow rate and heat fluxes.

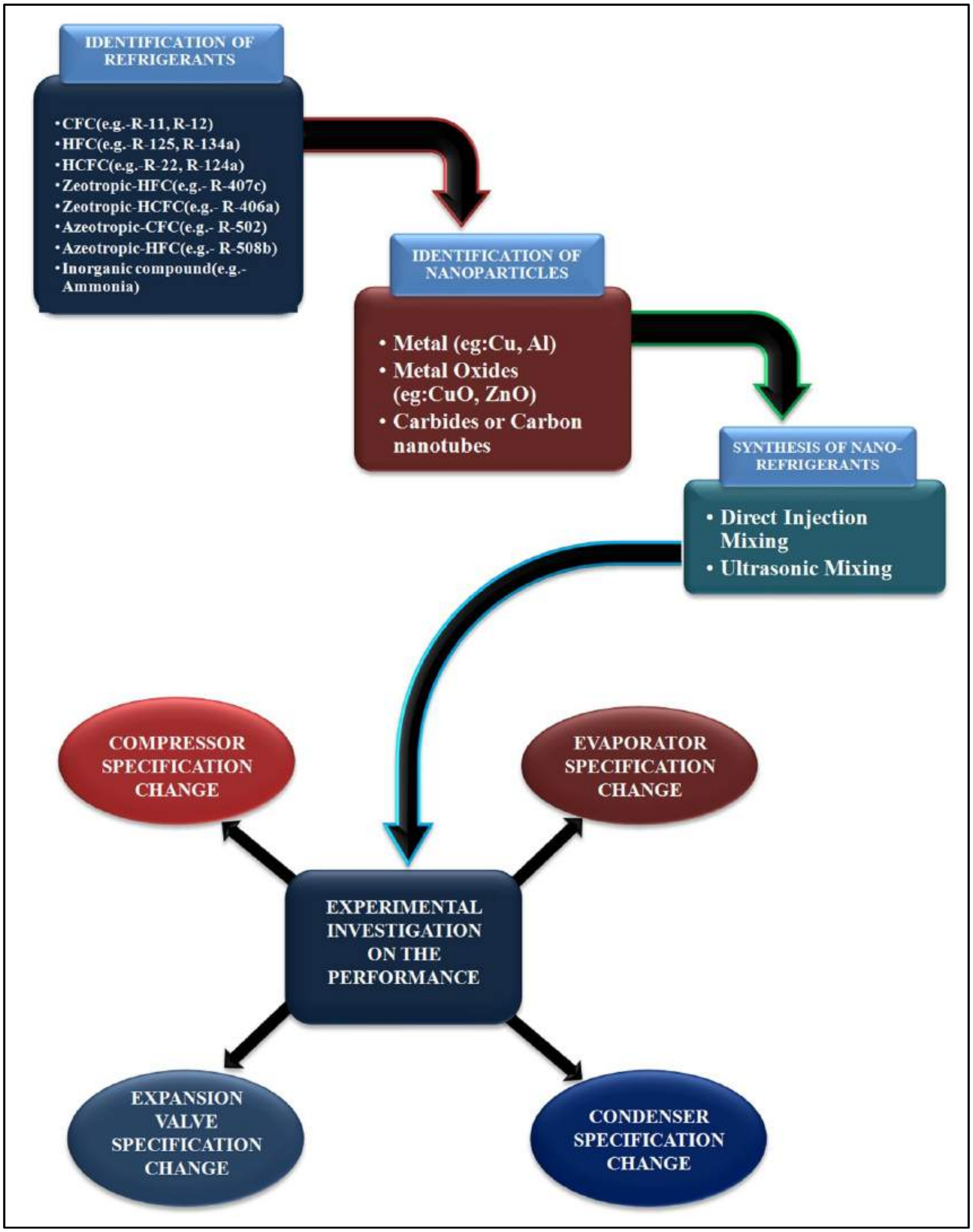

Figure 13. Step by step process in order to find optimum composition

6 Expected Outcomes

This present research work covers the thermophysical properties of Propane and Iso-butane at varying compositions and suspension of nPs of CuO in volume concentration ranging between 1% to 5% and pressure ranging from 3MPa to 7MPa. The heat fluxes are also included in boundary condition at variation of $100W/m^2$ to $500W/m^2$.

The following outcomes are as follows

- Density of a mixed Nano-refrigerant at various compositions may decreases with respect to heat flux.
- Viscosity of a mixed Nano-refrigerant at various compositions may decreases with respect to heat flux.
- Thermal conductivity of a mixed Nano-refrigerant at various compositions may decreases with respect to heat flux.
- Specific heat of a mixed Nano-refrigerant at various compositions may decreases with respect to heat flux.

7 Proposed Work Plan with Timeline

The research work commenced in January 2017 and was successfully completed by November 2017. Unmatched dedication, work coupled with awe-inspiring mentorship was the corner stone of this dissertation.

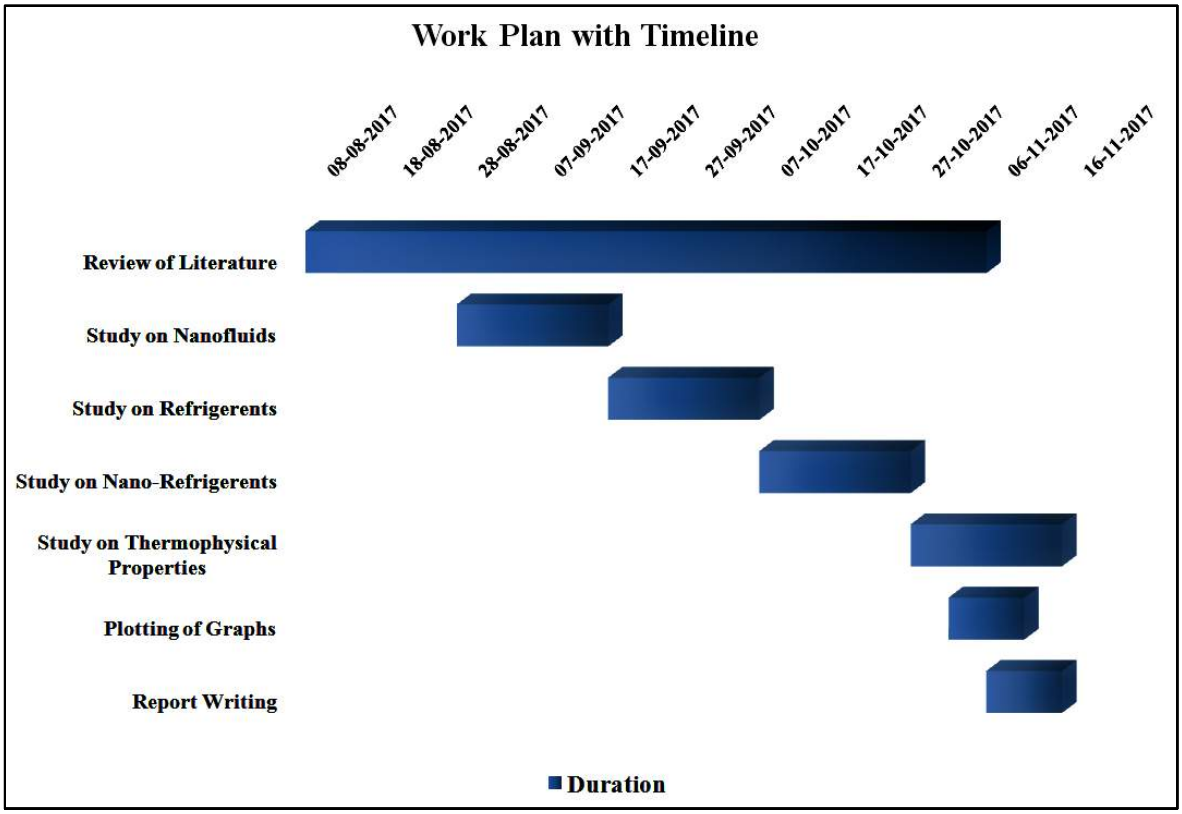

Figure 14. Work plan and timeline Gantt chart

8 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 Nano-refrigerants. Three different Nanoparticles CuO and TiO_2 were chosen. The operating conditions were taken to be 3 MPa and 4 MPa Pressure and 300 K temperature respectively. For each Nanoparticles, calculation of thermophysical properties was carried separately with different volume concentrations (1-5%) respectively.

8.1 Thermophysical properties of CuO at Pressure 3 MPa

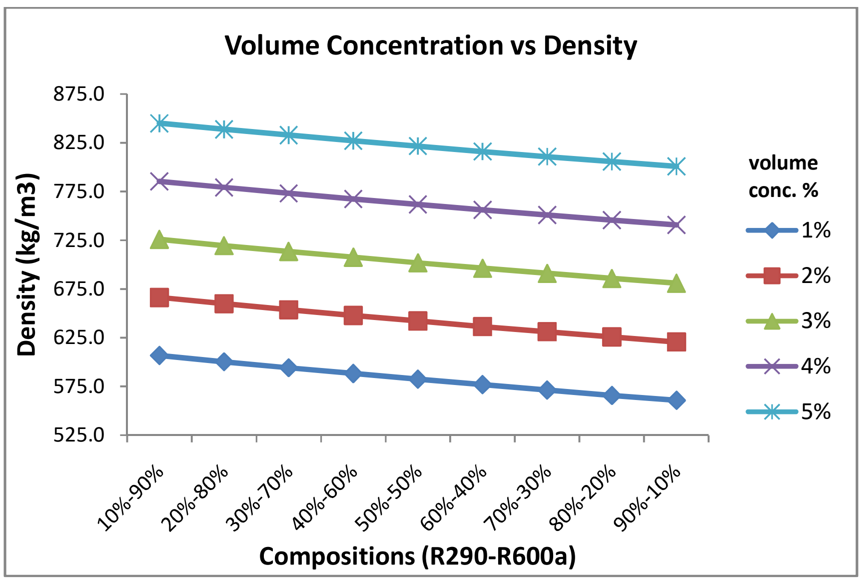

Figure 15. Density as a function of Composition at pressure 3 MPa.

Figure 15 represents Density as a function of Composition. As the volume conc. % of Nanoparticles increases, the density of mixed Nano-refrigerant increases. It was observed that, as the concentration of R600a decreases, density decreases.

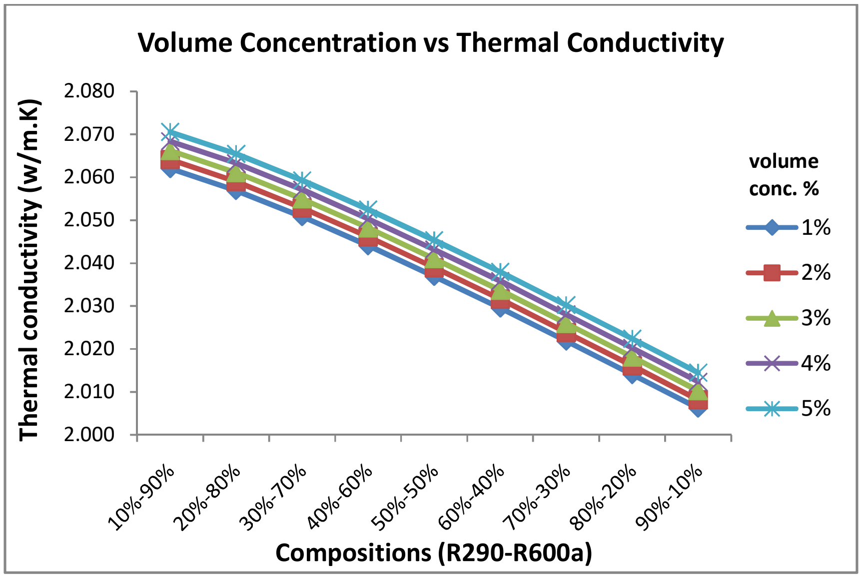

Figure 16 Thermal conductivity as a function of Composition at pressure 3 MPa.

Figure 16 represents thermal conductivity as a function of Composition. As the volume conc. % of Nanoparticles increases, the thermal conductivity of mixed Nano-refrigerant increases. It was observed that, as the concentration of R600a decreases, thermal conductivity decreases.

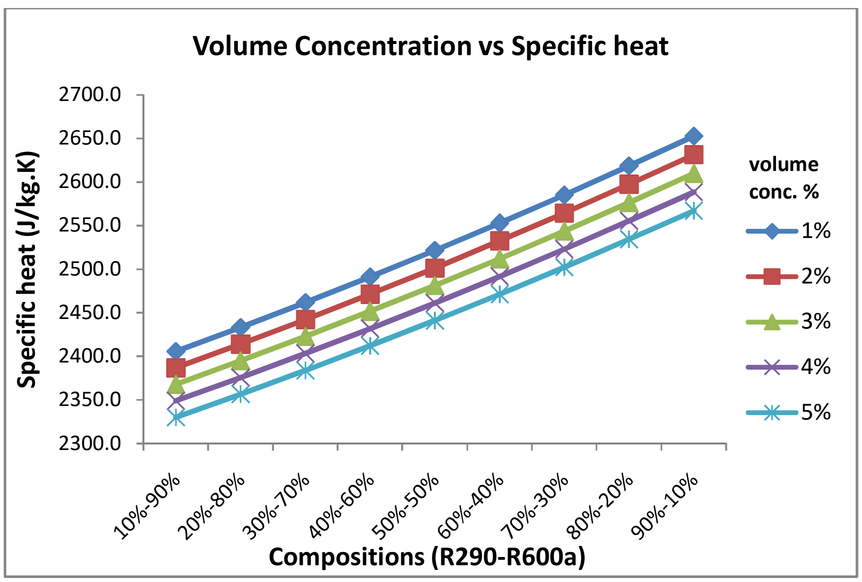

Figure 17 Specific heat as a function of Composition at pressure 3 MPa.

Figure 17 represents specific heat as a function of Composition. As the volume conc. % of Nanoparticles increases, the specific heat of mixed Nano-refrigerant decreases. It was observed that, as the concentration of R290 increases, specific heat increases.

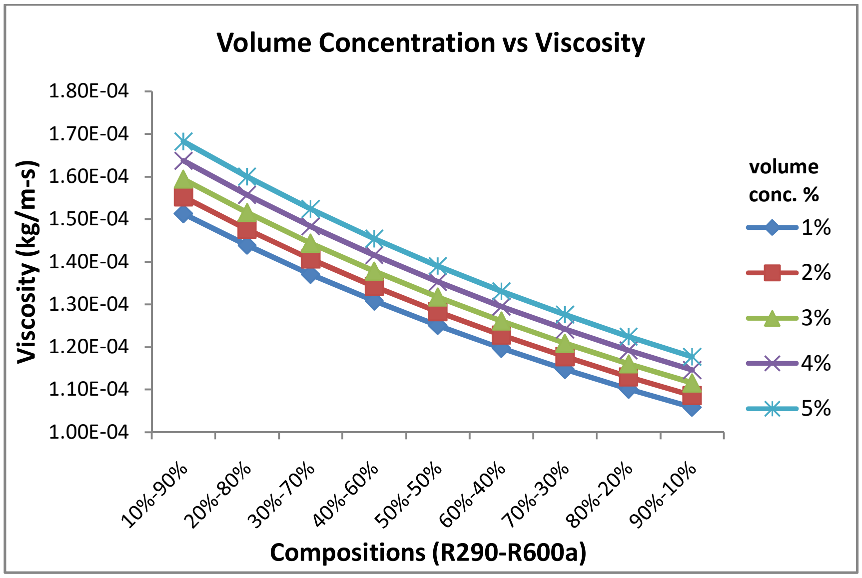

Figure 18 Viscosity as a function of Composition at pressure 3 MPa.

Figure 18 represents viscosity as a function of Composition. As the volume conc.% of Nanoparticles increases, the viscosity of mixed Nano-refrigerant increases. It was observed that, as the concentration of R290 increases, viscosity decreases.

8.2 Thermophysical properties of TiO_2 at Pressure 3 MPa

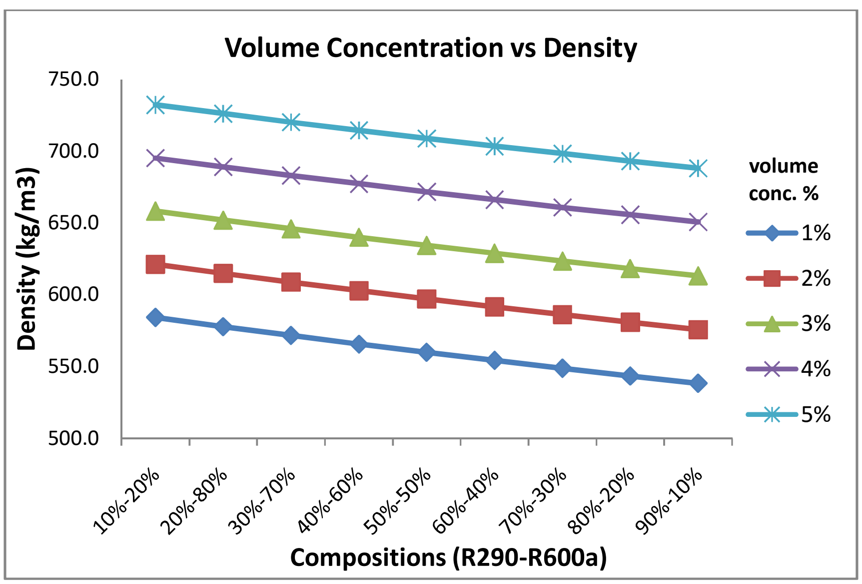

Figure 19 Density as a function of Composition at pressure 3 MPa.

Figure 19 represents Density as a function of Composition. As the volume conc.% of Nanoparticles increases, the density of mixed Nano-refrigerant increases. It was observed that, as the concentration of R600a decreases, density decreases.

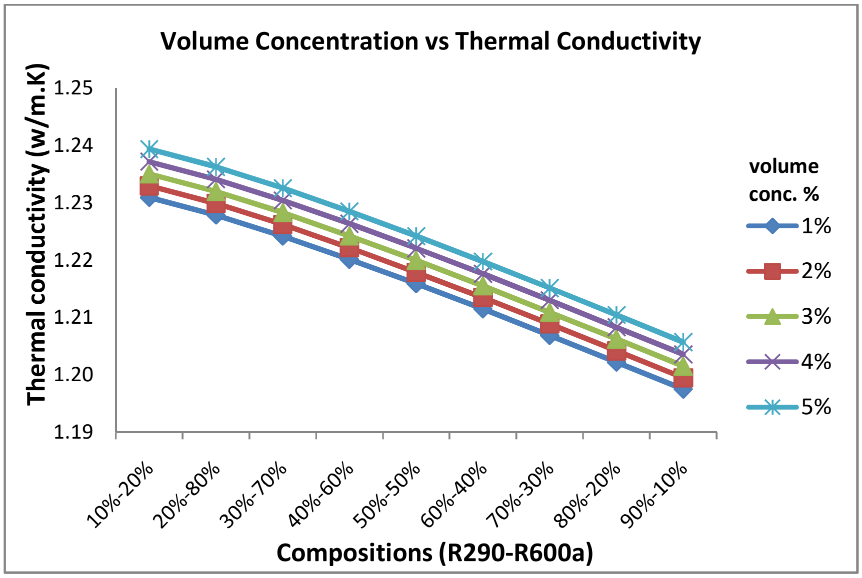

Figure 20 Thermal conductivity as a function of Composition at pressure 3 MPa.

Figure 20 represents thermal conductivity as a function of Composition. As the volume conc.% of Nanoparticles increases, the thermal conductivity of mixed Nano-refrigerant increases. It was observed that, as the concentration of R600a decreases, thermal conductivity decreases.

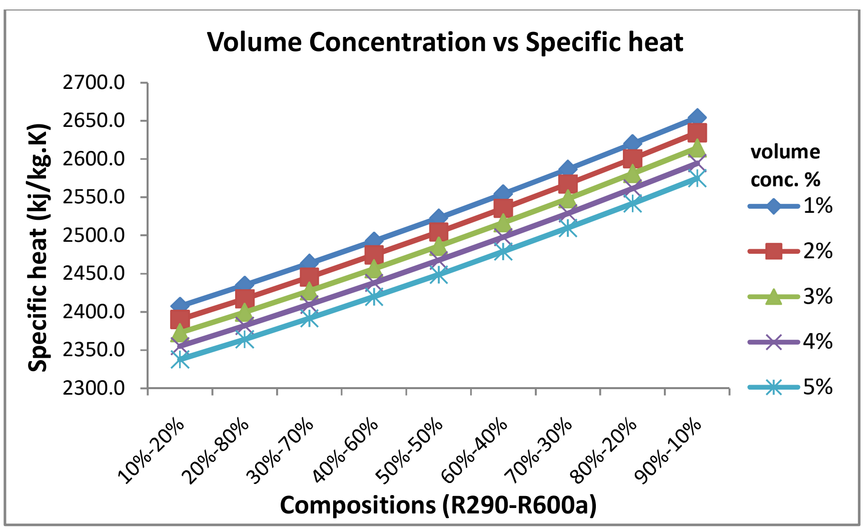

Figure 21 Specific heat as a function of Composition at pressure 3 MPa.

Figure 21 represents specific heat as a function of Composition. As the volume conc.% of Nanoparticles increases, the specific heat of mixed Nano-refrigerant decreases. It was observed that, as the concentration of R290 increases, specific heat increases.

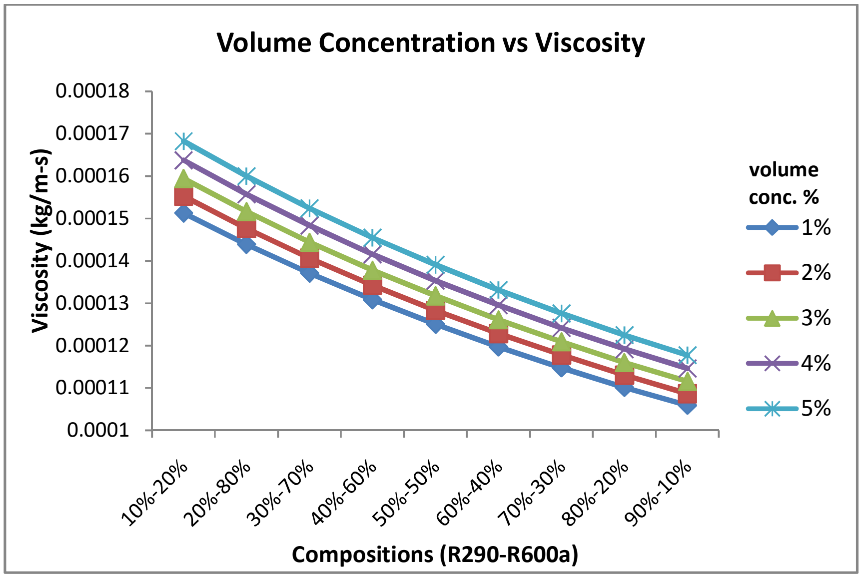

Figure 22 Viscosity as a function of Composition at pressure 3 MPa.

Figure 22 represents viscosity as a function of Composition. As the volume conc.% of Nanoparticles increases, the viscosity of mixed Nano-refrigerant increases. It was observed that, as the concentration of R290 increases, viscosity decreases.

8.3 Thermophysical properties of CuO at Pressure 4 MPa

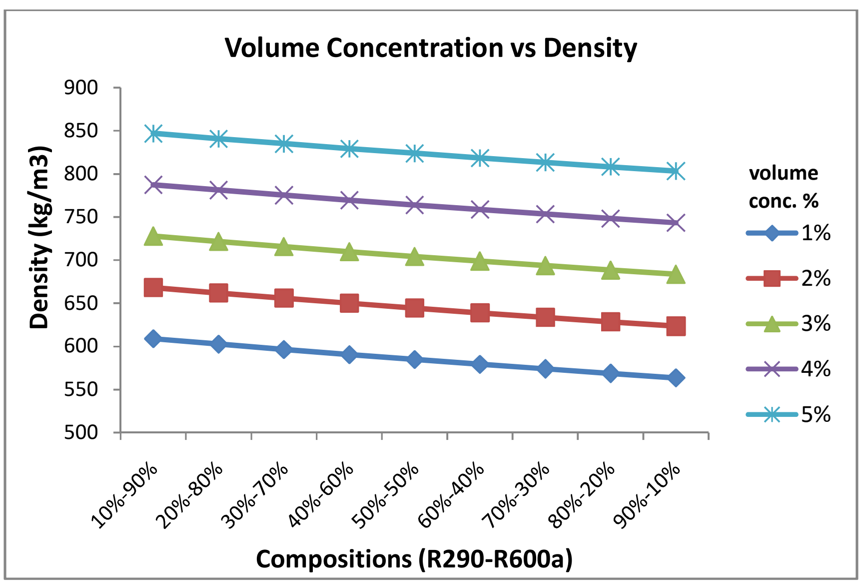

Figure 23 Density as a function of Composition at pressure 4 MPa.

Figure 23 represents Density as a function of Composition. As the volume conc.% of Nanoparticles increases, the density of mixed Nano-refrigerant increases. It was observed that, as the concentration of R600a decreases, density decreases.

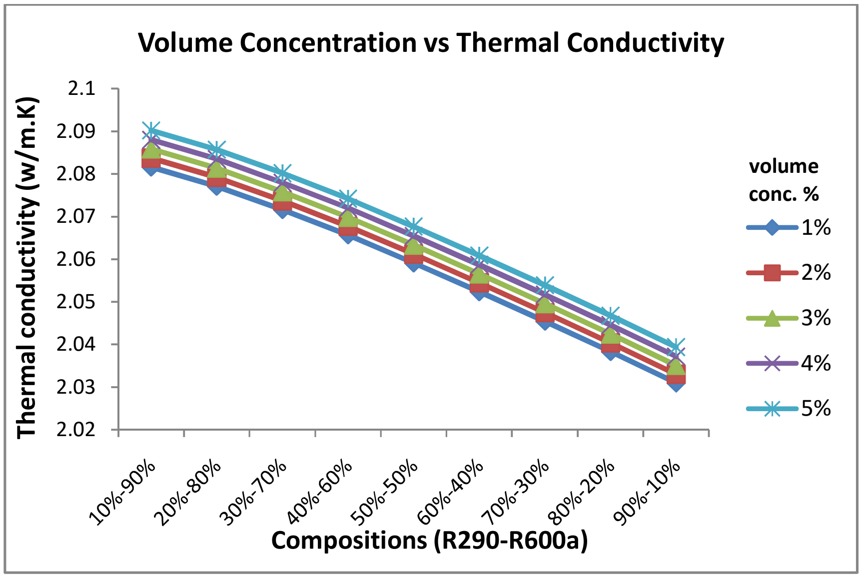

Figure 24 Thermal conductivity as a function of Composition at pressure 4 MPa.

Figure 24 represents thermal conductivity as a function of Composition. As the volume conc.% of Nanoparticles increases, the thermal conductivity of mixed Nano-refrigerant increases. It was observed that, as the concentration of R600a decreases, thermal conductivity decreases.

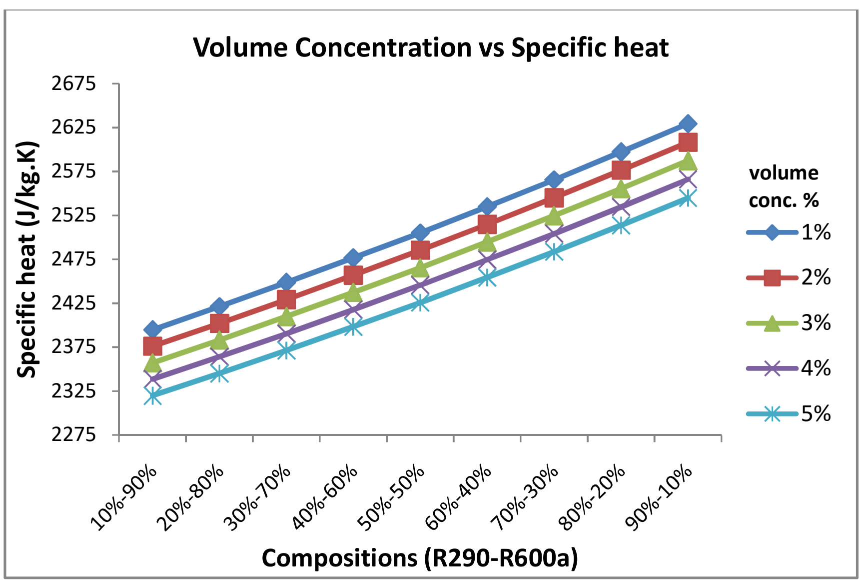

Figure 25 Specific heat as a function of Composition at pressure 4 MPa.

Figure 25 represents specific heat as a function of Composition. As the volume conc.% of Nanoparticles increases, the specific heat of mixed Nano-refrigerant decreases. It was observed that, as the concentration of R290 increases, specific heat increases.

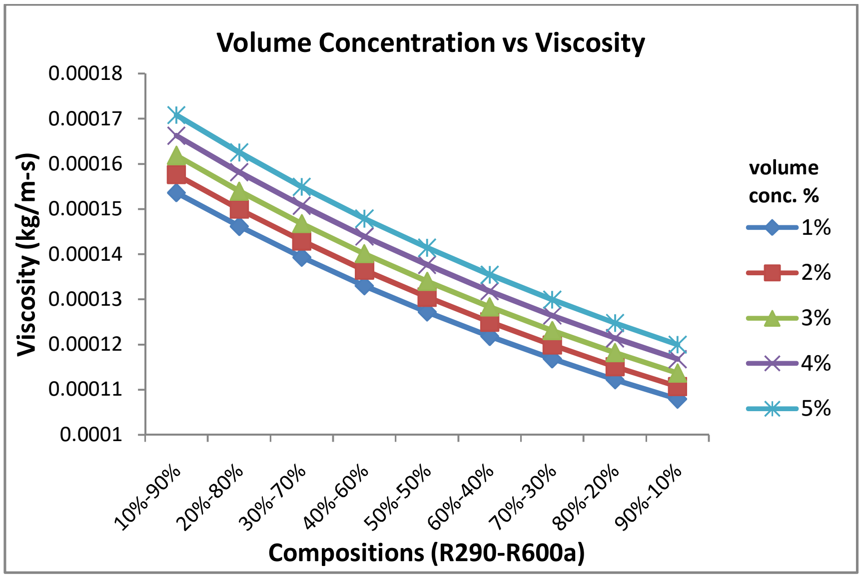

Figure 26 Viscosity as a function of Composition at pressure 4 MPa.

Figure 26 represents viscosity as a function of Composition. As the volume conc.% of Nanoparticles increases, the viscosity of mixed Nano-refrigerant increases. It was observed that, as the concentration of R290 increases, viscosity decreases.

8.4 Thermophysical properties of TiO_2 at Pressure 4 MPa

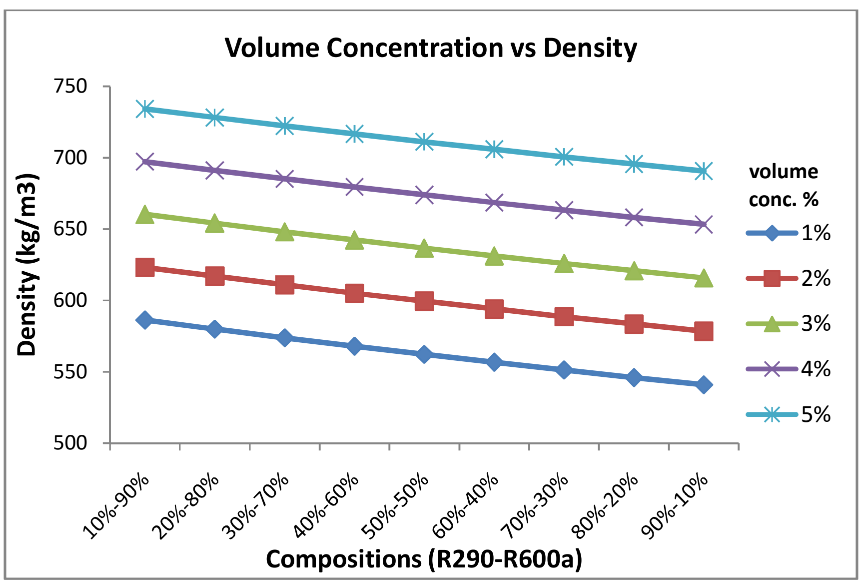

Figure 27 Density as a function of Composition at pressure 4 MPa.

Figure 27 represents Density as a function of Composition. As the volume conc.% of Nanoparticles increases, the density of mixed Nano-refrigerant increases. It was observed that, as the concentration of R600a decreases, density decreases.

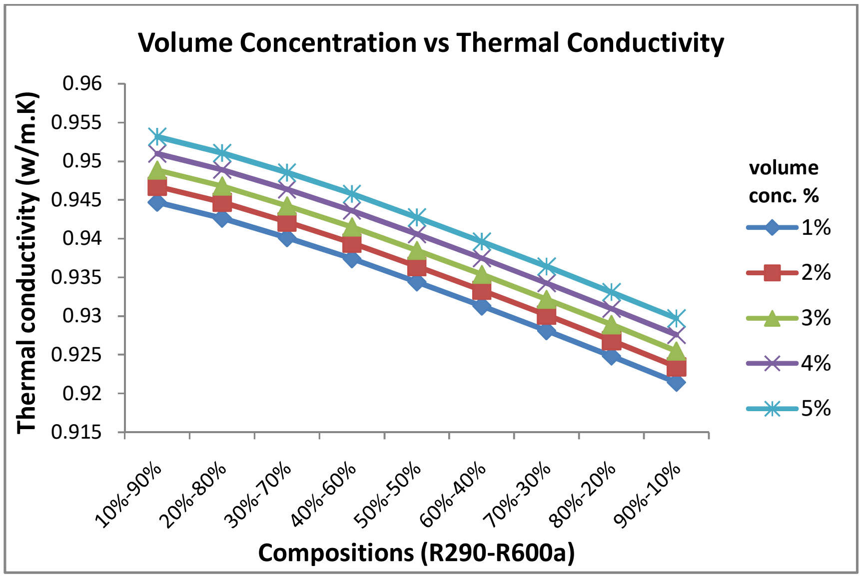

Figure 28 Thermal conductivity as a function of Composition at pressure 4 MPa.

Figure 28 represents thermal conductivity as a function of Composition. As the volume conc.% of Nanoparticles increases, the thermal conductivity of mixed Nano-refrigerant increases. It was observed that, as the concentration of R600a decreases, thermal conductivity decreases.

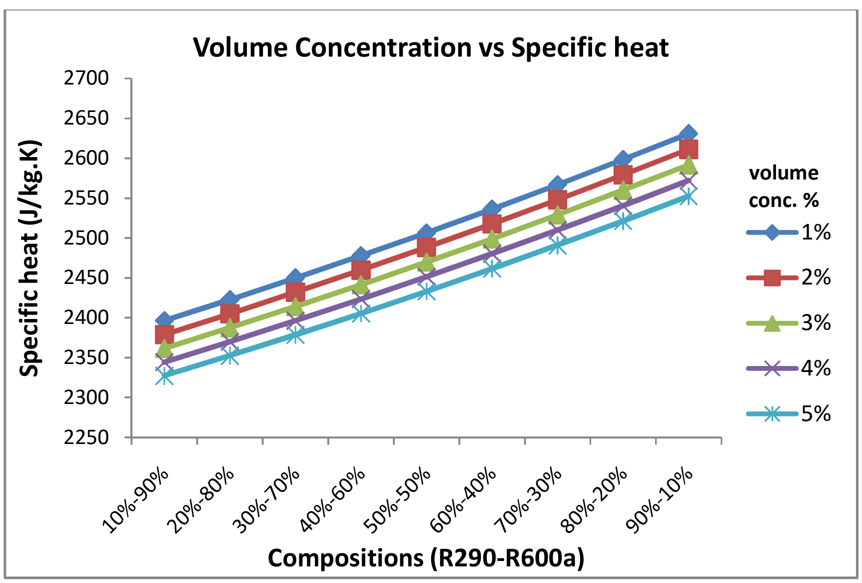

Figure 29 Specific heat as a function of Composition at pressure 4 MPa.

Figure 29 represents specific heat as a function of Composition. As the volume conc.% of Nanoparticles increases, the specific heat of mixed Nano-refrigerant decreases. It was observed that, as the concentration of R290 increases, specific heat increases.

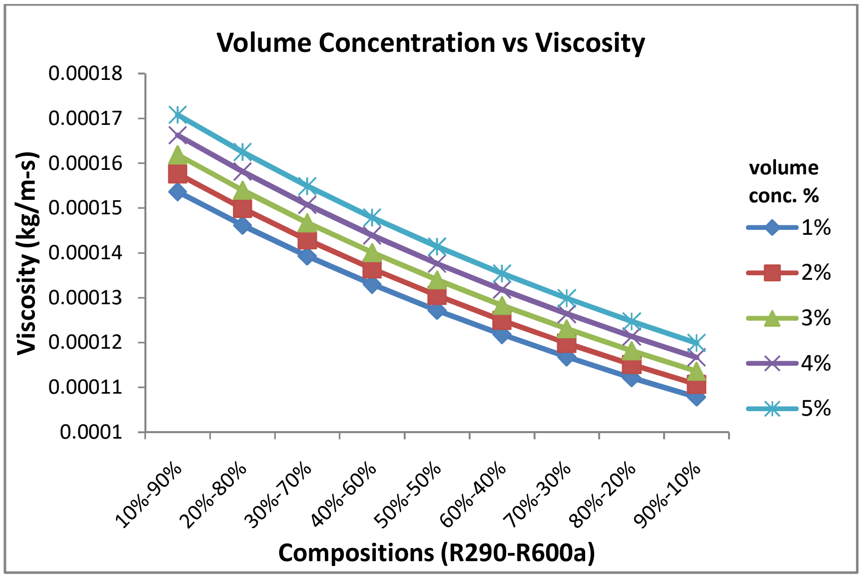

Figure 30 Viscosity as a function of Composition at pressure 4 MPa.

Figure 30 represents viscosity as a function of Composition. As the volume conc.% of Nanoparticles increases, the viscosity of mixed Nano-refrigerant increases. It was observed that, as the concentration of R290 increases, viscosity decreases.

9 Summary and Conclusions

In this present research work very similar pattern of calculations were observed in both CuO and TiO_2 Nanoparticles at 3 MPa and 4 MPa pressures. The observations are as follows.

- It was observed from the density calculations that as the volume conc. % of Nanoparticles increases, the density is increasing gradually. Whereas, when the conc. % of R-600a decreases, the density decreases.
- It was observed from the density calculations that as the volume conc. % of Nanoparticles increases, the specific heat is decreasing eventually. Whereas, when the conc. % of R-290 increases, the specific heat increases.
- It was observed from the density calculations that as the volume conc. % of Nanoparticles increases, the thermal conductivity increases. Whereas, when the conc. % of R-600a decreases the thermal conductivity decreases gradually.
- It was observed from the density calculations that as the volume conc. % of Nanoparticles increases, the viscosity is increasing. Whereas, when the conc. % of R-290 increases, the viscosity is decreases gradually.

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