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Research paper

Comparative Analysis of Thermohydraulic Properties of Nano-Refrigerants

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Abstract

The nano-particles achieved the focus of the researchers in the field of refrigeration, due to its capability to change the properties of refrigerants upto a large extent. Nanofluids based on refrigerant is known as nano refrigerants and provided an improvement in thermo-physical properties of various refrigerants in different terms. Different theoretical and experimental models are provided by the researchers have been used for the evaluation of different properties of refrigerant in terms of thermal conductivity, density, specific heat and viscosity of the refrigerants. In this effort, a number of models, and correlations have been used to result in the improvement in these properties of nano refrigerants. This is achieved by the addition of nanoparticles with varying volume concentration of 1% to 5 %. The analyses have been made within a temperature range of 190K- 269K at a constant pressure of 0.3 MPa. The study is elaborated to compare the various refrigerants which are R11, R12, R22, R134a and R141b with the addition of different nano-particles which are TiO_2, Al_2O_3, ZnO and CuO at evaporator conditions. The addition of ZnO has given a good impact on the thermal conductivity of refrigerants. Effective viscosity of nano refrigerants depends upon the viscosity of refrigerants and volumetric concentration of nano-sized particles. Specific Heat shows the negative variation with the addition of nanoparticles but increased with the rise in temperature. The density of nano refrigerants depends upon the density of base refrigerant, Density of nanoparticles, volumetric concentration of nanoparticles. In future, the study can be elaborated in terms of compressor work, power consumption and overall performance of refrigeration system.

Keywords: *Nano-Refrigerants, Viscosity, Thermal conductivity, Specific Heat*

1. Introduction

Contribution towards society, optimum utilization of recourses and the benefits in terms of money always encourages the researchers to do the new advancements in their field. The environmental consideration, feel for the ozone layer and responsibility against global warming and energy crises are also the major issues which push to modify the conventional refrigerants. Nanorefrigerants are defined as the colloidal solution involving nanoparticles in the refrigerants. This affects the properties of the base fluid. The indication by various Models both analytical and experimental suggests the possible enhancement in the key properties of the refrigerants. Nanorefrigerants are prepared by using two techniques. In the first technique, nanoparticles are made and then added to the base fluid. Magnetic stirring and ultra-sonication are the two methods used in this technique for complete mixing of nanoparticles in the refrigerant. In the second technique which is called as physical vapour deposition technique or liquid-chemical method, the metal vapours are directly condensed into nanoparticles when the vapours come in contact with the low-pressure base fluid. To calculate the required properties different equations has been used. The database for the properties of the refrigerant at different temperature and pressure has been collected from National Institute of Standards & Technology (NIST). The Valuable changes of these properties in the refrigerants will make them more effective and to be used in a domestic refrigeration system, industrial refrigeration system, air conditioning system, storage of perishable products such as meat, fish, insulin, Milk etc., water chilled system, heat exchangers, engines for the purpose of coolant.

2. Literature review

In the history of nano refrigerants number of researchers has done a lot of work and provided their results for future references. It is better to measure the existing work in this field which will help to proceed for next step of the research work on this path. In this part a review has been made on different results which are as follow:
Gabriela et. al. [1] studied that thermal conductivity and dynamic viscosity were directly related to volume concentrations of Nanofluids, particle shape, particle size, mixture combination and slip mechanism. As the concentration of nanoparticles is increased, the performance of heat exchangers was observed as improved. The process showed increment in thermal conductivity, density, viscosity and deduction in heat capacity. Kole et al. [2] studied that the viscosity of nano-fluid increased with the increased concentration nanoparticles and falls with increment in temperature. Newtonian fluids converted to Non-Newtonian fluids mixed with

nanoparticles. The viscosity of nanofluids decreased exponentially with increase in temperature of nanofluid because of weakening forces of attraction between particles and molecules. Kole et al. [3] observed that the thermal conductivity rose by 24% with the addition of 2% volumetric concentration of Cu nanoparticles in oil. There was a non-linear increment in the thermal conductivity with the addition of copper nanoparticles in gear oil and temperature of nanofluid. Bi et al. [4] observed that nano refrigerants can work sufficiently well in the refrigeration system. The refrigeration system using TiO2-R600a nano-refrigerant performs better than refrigeration system with only R600a. 9.6% of less energy used with the addition of 0.5 g/ litre of TiO2 in R-600a. The thermal conductivity and heat transfer characteristics were also enhanced with the addition of nanoparticles. Marilainon et al. [5] explained that the increase in pumping power cancelled the effect of heat transfer coefficient which rises due to increase in viscosity of fluid due to the addition of nanoparticles. The ratio of Nanofluid viscosity to the water viscosity increased as volumetric percentage increases but it is independent of temperature. Nasiri et al. [6] analysed that Nusselt number of nanofluids was more than the nusselt number of a base fluid for the same specific peclet number. Nusselt number was increased by the increment in the volumetric concentration of the nanoparticles. Stephen et al. [7] examined that to enhance thermal conductivity, suspension of metals and metal oxides are added to base fluids. The addition of nanoparticles reduced the pumping power in the heat exchanger. Manay et al. [8] investigated that transfer of heat rise with an increase in Reynolds number and volume concentration of particle. Up to 2% volume concentration of nanoparticles, friction factor has shown a little change. Xuan et al. [9] Studied that nanoparticles increased the surface area hence there is a rise in heat capacity of fluid. Hamilton and crosser model and Wasp model were used to obtain thermal conductivity of solid-liquid mixture. Chook Pak et al. [10] found that the viscosity of the dispersed fluid with Al_2O_3 and TiO_2 particles at a 10% volume concentration becomes 200 and 3 times larger than water. Darcy friction factor for the dispersed fluid changes by 2% to 3%. Murshed et al. [11] found that the thermal conductivity of nanofluids also depends upon the variation in temperature. Thermal conductivity also depends upon particle size, shape, interfacial layer. Nanofluid contains highly thermal conductive nanoparticles such as Al having high thermal conductivity as compared to TiO2. Wang et al. [12] achieved the method for the use of HFCS with nanoparticles to establish the energy efficient retrofitted residential air conditioner. NiFe2O4 nanoparticles are added into oil B32 which is naphthalene based, was used in R410a as a refrigerant. Mineral based nano refrigerant oil added with R410a works normally in RAC. Mahbubul et al. [13,14] investigated that with the raised temperature and concentration of nanoparticles in terms of volume the thermal conductivity of nano-refrigerant also enhanced. The viscosity of the nano-refrigerant increased as the volume concentration increased and decreased with rising in temperature. Mahbubul et al. [15] observed that thermal conductivity of nano-refrigerant enhanced as the temperature and volume concentration of nanoparticles are raised. An Increase in the volume concentration of nanoparticles in the refrigerant increases pressure drop which further increases the pumping power. Sun and Yang [16] noticed that with the addition of Cu, CuO, Al, and Al_2O_3 nanoparticles R141b based nano-refrigerant convective heat transfer coefficient also increased. The enhancement in the heat transfer coefficient was observed maximum with Cu nanoparticles as compared to other.

These results were obtained after conducting the experiments, by considering the combination of refrigerant with different nanoparticles and no doubt these results were found to be good. These results were in the term of thermal conductivity, specific heat, viscosity and density of nano refrigerants.

3. Research Methodology

To analyse the change in different properties of refrigerant a procedure has been framed which includes the use of experiments, models and correlations. The refrigerants used for the research purpose is R11, R12, R22, R134a, R-141 b. This process is applied to the evaporators, which acts as heat exchangers. They work at low pressure varies from 0.2 MPa to 0.4 MPa. But the temperature range varies from application to application. The properties of refrigerants at different temperatures are obtained and comparing them at that these temperatures. Table 1 shows the temperature range in the evaporator for different refrigerants.

Table 1: Applicable Temperature Range of various refrigerants

Refrigerants	Temperature Range
R-11	198 K- 277 K
R-12	173 K-260 K
R-22	173 K-247 K
R-134 a	173 K- 263 K
R-141 b	173 K- 277K

The thermo-hydraulic properties searched from the reference fluid thermodynamic and transport properties database and have been analysed for different pressure and temperature. Thermo-hydraulic properties include thermal conductivity, viscosity, density, and specific heat. The next step is to find out the Nanoparticles which can be added into these refrigerants and then by using correlations given by different researchers being used and the results will obtain for the Nanorefrigerants which use the different concentration of Nanoparticles. The concentration is limited up to 5% otherwise the power losses will be more in the compressor. The nanoparticles used are TiO_2, CuO, ZnO and Al_2O_3. The analytical approach is used for the research. There are many correlations which are used by different researchers for finding out the thermal properties and viscosity of nanofluids and some of which are applicable to the nano refrigerants. The graphs are obtained to see the variation of properties of refrigerants with a change in concentration of Nanoparticles. Einstein theoretical model and Brinkman Experimental model for viscosity, Maxwell equation and Timofeeva equation are used for calculating theoretical and experimental thermal conductivity, the Xuan and Roetzel equation is used for calculating the effective density, Pak and Cho correlation is used for the specific heat of nano refrigerants.

Table 2: Various Theoretical and Experimental models and Equations

Model	**Correlations**
Einstein[17]	$\frac{\mu_{eff}}{\mu_f} = 1 + 2.5\varphi$
Brinkman [18]	$\frac{\mu_{eff}}{\mu_f} = \frac{1}{(1-\varphi)^{2.5}}$
Maxwell [19]	$\frac{K_{eff}}{K_f} = \frac{K_p + 2K_f + 2\varphi(K_p - K_f)}{K_p + 2K_f - \varphi(K_p - K_f)}$
Timofeeva et al. [20]	$K_{NF} = (1 + 3\varphi)K_f$

The Xuan and Roetzel [21] equation to estimate the effective density of nano refrigerants and is given by:

$$\rho_{NF} = (1-\varphi)\rho_{BF} + \varphi\rho_{NP}$$

Accordingly, the effective density of refrigerant depends upon the volumetric concentration, mass density of refrigerant and nano-sized particles.

Pak and Cho [22] equation are used for verifying the specific heat which shows its dependence on volumetric concentration, mass density, the specific heat of refrigerant and nano-sized particles.

$$C_{pNF} = \frac{(1-\varphi)(\rho C_p)_{BF} + \varphi(\rho C_p)_{NP}}{(1-\varphi)\rho_{BF} + \varphi\rho_{NP}}$$

4. Result and discussion

The analytical study has been done to observe the enhancement of thermohydraulic properties of various refrigerants and nano refrigerants. Certain comparisons have been established between the nano refrigerants with varying the temperature and volumetric concentration of nanoparticles. The present section explores the comparative analysis between various nano refrigerants under evaporator conditions. The pressure in the evaporator can vary from 0.2 MPa to 0.4 MPa. The similar results are obtained at each pressure consideration. In the present research, the analysis has been done at a constant pressure of 0.2 MPa.

4.1 Analysis of thermal conductivity of various refrigerants with the addition of nanoparticles.

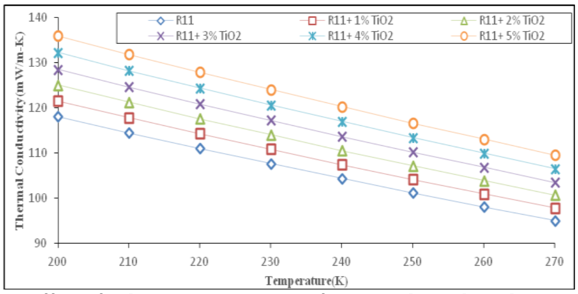

Fig. 1: effect of volume concentrations of TiO_2 on thermal conductivity of R11 w.r.t Temperature

Figure 1 reveals the effect of volume concentrations of TiO_2 on thermal conductivity of R11. The graph suggests the thermal conductivity of nano refrigerants formed by the addition of TiO_2 nanoparticles in the R11 shows downfall in values w.r.t temperature. The graph depicts that with an addition in the amount of TiO_2, the thermal conductivity of R11 rises at all temperature range. The effect is due to the addition of solid metal oxide suspensions in the fluid. Hence with the uprising in the concentration of TiO_2, the thermal conductivity of base refrigerant i.e. R11 increases. Similar trends are shown with other refrigerants in combination with different nanoparticles.

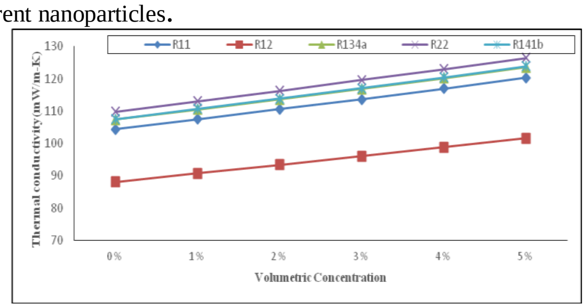

Fig. 2: Comparison of thermal conductivity with a volumetric concentration of TiO_2 at 240K in various refrigerants

Figure 2 shows the comparison of thermal conductivity with a volumetric concentration of TiO_2 in various refrigerants at 240K. The graph suggests increment in the volume concentration of TiO_2 leads to increment in the effective thermal conductivity of various refrigerants used. Nanorefrigerants having R22 as base refrigerant shows the maximum of thermal conductivity and nano refrigerants having R12 as base refrigerant shows the least of thermal conductivity at all volume concentration from 1% to 5%. Similar trends are shown with other refrigerants combination with the different volumetric concentration of nanoparticles.

4.2 Analysis of Viscosity of various refrigerants with the addition of nanoparticles.

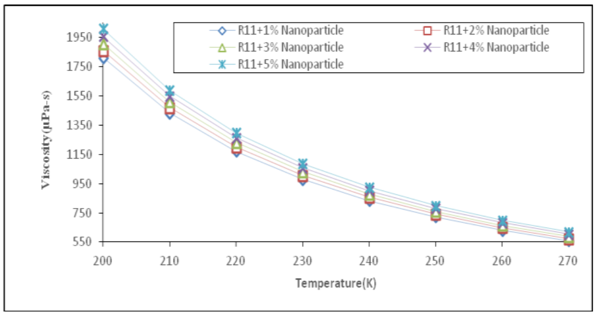

Fig. 3: Effect on viscosity with a different volumetric concentration of nanoparticles in R11 w.r.t temperature

Figure 3 explores the effect on viscosity of base refrigerant R11 with different amount of nanoparticles addition suggest there is a decrement in the value of viscosity of nano refrigerants with increment in the temperature and there is an increment in the viscosity of the base refrigerant when the amount of nanoparticles rises. the increment of the solid suspension creates more friction in the pipe and hence velocity gradient increases. Hence, viscosity increases with the volumetric concentration of nanoparticles. Similar trends are shown with other refrigerants in combination with the different volumetric concentration of nanoparticles.

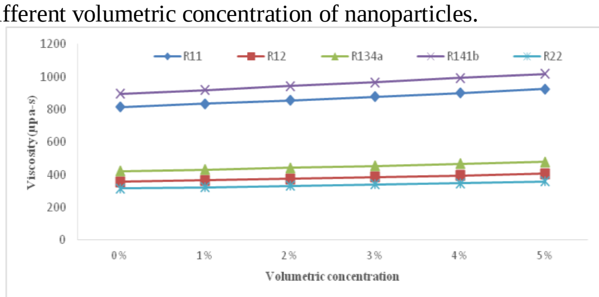

Fig. 4: Comparison of various refrigerants on basis of viscosity with different composition of nanoparticles at 240K

Figure 4 shows the Comparison of various refrigerants on basis of viscosity with different composition of nanoparticles at 240K. The graph suggests all refrigerants at a given temperature shows an increment in their viscosity with increment in the number of nanoparticles. R141b possess a maximum value of viscosity at all volumetric concentration and R22 has the least value of viscosity at all volumetric concentration amongst all refrigerants.

4.3 Analysis of density of various refrigerants with the addition of nanoparticles

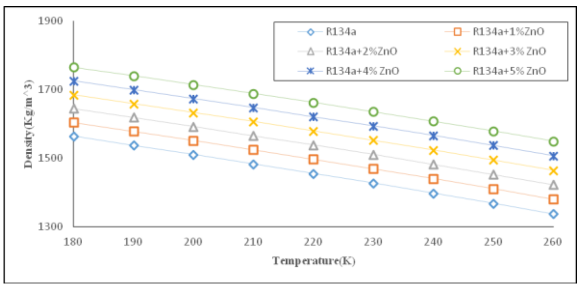

Fig. 5: Variation of density with the temperature at different volume concentrations of ZnO nanoparticles in R134a

Figure 5 reveals the change in density with the temperature at different volume concentrations of ZnO nanoparticles in R134a.

The graph suggests with the rise in temperature the density of the nano refrigerants decreases and at a specific temperature increment in the volume concentration of nanoparticles will lead to increase in the density. Similar trends are shown with other refrigerants combination with the different volumetric concentration of nanoparticles.

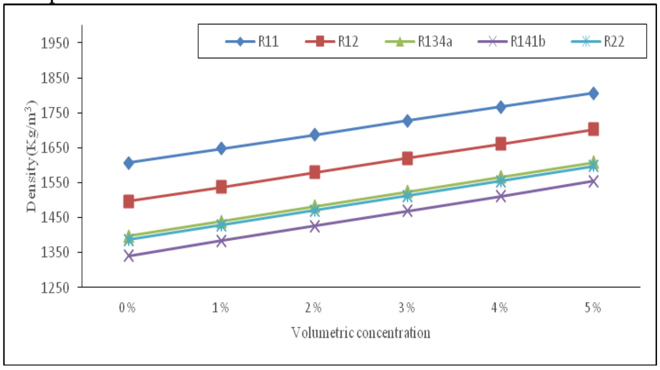

Fig. 6: Comparison of density with a volumetric concentration of ZnO at 240K in various refrigerants

Figure 6 explores the comparison of density with a volumetric concentration of ZnO at 240K in various refrigerants. The graph suggests a density of base refrigerant at a specific temperature shows a positive variation with the addition of nano-sized particles. R11 is having the maximum value of density at all volume concentration of nanoparticles and R141b is having the least density at all volume concentration of nanoparticles amongst the refrigerant.

4.4 Analysis of specific heat of various refrigerants with the addition of nanoparticles

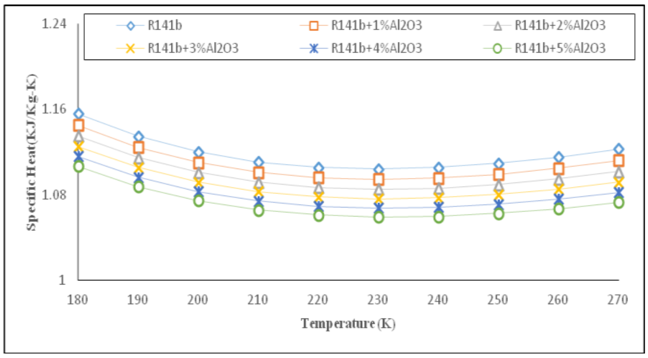

Fig. 7: Effect on the specific heat with different vol. conc. of Al_2O_3 nanoparticles in R141b w.r.t temperature

Figure 7 Effect on the specific heat with different vol. conc. of Al_2O_3 nanoparticles in R141b w.r.t temperature. The graph suggests an increase in temperature specific heat of the nano refrigerants increases and at a specific temperature, specific heat shows negative variation w.r.t. the volume concentration of nanoparticles. The observed data suggest that less amount of heat is required to up the temperature of the nano refrigerants with reference to the base refrigerants.

Similar trends are shown with other refrigerants combination with different volumetric concentration of nanoparticles.

5. Conclusion

Figure 8 shows thermal conductivity comparison of different nano refrigerants at the same temperature and at 1% Vol. Conc. of nanoparticles. The graph suggests nanorefrigerants having ZnO as nanoparticle has more value of thermal conductivity followed by Al_2O_3, CuO and TiO_2 respectively. ZnO nanoparticles addition shows more value of thermal conductivity with the base refrigerants than other nanoparticles.

The addition of nanoparticles increases shear stress in the refrigerant flow. More over the addition of nanoparticles in causes more friction between the surface of the pipe and nano refrigerants. Hence more power is required for nanofluid flow.

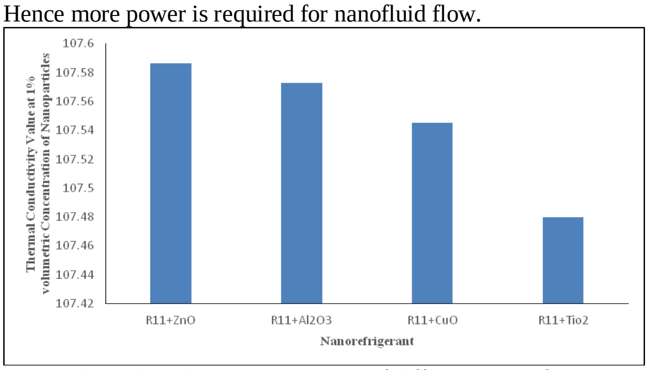

Fig. 8: Thermal conductivity comparison of different nano refrigerants at the same temperature and at 1% volumetric concentration of nanoparticles

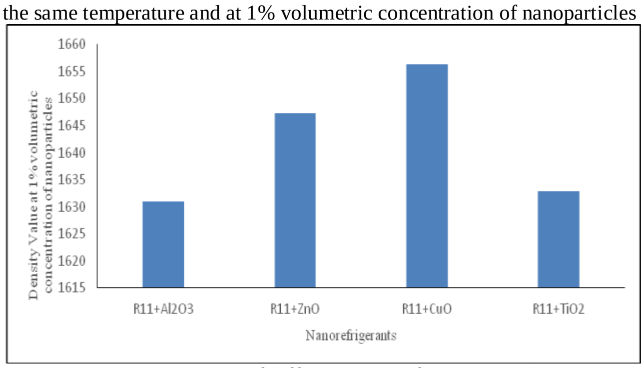

Fig. 9: Density comparison of different nano refrigerants at the same temperature and at 1% volumetric concentration of nanoparticles

The addition of metal oxide particles in the base refrigerant increases the density of base refrigerant. Moreover, the density of nano refrigerants decreases with rising in temperature. Figure 9 shows the density comparison of different nano refrigerants at the same temperature and at 1% volume concentration of nanoparticles. The graph suggests summation of CuO nanosized particles in the refrigerant causes more increment in the value of density followed by ZnO, TiO_2 and Al_2O_3 respectively.

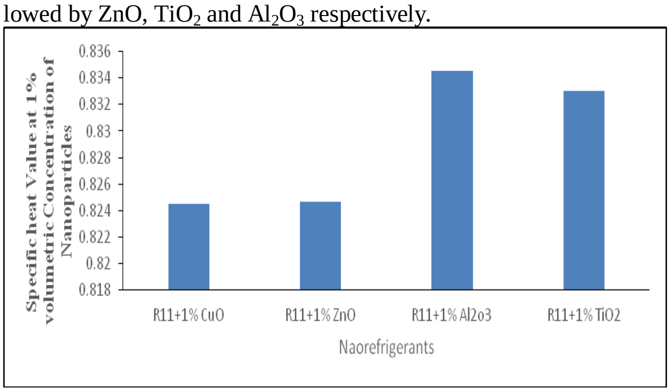

Fig. 10: Specific heat comparison of different nano refrigerants at the same temperature and at 1% volumetric concentration of nanoparticles

Figure 10 suggests that Heat capacity has the least value in case of addition of CuO nanoparticles and maximum in case of addition of Al_2O_3 nanoparticles. In the coming era, the nano refrigerants will replace the traditional refrigerants because of they enhance thermophysical properties.

The thermal conductivity of fluid can be improved along with MWCNT. The production process of nanofluid still needs to be improved in terms of its effectiveness and cost. On the other hand, the un-stability of nanoparticle with refrigerant during the cycle is one of the issues. The particles are not stable for a long time during the cycle. The addition of nanoparticle increases the viscosity of refrigerant hence increases the pump work.

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