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An Investigation into the Performance of a Nanorefrigerant ($R134a+Al_2O_3$) Based Refrigeration System

[1]Kuljeet Singh, [2]Kundan Lal
[1,2]Dept. of Mechanical Engineering, Thapar University Patiala, Punjab, India

Abstract
The use of nanopowder along with the conventional refrigerants in vapour compression cycle is a relatively a new idea, where nanorefrigerants, so obtained are found to have their improved thermal, physical properties over the conventional refrigerants. Nanoparticles can be used along with refrigerant in order to improve the performance of vapour compression refrigeration system. In this study, alumina (Al_2O_3) nanoparticles of 20 nm diameter are dispersed in refrigerant R134a to improve its heat transfer performance. After conducting experimental study, it has been found out that performance of the system has been improved. The improvement in coefficient of performance (COP) is maximum (7.2 to 8.5%) with 0.5% Al2O3 (% wt.) nanoparticles. When the mass fraction of nanoparticles increased to 1% in refrigerant COP is found to be lower than even from pure R134a. Further, increased mass fraction of Al_2O_3 (1%), lowers down the pressure and temperature after expansion of the nanorefrigerant in the expansion valve. In addition to this the specific heat of refrigerant gets decreased. So these both factor will results in decrease in the refrigeration effect, hence COP. Moreover, system works normal with nanorefrigerant.

Keywords
Alumina (Al_2O_3), Nanolubricant, Nanorefrigerant, Coefficient of Performance (COP)

I. Introduction
Nanoparticles directed the innovative world into a new direction by its ability to influence working properties of fluid. Nanofluids are advanced class of fluids with particles of nano size (1-100 nm). The concept is based on the fact that solids have high heat capacity as compared to fluid. So nano sized particles or nanoparticles are dispersed into a base fluid in order to enhance physical properties of base fluid. The nanoparticle materials are usually of metal, non-metal and their oxides, which enhance the heat transfer performance of base fluids. Hence, there is huge scope of its application in heat transfer area. Recently, some investigations revealed the application of nanoparticles in refrigeration systems and significant improvement in performance has been observed. In refrigeration systems the nanoparticles can be either added to compressor lubricating oil or to refrigerant. Dispersion of nanoparticles into lubricating oil (nanolubricant) improves the lubrication of compressor or decrease friction of moving parts. Additionally, the in case hermetically sealed compressor fractional amount of lubrication oil is carried away by refrigerant in compressor dome. So, by this means the heat transfer characteristics can be improved and hence performance of the refrigeration system. On other hand when nanoparticles are dispersed into refrigerant (termed as nanorefrigerant), then it directly enhance the refrigerant thermal properties and thereby performance of refrigeration system is found to be improved. Sabareesh et al. [1] carried out an experimental study on refrigerant R12 based vapour compression system. In this system mineral oil based nanofluid (termed as nanolubricant) with small concentrations of TiO_2 (30-40 nm) was used as lubricant. This study found that addition of nanoparticles to mineral oil (lubricant) increases the viscosity of lubricant, but coefficient of friction was found to be decreased with increase in volume concentration of nanoparticles. Volume fraction of 0.01% was found optimum as it improved the rate of heat transfer by 3.6%. In addition to this the reduction in compressor work was observed, which was around 11%, hence this result increase in coefficient of performance (COP) by 17%. This study concluded that use of nanoparticles in lubricant is useful to improve the performance of vapour compression system. Trisaksri et al. [2] carried out an experiment to study the behavior of nanorefrigerant during nucleate pool boiling. In this study R141b is used as base refrigerant with TiO_2 nanoparticles and a horizontal cylinder of copper of 28.5 mm diameter was used for boiling. It was found that adding a small quantity of nanoparticles to refrigerant R141b did not affect on boiling heat transfer rate, but when dispersion of TiO_2 nanoparticles is increased from 0.03% to 0.05% (vol.), it reduces the boiling heat transfer rate. In addition to this, at higher heat flux the boiling heat transfer coefficient was found to be decreasing with increase in particle volume concentrations. Jwo et al. [3] conducted an experimental study on a vapour compression refrigeration system in which refrigerant R-134a and polyester lubricating oil had been replaced with a hydrocarbon refrigerant and mineral oil lubricant. Al_2O_3 nanoparticles were dispersed in mineral lubricant to improve the heat-transfer characteristics and lubrication properties. In this study 60 gm R-134a and 0.1 wt % Al_2O_3 nanoparticles were found optimal. With above conditions, there was 2.4% reduction in power consumption and the coefficient of performance (COP) was increased by 4.4%. Peng et. al. [4] reported an investigation, which has also been done on the heat transfer characteristics of refrigerant + nanolubricant mixture with diamond nano particles during nucleate pool boiling. R113 was used as refrigerant and VG68 was used as oil. In this study the heat transfer coefficient of R113 + oil + diamond nanoparticles was found to be greater than the R113 + oil mixture during nucleate pool boiling. Park et al. [5] conducted a study to evaluate effect on heat transfer coefficient for nanofluid based refrigerant during pool boiling. For this purpose different refrigerant (R22, R123 and R134) and carbon nanotubes were used. Three types of nanofluid samples were prepared for this purpose, listed as R22 + CNT, R123 + CNT and R134a + CNT. In this investigation it was found that in horizontal smooth tube CNTs improved the pool boiling heat transfer coefficients of base fluid (refrigerants). It had been also reported that the improvement became more prominent at lower value of heat flux and the maximum improvement of 36.6% could be reached. Hence use of CNTs in refrigerants was found to be effective in order to enhance heat transfer coefficient. Bi et al. [6] conducted out an experimental investigation on a domestic refrigerator. In following study TiO_2 nanoparticles were dispersed into mineral oil to prepare nano-lubricant and R134a was used as refrigerant. This study found that the refrigeration system work efficiently and normally with the above combination of nanolubricant and R134a. There was 26.1% reduction in energy consumption as compared to energy consumed by pure R134a and POE oil based system. Kumar et al. [7] carried out a study in which Al_2O_3 (40-

50 nm) nanoparticles were dispersed into PAG oil in order to prepare nanolubricant whereas R134a was used as refrigerant in vapour compression refrigeration system. Experiments were conducted by charging different mass of refrigerant (150 gm, 180 gm and 200 gm) into the refrigeration system. In this study, the reduction in power consumption was observed, which was in order of 10.32% and length of capillary was also found to be decreased for same refrigeration capacity. Results also reported prominent improvement in heat transfer coefficient and the system worked normally with above combination.

So from above discussion it is very much clear that nanoparticles can be used in refrigeration system to improve its performance. Further by using nano-lubricant or nano-refrigerant, the size of refrigeration systems can be reduced for same refrigerating capacity. In following study it is decided to investigate the performance of vapour compression based refrigeration system by using nano-refrigerant. Refrigerant R134a is used as base fluid and Alumina (Al_2O_3) nanoparticles are dispersed in it in order to improve heat transfer characteristics of base refrigerant.

II. Experimental Setup

To conduct experimental study by using nanorefrigerant a experimental setup has been fabricated. The schematic diagram of this experimental setup is shown in fig. 1. This setup is fabricated with reference to 165 litre domestic refrigerator. Major components include hermetically sealed reciprocating compressor (used in 165 litre domestic refrigerator), air-cooled wire and tube condenser, expansion valve (hand operated type), evaporator and heating arrangement. The evaporator of this setup is dipped in water (10.5 litre) and measured heat flux is supplied to evaporator by means of heater (230 W) and temperature controller. This temperature controller controls the temperature of water around the evaporator by switching on/off the heater, hence maintaining constant heat flux. In order to maintain homogeneous conditions within the container, the water is continuously agitated by a pump. Volume flow rate of refrigerant is measured by means of glass tube rotameter (range, 0-40 LPH). In addition to these components, two energy meters are used in this setup. One energy meter is connected to compressor in order to measure its power consumption and other energy meter is connected to heater to measure its power consumption. Furthermore, voltmeter and ampere meters are also used in the experimental setup. As shown in fig. 1, pressure gauges and mercury thermometers are installed at all salient point of the setup to measure pressure and temperature of refrigerant.

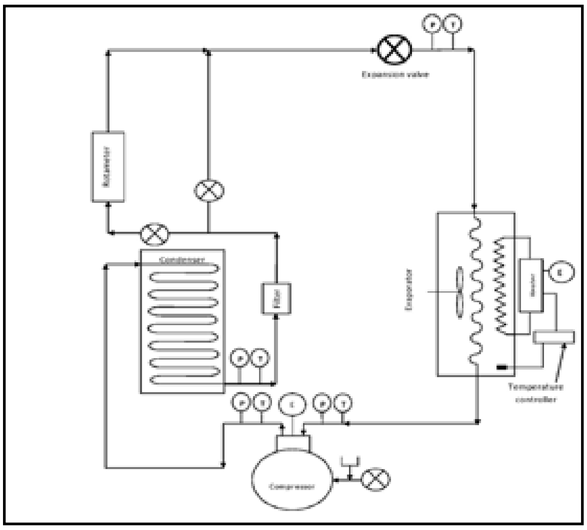

Fig. 1: Schematic Diagram of System

III. Methodology

The experimental setup has been installed in laboratory at almost constant room temperature with temperature fluctuation of ±1ºC. The adequate insulation has been provided in order to minimize the heat losses to environment. Refrigerant R134a is used as base refrigerant and Al_2O_3 used as nanoparticles with 20 nm diameter. The flow rate of refrigerant is maintained as 6.5 LPH through the evaporator. Evaporator is installed in water container and two constant heat fluxes at temperature 16ºC and 30.5ºC are supplied for different experiments. Experiments are first carried out by using pure R134a and then by using nano-refrigerant having 0.5% and 1% (wt %) Al_2O_3 nanoparticles in base refrigerant R134a. Investigation includes study of COP and temperature at all salient points at two different heat fluxes and ambient temperatures (21ºC and 28ºC). External compressor is used for system evacuation before charging in order to remove moisture from system. Refrigerant mass to be charged into the system is taken as 100 gm. All readings are taken after achieving steady state at 15 minutes time interval and average of all readings has been calculated at the end.

IV. Results and Discussion

The results of the experimental study by using pure R134a, R134a + 0.5% Al_2O_3, R134a + 1% Al_2O_3 have been discussed as under:

A. Coefficient of Performance

In order to evaluate the performance of a refrigeration system the coefficient of performance is used to quantify the performance. COP is ratio of refrigerating effect and work input. In this study, COP has been calculated with help of experimental data. Refrigeration effect is estimated by means of energy meter connected to heater. Ultimately the heater is supplying heat to evaporator by means of heating water and same amount of heat is removed by refrigerant after achieving study state.

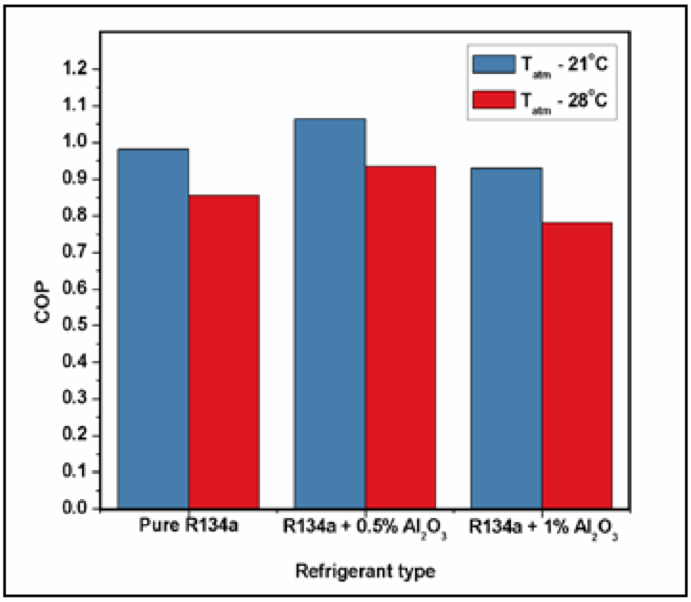

Fig. 2: COP Comparison for 6.5 LPH Volume Flow Rate, Evaporator Load at 15-17ºC Operating at Ambient Temperature 21ºC and 28ºC

As shown in fig. 2, when experiments are conducted at 21ºC ambient temperature supplying constant heat flux at 16ºC, the COP is evaluated as 0.98 for pure R134a. On the other hand, with R134a+0.5% Al_2O_3 and for R134a+1% Al_2O_3 COP is found to be

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1.07 and 0.93. Hence, R134a+0.5% Al_2O_3 shows the improvement in COP by 8.5% and R134a+1% Al_2O_3 results decrease in COP by around 5.4%. When the same experiment is conducted at increased ambient of 28ºC, the COP is estimated 0.86, 0.94 and 0.78 for pure R134a, 0.5% and 1% nanorefrigerant samples respectively. So again same trend has been found at higher ambient temperature that 0.5% Al_2O_3 in base refrigerant improving the system COP and 1% Al_2O_3 diminishing the COP of refrigeration system. Further, with increase in ambient temperature the COP of the refrigeration system decreasing for pure refrigerant R134a as well as for R134a based nanorefrigerant. Pure refrigerant R134a at 28oC ambient temperature gives 12.3% less COP as compared to COP of system operating at 21°C ambient temperature. Similarly, nanorefrigerant with 0.5% Al_2O_3 and 1% Al_2O_3 operating at 28ºC gives 12.2% and 15.9% less COP when compared to COP of system at 21°C ambient temperature. But at both ambient temperatures R134a+0.5% Al_2O_3 gives maximum COP.

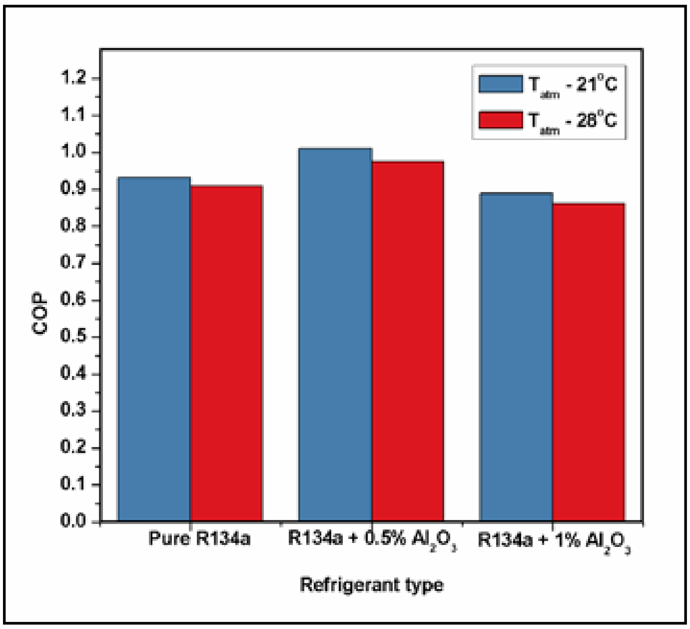

Fig. 3: COP Comparison for 6.5 LPH Volume Flow Rate, Evaporator Load at 30-31°C Operating at Ambient Temperature 21ºC and 28ºC

Experiment is then performed at higher evaporator load temperature by increasing the constant heat load temperature to 30.5ºC. As fig. 3 shows, at 21ºC ambient temperature, COP is evaluated as 0.93, 1.01 and 0.89 with R134a, R134a+0.5% Al_2O_3 and R134a+1% Al_2O_3 respectively. So with 0.5% Al_2O_3 in base refrigerant R134a COP gets improved by 8.6% and with 1% Al_2O_3 in base refrigerant COP decreases by 4.5% when compared with COP of pure R134a. When the experiments are carried out at 28ºC ambient temperature, the pure R134a, R134a+0.5% Al2O3 and R134a+1% Al_2O_3 gives COP in order of 0.91, 0.98 and 0.86 respectively. So with 0.5% Al_2O_3 in base refrigerant the COP is found to be improved by 7.2%, whereas with 1% Al_2O_3 particles in base refrigerant COP is found to be decreased by 5.28% as compared to the COP of pure R134a. In this case COP is also decreasing with increase in ambient temperature. It is seen that pure R134 operating at 28ºC ambient temperature gives 2.3% less COP than system operating at 21ºC ambient temperature. Whereas R134a+0.5% Al_2O_3 and R134a+1% Al_2O_3 operating at 28ºC ambient gives less COP of the order of 3.6% and 3.1% respectively, when compared to COP for system operating ambient temperature 21ºC. Whereas COP is maximum with R134a+0.5% Al_2O_3 sample.

B. Temperatures at Salient Points

For the above experiments the temperatures at all salient points have been recorded and are discussed in following section. T_1 and T_2 refer the temperatures at compressor discharge and condenser outlet. Whereas T_3 and T_4 are temperatures at expansion valve outlet and evaporator outlet. Fig. 4 shows the temperatures at different points with 6.5 LPH flow rate and evaporator heat load at 16ºC, while the experimental setup is kept in 21ºC ambient temperature. So it is observed that by using R134a+0.5% Al_2O_3 the compressor discharge temperature and condenser outlet temperatures are lower than using pure R134a. Temperature drop across the condenser is also increased by 4.6% and 18.3% by using R134a+0.5% Al_2O_3 and R134a+1% Al_2O_3.

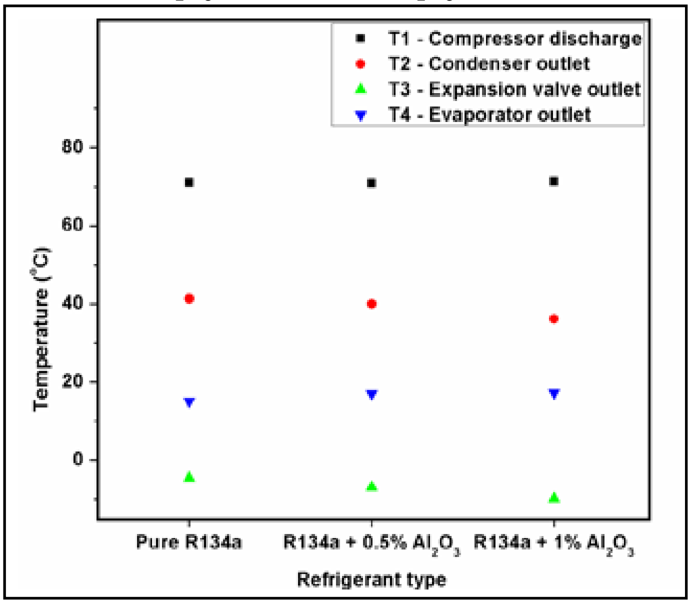

Fig. 4: Temperatures at Four Salient Points for Pure R134 and Nanorefrigerants at 16ºC Evaporator Heat Load Temperature and 21ºC Ambient Temperature

Similarly temperature drop across the evaporator is also increased. But, with same operating parameters, the COP gets improved only in the case of 0.5% Al_2O_3 based nanorefrigerant, whereas it decreases in case of 1% Al_2O_3 based nanorefrigerant.

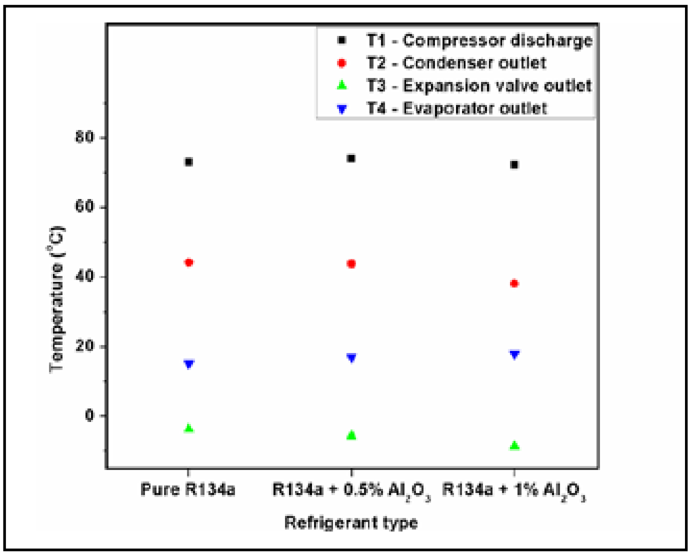

Fig. 5: Temperatures at Four Salient Points for Pure R134 and Nanorefrigerants at 16ºC Evaporator Heat Load Temperature and 28ºC Ambient Temperature

While, the temperature difference across the condenser and evaporator is increasing, even higher drop is achieved with 1% Al_2O_3 in base refrigerant. So, this higher drop does not mean that there is improvement in heat transfer properties. Hence, means there is significant improvement in heat transfer characteristics in case of R134a+0.5% Al_2O_3. Moreover, when the mass fraction of Al_2O_3 is increased to 1% in base refrigerant R134a, it results significant decrease in specific heat of refrigerant, thus increase in temperature difference across condenser and evaporator. Further, in case of R134a+1% Al_2O_3 there is prominent decrease in the after expansion pressure and this lead to lower T_3 (temperature at expansion valve outlet).

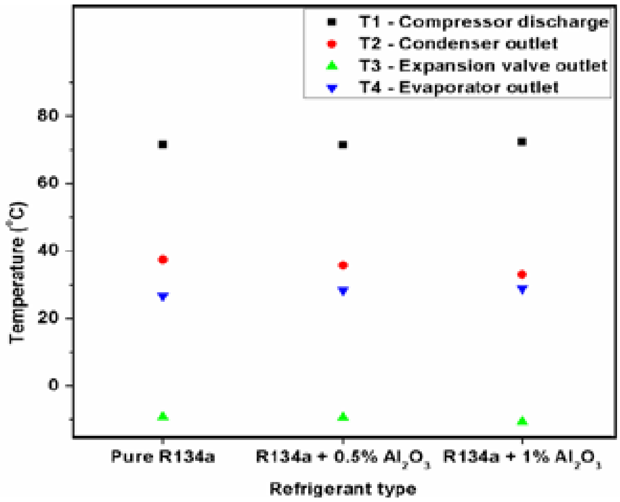

Fig. 6: Temperatures at Four Salient Points for Pure R134 and Nanorefrigerants at 30.5ºC evaporator heat load temperature and 21ºC Ambient Temperature

So if this phenomenon is related with pressure enthalpy (p-h) diagram of vapour compression cycle, decrease in after expansion pressure results lower refrigeration effect. Thereby, decrease in specific heat of refrigerant and decrease in T_3 are actually decreasing the refrigeration effect, hence decreasing COP in case of 1% Al_2O_3 in base refrigerant R134a. But these the operating conditions are optimum in case of R134a+0.5% Al_2O_3 nanorefrigerant sample, hence system operating at higher value of COP. Similar trends has been found in with increased evaporator heat load temperature (30.5ºC) and at increased ambient temperature of 28ºC (refer Fig. 5,6 and 7).

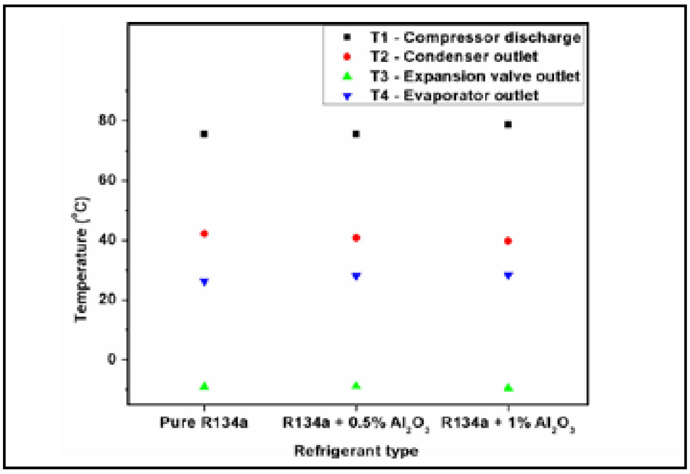

Fig. 7: Temperatures at Four Salient Points for Pure R134 and Nanorefrigerants at 30.5ºC Evaporator Heat Load Temperature and 28ºC Ambient Temperature

V. Conclusion

1. Coefficient of performance (COP) of domestic refrigerator can be improved by mixing Al_2O_3 nanoparticles in base refrigerant R134a. Improvement is found to be maximum by using nanorefrigerant R134a+0.5% Al_2O_3 keeping refrigerant flow rate as 6.5 LPH. This maximum improvement in COP with 0.5% Al_2O_3 nanoparticles in refrigerant is observed at lower as well as higher evaporator operating temperatures. Whereas, increased mass fraction of Al_2O_3 (1%) in base refrigerant R134a results decrease in COP of the system as compared to pure R134a under above conditions.
2. The COP of refrigerator is decreasing with increase in ambient temperature from 21ºC to 28ºC.
3. Nanorefrigerant with 0.5% Al_2O_3 in base refrigerant R134a results increase in effectiveness of condenser and evaporator. Whereas, when mass fraction of Al_2O_3 is increased to 1%, the pressure and temperature after expansion have been decreased. In addition to this the specific heat of refrigerant gets decreased. So these both factor will results in decrease refrigeration effect, hence COP.
4. System works normally with nanorefrigerant and improvement in performance can be achieved by dispersing Al_2O_3 nanoparticles in base refrigerant R134a.

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Mr. Kuljeet Singh is working as Lecturer in Mechanical Engineering Department at Thapar University, Patiala. He has two years of industrial experience with Essar Steel India Limited. His research area is refrigeration and air conditioning, nanofluids and heat transfer systems. His ME thesis work was on Nanorefrigerant application in domestic refrigeration systems.

Mr. Kundan Lal is working as Assistant Professor in Mechanical Engineering Department at Thapar University, Patiala. His research area is heat transfer, refrigeration and air conditioning, fluid mechanics and nanofluidics. He has been a faculty member since last eleven years. He has guided about fifteen ME thesis and has around ten research papers in International and National Journals.