Abstract - Aiming to improve the characteristics of the traditional refrigerants, nanofluid is a new invention to enable vapor compression systems to take advantage of nanoparticles. Recent studies show that use of nanoparticles in refrigeration systems leads to remarkable improvement in thermophysical properties and heat transfer capabilities, thus enhances the efficiency and reliability of refrigeration and air conditioning system. Refrigerant based nanofluids are termed as nanorefrigerants. They have the potential to enhance the heat transfer performances of refrigeration and air-conditioning systems. The present work deals with the investigation on a vapour compression refrigeration system with pure R134a and R134a with different nanoparticles concentration added to it. Stable nanolubricant has been prepared with VG68 polyolester oil for the study. Three different mass concentration 0.04%, 0.06% and 0.08% of Al2O3 nanoparticles with 20 nm size has been used. The system performance was investigated using energy consumption test and freeze capacity test. The results indicate that refrigeration system with nanorefrigerant works normally and safely. It is found that the freezing capacity is higher and power consumption reduces by 14.71% and the coefficient of performance increases by 28.93%, when Al2O3 nanolubricant is used with 0.06% mass fraction giving optimum results.

Index terms - Nanofluids, Nanorefrigerant, Nanolubricant, Nanoparticles, Heat transfer, Al2O3.

I. INTRODUCTION

Thermal systems like refrigerators and air conditioners consume large amount of electric power hence in the face of imminent energy resource crunch, avenues of developing energy efficient refrigeration and air conditioning systems with nature friendly refrigerants need to be explored. With the technological advancement in the field of thermo science and thermal engineering, many efforts have been devoted to heat transfer enhancement. The most common technique consists in maximizing the heat transfer area in heat exchangers, and, at the moment, it seems no further improvement could be achieved. Another possibility could be given by increasing the heat transfer coefficient that, for an imposed flux, depends on the thermal properties of the fluid. To develop energy efficient thermal systems, among the various techniques, one of the techniques is the use of additives to liquid. Since the flow media themselves may be the controlling factor of limiting heat transfer performance, solid additives are suspended in the base liquids in order to change transport properties of flow and heat transfer features of the liquids. Conventional heat transfer fluids like water, ethylene glycol, propylene glycol and refrigerants have low thermal conductivity while the solids like metals, metal oxides and other composites have high thermal conductivity. Hence thermal conductivity of solid metallic or non metallic particles suspended in fluids is significantly higher than conventional fluid. But the presence of these particles in fluid creates the problem of clogging of flow passages.

With the rapid advancement in nanotechnology, the metals and metal oxides are available in nano sizes i.e. in the form of powders and which lead to emerging of new generation heat transfer fluids called nanofluids. Nanofluids are prepared by suspending nano sized particles (1-100 nm) in conventional fluids and have higher thermal conductivity than the base fluids. Nanofluids have been introduced by Steve Choi of Argonne’s Energy Technology Division and Jeff Eastman of the Materials Science Division on Argonne National Laboratory in 1995.

Nanofluids can be employed in the vapour compression refrigeration system to enhance the heat transfer rate. Recent research shows that use of nanofluids in refrigeration system leads to remarkable improvement in thermophysical and heat transfer capabilities to enhance efficiency and reliability of refrigeration and air conditioning system. Compared to conventional solid-liquid suspensions for heat transfer intensification, nanofluids possess the following advantages. i) High specific surface area and therefore more heat transfer surface between particles and fluids. ii) High dispersion stability with predominant Brownian motion of particles. iii) Reduced pumping power as compared to pure liquid to achieve equivalent heat transfer intensification. iv) Reduced particle clogging as compared to conventional slurries thus promoting system miniaturization. v) Adjustable properties, including thermal conductivity and surface wettability, by varying particle concentration to suit different application. N. Subramani et al.[2] established that addition of Al2O3 nano particles with mass fraction of 0.06% to the refrigerant R134. It was found that the freezing capacity was higher and the power consumption reduces by 25% when POE oil was replaced by a mixture of mineral oil and alumina nanoparticles. Calculation shows that the
enhancement factor in the evaporator was 1.53 when nanorefrigerant was used instead of pure refrigerant.

N. Subramani et al. [3] carried out research with three different types of nanoparticles, Al2O3, CuO and TiO2, which were dispersed in the mineral oil (SUNISO 3GS). The results show that the power consumption of the compressor is reduced by 15.4% and COP increases by 20% when TiO2 nanolubricant is used instead of SUNISO 3GS oil. The increase in COP with Al2O3 nanolubricant and CuO nanolubricant are 16% and 11% respectively. The energy enhancement factor in the evaporator with TiO2 nanoparticles is found to be 1.5353. R. Reji Kumar et al. [4] investigated the heat transfer enhancement of domestic refrigerator by using Al2O3 nanorefrigerants. The addition of 0.06% mass fraction of Al2O3 nanoparticles to the refrigerant results in improvements in the thermophysical properties and heat transfer characteristics of the refrigerator. It is found that the freezing capacity is higher and the power consumption reduces by 11.5% when POE oil is replaced by a mixture of mineral oil. Jwo et al. [5] conducted experimental study using Al2O3 nanoparticles and lubricant of R134a refrigeration system as a base fluid. They concluded that thermal conductivity enhances by 2.0%, 4.6% and 2.5% for 1.0, 1.5 and 2.0 wt. % of Al2O3 at 40 °C and the trend of growth rates of thermal conductivity is proportional to temperature.

Mahbulul et al. [6] experimentally investigated the thermal conductivity and viscosity of Al2O3/R141b nanorefrigerant for 0.5 to 2.0 volume % concentration at temperature of 5 to 20 °C. Thermal conductivity increases with the increase of concentration of nanoparticle, highest value observed to be 1.026 W/mK for 2.0 volume % concentration. Bi et al. [7] conducted an experimental study on the performance of a domestic refrigerator using TiO2-R600a nanorefrigerant as working fluid. 0.1 and 0.5g/litre concentration of TiO2 nanoparticles were dispersed in R600a refrigerant using ultrasonic oscillator. The result shows that the TiO2-R600a system worked normally and efficiently in the refrigerator and energy consumption of 0.865 KW h/day was least at nanoparticles concentration of 0.5g/L which is 9.6% less than pure R600a system. The investigation shows that both the pressures and evaporation temperature reduced for nanorefrigerant compared with pure R600a system. Eed Abdel-Hafez-Hadi et al. [8] studied the effect of using nano Cu-R134a in the vapour compression system. Measurements were performed for heat flux ranged from 10 to 40 kW/m² using nano CuO concentration ranged from 0.05% to 1% and particle size from 15 to 70nm. The measurements indicated also that the evaporating heat transfer coefficient increase with increasing nano CuO concentrations up to certain value then decreases.

Bi et al. [9] carried out experimentation on domestic refrigerator. They used TiO2 and Al2O3 nanoparticles having 0.06% and 0.1% mass concentration with HFC134a and mineral oil. The energy saving 26.13% was obtained with 0.1% TiO2 nanoparticles whereas 23.24% energy saved with 0.06% Al2O3. The author observed that the mixture of mineral oil and nanoparticles give better result than the system working with HFC134a and POE oil. The mineral oil gives high oil return ratio and nanoparticles enhance the refrigerator performance. Elcock [10] found that TiO2 nanoparticles can be used as additives to enhance the solubility of the mineral oil with hydro fluorocarbon (HFC) refrigerant. Authors also reported that refrigeration systems using a mixture of HFC134a and mineral oil with TiO2 nano particles appear to give better performance by returning more lubricant oil to the compressor with similar performance to systems using HFC134a and POE oil. In the present paper, analysis of VCR system with pure refrigerant and nanorefrigerant and the results obtained has been reported. The refrigerant R134a and alumina nanoparticles were used.

II. EXPERIMENTAL SETUP

The study was conducted on vapour compression refrigeration test rig. The test rig consist of a compressor, air-cooled condenser, capillary tube and an evaporator.

Figure 1: Vapour compression refrigeration test rig.

The compressor was hermetically sealed reciprocating compressor and the evaporator made of copper was in the form of cylindrical spiral coil and was completely immersed in water (cooling load). The heat flux was supplied to evaporator by means of heater (230 W) and automatic stirrer to continuously stir the water. The condenser was cooled using fan. The pressure gauges were installed at the salient point.
of the refrigeration system. Mercury in glass thermometers were used to measure temperature at various locations. The power consumption by the compressor and the heater was measured using energy meter. The heater power regulator is provided to adjust constant heat flux and maintained steady state condition.

The experimental setup used for the present study is shown in Figure 1. The test rig was filled with N2 gas at a pressure of 200 psi and this pressure was maintained for 5 hrs. The system was checked for the leakages thoroughly using traditional soap bubble method and ensured for no leakages. The system was evacuated by removing N2 gas. A vacuum pump was connected to the port provided in the compressor and the system was completely evacuated for the removal of any impurities. This process was carried out for all the trials. The compressor was filled with the nanolubricant and the refrigerant R134a was charged through the charging line to the compressor. Every time the system was allowed to stabilize for 20 min.

III. PREPARATION OF NANOLUBRICANT

The suspension of nanoparticles and compressor oil is termed as nanolubricant. When the refrigerant is circulated through the compressor it carries traces of lubricant and nanoparticles mixture (nanolubricants) so that the other parts of the system will have nanolubricant -refrigerant mixture. Then it is termed as nanorefrigerant. First step in the experimental analysis is the preparation of nanolubricants. Nanofluids are not simply liquid solid mixtures but the requirements are even, stable and durable suspension with negligible agglomeration of particles and no chemical change of the fluid. Such type of suspension can be prepared by two methods 1) Single step method and 2) Two step method. Here two step method has been used.

Commercially available nano-particles of aluminum oxide manufactured by NANOSHELL INC. with average size of 20 nm were used for the preparation of nanolubricant. The base fluid used here was compressor oil (polyester oil) as the refrigerant R134a is in the vapour form at the atmospheric pressure.

An ultrasonic vibrator (Micro clean 102, Oscar Ultrasonics) was used for uniform dispersion of nanoparticles and the prepared sample of lubricant and nanoparticles was kept for about 24 hours in the ultrasonic bath for agitation to achieve the same. Experimental observation shows that the stable dispersion of alumina nanoparticles can be kept for more than 3 days without coagulation or deposition. No surfactants has been used.

Three samples with the mass fraction of 0.04%, 0.06% and 0.08% has been prepared.

IV. PERFORMANCE ANALYSIS

From the above figure,
Process 1-2 - compression process in the compressor,
Process 2-3 - condensation process,
Process 3-4 expansion process in the expansion device
Process 4-1 - evaporation process.

For the heat transfer rate calculation from the evaporator and the condenser, the values of enthalpies at various points on the P-h diagram were taken referring to the evaporator pressure and corresponding saturation temperature, the condenser pressure and corresponding saturation temperature. The refrigeration table for R134a has been used.

The theoretical C.O.P is calculated using the equation
C.O.P = (h1 – h4) / (h2 – h1)

h1 – enthalpy of refrigerant at the inlet of the compressor
h2 – enthalpy of refrigerant at the outlet of the compressor
h4 – enthalpy of refrigerant at the inlet of the evaporator
The actual C.O.P is calculated using relation
C.O.Pact = cooling load / power input

V. RESULT AND DISCUSSION

In the experimental analysis, four cases have been considered. The hermetic compressor containing nanolubricant. For the graphical representation i) pure POE oil as R1 ii) POE oil and 0.04% alumina NPs as R2 iii) POE oil and 0.06% alumina NPs as R3 iv) POE oil and 0.08% alumina NPs as R4.

The cooling load temperature – time history is shown in Fig.4. In all the cases the evaporator pressure is 40 psi(3.75 bar) and condenser pressure is 205 psi(15.28 bar). No appreciable pressure drops due to friction were observed in the condenser and evaporator. It can be seen that the time required to reduce cooling load temperature is minimum when 0.06% of AL2O3 NPs is used with R134a.It takes about 17 minutes to reduce cooling load temperature from 28 °C to 5 °C.Similarly, when pure R134a is used it takes 22 mins. For 0.04%NP and 0.08%NP, it has taken about 20 and 19 min. respectively. So it can be concluded that the mass fraction of 0.06 % AL2O3 nanoparticles takes less time than any other.

It is clear from the Figure 5 that the freezing capacity of R134a + 0.06% AL2O3 nanoparticles is higher than the other three cases. This is due to the fact that the nanoparticles present in the refrigerant enhances the heat transfer rate in the refrigerant side of evaporator. Time taken to reduce temperature of cooling load from 28 °C to 1 °C is 23 mins. Time taken by pure R134a is 28 minutes while it takes 26 min and 25 min for R134a+0.04%NP and R134a+0.08%NP respectively.

Figure 6 shows drop in the refrigerant temperature in the condenser of the refrigeration system. Temperature drop of the refrigerant is high with nanorefrigerant when compared with the other cases. The temperature of the refrigerant at the inlet of the condenser is in the range 71 – 75 °C. The saturation temperature of R134a corresponding to the condenser pressure of 15.28 bar is 56 °C.In the case of R134a+0.06%AL2O3 nanoparticles mixture, the temperature at the exit of the condenser is 47 °C and the subcooling obtained is 9 °C. The enhanced heat transfer rate in the condenser is due to the presence of nanoparticles in the refrigerant.

Figure 7 shows the comparison of power consumption of the compressor; 14.71 % reduction in power consumption is found when compressor running with nanolubricant containing 0.06% AL2O3 nanoparticles. About 7.94% and 5.3% power saved when 0.04%NP and 0.08%NP is used with R134a. Nanorefrigerant reduces the power consumption as compared to pure refrigerant.
compression refrigeration system with pure refrigerant and nanorefrigerant. The three mass concentration 0.04%, 0.06% and 0.08% of Al2O3 nanoparticles has been used to evaluate the performance of system and analyzed with performance of pure refrigerant. The conclusions derived out of the present study are i) The system with R134a refrigerant and POE oil mixture with nanoparticles worked normally and safely, ii) Freezing capacity of the refrigeration system is higher with 0.06 % Al2O3 nanoparticles compared the system with pure refrigerant , 0.04%NP and 0.06% NP. iii) The power consumption of the compressor reduces by 14.71% when the nanorefrigerant with 0.06% AL2O3 nanoparticles is used ,whereas reduction in power consumption of 7.94% and 5.37% is observed with 0.04%NP and 0.08%NP. iv) The coefficient performance of the refrigeration system also increases by 28.93% when pure refrigerant is replaced by nanorefrigerant with 0.06% Al2O3 nanoparticles. The result obtained from this experimental analysis shows good agreement with the results in the literature review.

REFERENCES


Table 1 Temperature at salient points

<table>
<thead>
<tr>
<th>Quantity</th>
<th>R134a</th>
<th>R134a + 0.04% NPs°C</th>
<th>R134a + 0.06% NPs°C</th>
<th>R134a + 0.08% NPs°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. at inlet to compressor</td>
<td>15</td>
<td>14</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Temp. at inlet to condenser</td>
<td>75</td>
<td>73</td>
<td>71</td>
<td>73</td>
</tr>
<tr>
<td>Temp. at inlet to expansion valve</td>
<td>55</td>
<td>52</td>
<td>47</td>
<td>50</td>
</tr>
<tr>
<td>Temp. at inlet to evaporator</td>
<td>7</td>
<td>8</td>
<td>6</td>
<td>7</td>
</tr>
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</table>

CONCLUSION

The extensive experimentation carried out for the evaluation of performance parameters of vapour refrigeration system using R600a/mineral energy meter.

Figure 8 shows the coefficient of performance (COP) calculated using the experimental data. The actual COP is calculated using the cooling load and the power input. The theoretical values are also shown for comparison. In all cases the actual COP is less than the theoretical COP. The condenser pressure 205 Psi(15.15 bar) and the evaporator pressure is 40 Psi(3.75 bar). It is very much clear from the histogram that the R134a + 0.06% AL2O3 nanoparticles mixture has the highest COP when compared with the other cases. The advantages of adding nanoparticle to the lubricant is manifold. It reduces the power consumption of the compressor and there is sub cooling of the nanorefrigerant in the condenser which in turn increases the COP. The Actual COP is calculated using the energy meter reading and the cooling load. For the calculation of theoretical COP the enthalpy values at the salient points are taken from P-h chart for R134a. The temperatures at the salient points of the refrigeration system are shown in Table 1.