ISSN (Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization, Volume 2, Special Issue 1, December 2013

Proceedings of International Conference on Energy and Environment-2013 (ICEE 2013)

On 12th to 14th December Organized by

Department of Civil Engineering and Mechanical Engineering of Rajiv Gandhi Institute of Technology, Kottayam, Kerala, India

PERFORMANCE STUDIES ON A VAPOUR COMPRESSION REFRIGERATION SYSTEM USING NANO-LUBRICANT

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ABSTRACT

R134a is the most widely adopted alternative refrigerant in refrigeration equipment, such as domestic refrigerators and air conditioners. On account of the strong chemical polarity of R134a, the traditional mineral oil can be used as lubricant in refrigerating systems with R134a as working fluid. The present work deals with the investigation on a vapour compression refrigeration system with mineral oil and mineral oil with different nanoparticles added to it. The results indicate that refrigeration system with nanolubricant works normally and safely. It is found that power consumption reduces by 15.4% and the coefficient of performance increases by 20% when TiO_2 nanolubricant is used instead of SUNISO 3GS

NOMENCLATURE

C	Specific Heat
K	Thermal Conductivity
μ	Viscosity
ρ	Density
Ψ	Volume fraction
Ω	Mass fraction
h	Pool boiling heat transfer coefficient
q	Heat Flux

1.INTRODUCTION

In the face of imminent energy resource crunch there is need for developing thermal systems which are energy efficient. Thermal systems like refrigerators and air conditioners consume large amount of electric power. So avenues of developing energy efficient refrigeration and air conditioning systems with nature friendly refrigerants need to be explored

The rapid advances in nanotechnology have lead to emerging of new generation heat transfer fluids called nanofluids. Nanofluids are prepared by suspending nano sized particles (1-100nm) in conventional fluids and have higher thermal conductivity than the base fluids. Nanofluids have the following characteristics compared to the normal solid liquid suspensions. i) higher heat transfer between the particles and fluids due to the high surface area of the particles ii) better dispersion stability with predominant Brownian motion iii)reduces particle clogging iv) reduced pumping power as compared to base fluid to obtain equivalent heat transfer. Based on the application nanoparticles are currently made out of a very wide variety of materials, the most common of the new generation of nanoparticles being ceramics, which are best split into metal oxide ceramics, such as titanium, zinc, aluminium and iron oxides, to name a prominent few and silicate nanoparticles, generally in the form of nanoscale flakes of clay. Addition of nanoparticles changes the boiling characteristics of the base fluids. Nanoparticles can be used in refrigeration systems because of its remarkable improvement in thermophysical and heat transfer capabilities to enhance the performance of refrigeration systems. In a vapour compression refrigeration system the nanoparticles can be added to the lubricant (compressor oil) and the lubricant nanoparticles mixture is known as nanolubricant. When the refrigerant is circulated through the compressor it will carry traces nanolubricants so that the other parts of the system will have nanolubricant -refrigerant mixture. The advantages of adding nanoparticles to the refrigeration system are manifold (i) addition of nanoparticles to the lubricant improve tribological characteristics of the lubricant, so that there are improvements in the performance of the compressor. (ii)addition of nanoparticles to the refrigerants improves the thermo physical and heat transfer characteristics of the refrigerant which in turn results in the enhancement in the refrigerating effect(iii) presence of nanoparticles in the refrigeration system enhances the solubility between the lubricant and refrigerant and returns more lubricant oil back to the compressor

Recently, some investigators have conducted studies on vapour compression refrigeration systems, to study the effect of nanoparticles in the refrigerant/lubricant on its performance. Pawel Keblinski, Jeffrey.A.E & David.G.C (2005) conducted studies on nanofluids and found that there is the significant increase in the thermal conductivity of nanofluids compared to the base fluid. They also found that addition of nanoparticles results in significant increase in the critical heat flux. Shengshan Bi, Lin Shi & Lili Zhang (2007) conducted studies on a domestic refrigerator using nanorefrigerants. In their studies R134a was used the refrigerant, and a mixture of mineral oil TiO2 was used as the lubricant. They found that the refrigeration system with the nanorefrigerant worked normally and efficiently and the energy consumption reduces by 21.2%. When compared with R134a/POE oil system. Later Sheng shan Bi, Lin Shi & Lili Zhang, (2008) found that there is remarkable reduction in the power consumption and significant improvement in freezing capacity. They pointed out the improvement in the system performance is due to better thermo physical properties of mineral oil and the presence of nanoparticles in the refrigerant. Jwo *et.al* (2009) conducted studies on a refrigeration system replacing R-134a refrigerant and polyester lubricant with a hydrocarbon refrigerant and mineral lubricant. The mineral lubricant included added Al_2O_3 nanoparticles to improve the lubrication and heat-transfer performance. Their studies show that the 60% R-134a and 0.1 wt % Al_2O_3 nanoparticles were optimal. Under these conditions, the power consumption was reduced by about 2.4%, and the coefficient of performance was increased by 4.4%. Hao Peng *et.al* (2010) conducted experimental on the nucleate pool boiling heat transfer characteristics of refrigerant/oil mixture with diamond nano particles. The refrigerant used was R113 and the oil was VG68. They found out that the nucleate pool boiling heat transfer coefficient of R113/oil mixture with diamond nanoparticles is larger than the R113/oil mixture. They also proposed a general correlation for predicting the nucleate pool boiling heat transfer coefficient of refrigerant/oil mixture with nanoparticles, which well satisfies their experimental results. Kristen Henderson *et.al* (2010) conducted an experimental analysis on the flow boiling heat transfer of R134a based nanofluids in a horizontal tube. They found excellent dispersion of CuO nanoparticle with R134a and POE oil and the heat transfer coefficient increases more than 100% over baseline R134a/POE oil results. Sergio Bobbo *et.al*,(2010(conducted a study on the influence of dispersion of single wall carbon nanohorns (SWCNH) and TiO2 on the tribological properties of POE oil together with the effects on the solubility of R134a at different temperatures. They showed that the tribological behaviour of the base lubricant can be either improved or worsen by adding nanoparticles. On the other hand the nanoparticle dispersion did not affect significantly the solubility. Sheng Shan Bi, Kai Guo, Zhigang Liu (2011) conducted an experimental study on the performance of a domestic refrigerator using TiO2-R600a nanorefrigerant as working fluid. They showed that the TiO2-R600a system worked normally and efficiently in the refrigerator and an energy saving of 9.6%. They too cited that the freezing velocity of nano refrigerating system was more than that with pure R600a system. The purpose of this article is to report the results obtained from the experimental studies on a vapour compression system. In the present study the refrigerant selected is R134a and the nanoparticle is alumina.

2. EXPERIMENTAL SETUP

For the experimental studies a refrigeration test rig was designed and fabricated. The test rig consists of a compressor, air-cooled condenser, thermostatic expansion valve and an evaporator. The compressor used is a hermetically sealed reciprocating compressor. The evaporator is in the form of a cylindrical spiral coil and is completely immersed in water (cooling load) and it is made of copper. A serpentine coil finned tube heat exchanger is used as the condenser and it is also made of copper. The condenser is cooled using a fan. Bourdon tube pressure gauges are used to measure the pressures at the salient points of the refrigeration system, one each at the outlets of compressor, condenser, expansion device and evaporator. T- Type thermocouples (36 SWG) were used to measure the temperature at the various locations. Prior to experimental measurements the thermocouples were calibrated using a constant temperature bath (JulaboF25). The temperature data was acquired using a temperature scanner. The power consumption of the compressor is measured using a digital energy meter. Before charging the test rig with the refrigerant, the system was checked thoroughly for leaks. After the leak test the system was properly evacuated using a vacuum pump. The compressor was filled with nanolubricant and the system was charged with the refrigerant, in this case R134a which is widely accepted alternative refrigerant in refrigeration systems due to its low ozone depletion potential and closeness of its thermodynamic properties with R12, though its global warming potential is high. The compressor used in the system is reciprocating type and the expansion device is thermostatic expansion valve. The quantity of refrigerant charged in the system is 300 g.

Theoretical analysis

Calculation of thermophysical properties of nanolubricant

The following correlations are used to calculate the thermophysical properties of nanolubricant

Specific heat of nanolubricant

$$cp_{,n,o} = (1-\psi_n)\, cp_o + \psi_n\, cp_n$$

(Pak and Cho, 1998) (1)

Thermal conductivity nanolubricant,

$$k_{n,o} = k_o[(k_n+2k_o- 2\psi_n(k_o-k_n)) / (k_n+2k_o+ \psi_n (k_o-k_n))]$$

Hamilton and Crosser, 1962) (2)

Viscosity of nanolubricant,

$$\mu_{n,o} = \mu_o\, [1 / (1- \psi_n)^{2.5}] \quad \text{(Brinkman, 1952)} \qquad (3)$$

Density of nanolubricant,

$$\rho_{n,o} = (1- \psi_n)\ \rho_o + \psi_n\ \rho_n, \tag{4}$$

Volume fraction of nanoparticle in the nanoparticle-oil suspension,

$$\psi_n = \omega_n\ \rho_o / [\omega_n\rho_o + (1-\omega_n)\rho_n] \tag{5}$$

Mass fraction in the nanoparticle oil suspension,

$$\omega_n = m_n / (m_n+m_o) \tag{6}$$

Calculation of thermophysical properties nanorefrigerant

Specific heat of the nanorefrigerants

$cp_{,r,n,o,f} = (1-X_{n,o})\ cp_{,r,f} + X_{n,o}cp_{,n,o},$

(Jensen and Jackman, 1984) (7)

In order to investigate the influence of nanoparticles/oil suspension concentration (Xn,o) on the nucleate pool boiling heat transfer, the term Xno is used.

Viscosity of the nanorefrigerants

$\mu_{r,n,o,f} = \exp\ (X_{n,o}\ln\mu_{n,o} + (1\text{-}Xn,o)\ln\mu_{r,f}),$

(Kedzierski and Kaul, 1993) (8)

Thermal conductivity of the nanorefrigerants

$k_{r,n,o,f} = k_{r,f}(1-X_{n,o}) + (k_{n,o}X_{n,o}) - (0.72X_{n,o}\ (1- X_{n,o})(k_{n,o}-k_{r,f})),$

(Baustian et. al, 1988) (9)

Density of the nanorefrigerants

$$\rho_{r,n,o,f} = [(X_{n,o}/\rho_{n,o}) + ((1-X_{n,o})/\ \rho_{r,f})]^{-1} \tag{10}$$

Nanoparticle/oil suspension concentration,

$$X_{n,o} = m_{n,o} / (m_{n,o} + m_r) \tag{11}$$

Where, $m_{n,o}$ = the mass of nanoparticles/oil suspension in the refrigerant/oil mixture with nanoparticles)

Calculation of heat flux and transfer coefficient in the refrigerant side of the evaporator

The heat flux (q) is calculated from the formula proposed by Hao Peng et. al, (2010)

$$\Delta T_b = \frac{C_{sf} h_{fg}}{C_{p,r,n,o,f}} \left[\frac{q}{\mu_{r,n,o,f} h_{fg}} \sqrt{\frac{\sigma_{r,n,o}}{g\left(\rho_{r,n,o,f} - \rho_{r,g}\right)}} \right]^{0.33} \left[\frac{C_{p,r,n,o,f}\ \mu_{r,n,o,f}}{K_{r,n,o,f}} \right]^{n}$$

(12)

$$\Delta T_b = T_w - T_{sat}$$

(13)

Surface tension of nanorefrigerants

$$\sigma_{r,n,o} = \sigma_r + (\sigma_{n,o} - \sigma_r) X_{n,o}^{0.5},$$

(Jensen and Jackman, 1984) (14)

$$\mathbf{C_{sf}} = \exp(-8.062 - 1.789\omega_n + 2.786X_{n,o}) \text{ and } n = 1.085$$

(15)

Csf is an empirical constant which is used to calculate heat transfer coefficient in the refrigerant(refrigerant with traces of nanolubricant) side of the evaporator.

The nucleate pool boiling heat transfer coefficient of refrigerant/oil mixture with nano particles,

$$h_{r,n,o} = q / \Delta T_b$$

(16)

The value of heat transfer coefficient without nanoparticles is calculated using the boiling correlations for conventional refrigerants

The energy enhancement factor (E.F) is calculated using the equation

$$E.F = h_{r,n,o} / h_{r,o}$$

(17)

Where $h_{r,o}$ is the heat transfer coefficient of the refrigerant-oil mixture.

Experimental Procedure: Nanolubricants was prepared by mixing different nanoparticles into the mineral oil, (SUNISO 3GS) using ultrasonic oscillator. The mass concentrations of nanoparticles in the nanolubricant are same in the three cases and its value is 0.06%. Calculations show that the quantity of nanoparticle in the refrigerant is about 0.0012gm. The particles are spherical in shape and the average particle size is about 50 nm. Experiments have been conducted (i) with suniso 3GS oil (ii) alumina nanolubricant (iii) with CuO nanolubricant and (iv) TiO2 nano-lubricant

3. RESULTS AND DISCUSSION

Extensive experiments have been conducted on a vapour compression refrigeration system for its improvement in performance. The results obtained from the experimental and theoretical studies are described below.

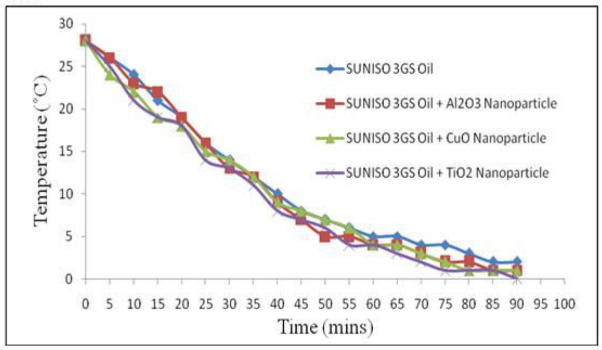

FIG.1. TEMPERATURE-TIME HISTORY

Figure 1 shows the variation of cooling load temperature with time. From the figure it is clear that, the time required for reducing temperature of the cooling load is less for the SUNISO 3GS oil with nano particle added compared with pure SUNISO 3GS oil. Also the time required for reducing cooling load temperature is least for SUNISO 3GS oil with TiO_2 nanoparticle.

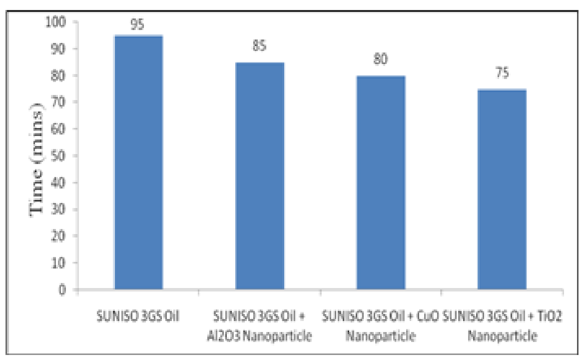

FIG.2. FREEZING CAPACITY

Figure 2 shows the time required for reducing the cooling load temperature from 28ºC to 1ºC for all the four cases. With SUNISO 3GS oil + TiO_2 nano particle, the time required to bring the cooling load temperature from 28^{o}C to 2^{o}C is 75 minutes where as that with alumina nanolubricant, CuO nanolubricant and SUNISO 3GS oil are 80,85 and 95 minutes respectively.

Figure 3 shows power consumption of the compressor. From the above histogram it is clear that there is considerable reduction in power consumption when nanolubricants are used. The reduction in power consumption is 15.4% when TiO_2 nanulubricant is used instead of SUNISO 3GS oil. The corresponding reductions in power consumption with CuO nanolubricant and Al_2O_3 nanolubricant are 11.9% and 8.4% respectively. The decrease in compressor work input may be attributed to better lubricity of the nanolubricants

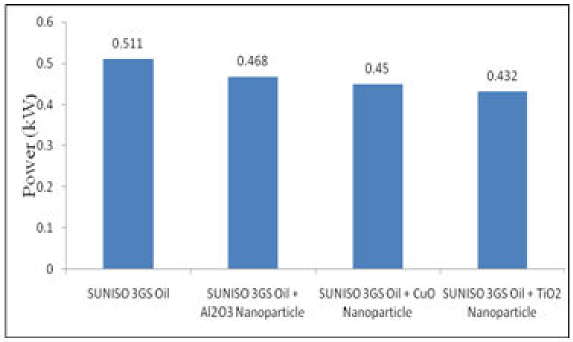

FIG.3. COMPARISON OF POWER CONSUMPTION

Figure 4 shows the improvements in coefficient of Performance (COP) of the refrigeration system when nanolubricants are used instead of pure SUNISO 3GS oil. The theoretical values of COP are also shown for comparison. It is very clear COP is more with nanolubricants when compared to pure lubricating oil. This may be due to the increase in heat transfer in the evaporator and condenser side of the refrigeration system and the decrease in work input to the compressor.

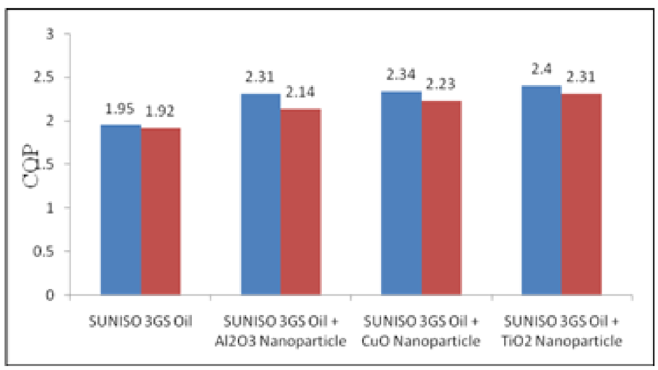

FIG.4. COMPARISON OF COP FOR THE FOUR CASES

The improvement in COP is 20.3 % when TiO_2 nano lubricant is used instead of SUNISO 3GS oil. The corresponding increase in COP with Al_2O_3 nanolubricant and CuO nanolubricant are 11.46% and 16.13% respectively. The refrigeration system with TiO_2 nanolubricant has the highest COP even though TiO_2 has lowest thermal conductivity compared to other nanoparticles used. This may be due to the stability and compatibility of TiO_2 nanoparticle with SUNISO 3GS oil compared to the other nanoparticles used.

The theoretical C.O.P is calculated using the equation $C.O.P_{th} = (h_1 - h_4) / (h_2 - h_1)$ (18)

where, h_1 – enthalpy of refrigerant at the inlet of the compressor
h_2 – enthalpy of refrigerant at the outlet of the compressor
h_4 – enthalpy of refrigerant at the inlet of the evaporator
The values of the enthalpy are taken from refrigerant tables.

The actual C.O.P is calculated using relation

$C.O.P_{act}$ = cooling load / power input (19)

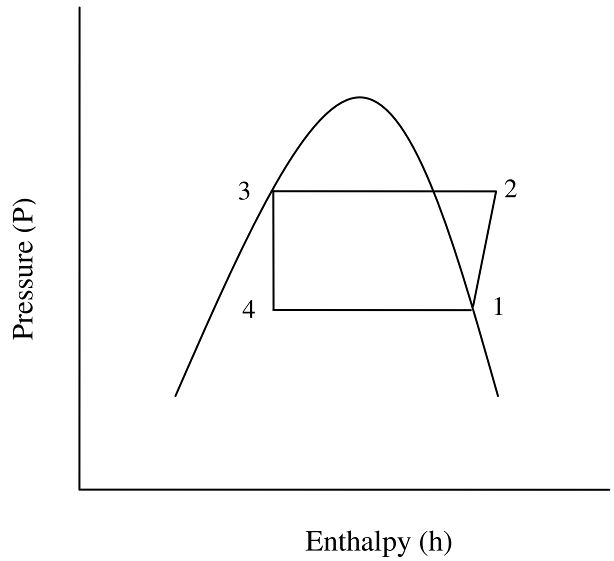

FIG.5. P-h diagram of a V.C. Refrigeration System

Figure 6 shows the compressor dome temperature for all the four cases. The compressor dome temperature is more for SUNISO 3GS oil and least with TiO_2 nanolubricant. The decrease in compressor dome temperature is 11°C for TiO_2 nanolubricant and the corresponding decrease in temperature with CuO nanolubricant and Al_2O_3 nanolubricants are 9°C and 8°C respectively. The reduction in compressor dome temperature may be due to decrease of friction with nanolubricant. Lower the compressor dome temperature, more stable will be the compressor oil and hence increase the life and performance of the refrigeration system.

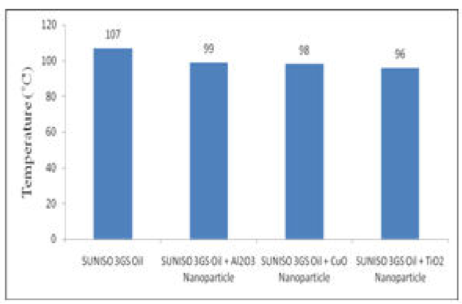

FIG.6. TEMPERATURE OF THE COMPRESSOR DOME

Figure 7 and 8 shows the temperature of the refrigerant at inlet and outlet of the condenser respectively.

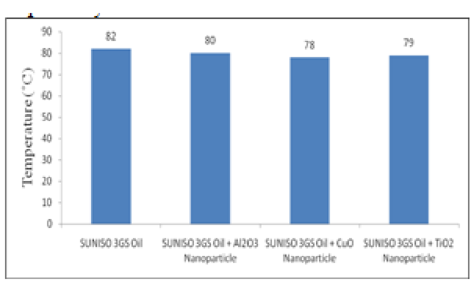

FIG.7. TEMPERATURE OF REFRIGERANT AT THE INLET OF THE CONDENSER

The temperature of the refrigerant at the inlet of the condenser is in the range 82– 79^{o}C. The saturation temperature of R134a corresponding to the condenser pressure of 1.2 MPa is 46.3^{o}C. TiO_2 nanorefrigerant has the lowest temperature at the outlet of the condenser and its value is 37^{o}C. In the case of Al2O3 nanorefrigerant and CuO nanorefrigerant the temperature at the exit of the condenser is 40^{o}C and 39^{o}C respectively and the sub-cooling obtained 6.3^{o}C and 7.3^{o}C respectively.

Theoretical analysis shows the energy enhancement factor in the evaporator coil is 1.5338, 1.5353 and 1.5449 respectively with Al_2O_3, TiO_2 and CuO nanolubricants. Hao Peng et.al (2009) has reported that the energy enhancement factor is in the range 1.17 to 1.63.

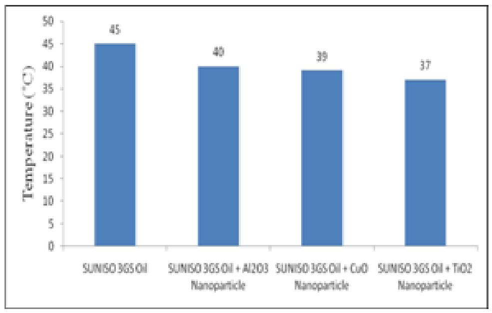

FIG.8. TEMPERATURE OF REFRIGERANT AT THE OUTLET OF THE CONDENSER

4. CONCLUSIONS

Extensive experimental and theoretical studies have been carried out to evaluate the performance parameters of a vapor compression system with pure SUNISO 3GS oil and with different nanolubricants. The conclusions drawn from the present study are

1. Freezing capacity is higher for TiO_2 nanolubricant compared with other three cases.
2. The power consumption of the compressor is reduced by 15.4% TiO_2 nanolubricant is used instead of SUNISO 3GS oil. The reductions in power consumption are 11.9% and 8.4% respectively with Al2O3 nanolubricant and CuO nanolubricant.
3. The coefficient of performance of the refrigeration system increases by 20% when TiO_2 nanolubricant is used instead of SUNISO 3GS oil. The increase in COP with Al_2O_3 nanolubricant and CuO nanolubricant are 16% and 11% respectively
4. The energy enhancement factor in the evaporator with Al_2O_3, TiO2 and CuO nanolubricants are 1.5338, 1.5353 and 1.5449 respectively.

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