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Enhancing performance of refrigeration system using nanoparticles

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ABSTRACT

Nowadays, refrigeration systems have become one of the most important systems for people's daily lives. Based from some research, the use of refrigerator and air conditioners consumes about 40% of the total of electricity used in a house. This means that the use of air conditioners consumes a lot of electricity.Convective heat transfer is very important in the HVAC, refrigeration and microelectronics cooling applications. R134a is most widely adopted alternate refrigerant in refrigeration equipment, such as domestic refrigerators and air conditioners. Though the global warming up potential of R134a is relatively high, it is affirmed that it is a long term alternate refrigerants in lots of countries. The addition of nanoparticles to the refrigerant results in improvements in the thermo physical properties and heat transfer characteristics of the refrigerant, thereby improving the performance of the refrigeration system.

The experimental studies indicate that the refrigeration system with nano-refrigerant works normally. It is found that the freezing capacity is higher and the power consumption reduces by 25 % when POE oil is replaced by a mixture of mineral oil and alumina nanoparticles. Also it is found that evaporator performance is better when nanorefrigerants are used instead of pure refrigerant. In this report, the effect of the suspended nanoparticles, into the refrigerant, which can be called as nanorefrigerant, is being studied.

Keywords- **Nanofluids, Nanoparticles, Thermal conductivity, heat transfer coefficient, COP.**

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I. INTRODUCTION

An evaporator is a device that can transform a liquid into vapour or gaseous form. Nowadays, the development of evaporator has increased largely, thus leading tomany different types of evaporator being produced. Two of the main types of evaporator that is commonly being used are Forced Circulation Evaporator and Falling Film Evaporator. Forced Circulation Evaporator is suitably used by liquids which tend to crystallize upon concentration and which have the tendency to scale. This type of evaporator is being used in the food processing industry and making dyes. Falling Film Evaporator is an industrial device to concentrate solutions, especially with heat sensitive components, thus making it the most frequently used type of evaporator. It is being used extensively in chemical process industry, food and paper industry.

In an evaporator, usually there is a working fluid called refrigerant. Refrigerant can be defined as a substance that is used in a heat cycle that undergoes a reversible phase change from a liquid to a gas. Before this, fluorocarbons, especially chlorofluorocarbons were traditionally used as the refrigerants. But as time goes by, these refrigerants are being phased out because of their ozone depletion effects and being replaced by other types of refrigerants. Other common types of refrigerants that are being used in various applications are sulphur dioxide, methane and ammonia.

Generally, nanofluid can be defined as a fluid that contains particles that are sized in nanometer and it is called nanoparticles. Usually, the nanoparticles that are used in nanofluids are typically made of metals, oxides, or carbon tubes. Furthermore,because of their novel properties, nanofluids have been potentially helpful in many applications of heat transfer nowadays, such as, fuel cells, microelectronics, pharmaceutical processes and hybrid powered engines

This study investigates the thermophysical properties, pressure drop and heat transfer performance of Al2O3 nanoparticles(15-20nm) suspended in 1, 1, 1, 2-tetrafluoroethane (R-134a). Suitable models from existing studies have been used to determine the thermal conductivity and viscosity of the nanorefrigerants for the nano particle concentrations of 1 to 5 vol%.Inthis study, the thermal conductivity of Al2O3/R-134a nanorefrigerant increased with the augmentation of particle

II. LITERATURE REVIEW

Bi et al. (2007) [1] conducted studies on a domestic refrigerator using nanorefrigerants. In their studies R134a was used as a 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.

Bi et al. (2008) [2] 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) [3] 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 Al2O3 nanoparticles to improve the lubrication and heat-transfer performance. Their studies show that the 60% R-134a and 0.1 wt % Al2O3 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%.

Henderson et al. (2010) [4] 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

Shengshan Bi, Kai Guo (2011) [5] conducted an experimental study on the performance of a domestic refrigerator using TiO_2 - R600a nanorefrigerant as working fluid. They showed that the TiO_2 - 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.

R.Saidur and S.N.Kazi(2011) [6] review on the performance of nanoparticles suspended with refrigerants and lubricating oils in refrigeration systemsresearch shows that HFC134a and mineral oil with TiO2 nanoparticles works normally and safely in the refrigerator with better performance. The energy consumption of the HFC134a refrigerant using mineral oil and nanoparticles mixture as lubricant saved 26.1% energy with 0.1% mass fraction TiO2 nanoparticles compared to the HFC134a and POE oil system. It was identified that fundamental properties (i.e. density, specific heat capacity, and surface tension) of nanorefrigerants were notexperimentally determined yet.

I.M. Mahbubul et al, (2013) [7] conducting experiment investigates the thermophysical properties, pressure drop and heattransfer performance of Al2O3 nanoparticles suspended in 1, 1, 1, 2-tetrafluoroethane (R-134a) conclude that the thermal conductivity of Al2O3/R-134a nanorefrigerant increased with the augmentation ofparticle concentration and temperature however, decreased with particle size intensification. In addition, the results of viscosity, pressure drop, and heat transfer coefficients of the nanorefrigerant show a significant increment with the increase of volume fractions.

Rejikumar and Sridhar (2013) [8] conducted an experimental study on the performance of a domestic refrigerator using R600a/mineral oil/nano-Al2O3 as working fluid nanorefrigerant as working fluid. They found that the refrigeration system with nano-refrigerant works normally. 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 and Aluminium oxide nanoparticles.

Jaafar Al badr and Satinder Tayal (2013) [9] Conducts an experimental study on the forced convective heat transfer and flow characteristics of a nanofluid consisting of water and different volume concentrations of Al2O3 nanofluid. TheAl2O3 nanoparticles of about 30 nm diameter are used The results show that the convective heat transfer coefficient of nanofluid is slightly higher than that of the base liquid at same mass flow rate and at same inlet temperature. The heat transfer coefficient of the nanofluid increases with an increase in the mass flow rate, also the heat transfer coefficient increases with the increase of the volume concentration of the Al2O3 nanofluid, however increasing the volume concentration cause increase in the viscosity of the nanofluid leading to increase in friction factor.

T. Coumaressin and K. Palaniradja (2014) [10] conducted an experimental study on the performance of a domestic refrigerator using CuO-R134a nano-refrigerant as working fluid. he conclude that Heattransfer coefficients were evaluated using FLUENT for heat flux ranged from 10 to 40 kW/m2, usingnano CuO concentrations ranged from 0.05 to 1% and particle size from 10 to 70 nm. The results indicate that evaporator heat transfer coefficient increases with the usage of nanoCuO.

- Concluding remarks: Based on the literature
- Significantly with nanoparticle concentration The addition of nanoparticles to the refrigerant results in improvements in the thermophysical properties and heat transfer characteristics of the refrigerant, thereby improving the performance of the refrigeration system.
- The experimental studies indicate that the refrigeration system with nanorefrigerant works normally. It is found that freezing capacity is higher and power consumption gets reduced when POE oil is replaced by mixture of mineral oil and nanoparticles.
- Heat transfer coefficients of the nanorefrigerants show a significant increment with the increase of volume fractions. Therefore, optimal volume fraction is important to be considered in producing nanorefrigerants that can enhance the performance of refrigeration system.
- Based on results available in the literatures, it has been found nanofluids have a much higher and strongly temperature dependent thermal conductivity at very low particle concentration than conventional fluids.
- The convective heat transfer coefficient and flow boiling heat transfer coefficient increase.

III.DESIGN & EXPERIMENTAL SETUP

For the 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 usinga fan.

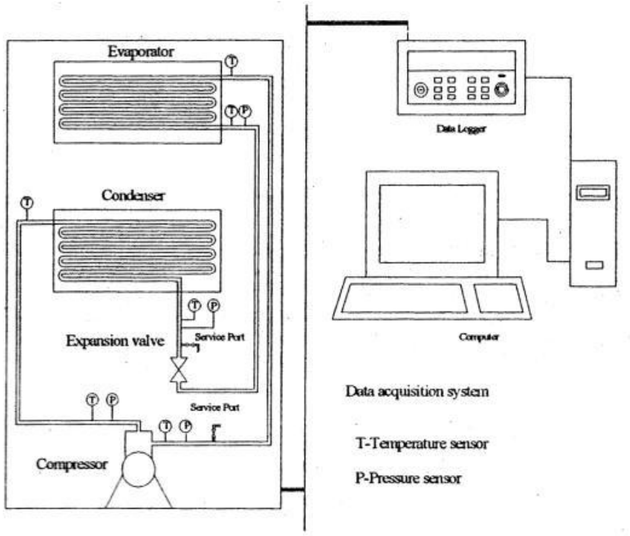

Fig3.1 Schematic of the experimental setup

3.1 Preparation of nanoparticles compressor oil mixture (nanolubricant)

Preparation of nanolubricants is the first step in the experimental studies on nanorefrigerants. Nanofluids are not simply liquid-solid mixtures. Special requirements are even, stable and durable suspension, negligible agglomeration of particles, and no chemical change of the fluid. Nanofluids can be prepared using single step or two step methods. In the present study two step procedure is used. Commercially available nanoparticles of aluminium oxide (manufactured by Sigma Aldrich) with average size <50nm and having density 0.26 g/cc were used for the preparation of nanolubricant. Mass fraction of nanoparticles in the nanoparticle–lubricant mixtures is 0.06%. An ultrasonic vibrator (Micro clean 102, Oscar Ultrasonics) was used for the uniform dispersion of the nanoparticles and it took about 24 hours of 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.

3.2 Testing Methodology

In order to estimate the heat transfer coefficient in the refrigerant side of the evaporator the thermophysical properties of the nanorefrigerant have to be calculated. The thermophysical properties of the nanorefrigerant are calculated in two steps. Firstly thermophysical properties of the nanoparticles oil mixture is calculated and this data is used to calculate the properties of nanorefrigerant.

3.2.1. Calculation of thermophysical properties of nanolubricant

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

- Specific heat of nanolubricant $C_{p,n,o} = (1-\psi_n) C_{po} + \psi_n C_{pn}$ (Pak and Cho, 1998)
- Thermal conductivity nanolubricanr, $K_{n,o} = K_o[(K_n+2K_o - 2\psi_n(K_o-K_n)) / (K_n+2K_o + \psi_n(K_o-K_n))]$ (Hamilton and Crosser, 1962)
- Viscosity of nanolubricant , $\mu_{n,o} = \mu_o[1 / (1-\psi_n)^{2.5}]$ (Brinkman, 1952)
- Density of nanolubricant, $\rho_{n,o} = (1-\psi_n)\rho_o + \psi_n\rho_n$,
- Volume fraction of nanoparticle in the nanoparticle-oil suspension,

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

- Mass fraction in the nanoparticle oil suspension, $\omega_n = m_n / (m_n+m_o)$

3.2.2 Calculation of thermophysical properties nanorefrigerant

- Specific heat of the nanorefrigerants $C_{p,r,n,o,f} = (1-X_{n,o}) C_{p,r,f} + X_{n,o}C_{p,n,o}$, (Jensen and Jackman, 1984) (7)
- Viscosity of the nanorefrigerants $\mu_{r,n,o,f} = \exp(X_{n,o}\ln\mu_{n,o} + (1-X_{n,o})\ln\mu_{r,f})$, (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 $\rho_{r,n,o,f} = [(X_{n,o}/\rho_{n,o}) + ((1-X_{n,o})/\rho_{r,f})]^{-1}$ (10)

Nanoparticle/oil suspension concentration, $X_{n,o} = m_{n,o}/(m_{n,o} + m_r)$

IV.RESULT & DISCUSSION

In the present experimental study, three cases have been considered. The hermetic compressor filled with i) pure POE oil ii)SUNISO 3GS oil (mineral oil) and iii) SUNISO 3GS+ alumina nanoparticles as lubricant. The mass fraction of the nanoparticles in the nanolubricant is 0.06 %.

From experimentation it is clear that, the time required for reducing cooling load temperature is less for the SUNISO 3GS oil + alumina nanoparticle mixture. For example, with SUNISO 3GS oil + alumina nanoparticle, the time required to bring the cooling load temperature from 28oC to 5oC is 50 minutes whereas that with SUNISO 3GS and POE oil is 60 and 70 minutes respectively.

The freezing capacity of the SUNISO 3GS + Alumina nanoparticle mixture is higher when compared with the other two cases The time taken to reduce the temperature of the cooling load from 28 oC to 1 oC with POE oil is 110 minutes and it reduces by 27 % if SUNINSO 3GS oil + alumina nanoparticle is used.

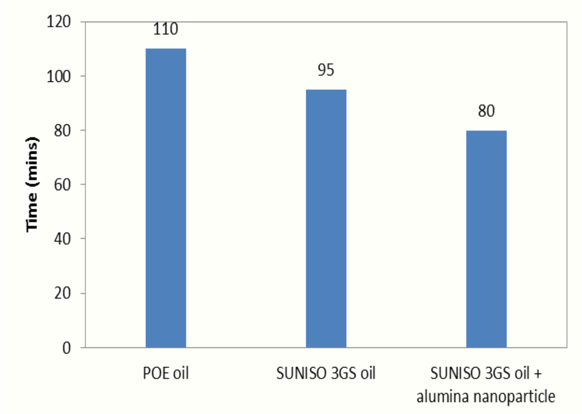

Fig4.1 Effect of nanoparticle on the freezing Capacity

Experimental readings shows that the the reduction in power consumption is 18% if theSUNISO 3GS is used instead of POE Oil and a reduction of 25% is observed when SUNISO 3GS is mixed with nanoparticles.

The temperatures at the salient points of the refrigeration system are shown in Table 4.1 It is very much clear from the histogram shown below that the SUNISO 3GS + alumina nanoparticle 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.

Quantity	POE oil oC	SUNISO 3GS oil oC	SUNISO 3GS oil with Al2O3 nanoparticle oC
Temperature at the inlet to the compressor	19	19	4
Temperature at the inlet to the condensor	85	82	80
Temperature at the outlet of the condenser	50	45	38
Temperature at the outlet of the expansion device	-7	-8	-7
Temperature at the inlet to the evaporator	-6	-7	-6

Table 4.1 Temperatures at salient points

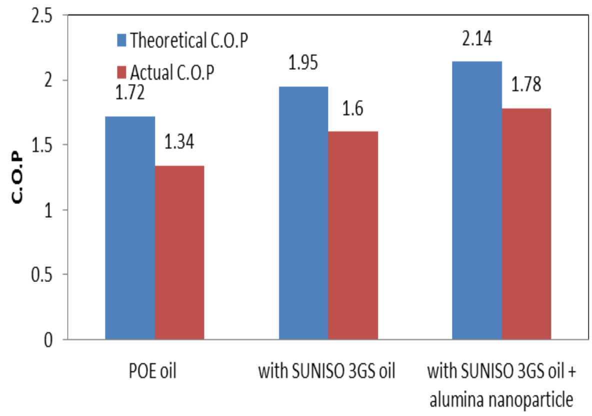

Figure 4.2 Comparison of Coefficient of Performance (COP) for the three cases

Figure 4.3 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.

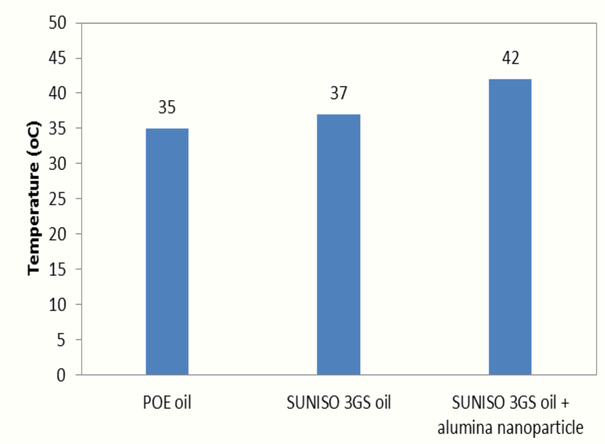

Figure 4.3 Reduction in refrigerant temperature while passing through condenser

V.CONCLUSION

Extensive experimental studies have been conducted to evaluate the performance parameters of a vapour compressionrefrigeration system with different lubricants including nanolubricants. The conclusions derived out of the present study are

i. The R134a refrigerant and mineral oil mixture with nanoparticles worked normally.
ii. Freezing capacity of the refrigeration system is higher with SUNISO 3GS + alumina nanoparticles oil mixture compared the system with POE oil
iii. The power consumption of the compressor reduces by 25% when the nanolubricant is used instead of conventional POE oil.
iv. The coefficient of performance of the refrigeration system also increases by 33% when the conventional POE oil is replaced with nanorefrigerant
v. the energy enhancement factor in the evaporator is 1.53.

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