Performance Analysis of a Nano Refrigerant Mixtures in a Domestic Refrigeration System

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ABSTRACT
This analysis deals with performance analysis of nano-refrigerant (Al2O3-R290/R600a) in a Vapour Compression Refrigeration System. Analysis was done by writing a simulation program based on the steady state mathematical models of the VCR system. The effects of performance parameters such as mass flow rate, actual piston displacement of compressor, heat rejected in condenser and compressor power on the system performance was investigated by varying evaporating and condensing temperatures. The results indicates that when using Nano-refrigerant mixture, the Coefficient of performance, mass flow rate, actual piston displacement of compressor is slightly increased whereas heat rejected in condenser and compressor power is slightly decreased.

KEYWORDS: Nano-Refrigerant, Al2O3-R290/R600a, Coefficient of performance, VCR

INTRODUCTION
The most common refrigerant in current time is R134a in all the refrigeration systems like vapour compression refrigeration system, domestic refrigerators and air conditioners. But the only problem with this type of refrigerant is they need large amount of electric power. The new technology which is being introduced in present time is nanotechnology. By the help of nanotechnology nano refrigerants are formed. As compared to alternative refrigerant the nano refrigerant has better heat transfer. We have seen some research has been done by taking the nano refrigerant and they have found better heat transfer and energy consumption.

Sheng-shan Bi et al. [5] studied the nanoparticles application in domestic refrigerators. They observed that HFC134a and mineral oil with TiO2 nanoparticles works safely in the refrigerator. The HFC134a and nano particle/mineral oil system improves the refrigerator performance and TiO2-R134a consumed less energy of 26.1%. Kai Guo et al. [6] states that TiO2 –R600a can work normally and efficiently in refrigerators. Compared with refrigerator with pure R600a as working fluids, 0.1 and 0.5 g/L concentrations of TiO2-R600a can save 5.94% and 9.60% energy consumption respectively. Sabareesh et al. [7] presents the application of TiO2 nanoparticles in vapour compression refrigeration systems-an experimental investigation. According to their results, the usage of nano refrigerant in the VCR system decreases compressor work by 11% and increases the COP. D. Sendil Kumar et al. [8] studied on Al2O3-R134a Nano Refrigerant in VCR System. They found that the replaced nano refrigerant increases the heat transfer rate. The system performance was improved with 10.2% less energy consumption when 0.2%v Al2O3-R134a refrigerant was added. Subramani et al. [9] investigated the performance of refrigeration system with the help of nano-lubricant. The results showed that SUNISO 3GS...
lubricant oil produced a very effective result. By usage of TiO₂ nano particles with R134a, the COP was increased and 15.4% less energy was consumed.

In another work, D. Sendil kumar et al. [10] presents the ZnO nano refrigerant in R152a refrigeration system for energy conservation and green environment. The result indicates that ZnO nano particles improved the thermo physical properties of refrigerant. The system performance was significantly improved and 0.5%v ZnO-R152a refrigerant can save 21% energy consumption. T.Coumaressin et al. [11] presents the performance analysis of a vapour compression refrigeration system using CuO nano fluid. In this paper the VCR system was analyzed on FLUENT software with CuO-R134a as working fluid. The results showed that the evaporating heat transfer is improved by adding CuO nano particles to an alternate refrigerant R134a. Fadhilah et al. [12] presents the Copper oxide nano particles for advance refrigerant thermo physical properties. They noted that the Al₂O₃ nano-particle used with R134a reduces the energy consumption by 10.32% while TiO₂ nano-particles with R600a can reduce the power consumption by 5.94% with a nano particle concentration of 0.1g/L. Melih Aktas et al. [13] presents a theoretical comparative study on nano refrigerant performance in a single-stage vapour-compression refrigeration cycle. In this paper five different nano refrigerants such as R12, R134a, R430a, R436a, and R600a with Al₂O₃ nanoparticles was used. The compressor work and Coefficient of performance (COP) are investigated at various condenser and evaporation temperatures. The nano refrigerants enthalpy is obtained through the density. The results showed that COP is enhanced by adding nanoparticles (Al₂O₃) to the pure (R600a) refrigerant. Jose Vicente Hallak d’Angelo et al. [14] presents a performance evaluation of a vapour injection refrigeration system using a mixture refrigerant R290/R600a, through steady-state simulations used to accomplish a parametric analysis such as COP, power consumption by compressor, Refrigerant mass flow rate. The results showed that a maximum COP was obtained when mixture containing 60 wt% of R600a and 40 wt% of R290.

**Theoretical Analysis:**

T-s and p-h diagram of simple vapour compression refrigeration system is shown in fig 1 respectively. It consists of the following four processes:

1. (1-2) Compressing refrigerant in compressor isentropically,
2. (2-3) Condensation at constant pressure,
3. (3-4) Adiabatic expansion in the expansion valve,
4. (4-1) Evaporation at constant pressure.

![Fig. 1: p-h and T-s diagram of vapour compression refrigeration system](image)

The work required to compressor is calculated as follows:

For isentropic compression, $W_C = m (h_2 - h_1)$ (1)

For non-isentropic compression, $W_C = \frac{\left( \frac{h_2}{\eta_c} - \frac{h_2}{\eta_c} \right)}{\eta_c}$ (2)

Heat rejection in condenser is calculated as follows:

$Q_c = m (h_2 - h_3)$ (3)

Heat addition in evaporator is calculated as follows:

$Q_e = m (h_1 - h_4)$ (4)

Mass flow rate of refrigerant is expressed as follows:

$m = \frac{Q_0}{q_0}$ (5)

Where, $Q_0$ is refrigerant capacity and $q_0$ is refrigerating effect

Actual Piston displacement of compressor is calculated as follows:

$V_p = \frac{m_0 \theta_1}{\eta_p}$ (6)

Where, $\theta_1$ is specific volume at inlet of compressor and $\eta_p$ is the volumetric efficiency
The performance of vapour compression refrigeration system can be measured in terms of coefficient of performance (COP), which is expressed as follows:

\[
\text{COP} = \frac{\text{Refrigerating Effect}}{\text{Work Done}} = \frac{(h_1-h_4)}{(h_2-h_1)}
\]  

(7)

A. Thermo-Physical Properties of the Nano Fluid:

Thermo-physical properties of nano fluids are preconditions for analyze of vapour compression system performance.

1) Density of Nano Fluid:

The nano fluid density for different concentrations of nano particles is developed by Pak and Cho [1] and it is given below.

\[
\text{Density of Nano fluid} (\rho_{nf}) = \Phi \rho_{np} + (1 - \Phi) \rho_{bf}
\]  

(8)

2) Isobaric Specific Heat of Nano Fluid:

The equation for evaluating specific heat of nano refrigerant is developed by J. Lee et al [2] and it is given below.

\[
\text{Isobaric specific heat of nano fluid} (C_{nf}) = \Phi C_{np} + (1 - \Phi) C_{bf}
\]  

(9)

3) Thermal conductivity of Nano Fluid:

The equation for evaluating thermal conductivity is developed by Maxwell et al [3] and it is given below.

\[
\text{Thermal conductivity of nano fluid} (K_{nf}) = K_{bf} \left\{ \frac{\left[ \left( 1 + 2\Phi \right) \left( 1 - \Phi \right) \right] / (2 \left( K_{bf} + K_{np} \right))}{\left( 1 - \Phi \right)} \right\}
\]  

(10)

4) Viscosity of Nano Fluid:

The equation for evaluating the viscosity of the nano fluid is developed by H. Brinkman et al [4] and it is given below.

\[
\text{Viscosity of nano fluid} (\mu_{nf}) = \mu_{bf} \left( \frac{1}{1 - \Phi} \right)^{2.5}
\]  

(11)

Methodology:

The various thermo physical properties of the chosen In this paper performance of analysis nano refrigerant (Al$_2$O$_3$/R290/R600a) with alternate refrigerant mixture (R290/R600a) in vapour compression refrigeration system has been carried out with help of Refprop software and Visual Basic software. The simulation programme was written based on the mathematical formula of vapour compression refrigeration system. The programming language used for writing the simulation program was Visual Basic .NET. Visual Basic .NET (VB.NET) is a multi-paradigm, object oriented programming language .The tool used for supporting the Programming language was Microsoft Visual Studio.

Fig. 2: Performance comparison of various proportion of R290/R600a mixture.
RESULTS AND DISCUSSION

Comparison of performance of R290/R600a mixture with adding nano particles to the same mixture in vapour compression refrigeration system has been carried out with the help of Refprop software and mathematical coding is developed by using visual studio software and graphs are plotted as below.

5.1 Comparison of Coefficient of performance with various proportion of R290/R600a mixture:

Figure 2 shows that the comparison of Coefficient of performance of various proportion of R290/R600a mixture. It is concluded from fig.2 R290/R600a (0.9/0.1) have notably high coefficient of performance than other proportion of R290/R600a mixture. Therefore, R290/R600a (0.9/0.1) can be suitable alternate mixture for adding the nano particles.

5.2 Comparison of Coefficient of performance with Nano refrigerant (Al$_2$O$_3$/R290/R600a):

Figure 3 shows that the comparison of Coefficient of performance of R290/R600a (0.9/0.1) with adding Al$_2$O$_3$ with different proportion. It is concluded from fig.3 by adding nano particles (Al$_2$O$_3$) to alternate refrigerant mixture (R290/R600a), the coefficient of performance will be improved based on concentration of nano particles.

Fig. 3: Performance comparison of R290/R600a (0.9/0.1) with adding Al$_2$O$_3$ with different proportion.

Fig. 4: Effect of evaporator temperature on Coefficient of performance.

Fig. 5: Effect of evaporator temperature on mass flow rate of refrigerant.

Figure 4 shows the effect of evaporator temperature on Coefficient of performance of R290/R600a (0.9/0.1) mixture and Al$_2$O$_3$/R290/R600a (0.04/0.9/0.1). It is concluded from figure 4 Coefficient of performance
increases with increase in evaporator temperature till the optimum evaporator temperature and here, Al₂O₃/R290/R600a (0.04/0.9/0.1) have significantly high Coefficient of performance than R290/R600a (0.9/0.1). Therefore, by adding the nano particles (Al₂O₃) to the alternate refrigerant mixture (R290/R600a) the Coefficient of performance is slightly increases.

Figure 5 shows the effect of evaporator temperature on mass flow rate of refrigerant of R290/R600a (0.9/0.1) mixture and Al₂O₃/R290/R600a (0.04/0.9/0.1). It is concluded from figure 5 mass flow rate of refrigerant decreases with increase in evaporator temperature till the optimum evaporator temperature and here, Al₂O₃/R290/R600a (0.04/0.9/0.1) have significantly higher mass flow rate of refrigerant than R290/R600a (0.9/0.1). Therefore, by adding the nano particles (Al₂O₃) to the alternate refrigerant mixture (R290/R600a) the mass flow rate of refrigerant is slightly increases.

Fig. 5: Effect of evaporator temperature on mass flow rate of refrigerant.

Figure 6 shows the effect of evaporator temperature on heat rejected in condenser of R290/R600a (0.9/0.1) mixture and Al₂O₃/R290/R600a (0.04/0.9/0.1). It is concluded from figure 6 heat rejected in condenser decreases with increase in evaporator temperature till the optimum evaporator temperature and here, Al₂O₃/R290/R600a (0.04/0.9/0.1) have significantly lower heat rejected in condenser than R290/R600a (0.9/0.1). Therefore, by adding the nano particles (Al₂O₃) to the alternate refrigerant mixture (R290/R600a) the heat rejected in condenser is slightly decreases.

Fig. 6: Effect of evaporator temperature on heat rejected in condenser.

Figure 7 shows the effect of evaporator temperature power consumption by compressor of R290/R600a (0.9/0.1) mixture and Al₂O₃/R290/R600a (0.04/0.9/0.1). It is concluded from figure 7 power consumption by compressor decreases with increase in evaporator temperature till the optimum evaporator temperature and here, Al₂O₃/R290/R600a (0.04/0.9/0.1) have significantly lower power consumption by compressor than R290/R600a (0.9/0.1). Therefore, by adding the nano particles (Al₂O₃) to the alternate refrigerant mixture (R290/R600a) the power consumption by compressor is slightly decreases.

Fig. 7: Effect of evaporator temperature on power consumption by compressor.
Fig. 8: Effect of evaporator temperature on piston displacement of compressor.

Figure 8 shows the effect of evaporator temperature piston displacement of compressor of R290/R600a (0.9/0.1) mixture and Al$_2$O$_3$/R290/R600a (0.04/0.9/0.1). It is concluded from figure 8 piston displacement of compressor decreases with increase in evaporator temperature till the optimum evaporator temperature and here, Al$_2$O$_3$/R290/R600a (0.04/0.9/0.1) have significantly higher piston displacement of compressor than R290/R600a (0.9/0.1). Therefore, by adding the nano particles (Al$_2$O$_3$) to the alternate refrigerant mixture (R290/R600a) the piston displacement of compressor is slightly increases.

Fig. 9: Effect of condenser temperature on Coefficient of performance.

Figure 9 shows the effect of condenser temperature on Coefficient of performance of R290/R600a (0.9/0.1) mixture and Al$_2$O$_3$/R290/R600a (0.04/0.9/0.1). The pressure ratio across the compressor increases, with increase in condenser temperature causing work required by the compressor increases and cooling capacity decreases due to decrease in latent heat of evaporation. Hence, the combined effects of these two parameters decrease the Coefficient of performance decreases with increase in condenser temperature. It is concluded from figure 9 Al$_2$O$_3$/R290/R600a (0.04/0.9/0.1) have significantly higher Coefficient of performance than R290/R600a (0.9/0.1). Therefore, by adding the nano particles (Al$_2$O$_3$) to the alternate refrigerant mixture (R290/R600a) the Coefficient of performance is slightly increases.

Fig. 10: Effect of condenser temperature on mass flow rate of refrigerant.
Figure 10 shows the effect of condenser temperature on mass flow rate of refrigerant of R290/R600a (0.9/0.1) mixture and Al2O3/R290/R600a (0.04/0.9/0.1). It is concluded from figure 10 mass flow rate of refrigerant increases with increase in condenser temperature till the optimum condenser temperature and here, Al2O3/R290/R600a (0.04/0.9/0.1) have significantly higher mass flow rate of refrigerant than R290/R600a (0.9/0.1). Therefore, by adding the nano particles (Al2O3) to the alternate refrigerant mixture (R290/R600a) the mass flow rate of refrigerant is slightly increases.

Fig.11: Effect of condenser temperature on heat rejected in condenser.

Figure 11 shows the effect of condenser temperature on heat rejected in condenser of R290/R600a (0.9/0.1) mixture and Al2O3/R290/R600a (0.04/0.9/0.1). It is concluded from figure 11 heat rejected in condenser increases with increase in condenser temperature till the optimum condenser temperature and here, Al2O3/R290/R600a (0.04/0.9/0.1) have significantly lower heat rejected in condenser than R290/R600a (0.9/0.1). Therefore, by adding the nano particles (Al2O3) to the alternate refrigerant mixture (R290/R600a) the heat rejected in condenser is slightly decreases.

Fig. 12: Effect of condenser temperature on power consumption by compressor.

Fig. 13: Effect of condenser temperature on piston displacement of compressor.
Figure 12 shows the effect of condenser temperature power consumption by compressor of R290/R600a (0.9/0.1) mixture and Al2O3/R290/R600a (0.04/0.9/0.1). It is concluded from figure 12 power consumption by compressor increases with increase in condenser temperature till the optimum condenser temperature and here, Al2O3/R290/R600a (0.04/0.9/0.1) have significantly lower power consumption by compressor than R290/R600a (0.9/0.1). Therefore, by adding the nano particles (Al2O3) to the alternate refrigerant mixture (R290/R600a) the power consumption by compressor is slightly decreases.

Figure 13 shows the effect of condenser temperature piston displacement of compressor of R290/R600a (0.9/0.1) mixture and Al2O3/R290/R600a (0.04/0.9/0.1). It is concluded from figure 13 piston displacement of compressor increases with increase in condenser temperature till the optimum condenser temperature and here, Al2O3/R290/R600a (0.04/0.9/0.1) have significantly higher piston displacement of compressor than R290/R600a (0.9/0.1). Therefore, by adding the nano particles (Al2O3) to the alternate refrigerant mixture (R290/R600a) the piston displacement of compressor is slightly increases.

**Conclusion:**

In this paper performance analysis nano refrigerant (Al2O3/R290/R600a) with alternate refrigerant mixture (R290/R600a) in vapour compression refrigeration system has been carried out with help of Refprop software and Mathematical coding is developed by using visual studio software. The conclusions present in this analysis are given as follows.

- R290/R600a (0.9/0.1) have higher coefficient of performance than other proportion of R290/R600a mixture. Therefore, R290/R600a (0.9/0.1) can be suitable alternate mixture for adding the nano particles.
- By adding nano particles (Al2O3) to alternate refrigerant mixture (R290/R600a), the coefficient of performance will be improved based on concentration of nano particles.
- Al2O3/R290/R600a (0.04/0.9/0.1) has significantly higher Coefficient of performance, mass flow rate of refrigerant, actual piston displacement of compressor than R290/R600a (0.9/0.1). Therefore, by adding the nano particles (Al2O3) to the alternate refrigerant mixture (R290/R600a) the Coefficient of performance, mass flow rate of refrigerant, actual piston displacement of compressor is slightly increases.
- Al2O3/R290/R600a (0.04/0.9/0.1) has significantly lower heat rejected in condenser, power consumption by compressor than R290/R600a (0.9/0.1). Therefore, by adding the nano particles (Al2O3) to the alternate refrigerant mixture (R290/R600a) the heat rejected in condenser, power consumption by compressor is slightly decreases.
- With increasing evaporator temperature the Coefficient of performance increases, where mass flow rate of refrigerant, actual piston displacement of compressor, heat rejected in condenser and power consumption by compressor are decreases.
- With increasing condenser temperature the Coefficient of performance decreases, where mass flow rate of refrigerant, actual piston displacement of compressor, heat rejected in condenser and power consumption by compressor are increases.

**REFERENCES**