# Analysis of air conditioning system by using nanorefrigerant

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ABSTRACT. *Energy is essential for the existence of human life and it plays a vital role in programmer of nation.Based on some research, the use of air conditioners consumes about 40% of the total of electricity used in a house. So the objective is to carry out the analysis of an air conditioning system with and without Nano-refrigerant by experimental and analytical method to improve the performance of the system.The experimentation, mathematic modeling and simulation of air conditioning system is carried out at off design condition. For the analysis purpose R134a refrigerant and* $Al_2O_3$ *nanoparticles were used. The experimental studies indicate that the air conditioning system with nanorefrigerant works normally. It is found that the coefficient of performance is increased by 11% and the power consumption reduces nearly by 14% when POE oil is replaced by a mixture of POE oil and* $Al_2O_3$ *nanoparticles. Simulation of the system is carried out by developing a computer code in MATLAB, the above experimental results are validated with the simulation results. The software results are found more accurate than the experimental results.*

RÉSUMÉ. *L'énergie est essentielle pour l'existence de la vie humaine et joue un rôle indispensable en tant que programmeur d'une nation. D'après certaines recherches, l'utilisation de climatiseurs consomme environ 40% du total de l'électricité utilisée dans une maison. L'objectif est donc de procéder à l'analyse d'un système de climatisation avec et sans nano-réfrigérant par une méthode expérimentale et analytique afin d'améliorer les performances du système. L'expérimentation, la modélisation mathématique et la simulation du système de climatisation sont effectuées dans les conditions hors conception. Afin d'atteindre le but d'analyse, on a utilisé le réfrigérant R134a et les nanoparticules d'*$Al_2O_3$*. Les études expérimentales indiquent que le système de climatisation à l'aide de nanoréfrigérant fonctionne de façon normale. Il est constaté qu le coefficient de performance est augmenté de 11% et que la consommation d'énergie diminue de près de 14% lorsque l'huile POE est remplacée par un mélange d'huile POE et de nanoparticules d'*$Al_2O_3$*. La simulation du système est réalisée en développant un code informatique dans MATLAB. Les résultats expérimentaux ci-dessus sont validés avec les résultats de cette simulation. Les résultats du logiciel sont plus précis que les résultats expérimentaux.*

KEYWORDS: *air conditioning system, nanoparticles, COP, Nano-refrigerant, power consumption.*

*MOTS-CLÉS: système de climatisation, nanoparticules d' d'$Al_2O_3$, COP, Nano-réfrigérant, consommation d'énergie.*

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## 1. Introduction

Rapid industrialization has led to unprecedented growth, development and technological advancement across the globe. Now-a-days global warming and ozone layer depletion on the one hand and spiraling oil prices on the other hand have become main challenges. Excessive use of fossil fuels is leading to their sharp diminution and nuclear energy is not out of harm's. 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 it is necessary to develop energy efficient refrigeration and air conditioning systems. The rapid advances in nanotechnology have led 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 (Subramani and Prakash, 2011). Addition of nanoparticles changes the boiling characteristics of the base fluids. Nanoparticles can be used in air conditioning systems because of its remarkable improvement in thermo-physical and heat transfer capabilities to enhance the performance of air conditioning systems. In air conditioning system the nanoparticles can be added to the lubricant (compressor oil). When the refrigerant is circulated through the compressor it carries traces of lubricant + nanoparticles mixture (Nano-lubricants) so that the other parts of the system will have Nano-lubricant -refrigerant mixture.

Various methods have been tried out for improving the COP of the vapor compression refrigeration system, as reported in the literature. Krishna Sabareesh *et al*. conducted an experimental study on the performance of a domestic refrigerator using $TiO_2$ - R12 Nano refrigerant as working fluid. They found that the freezing capacity increased and heat transfer coefficient increases by 3.6 %, compression work reduced by 11% and also coefficient of performance increases by 17% due to the addition of nanoparticles in the lubricating oil (Krishna Sabareesh, 2012). Sheng Shan Bi *et al*. conducted an experimental study on the performance of a domestic refrigerator using $TiO_2$-R600a Nano refrigerant 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. The purpose of this article is to report the results obtained from the experimental studies on a vapour compression system (Bi *et al*., 2011). Sergio Bobbo *et al*. conducted a study on the influence of dispersion of single wall carbon Nano horns (SWCNH) and $TiO_2$ on the tribological properties of POE (Poly-Ester) oil together with the effects on the solubility of R134a at different temperatures. They showed that the tribological behavior 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 (Bobbo *et al.*, 2010). Sheng-Shan Bi *et al*. investigated the performance of a domestic refrigerator with SUNISO 3GS mineral oil and Nano particles in the working fluid. The results indicated that the energy consumption of the HFC134a refrigerant using SUNISO 3GS mineral oil and 0.06% mass fraction of Nano particle mixture as lubricant reduced the energy consumption by 21.2% when compared to that of HFC134a and POE (Poly-Ester) oil system (Bi *et al.*, 2008). Sheng Shan Bi et al. conducted studies on a domestic refrigerator using Nano refrigerants. In their studies R134a was used the refrigerant, and a mixture of mineral oil $TiO_2$ was used as the lubricant. They found that the refrigeration system with the Nano refrigerant worked normally and efficiently and the energy consumption reduces by 21.2%. When compared with R134a/POE oil system. Later he 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 (Bi *et al*., 2007; Elahmer *et al.*,2017; Boutra *et al*., 2017).

The purpose of this experimentation is to report and compare the results obtained from the experimental and analytical studies on air conditioning system. In the present study the refrigerant selected is R134a and the nanoparticlesare $Al_2O_3$.

## 2. Experimental set-up


*Figure 1. Photograph of the experimental set up*

For the studies an air conditioner trainer is used. The system consists of 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 finned tube and made of copper. A finned tube heat exchanger is used as condenser and it also made of copper. The experimental setup used for the present study is shown in Figure 1.Before charging the system with the refrigerant; the system was checked thoroughly for leaks. Leak testing was carried out by charging the system with nitrogen at a pressure of 200 Psi. After the leak test the system was properly evacuated using a vacuum pump. The compressor was filled with nano-lubricant and the system was charged with the refrigerant, in this case R134a.

## 3. Methodology

For controlling the temperature of air within a set of limits in the required season at various loads the methodology used in the experimentation can be done with this set-up. The operating procedure of experimental set-up is given below.

### *3.1. Preparation of nanofluid*

Preparation of Nano-lubricant is the first step in the experimental studies on Nano-refrigerants. Nanofluids can be prepared using single step or two step methods. In the present study two step method is used. Commercially available nanoparticles of aluminium oxide (manufactured by Sigma Aldrich) with average size <50nm were used for the preparation of Nano-lubricant. The experimentation is done with mass fraction of nanoparticles in the nanoparticle–lubricant mixtures for 1% and 2% by mass. An ultrasonic vibrator is used for the uniform dispersion of the nanoparticles and it took about 24 hours of agitation to achieve the same.

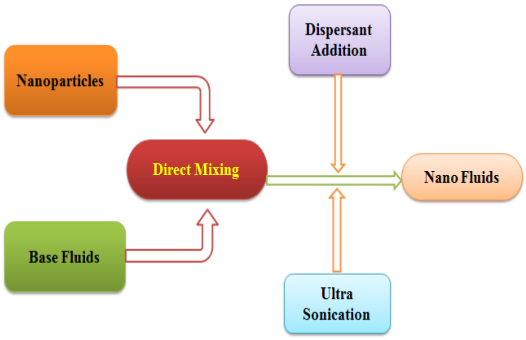


*Figure 2. Two-step method*

### *3.2. Calculation of nano-particles required for nanofluid*

Calculation for $Al_2O_3$ and POE oil based nanofluid for 2% mass fraction.

For 2% mass fraction how much weight of Nano-powder is to be added in 710ml of poly-ester oil (POE) is calculated below.

$$\text{Ø}\,\% = \frac{Mass\ of\ Nano{-}particles\ in\ grams}{Mass\ of\ fluid\ in\ grams}$$

$$2\% = \frac{m_p}{m_f}$$

$$0.02 = \frac{m_p}{677.03}$$

$$m_p = 13.46 \approx 13.50 \text{ gm.}$$

Hence for 2% mass fraction add 13.50 gm of powder into 710ml of poly-ester oil.

### *3.3. Procedure for preparation of nanofluid*

i) For known mass fraction find out weight of $Al_2O_3$Nano-powder required to add into base fluid of known quantity.

ii) After finding required weight of powder, measure weight of powder and took quantity of powder that we required.

iii) Add measured quantity of powder into known quantity of base-fluid.

iv) Put this mixture on Ultrasonic cleaner for 4 – 6 hrs for well dispersion of powder into base fluid.

v) Repeat this procedure by taking various mass fractions and prepare nanofluid of various concentrations.

### *3.4. Prepared nanofluid*

Preparation of Nano-lubricants is the first step in the experimental studies on Nano-refrigerant. By following the above steps the Nano-lubricant is prepared. For the preparation of Nano-lubricant Poly-Ester (POE) oil is used as base-fluid and $Al_2O_3$ is used as nanoparticles for predict the performance of the system.

*Figure 3. (a) Nanofluid before use; (b) Nanofluid after use*

### ***3.5. Stepsin system simulation***

Thermal system simulation involves the six basic steps i.e. defining the problem, mathematical modeling of system components, solving these equations by suitable iterative technique, parametric study, analysis of results and validation of developed models.

#### *3.5.1. Defining the problem*

The system to be simulated must be identified. Major components and their role need to be understood. Parameter for simulation has to be done. There may be number of different output parameters of the system.

#### *3.5.2. Mathematical modeling of system components*

Once the problem stated and components are identified, they need to represent in the form of equations i.e. mathematical modeling is done. The equations may be linear, non-linear simultaneous depending on the components. In many cases equations depend on energy balance and other physics. But in few cases the equations are to be developed from experimental data or performance characteristics of that component. After these equations are developed, they must be validated with some reference. Then and then only one can assure that the developed models are correct.

#### *3.5.3. Solving these equations by suitable iterative technique the equations are to be solved by suitable iterative technique.*

#### *3.5.4. Parametric study*

After the basic simulation procedure, the calculations have to be extended for parametric study. While defining the problem, we have already selected the varying parameters. Now these parameters are to be varied one by one and the system performance is calculated.

#### *3.5.5. Analysis of result*

This step deals with analyzing the results. Dependency of parameters can be found out. Also prediction of system off the design conditions can be studied.

### ***3.6. Methodology for simulation of air conditioning system***

Mathematical modeling is carried out for the components of the air conditioning system. Major components of system are hermetically sealed reciprocating compressor, condenser, evaporator and expansion valve etc.

#### *3.6.1. Refrigeration compressors*

These types of compressors are modeled byusing curve fitting the data from performance characteristics or experimental data. This method uses compressor performance data to curve fit coefficients of polynomial equations. The equations are of the form,

$$p = c_1 + c_2 t_e + c_3 t_e^2 + c_4 t_c + c_5 t_c^2 + c_6 t_c t_e + c_7 t_e^2 t_c + c_8 t_e t_c^2 + c_9 t_c^2 t_e^2 \quad (1)$$

By knowing performance characteristics of particular compressor model for power, cooling capacity (equation 1) or mass flow rate, we can determine the constants C1 to C9. By substituting the constants in equation 1, a generalized equation can be developed for respective compressor. Once this equation is developed, we can find the power required, cooling capacity, mass flow rate for different evaporating and condensing temperatures.

*3.6.2. Condensers and evaporators*

These components play a very important role in most of the thermal systems. One of the fluid changes its phase while flowing through this components. One important assumption while modeling these equations is that, no superheating or sub cooling of fluid that changes phase. The fluid changes phase at constant temperature. Here LMTD equation still applies in combination of energy balance. A generalized equation for finding out outlet temperature of fluid that does not change the phase can be developed for condenser and evaporator.

Condenser

$$t_b = t_c + (t_b - t_c)[1 - e^{-UA/wCp}] \text{ …… …………….(2)}$$

Evaporator

$$t_a = t_e + (t_a - t_e)[1 - e^{-UA/wCp}] \text{ …………………(3)}$$

By using equations (2) and (3) one can find the outlet temperature of condenser and evaporator when inlet temperatures are known.

## 4. Experimental result

In the present experimental study, two cases have been considered. The hermetic compressor filled with i) pure POE oil (poly-ester oil) ii) POE oil + alumina nanoparticles as lubricant. The mass fraction of the nanoparticles in the Nano-lubricant is 1% & 2% were considered.

### ***4.1. Ambient temperature Vs theoretical COP***

Figure 4 shows the variation of ambient temperature with respect to theoretical COP. From Figure 4 it clears that the theoretical COP of the system is increases if the Nano-lubricant is used instead of pure POE oil.At $24^0C$,the COP of system for pure POE oil is 5.79, for mixture of POE oil and 1% $Al_2O_3$ the COP is 6.9 & for mixture of POE oil and 2% $Al_2O_3$ the COP is 8.17. Similarly at $26^0C$, the corresponding COP of system is 5.78, 6.66 and 7.92. And at 28$^0C$ the COP is 5.4, 6.25 and 7.64. For the calculations of theoretical COP the enthalpies values at salient points are taken from P-h chart of R134a.

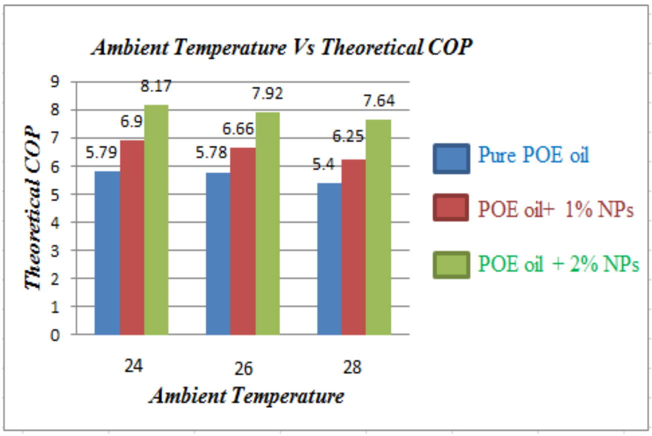


*Figure 4. Ambient temperature Vs Theoretical COP*

### *4.2. Ambient temperature Vs carnot COP*

Figure 5 shows the variation of Carnot COP with respect to ambient temperature. From Figure 5 it is clear that the Carnot COP of the system is increases if the Nano-lubricant is used instead of pure POE oil. At 24$^oC$, the COP of system for pure oil is 6.35, for mixture of POE oil and 1% $Al_2O_3$ nanoparticles the COP is 7.13 & for mixture of POE oil and 2% $Al_2O_3$ nanoparticles the COP is 8.4. Similarly, at 26$^oC$the corresponding COP of system is 6.35, 7.48 and 8.72. At 28$^0C$the COP of system is 6.6, 7.91and 8.89.

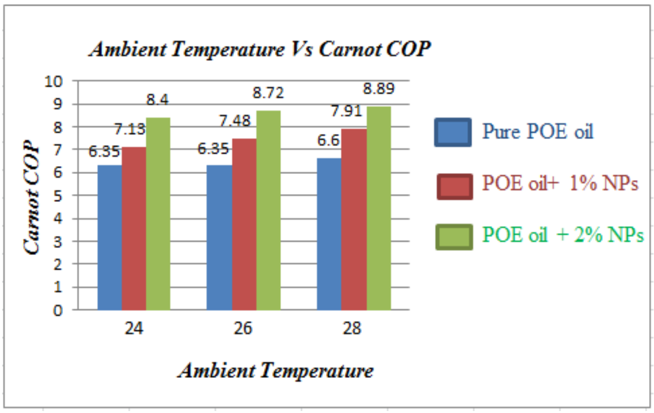


*Figure 5. Ambient temperature Vs Carnot COP*

### 4.3. Ambient temperature Vs actual COP

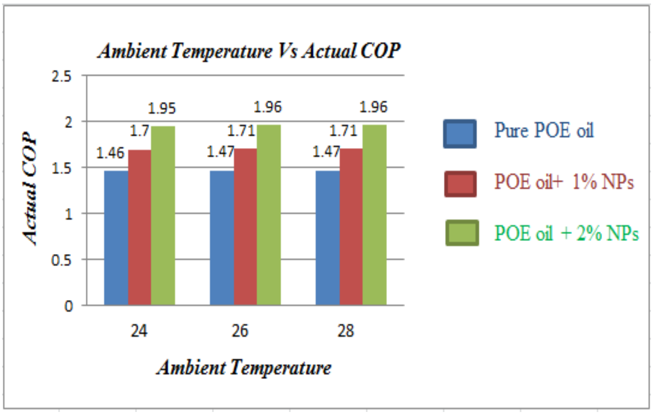


*Figure 6. Ambient temperature Vs Actual COP*

Figure 6 shows the variation of actual COP with respect to ambient temperature. From Figure 6, it is clear that the actual COP of the system is increases if the Nano-lubricant is used instead of pure POE oil. At 24$^oC$the COP of system for pure POE oil is 1.46, for mixture of POE oil and 1% $Al_2O_3$ the COP is 1.7 & for mixture of POE oil and 2% $Al_2O_3$ the COP is 1.95. Similarly at 26$^oC$the corresponding COP of system is 1.47, 1.71 and 1.96 respectively. And at 28$^oC$ the COP of system is 1.47, 1.71 and 1.96 respectively.

### 4.4. Ambient temperature Vs power consumption

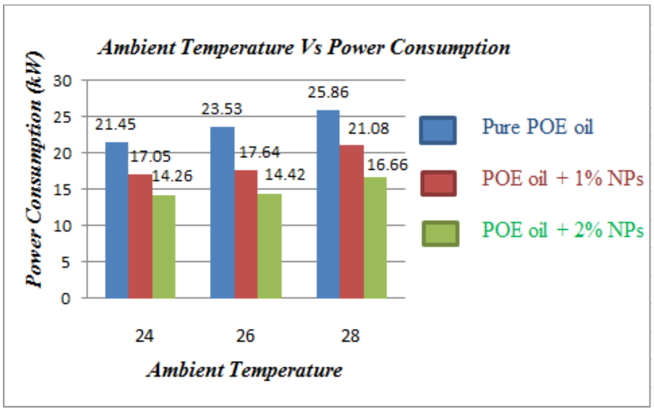


*Figure 7. Ambient temperature Vs power consumption*

Figure 7 shows that the comparison of power consumption of the system. The reduction in power consumption is nearly 20 % if mixture of $Al_2O_3$nanoparticles & POE oil is used instead of POE oil. At 24$^oC$the power consumption of system for pure POE oil is 21.45 kW, for mixture of POE oil and 1% $Al_2O_3$ nanoparticles the power consumption is 17.05 kW & for mixture of POE oil and 2% $Al_2O_3$ nanoparticles the power consumption is 14.26 kW. Similarly at 26$^oC$the power consumption is 23.53 kW for pure POE oil, 17.64 kW for 1% nanoparticles and 14.42 kW for 2% nanoparticles. Similarly at 28$^oC$the power consumption is 25.86 kW for pure POE oil, 21.08 kW for 1% nanoparticles and 16.66 kW for 2% nanoparticles added into the POE oil.

## 5. Mathematical modeling of system

Mathematical modeling is carried out for the components of the air conditioning system. Major components in the above system are hermetically sealed reciprocating compressor, condenser and evaporator. Equations are developed from experimental data i.e. power and cooling capacity. For condenser and evaporator equation no 2 and 3 is used respectively. Hence there are four equations and four unknowns. Before going to actual iterative process some assumptions are stated. They are:

(i) Steady state simulation

(ii) Air properties at 299 K

By using the models following are the equations developed for compressor power and cooling capacity.

Evaporator

$$f_1 = wC_p(t_a - t_e)\left(1 - e^{\left(-UA/wC_p\right)}\right) - q_e$$

Condenser

$$f_2 = wC_p(t_b - t_c)\left(1 - e^{\left(-UA/wC_p\right)}\right) - q_c$$

Refrigeration Capacity

$$f_3 = 82.015 + 9.2443t_c - 0.131{t_c}^2 + 304.71t_e - 21.332t_ct_e + 0.3216t_e{t_c}^2 - 25.571{t_e}^2 + 1.7861t_c{t_e}^2 - 0.0269{t_c}^2{t_e}^2 - q_e$$

Compressor Power

$$f_4 = -22.05 + 2.9375t_c - 0.0474{t_c}^2 + 36.659t_e - 2.3307t_c + 0.0356t_e{t_c}^2 - 5.7501{t_e}^2 + 0.3543t_c{t_e}^2 - 0.0054{t_c}^2{t_e}^2 - p$$

These are the Governing equations for air conditioning system.

### *5.1. Simulation result*

*Table 1. Results by NR techniques*

| $t_a(o_C)$ | $t_b(o_C)$ | $t_e(o_c)$ | $t_c(o_c)$ | $q_e(kW)$ | P (kW) |
|---|---|---|---|---|---|
| 20 | 20 | 4.6066 | 30.0217 | 0.4618 | 17.6626 |
| 20 | 25 | 4.6068 | 30.0264 | 0.4618 | 17.6679 |
| 20 | 15 | 4.6063 | 30.0171 | 0.4618 | 17.6574 |
| 25 | 25 | 4.6118 | 30.0264 | 0.3116 | 17.6673 |
| 20 | 30 | 4.6071 | 30.0310 | 0.4618 | 17.6731 |
| 15 | 30 | 4.6021 | 30.0310 | 0.3119 | 17.6773 |
| 30 | 25 | 4.6167 | 30.0264 | 0.7615 | 17.6595 |
| 30 | 30 | 4.6170 | 30.0310 | 0.7615 | 17.6647 |
| 28 | 30 | 4.6150 | 30.0310 | 0.7015 | 17.6664 |

Simulation of the system is carried out by developing a computer code in MATLAB software as per the steps mentioned above. The program is executed for different values. Input data for simulation isas; $UA_e$ =0.35W/K, $UA_c$ =0.5W/K, $W_e$ =0.025Kg/s, $W_c$ =0.070Kg/s, $C_p$ =1.2 $^{kJ}/_{kgK}$, u=1 By selecting trial values for the unknown variables i.e. $t_b$ =30 , $t_c$ =30 , $t_a$ =30 , $t_e$ =10 , $q_e$ =1kw, p =1kw, these values are substituted in the governing equations ,and source matrix is obtained. From above governing equations partial derivatives of all variables with respect to each other are computed and coefficient matrix is obtained. The coefficient and source matrix is as given below.

$$\begin{bmatrix} -0.0300 & 0 & -1.0000 & 0 \\ 0 & 32.2281 & 0 & 0 \\ 30.2300 & -1.7657 & -1.0000 & 0 \\ -0.8440 & 1.1765 & 0 & -1.0000 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} = \begin{bmatrix} -0.4000 \\ -1.0000 \\ 162.5440 \\ 12.0850 \end{bmatrix}$$

The outputs of NRT method are shown in the table. The calculations converged satisfactorily. The above matrix is solved by Gauss eliminations method.

### *5.2. Comparison of experimental and simulation result*

Simulation of Air conditioning system is made for varying inlet temperatures of condensers and evaporator. Table 1 gives the comparison results at Ta = 28 and Tb = 30°C. Simulated results are on higher side, as losses from condenser, evaporator, compressor, insulations are not considered in mathematical modeling. Deviation between simulated and experimental results is due to unaccountability of losses in mathematical models. The deviations obtained in refrigeration capacity, compressor power, evaporative temperature and condenser temperature are 8.16%, 5.69 %, 13.32% and 6.76% respectively is shown in table 2.

*Table 2. Comparison of simulated results and experimental results*

| Results | $q_e(kW)$ | $P(kW)$ | $t_e(o_C)$ | $t_c(o_C)$ |
|---|---|---|---|---|
| Simulation | 0.7015 | 17.6664 | 4.6150 | 30.0310 |
| Experimental | 0.6442 | 17.44 | 4 | 28 |

## 6. Conclusion

i) First the experimental observations are made for base refrigerant and nanorefrigerant and also the calculations are done theoretically.

ii) The mathematical models for individual components are developed.

iii) Methodology for system simulation is applied to Air conditioning system.

iv) The results are improved when the nanoparticles is added in the base refrigerant which increases the coefficient of performance of the system by nearly 11% and also reduces the power consumption of the system nearly 15%.

v) The experimental results are compared with the MATLAB result and it is found that the software results are more accurate than experimental results.

## 7. Future scope

The above experimental observations are made with newly available hydro carbon refrigerant will be considered as a long-term alternative for halogenated refrigerants.

Future research is required to investigate the influence of the particle material. Its shape, size, distribution, and concentration on refrigerant boiling performance.

Future research will be done on simulation technique. The Matrix method of simulation will be used instead of Newton-Raphson Technique (NRT), because the Matrix method takes the less iteration time than NRT method.

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