# Performance Enhancement of Vapor Compression Cycle Using Nano Materials


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***Abstract*—The performance of a vapor compression cycle with nanomaterials additives to the working fluid is investigated theoretically and experimentally. Polyolester (POE) oil with $AL_2O_3$ nanomaterials additives is used to enhance the performance in the vapor compression cycle with R-143a refrigerant. The stability of nanofluid was first tested by using sedimentation test. The performance of cycle with the nanomaterials was then studied using energy consumption and freezing capacity tests. Theoretical analysis shows that the heat transfer coefficient in the evaporator with nanorefrigerant increases by 50%. Moreover, exergy loss decreases by 28 % when nanorefrigerant is used .The experimental results indicate that R-134a and Polyolester (POE) oil with $AL_2O_3$ nanoparticles enhance the vapor compression cycle performance by 10.5 % with 13.5 % lees energy consumption. These results were obtained with 0.1% mass fraction of nano-lubricant oil.**



***Keywords-component; Vapor compression cycle, Refrigeration, Nanomaterial, Experimental***


## *Nomenclature*

| | |
|---|---|
| $A_s$ | *surface area of evaporator coil area ($m^2$)* |
| $C_w$ | *water specific heat (kJ/kg K)* |
| $C_p$ | *specific heat (kJ/kg K)* |
| $h_{1\text{-}4}$ | *enthalpy of refrigerant at different locations of cycle (kJ/kg)* |
| $h$ | *heat transfer coefficient of water ($W/m^2$ K)* |
| $h_{fg}$ | *latent heat of vaporization (kJ/kg)* |
| $I_{ev}$ | *exergy loss in evaporator (kJ/kg)* |
| $I_{Comp}$ | *exergy loss in compressor (kJ/kg)* |
| $I_{cond}$ | *exergy loss in condenser(kJ/kg)* |
| $I_{cap}$ | *exergy loss in capillary tube (kJ/kg)* |
| $k$ | *thermal conductivity (W/m K)* |
| $m_w$ | *mass of water (cooling load) (kg)* |
| $q$ | *heat flux ($w/m^2$)* |
| $q_c$ | *heat removed from refrigerant (kJ/kg)* |
| $q_e$ | *heat added to refrigerant (refrigeration effect) (kJ/kg)* |
| $s_{1\text{-}4}$ | *entropy of refrigerant at different locations of cycle (kJ/kg)* |
| $T_s$ | *surface temperature of evaporator coil (K)* |
| $T_\infty$ | *average water temperature (K)* |
| $\Delta T_w$ | *water temperature difference* |
| $W$ | *compressor work (kJ/kg)* |
| $X'$ | *specific exergy* |

***Greek letters***

| | |
|---|---|
| $\rho$ | *Density* |
| $\mu$ | *Viscosity* |
| $\omega$ | *concentration of nanoparticle in the nanoparticle-oil mixture* |

***Subscripts***

| | |
|---|---|
| *COP* | *coefficient of performance* |
| *WN* | *with using nanoparticle* |
| *WON* | *without using nanoparticles* |
| *l* | *liquid* |
| *g* | *gas* |
| *n* | *nanoparticle* |
| *o* | *oil* |
| *r* | *refrigerant* |
| *n,o* | *nanoparticle with oil* |
| *r,o* | *refrigerant with oil* |
| *r,n,o* | *refrigerant with nanoparticle and oil* |

## I. Introduction

Recently, Egypt is facing an energy shortage problem. In the face of this problem there are two ways; first Egypt should be more interested in renewable energy resources and the second is the efficient use of energy. Refrigerators and air conditioners has a large consumption of electrical power as any other thermal system. So, developing energy efficient thermal systems with lower electric consumption need to be explored.

Nanomaterials usage in refrigeration systems is useful because of its salient enhancement in thermo physical and heat transfer capabilities, where it can be added to the system by adding it to the compressor oil (lubricant). When the refrigerant passed through the compressor it have some of lubricant nanomaterials mixture with (nanolubricants) so that all parts of the system will have nanolubricant and refrigerant mixture.

Recently, there are some research on the on vapor compression refrigeration systems with nanomaterials additives to study the effect of it on system performance. **Bi and Shi [1]** investigated the refrigerator energy consumption experimentally with the usage of R134a/$TiO_2$ mixture as working fluid. Their results showed that the system energy consumption reduced by 7% when nanorefrigerant is used. **Jwo *et al.* [2]** discusses the usage of a hydrocarbon refrigerant and mineral lubricant instead of the R134a refrigerant and polyester lubricant. $Al_2O_3$ nanoparticles with concentration (0.05, 0.1, and 0.2 wt %) was added to mineral oil to improve the lubricating process and heat transfer capabilities. Their results showed that the optimal mixture was 60% R134a and 0.1 wt % $Al_2O_3$. The consumption of power reduced by about 2.4%, and there was increasing in coefficient of performance (COP) by 4.4%. **Bi *et al*. [3]** investigated the performance of a domestic refrigerator without any system addition. R600a with $TiO_2$ nanomaterial additives was used instead of pure R600a .Their results showed that the refrigerator energy consumption was reduced by 5.94% and freezing rate increased by 9.60% when 0.1 concentrations of R600a/$TiO_2$ instead of pure R600a **Subramanian and Prakash [4]** studied the performance parameters of a vapor compression refrigeration cycle with R134a/ $Al_2O_3$ nanorefrigerant as working fluid. They used POE oil, SUSISO 3GS oil and SUSISO 3GS oil/ $Al_2O_3$ nanoparticle as lubricant. Their experimental result showed that, the compressor energy consumption decreased by 25% and the refrigeration system COP increased by 33% by using SUSISO 3GS oil/$Al_2O_3$ nanoparticle instead of POE oil. The refrigeration system freezing capacity was also increased when using R134a/$Al_2O_3$ nanorefrigerant in the refrigerant system. **Sabareesh *et al*. [5]** investigated the performance of vapor compression cycle experimentally. They used nanomaterials with volumetric concentrations of 0.050%, 0.010%, and 0.015% .Their result showed that the optimum nanomaterial volumetric concentration is 0.010%. Moreover the compressor work decreased by 11 % while the COP increased by 17% and the average heat transfer rate increases by 3.6% by the usage of R12/$TiO_2$/mineral oil nanorefrigerant in the vapor compression refrigeration system (instead of R12/mineral oil mixture). **Javadi and Saidur [6]** investigated the performance of a domestic refrigerator and how to reduce its power and $CO_2$ emissions in Malaysia. They studied the effects of adding $Al_2O_3$ and $TiO_2$ nanoparticles with weight concentration of 0.06% and 0.10% to mineral oil R134a refrigerant. The results show that the maximum energy savings is 25% when adding 0.10% of $TiO_2$ nanoparticles to mineral oil R134a. Moreover the $CO_2$ reduction rate will increase when using nanorefrigerant in refrigeration systems. According to their study, more than 7 million tons of CO2 by the year of 2030 will be saved when using mineral oil -R134a with 0.10% TiO2 nanoparticle mixture.

The above literature shows few studies have investigated the nano materials additives effect on the vapor compression cycle performance, however studies for a long time operation for the cycle and exergy analysis are very limited. Therefore, the present study aims to investigate, experimentally and theoretically, the performance of the vapor compression cycle with nano materials additives .small vapor compression cycle has been designed, fabricated and tested. Moreover, theoretical and exergy analysis have been done to investigate the effect of nanomaterials additive on vapor compression cycle theoriticaly.

## II. EXPERIMENTAL SETUP AND PROCEDURES

An experimental setup has been developed to investigate the performance of vapor compression cycle with and without nanoparticles. A vapor compression cycle has been designed and fabricated. Experimental setup photograph is shown in Fig. 1 and schematic diagram of experimental setup shown in Fig. 2. The experimental setup consists of the following four main components: a hermetically sealed compressor reciprocating type with 0.25 horsepower, air-cooled condenser which is serpentine coil cooled by air coming from a fan, capillary tube and an evaporator which is in form of copper spiral coil cylindrical shape and it is totally immersed in water (cooling load) (20 litter) .at outlet and inlet of each component thermocouples type K are used to measure temperature .Moreover, bourdon tube pressure gauge are used to measure pressure at the outlet of each component . Those thermocouples are connected to OM320 data logger. The compressor power consumption is measured using clamp ampere and voltammeter. Before conducting the experimental system was checked for leakage by charging the system with gas and checks the leak by using ultrasonic detector. After that the system was evacuated. Then the compressor was filled with the nanolubricant mixture and the whole system charged with R-143a refrigerant. The experimental measurements were done on the Energy Resources Engineering (ERE) department building at Egypt-Japan University of Science and Technology (E-JUST) in new Borg El-Arab city, Alexandria-Egypt.

Fig. 1: A photographs of Experimental setup

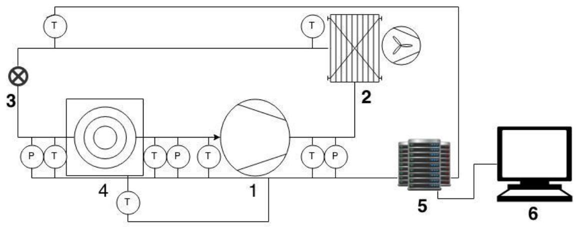



Fig. 2: A schematic diagram of Experimental setup
1- Compressor 2- Air cooled condenser 3- Capillary tube
4- Evaporator (tank and coil) 5- Data logger 6- PC
T - Stands for thermocouples P -Stands for pressure gauges

Figure 3 shows the pressure - specific enthalpy schematic diagram of an ideal vapor compression cycle. Here process 1-2 is the compression process, 2-3 is the condensation process, 3-4 is the expansion process and 4-1 is the evaporation process.

The theoretical COP is calculated using the following equation

$$COP_{th} = (h_1 - h_4) / (h_2 - h_1) \quad (1)$$
$$q_c = h_2 - h_3 \quad (2)$$
$$q_e = h_1 - h_4 \quad (3)$$
$$w = h_2 - h_1 \quad (4)$$

The enthalpy values are taken from refrigerant tables and charts

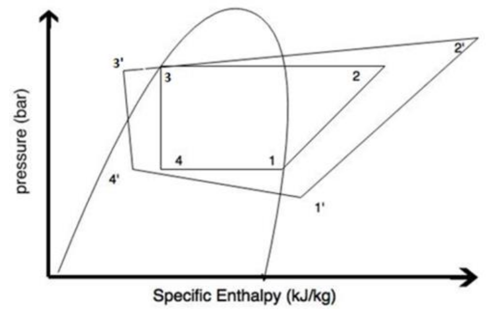



Fig. 3: Pressure (bar) Specific enthalpy(KJ/Kg) schematic diagram of the vapor compression system

The actual COP is calculated using relation

$$COP_{act} = \text{cooling load / power input} \quad (5)$$

For calculation of heat transfer coefficient of water

$$m_w C_w \Delta T_w = h A_s (T_s - T_\infty) \quad (6)$$

**Calculation of thermal and physical properties of nano-lubricant mixture**

Specific heat of nanolubricant [7]

$$C_{p,n,o} = (1-\psi n) C_{p,o} + \psi_n C_{p,n} \quad (7)$$

Thermal conductivity of nanolubricanrt [8],

$$K_{n,o} = K_o[(K_n+2K_o- 2\psi_n(K_o-K_n)) / (K_n+2K_o+ \psi_n (K_o-K_n))] \quad (8)$$

Viscosity of nanolubricant [9],

$$\mu_{n,o} = \mu_o [1 / (1- \psi_n) 2.5] \quad (9)$$

Density of nanolubricant [4],

$$\rho_{n,o} = (1- \psi_n) \rho_o + \psi_n \rho_n, \quad (10)$$

Where $\psi_n$ Nano particle volume fraction in the nanoparticle-oil suspension.

**Calculation of thermophysical properties of nanorefrigerant:**

Specific heat of the nanorefrigerants [10]

$$Cp_{,r,n,o,l} = (1-X_{n,o}) Cp_{r,f} + X_{n,o} C_{p,n,o}, \quad (11)$$

Viscosity of the nanorefrigerants [11]

$$\mu_{r,n,o,l} = \exp (X_{n,o} \ln\mu_{n,o} + (1-X_{n,o}) \ln_{\mu r,f}) \quad (12)$$

Thermal conductivity of the nanorefrigerants [12]

$$K_{r,n,o,l} = K_{r,l}(1-X_{n,o}) + (K_{n,o}X_{n,o)} – (0.72X_{n,o} (1- X_{n,o}) (K_{n,o}-K_{r,l})) \quad (13)$$

Density of the nanorefrigerants is given as [5]

$$\rho_{r,n,o,l} = [(X_{n,o}/\rho_{n,o}) + ((1-X_{n,o})/ \rho_{r,l})] -1 \quad (14)$$

Where $X_{n,o}$ Nanoparticle/oil suspension concentration.

**Calculation of heat transfer coefficient in the evaporator refrigerant side:**

The heat flux (q) is calculated from the formula (eq.10) proposed by [13].

$$\Delta T_b = Tw - Tsat \quad (15)$$

The boiling heat transfer coefficient of refrigerant/oil mixture with nanoparticles,

$$h_{r,n,o} = q / \Delta T_b \quad (16)$$

**Exergy analysis of the system:**

**Exergy loss:**

For evaporator:

$$I_{ev} = (X'_4 - X'_1) + q_e$$
$$I_{ev} = [(h_4 - h_1) - T_0 (s_4 - s_1)] + q_e (1-(T_0 /T_l)) \quad (17)$$

For compressor:

$$I_{comp} = (X'_1 -X'_2) + w = [(h_1 - h_2)-T_0 (s_1 - s_2)] + w \quad (18)$$

For condenser:

$$I_{cond} = (X'_2 -X'_3) - q_c = (h_2 - h_4) -T_0 (s_2 - s_3) - q_c (1-(T_0/T_h) \quad (19)$$

For capillary:

$$I_{exp} = (X'_4 - X'_3) = T_0 (s_4 - s_3) \text{ [Throttling, } h_4 = h_1] \quad (20)$$

Total loss,

$$I_{total} = I_{cond} + I_{cap} + I_{comp} + I_{evap} \quad (21)$$

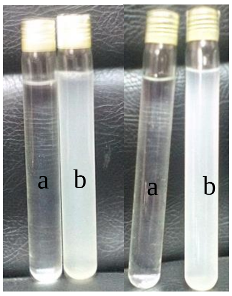
## III. PREPARATION OF NANOPARTICLES LUBRICANT-OIL

The first step in the present experimental study is the preparation of nanolubricants. Commercially available nanomaterials of aluminum oxide (sigma Aldrich providers) with size less than 50nm and its density is 3600 kg/m$^3$ were used. Weight concentration of nanoparticles in the nano–lubricant mixtures is 0.1%. Magnetic stirrer and an ultrasonic vibrator was used for preparation of nanolubricant mixture. Figure 4 shows photos for nanolubricant after preparation and after 3 days of preparation. It is clear that after 3 days of preparation the nanolubricant was stable

## IV. RESULTS AND DISCUSSION

In this study, two cases have been considered. The reciprocating compressor filled with 1) POE (Polyol ester oil) 2) POE (Polyol ester oil) + $Al_2O_3$ nanomaterials as lubricant. The weight concentration of the nanomaterials in the nanolubricant is 0.1 %. Theoretical results show that the heat transfer coefficient increases by 50% when POE (Polyol ester oil) + $Al_2O_3$ nanomaterials as lubricant is used instead of pure POE. Moreover, exergy analysis shows that the exergy loss decreases by 28% when nanorefrigerant is used instead of R134a. Table 1 shows the theoretical result and the exergy analysis results.

Experimental results show that the system works good and safely with nanoparticles additives Moreover the use of nanoparticles additives in vapor compression cycle increases its performance. Figure 5 shows the nanoparticles effect on the $q_c$, $q_e$ and w. It is clear that the use of nanomaterials increases the refrigeration effect, heat rejected in condenser and decreasing the work by 4.64 %, 2.49 % and 4.10%; respectively. So the COP theoretically increases by 9.11%. Figure 6 shows the nanoparticles effect on the COP theoretically and actually. It is clear that the use of nanomaterials also increases the actual COP by 10.53%. Moreover, the system consumes 13.30% less energy when nanoparticles are used. Figure 7 shows the effect of using nanoparticles on energy consumption.



(1) (2)

Fig. 4: Photographs of lubricant (1) after preparation (2) after 3 days of preparation for (a) pure lubricant POE (b) nanolubricant

**Table 1: The theoretical result and the exergy analysis results**

| | WON | WN |
|---|---|---|
| Theoretical boiling heat transfer coefficient (W/m²k) | 835.47 | 1224.806 |
| Total exergy loss (kJ/kg) | 10.70 | 8.338 |

Moreover, the system took about 120 min for reaching water temperature 0°C from 29°C without using nanoparticles and it took about 90 min only with the use of nanoparticles. The effect of nanoparticles on the freezing capacity is shown in Fig. 8.

Figure 9 shows the time temperature curve for cooling load (water) without using and with using nanoparticles. It is clear that, when using nanoparticles the time reduces and that is the reason of reducing the energy consumption. The temperatures at different points for the two cases are shown in Table 2. Moreover, water heat transfer coefficient is increased by 70.83% when using nanoparticles. The nanoparticles effect on heat transfer coefficient of water is shown in Fig. 10.

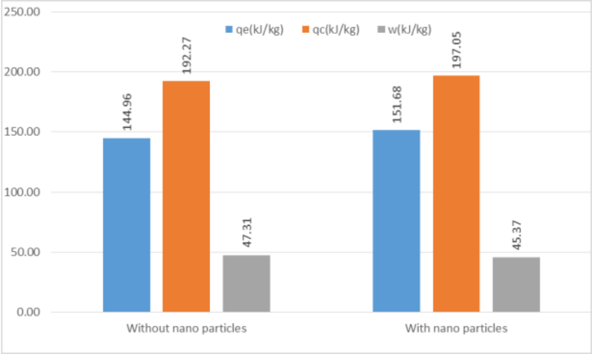


Fig. 5: The effect of using nano particles on qe ,qc ,w

Comparison of the present experimental results with thaose obtained by Subramanian and Prakash [4] are shown in Figs. 11 and 12. Subramanian and Prakash [4] used pure SUSISO 3GS oil and SUSISO 3GS oil with $Al_2O_3$ nanoparticle as lubricant with 0.06% mass fraction and the refrigerant was R-143a. It is clear that the percentage of increase is in good agreement with the present work.

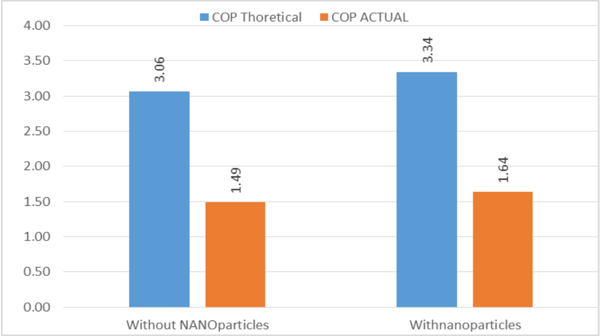


Fig. 6: The effect of using nano particles on actual and theoritical COP

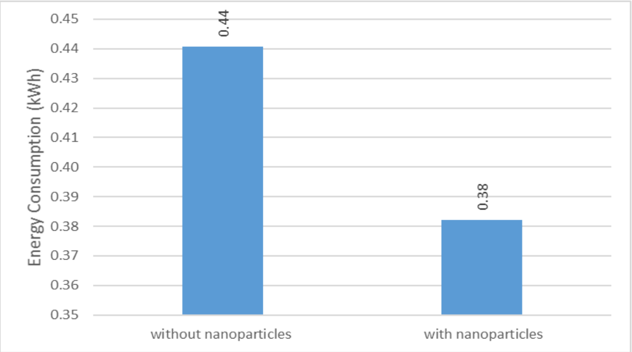


Fig. 7: The using nano particles effect on energy consumption

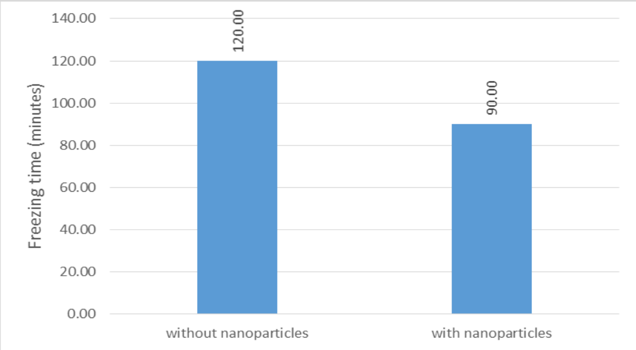


Fig. 8: The effect of using nano particles on freezing time

Finally, Table 3 show the values of $q_e$, $q_c$, w, COP theoritical, COP actual and energy consumption for the present study after 40 days of operation. It is clear that performance of system is less than the first run but with small percentage.

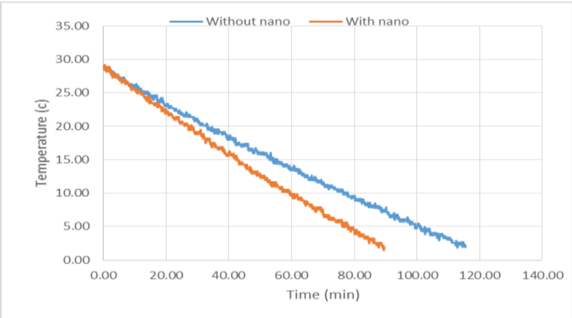


Fig. 9: The effect of using nano particles on water temperature

**Table 2: The temperatures at different points of the system**

| | WON | WN |
|---|---|---|
| Temp at Condenser inlet | 57.23025 | 58.37373 |
| Temp at Condenser outlet | 36.91139 | 34.01335 |
| Temp at evaporator inlet | -1.16007 | 3.084879 |
| Temp at compressor inlet | 23.75815 | 20.52889 |
| Temp at compressor outlet | 61.18986 | 60.47968 |
| Temp at Capillary inlet | 37.33787 | 35.0893 |
| ΔT condenser | 20.32 | 24.36 |

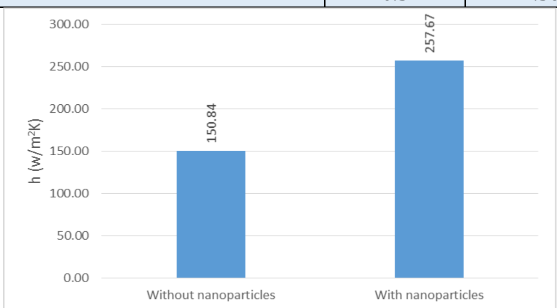


Fig. 10: The effect of using nano particles on water heat transfer coefficient

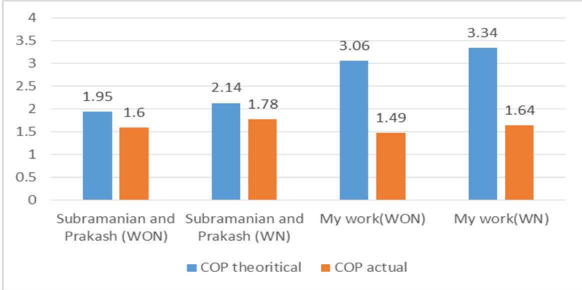


Fig. 11: Comparison of the present experimental work results and Subramanian and Prakash [7] results (COP actual and theoritcal in case of using and not using nanomaterials)

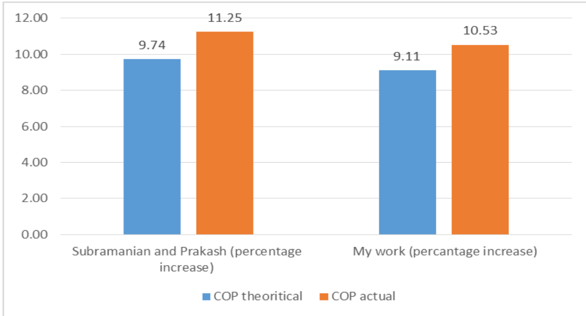


Fig. 12: Comparison of the present experimental work results and Subramanian and Prakash [7] results (COP actual and theoritcal percentage increase after nanomaterials)

**Table 3: The performance paremetars of cycle**

| | WON | WN | WN after 40 days |
|---|---|---|---|
| $q_e$ | 144.96 | 151.68 | 151.45 |
| $q_c$ | 192.27 | 197.05 | 197.28 |
| W | 47.31 | 45.37 | 45.83 |
| COP (theoretical) | 3.06 | 3.34 | 3.30 |
| Increase in COP (theoretical) (%) | 0.00 | 9.11 | 7.85 |
| COP (actual) | 1.49 | 1.64 | 1.63 |
| Increase in COP (actual) (%) | 0.00 | 10.53 | 9.74 |
| Energy consumption (kWh) | 0.44 | 0.38 | 0.39 |
| Decrease in energy consumption (%) | 0.00 | 13.30 | 12.17 |

## V. CONCLUSION

Experimental study carried out to investigate the vapor compression performance of cycle with and without using nanoparticles. Theoretical analysis shows that the heat transfer coefficient in the evaporator with nanorefrigerant increases by 50%. Moreover, exergy loss decreases by 28 % when nanorefrigerant is used. Experimental results showed that the COP of the system with the use of nanomaterials is higher than the COP of the system without using nanoparticles by 9.11% theoretically and 10.53% actually. The energy consumption is reduced by 13.30% when using nanoparticles and heat transfer coefficient is increased by 70.83%. Finally experimental results after 40 days of operation showed that the COP of the system with the use of nanomaterials is higher than the COP of the system without using nanoparticles by 7.85% theoretically and 9.74% actually .

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