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Experimental study of vapor compression refrigeration system using mixing refrigerant (R290/R600a) compare with nano refrigerant (R600a/Al_2O_3)

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ABSTRACT

Energy conservation and environmental pollution elimination are among the most important factors that contribute to improving refrigeration and air conditioning systems. This article focused on the effect of nanoparticles Al_2O_3 mixed with PAG oil in concertation 0.14% used base fluid R600a (isobutane) on a one ton vapor compression refrigeration system's performance and compare it with the mixed refrigerant (R290/R600a) in ratio 60% /40%, in vapour compression system with double tube heat exchanger experimentally three ratios were tested (0.1%, 0.12%, 0.14%) and it was noted that 0.14% was the ratio that had the most impact on the results. Adding Al_2O_3 in concertation 0.14% with R600a the reading recorded in time about 80 min operation, the study noted increased in COP approximately in (R600a/Al_2O_3) is 35% compared with COP in mixed refrigerant 60%/40% R290/R600a is 28%, and noted reduced in work of compressor is 102 kJ/kg compare with mixed refrigerant (R290/R600a) ratio 60%/40% that 110 kJ/kg improvement about 9%. The evaporator inlet temperature reach to -20 °C in (R600a/Al_2O_3) and -15 °C in mixed refrigerant (R290/R600a) 60%/40%, so the refrigerating effect of (R600a/Al_2O_3) nano refrigerant at a concentration of 0.14% is 438 kJ/kg showed an improvement of approximately 29%. due to decreased in temperature inlet to evaporator. Theoretical results were determined using simulation software ProII and EES software based on mathematical models of vapour compression system components, the COP shows 15% difference due to measurement errors.

Keywords: vapour compression refrigeration system, hydrocarbon refrigerant, coefficient of performance, nano refrigerant, polyalkyline glycol oil.

INTRODUCTION

Cooling services is growing rapidly, driven by population growth, economic booms and rising global average temperatures. Refrigeration is essential for sustainable development, but growing demand in this sector would further accelerate climate change. For this, most recent studies have begun to focus on protect the ozone layer from the negative effects of refrigerants and reduce the global warming effect (1).

A new technological solutions and cost implications, voluntary agreements, and industry pledges are all pointing to the use of low global warming potential (GWP) refrigerants as alternatives, as (CFCs and HCFCs). HCs have no ozone depletion potential (ODP) and an exceptionally low GWP as compared to (CFCs, HCFCs, and HFCs), and they provide excellent efficiency, lower refrigerant costs, and a variety of additional benefits such as mineral oil compatibility. The performance of the refrigeration system is directly related to the thermophysical properties of the refrigerant. Improving the thermophysical properties of the refrigerant can improve the system's performance. A Nano refrigerant is one kind of nanofluids for which the base fluid is a refrigerant to enhance the thermal performance of refrigeration and air-conditioning systems because of the higher thermal conductivity (1, 2).

Recently, the focus has been on using the refrigerant that have the least impact on the climate. Implementing environmentally friendly refrigerants and enhancing the efficiency of refrigeration systems can substantially reduce CO_2 emissions. The adoption of hydrocarbons has been shown to decrease the carbon footprint by 50%. Additionally, incorporating internal heat exchangers and flash tank vapor injection can lead to reductions in emissions ranging from 1% to 8% (3). Nano particles like Al_2O_3, TiO_2, and ZnO added in lubricant for refrigeration systems with 290/600 refrigerant showed a reduction in work input ranging from 39.8%, a shorter pull-down time, a lower evaporator temperature, an increased coefficient of performance (COP), and a higher cooling capacity of 9.1% (4, 5). The study concluded that R290/R600a (50/50%) zeotropic blend can be a good option as a replacement of R134a. For consider composition or weight (135gm) blended mixture (R290/R600a) was given good performance, less power consumption high cooling rate and less GWP compared to R134a (6, 7). Al_2O_3 nanofluids were prepared using the two-step method with base fluid mixtures of water and ethylene glycol in volume ratios of 60:40, 50:50, and 40:60. Experimental results indicate that the 60:40 base mixture exhibited the highest performance enhancement, achieving a 24.6% improvement at a 1.0% nanoparticle concentration and a temperature of 70 °C (8). in car radiator used alumina (Al_2O_3) in ethylene glycol (EG) as nanofluids to heat transfer enhancement with volume concentrations of 0.08%, 0.5% and 1% resulted the thermal performance enhancement up to 5% (9). Al_2O_3 nanofluids were prepared by dispersing 13 nm Al_2O_3 nanoparticles into water and ethylene glycol (EG) mixtures in volume ratios of 40:60, 50:50, and 60:40. Experimental measurements revealed that the thermal conductivity of these nanofluids increased with both nanoparticle concentration and temperature. The maximum enhancement occurred at a 2.0% volume concentration and a temperature of 70 °C for all base fluids. Additionally, the effective thermal conductivity improved with higher particle volume fractions and decreased particle sizes (10, 11). Studies have investigated the impact of copper oxide (CuO) nanoparticle concentrations on heat pipe performance. Increasing the CuO mass concentration enhances the heat pipe's effectiveness. For instance, a study found that adding CuO nanoparticles to a heat pipe improved its thermal performance by 15–20% at a concentration of 0.15 wt.% (12). The thermal conductivity increased by 3.2% and 9.6% for 0.5 vol.% SiO_2_EG and 1.0 vol.% SiO_2_EG, respectively, which is higher than the increase observed in DW-based nanofluids (1.0% and 3.4%) (13, 14). The study demonstrated peak performance with the addition of 0.14% alumina nanoparticles, leading to a 46.14% increase in the coefficient of performance (COP) and significant power savings of up to 31.59%. (15, 16) Meanwhile, the addition of CuO and TiO_2 resulted in an increase in COP and a reduction in compressor power consumption (17, 18). The experimental analysis included 0.1%, 0.5%, and 1% addition of 78 nm nanoparticles (Al_2O_3) the COP was improved by 50% with 1% of Al_2O_3 (19, 20).

In this work, we demonstrated the possibility of improving the performance of a compression system by adding a nano refrigerant (R600a/Al_2O_3) at a concentration 0.14%, and we practically observed an increase in COP of the system by 35%.

Numerical simulation

Refrigeration is the process of transfer heat from one location to another by means of refrigerant in a closed refrigeration cycle. The refrigeration is developed and applied to use in various purposes such as food saving, chemical industry and air conditioning for sustainable well-being. The air conditioning system is commonly used in a wide range for residence, building, office and hotel this system explain in Figure 1 that shown simple vapour compression cycle and p-h diagram (21–23).

The simulation was performed with a package in REFPROP and PROII software and the modeling of (compressor, condenser, expansion valve, heat exchanger, evaporator) It was formulated by EES program. The basic vapour compression cycle consists of the following components (as shown in Figure 2):

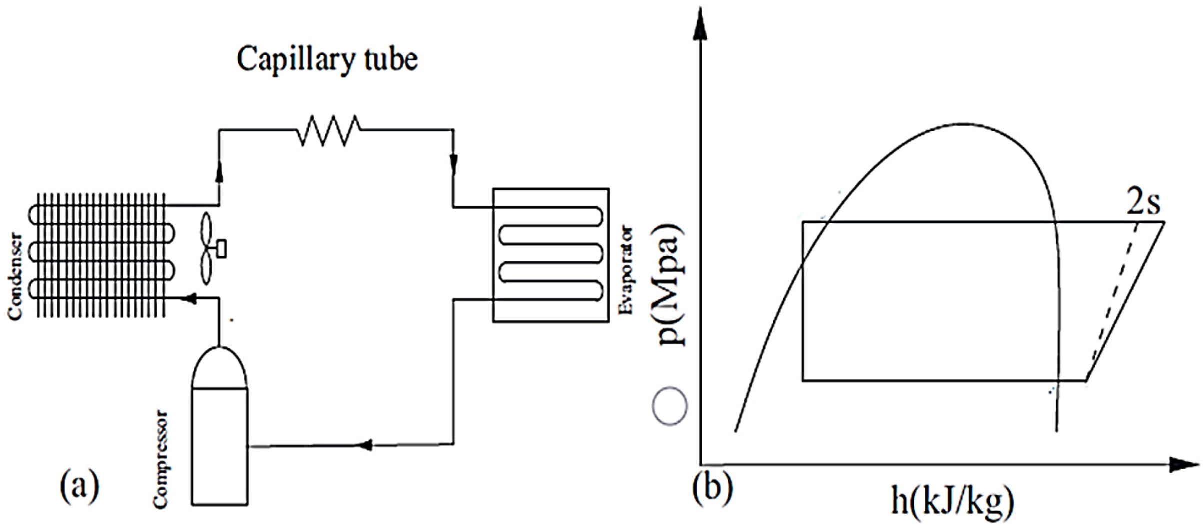

Figure 1. (a) schematic of vapour compression system, (b) p-h diagram of VCP (23)

- Compressor – process isentropic compression in compressor.
- Condenser – process constant pressure heat dissipation the temperature ranges from 0 to 48 °C.
- Phase separator.
- Heat exchanger – heat transfer process.
- Expansion valve – process isenthalpic throttling process in an expansion device.
- Evaporator – process constant pressure heat extraction the temperature ranges from 0 to -18°C.
- Accumulator.

Modeling of simple vapour compression system. Work input to the compressor, can be determined as follows:

$$W_{comp} = (h_2 - h_1) \tag{1}$$

The refrigeration effect qev can be determined by:

$$q_{ev} = (h_{10} - h_9) \tag{2}$$

The coefficient of performance (COP) of vapour compression system is unitless defined as the ratio of refrigeration effect to the work done by the compressor and can be calculated by:

$$COP = (q_{ev} / W_{comp}) \tag{3}$$

The condensation effect q_{cond} can determined by:

$$q_{cond} = (h3 - h4) \tag{4}$$

Theoretical models for thermal conductivity of nanofluids (10).

$$\emptyset = \frac{({}^{m_p}/_{\rho_p})}{\frac{m_p}{\rho_p} + V_{BF}} \times 100 \tag{5}$$

$$k_{nf} = 0.634(1+\emptyset)^{0.1045} (\frac{T}{70})^{0.1094}(1+BR)^{-1.1590} \tag{6}$$

The system was created theoretically by using PROII software as shown in Figure 2. It contains the parts of the vapor compression system, such as the compressor, condenser, evaporator, heat exchanger. The system was connected and gives the input and the output points for each part were determined. In this application, the entry and exit temperatures and pressures are also entered to obtain the results as COP, refrigerating effect and work of compressor.

EXPERIMENTAL WORK

System setup

A vapour compression refrigeration system in (one-ton) capacity it was manufactured in this work and used hydrocarbon refrigerants (R290/R600a) compared with Nano refrigerant (R600a/AL_2O_3) to obtain more performance in one compressor system as shown in Figure 2 and Figure 3. The experimental cycle setup is consisting of, compressor model Hermetic type compressor with integral 1/2 horsepower motor drawing

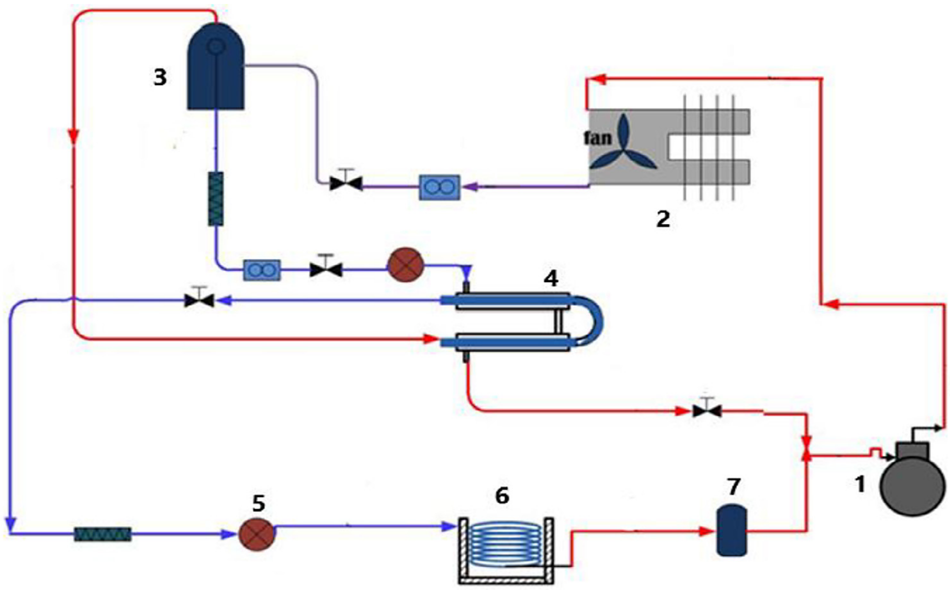

Figure 2. Schematic of vapour compression system in PROII program (10)

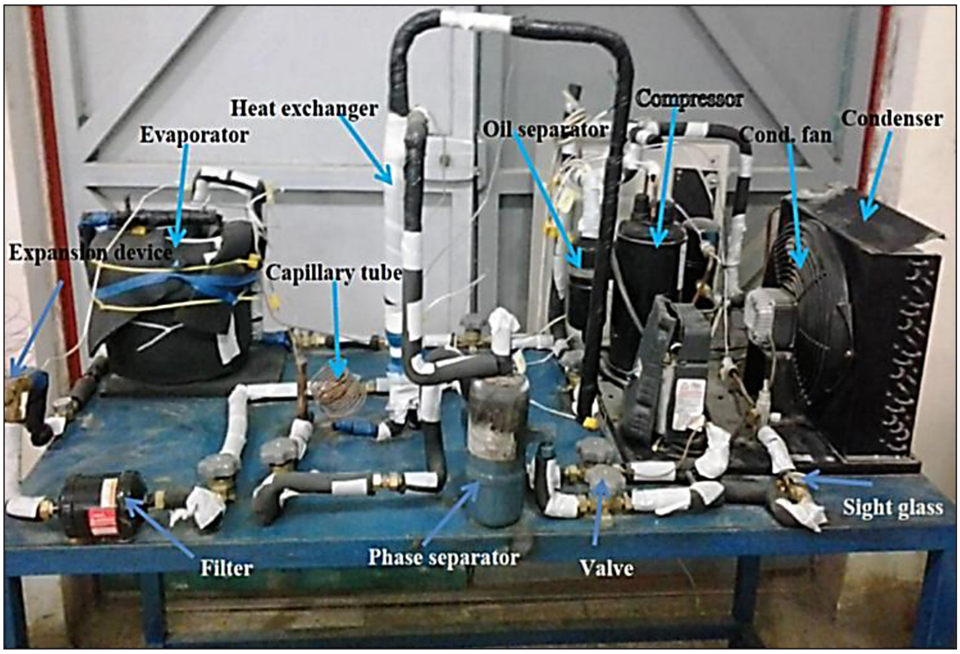

Figure 3. Experimental setup of vapour compression system

approximately 372 W (max). The compressor is a single cylinder reciprocating type with a displacement of 17.4 cubic centimeters, finned tube of 7 mm diameter arranged in double rows air cooled condenser, shell and coil evaporator consists of 13 turns of 6.4 mm diameter copper pipe inserted in 25 cm diameter and 20 cm height galvanized steel shell,tube with tube heat exchanger, phase separator, expansion devices thermostatic expansion valve, flow meters, oil separator, accumulators, pressure gauges type Bourdon gauge (suction line range from 76 mmHg vacuum to 18 bar and discharge line range from 0 bar to 34.29 bar) the error rate about (0.06), K-type thermocouple operating in the range of -200 to 1250 °C the error rate (2.2) with digital readers and other accessories.

Preparation of nano- refrigerant

The preparation of nano-coolants for refrigeration systems has attracted significant interest due to their enhanced thermal properties compared to traditional coolants. These coolants consist of nanometer-sized particles (typically ranging from 1 to 100 nm) suspended in a base fluid, in this work we prepare three volume concentration (0.1%, 0.12%, 0.14%) of Al_2O_3 this nanoparticle in size 20 nm added to 195ml of PAG oil. This nanoparticle has been selected to improve the thermal conductivity and heat transfer capabilities of the coolant and to achieve optimal performance (19). Regarding the base fluid, R600a (isobutane) was chosen as the refrigerant for this work. Al_2O_3 nanoparticles, with a size of approximately 30nm, were mixed with PAG. This concentration 0.14% was selected based on the experiment conducted on the refrigeration system, in which three different concentrations (0.1, 0.12 0.14)% were tested, and this one had the most significant impact on the system's performance coefficient. Aluminum oxide was chosen because it has many thermodynamic properties like enhanced thermal conductivity, improved energy efficiency, better performance at high temperatures, good chemical stability, stable dispersion in fluids. In order to create a homogenous mixture of nanoparticles and the base liquid, the mass of nanoparticles was added to 250 ml of PAG using a precision electronic balance, as shown in Figure 4a. The mixture was then placed on a magnetic stirrer, as shown in Figure 4b, and left for an hour. Finally, it was moved to an ultrasonic cleaner, as shown in Figure 4c (16), for three hours in order to agitate and disperse the nanoparticles into fine particles, ready to be charged into the system compressor.

This process helps overcome van der Waals forces between the nanoparticles, enhancing their dispersion and stability.

Refrigerant preparation

The system was first charged with pure refrigerant R134a, and the readings were recorded as a baseline for comparison with other refrigerants, such as a 60/40% mixture of R-290/R600a and R600a/Al_2O_3. This was done to evaluate the potential of replacing R134a with more efficient refrigerants that enhance system performance. The system was then evacuated Performance tests were conducted using a mixture of hydrocarbon refrigerants – propane (R290) and isobutane (R600a) – with 97.3% purity, at mass fractions of 60/40. The refrigerant charge was measured using a digital balance and a refrigerant charging device, based on the specific volume ratio of the hydrocarbon refrigerants, and compared with an 816 g charge of R134a used in the system. The readings of temperature, pressures (suction and discharge), refrigerant mass flow rate at different points in the system and power consumption in compressor are taken every 5 minutes until reaching steady state within about 90 min of system operation. The system has been emptied to charge it in nano refrigerant (R600a/AL_2O_3) nano additives at volume concentrations (0.14%). Aluminum oxide nanoparticles are incorporated into the polyalkylene glycol (PAG) oil prior to their introduction into the compressor of the refrigeration system, they are then charged into the system's compressor, after discharging the device before charging it to eliminate the effect of moisture. Then it is done precisely measure (± 2% tolerance) of compressor-grade lubricant using a calibrated graduated beaker to ensure volumetric accuracy.

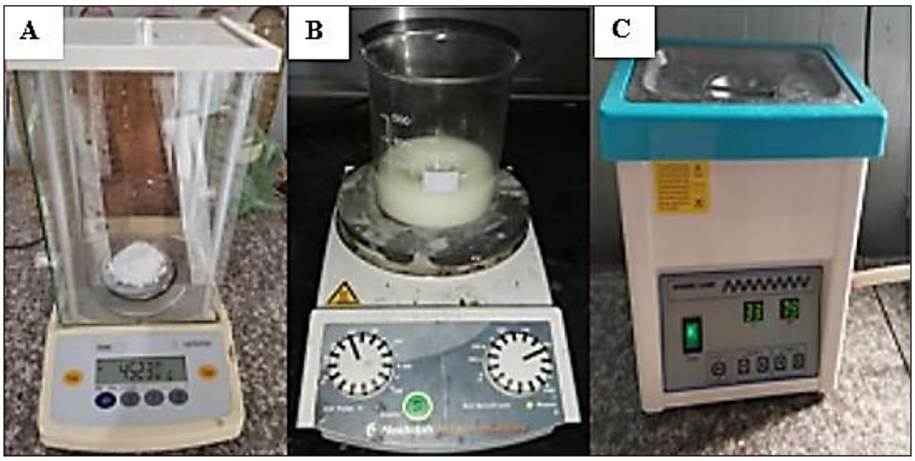

Figure 4. Equipment used in the preparation of nano-fluid: (A) electronic balance, (B) stirring hotplate, (C) ultrasonic device (16)

Securely connect a compatible rubber hose to the charging nozzle interface, ensuring leak-free connection via compression fittings. Submerge the distal end of the charging hose into the measured lubricant, maintaining a minimum immersion depth of 25 mm to prevent air ingestion during charging. Energize the compressor unit to establish pneumatic pressure differentials, facilitating controlled lubricant displacement through the charging circuit. and allowed to settle for 15–20 minutes. The system is then charged with the required refrigerant (24, 25).The arrangement and solidity of this grease and the nanoparticle mixture are very important. Oil, a type commonly used in refrigeration and air conditioning systems, is usually (polyol ester) as the base fluid of the PAG nano lubricant. After the PAG lubricant oil used as compressor oil was drained from the compressor, the compressor was cleaned with nitrogen gas. Then, the previously prepared nanofluid was added. The reading recorded every 5 minutes until reach to 90 min steady state.

RESULTS AND DISCUSSION

For this system that charging in two types of refrigerants calculated the performance parameter (COP (unitless), refrigerating effect (kJ/kg), work of compressor (kJ/kg)) experimentally and theoretically the results presented by Excel program. The experimental results were obtained from recording the temperature and pressure in the system for a period of 80 min, and the theoretical outputs was obtained from the system design in the PROII software. Firstly, the system charging in pure refrigerant R134a without heat exchanger and with heat exchanger as shown in Figure 5, the COP of the system recorded. To calculate the COP, we took the inlet and outlet temperatures for condenser in high stage, inlet and outlet for evaporator in low stage the temperature recorded in every 5 min for the period 80 min by using digital thermocouples in ambient temperature 48 °C. Figure 6–8 explain the effect of charging by zeotropic mixture of hydrocarbon refrigerants R-290 and R600a in ratio of (60/40)% on COP, refrigerating effect and wok of compressor, the experimental result of COP increased in 28% due to the temperature of evaporator decrease with ambient temperature is 45 °C, the refrigerating effect increased about 25% and decreased in compressor work about 7% comparing with pure refrigerant R134a in the system with using heat exchanger, due to the increase in R-290 mass relative to R-600a in the mixture, the boiling point of R-290 is much less than that for R-600a, at a given pressure makes the thermodynamic and physical properties of R-290 to be dominated in the mixture.

The theoretical results of COP that obtained from software observed it's almost similar to experimental results. When addition the Al_2O_3 nanoparticles to the R-600a refrigerant the refrigeration system refrigerating effect and COP increased, while the discharge temperatures of the compressor have been reduced in volume concentration 0.14% the COP increased about 35% and refrigerating effect 29%, the work of compressor decreased about 9% as shown in Figures 9–11.

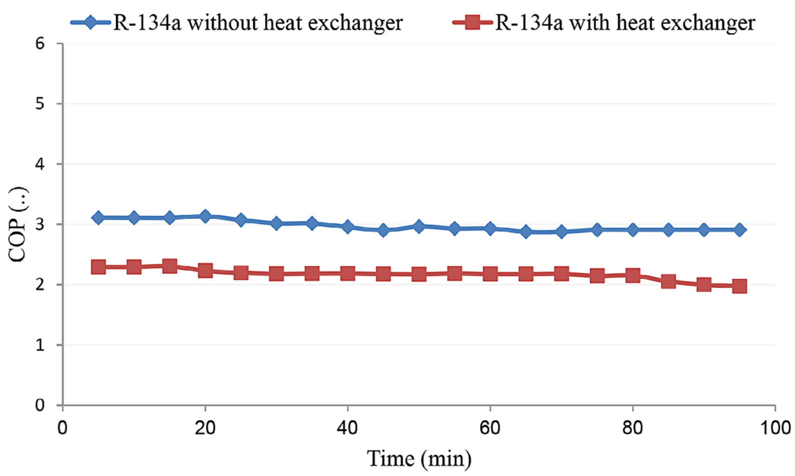

Figure 5. COP of the system in base operation with R134a

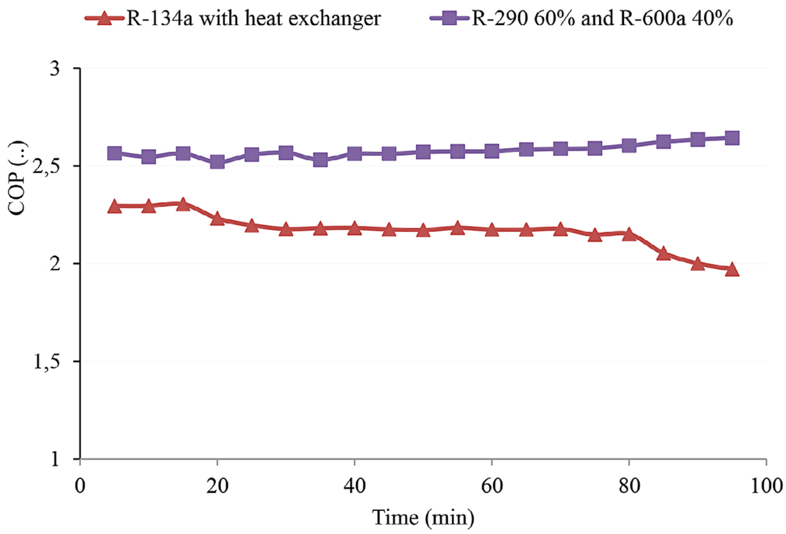

Figure 6. R134a with heat exchanger COP compare with (60%/40%) R290/R600a

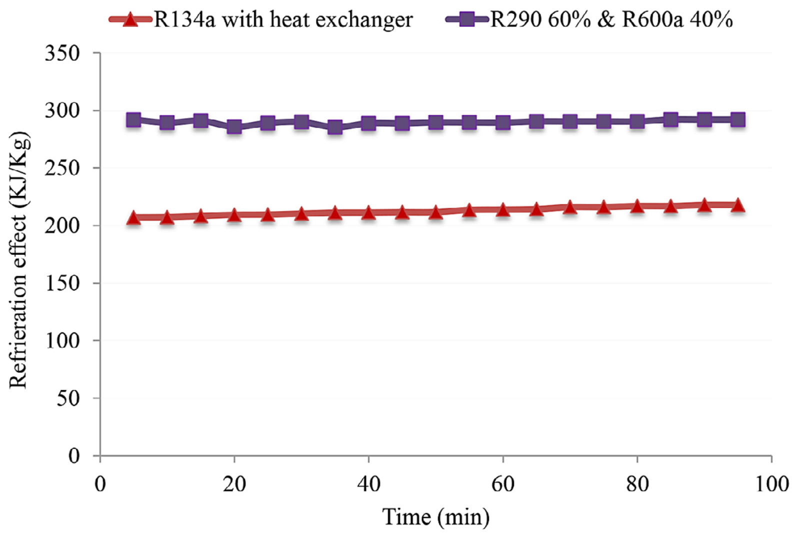

Figure 7. R134a refrigerating effect compare with (60 %/40%) R290/R600a

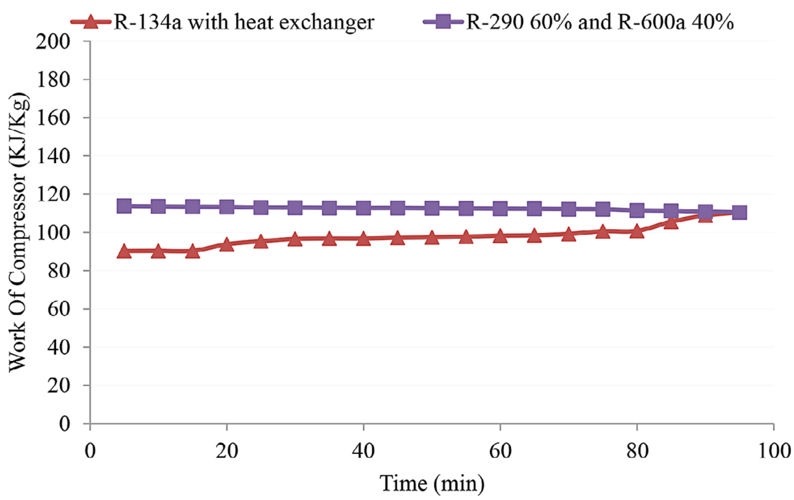

Figure 8. R134a work of compressor compare with (60%/40%) R290/R600a

Table 1. Thermophysical properties of different component that used as refrigerant

Material	Thermal conductivity (W/m K)	Specific heat (J/kg K)	Density (kg/m^3)	ODP	GWP
Al_2O_3 (27)	25	880	3960	0	0
R-600a (28)	0.014	2.38	551	0	0.1
R290 (29)	0.0676	0.852	20.6	0	3

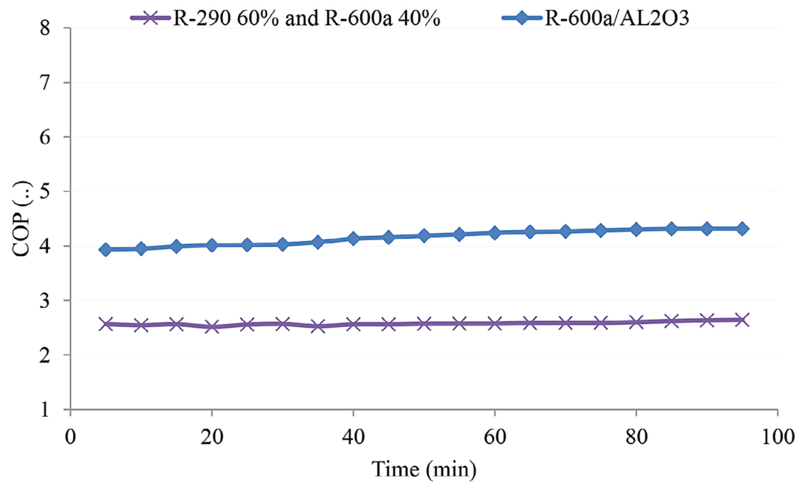

Figure 9. Comparison COP between (60%/40%) R290/R600a & R600a/AL_2O_3

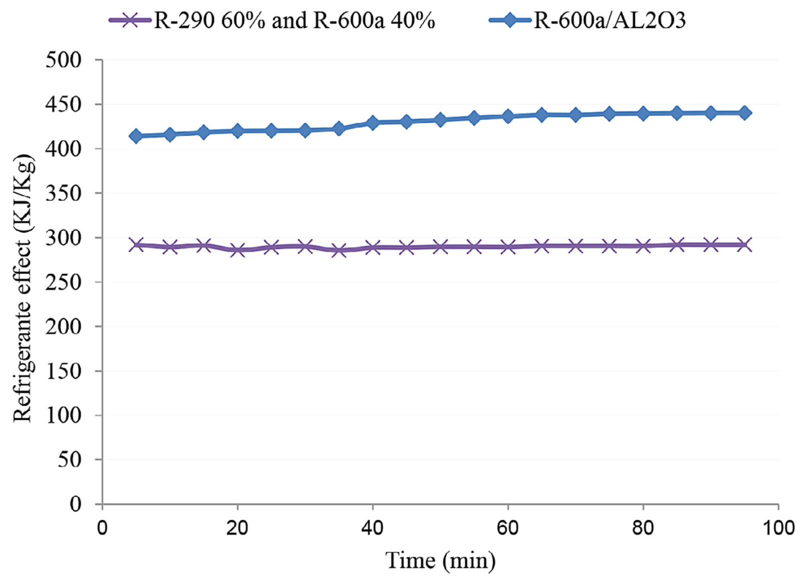

Figure 10. Comparison refrigerating effect between (60%/40%) R290/R600a & R600a/Al_2O_3

This improvement in performance is due to the thermal properties of Al_2O_3 as shown in Table 1.

It's observed that, as shown in Figure 12 the inlet evaporator temperature was decreasing with time and approached a relatively lower value -12 °C for mass ratio (60/40) after 60 min of system operation. And in (R-600a/ Al_2O_3) the inlet evaporator temperature was decreasing to (-18 °C) after 60 min from operation. Figure 13 shown the temperature out of compressor to the mixed refrigerant R-290/R-600a in ratio 60%/40% in time 20 min increased until reached to 85 °C and when using (R-600a /Al_2O_3) the temperature decreased in 90 min from operation reach to 60 °C. The experimental results are compared with numerical results that determined using (Pro II) and (EES) software as a simulation environment for vapour compression system operation. Figure 14 shown

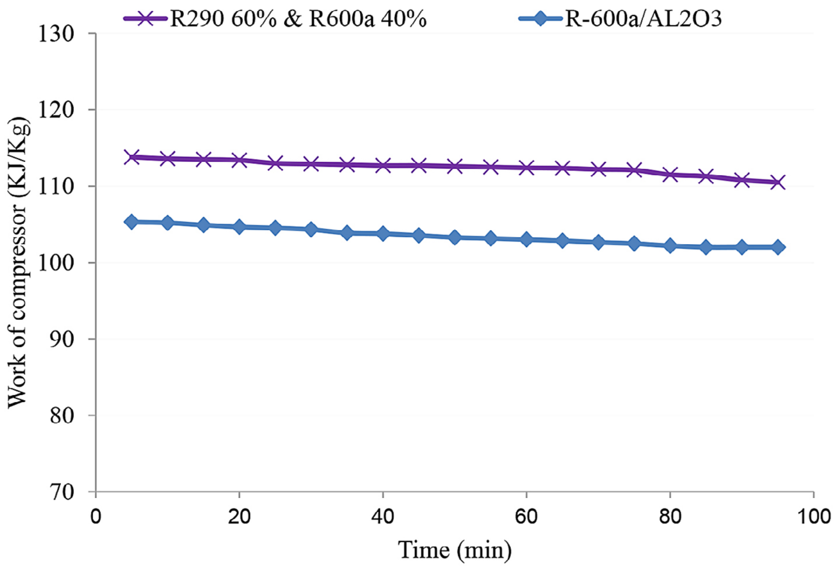

Figure 11. Comparison work of compressor between (60%/40%) R290/R600a & R600a/Al_2O_3

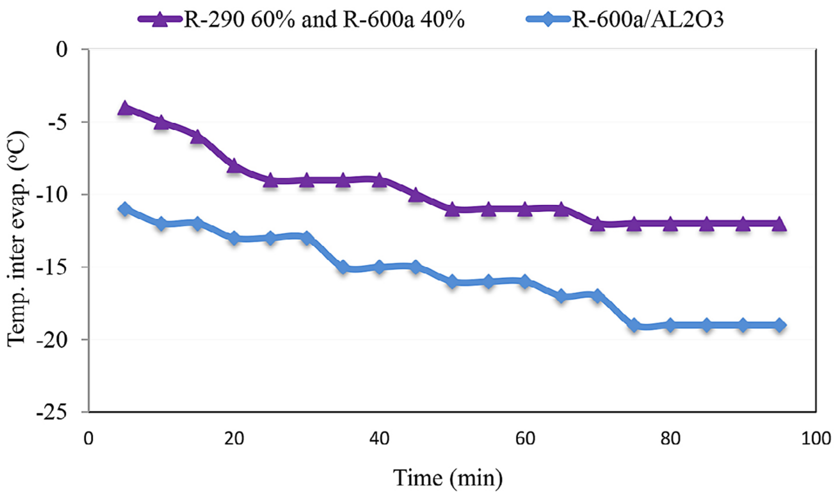

Figure 12. Comparison temp. inter evap. between (60 %/40 %) R290/R600a & R600a/Al_2O_3

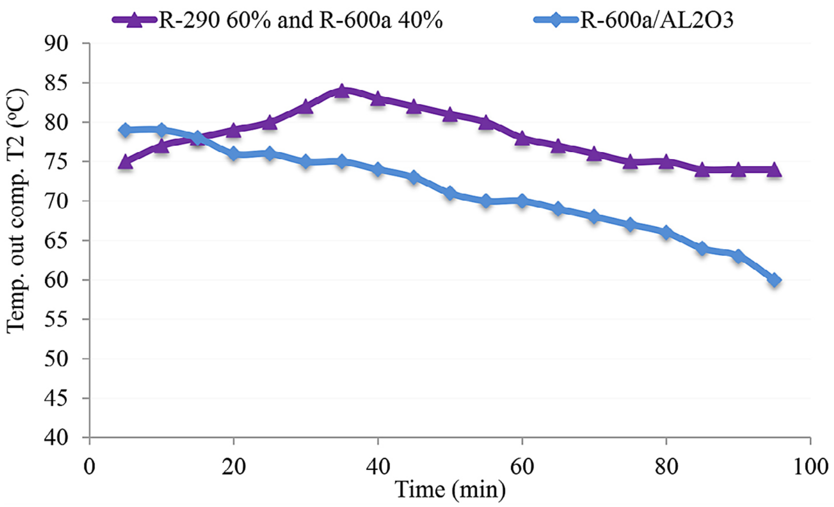

Figure 13. Comparison temp. out comp. between (60 %/40 %) R290/R600a & R600a/Al_2O_3

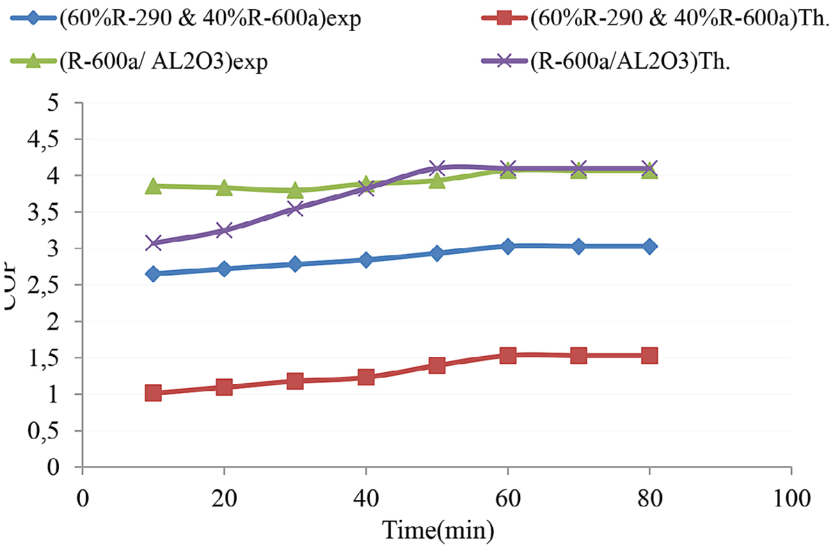

Figure 14. difference between experimental & theoretical result of COP for (60 /40) % R290/R600a & R600a/Al_2O_3

the difference between the experimental and theoretical results in COP for zeotropic mixture of hydrocarbon refrigerants R290 /R600a in ratio (60/40)% about 15% and for (R600a/Al_2O_3) the difference between theoretical and experimental results about 8% due to some measurement errors for experimental work.

In Figure 15 noted that The difference between experimental and theoretical work of compressor in mixed refrigerant R290/R600a (60/40)% about 8% and for AL_2O_3/R600a about 3%. The refrigerating effect shown in Figure 16 that explain the result of experimental and theoretical difference in nano refrigerant about 5% and in mixed refrigerant 12%.

In Figure 17 displays the difference in experimental work of compressor at ambient temperature 48 °C in summer season noted the work of compressor decreased about 103.8 kJ/kg when using AL_2O_3 particles, while the work of compressor highest value in R134a without heat exchanger reached to 150 kJ/kg and when using R134a with heat exchanger reached to 120 kJ/kg), in zeotropic mixture of hydrocarbon refrigerants R-290 and R600a in ratio of (60/40)% reached to 110.8 kJ/kg).

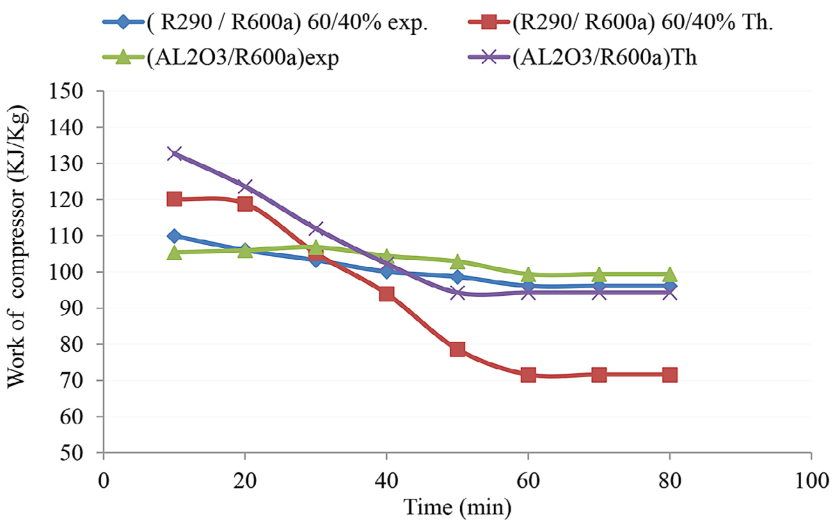

Figure 15. Difference between experimental & theoretical result of work of compressor for (60 /40)% R290/R600a & R600a/Al_2O_3

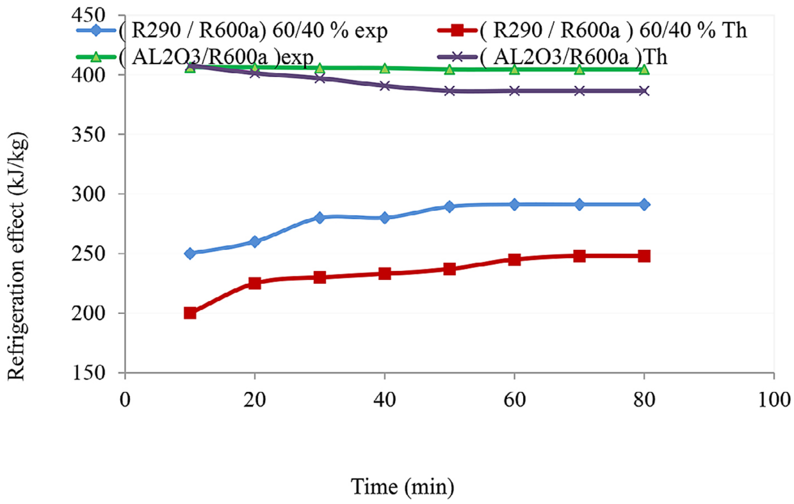

Figure 16. Difference between experimental & theoretical result of refrigerating effect for (60 /40)% R290/R600a & R600a/Al_2O_3

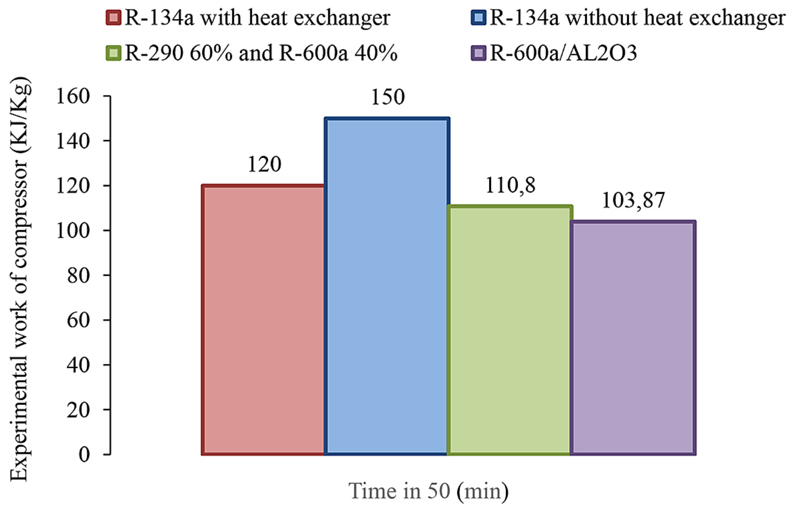

Figure 17. Experimental work of compressor in ambient temperature 48 °C for all refrigerants

CONCLUSIONS

In this system, the conclusion has been made the performance improves when adding the nano particle Al_2O_3 to the refrigerant R-600a due to the thermophysical properties of the nanoparticles compare using mixed refrigerant in ratio (60%/40%) R290/R600a.

1. In vapour compression system the COP increased in mixed refrigerant R290/R600a (60%/40%) about 28% and when using nanoparticles Al_2O_3 the COP increased in 35%.
2. The refrigerating effect in mixed refrigerant ratio (60%/40%) R290/R600a is 25% comparison with (R600a/Al_2O_3) in consecration 0.14% about 29% due to decreased in temperature inlet to evaporator.
3. Enhancement in COP when charging in (R600a/A_2O_3) in consecration 0.14% about 14% compare with R134a.
4. The percentage work of compressor decreased in (R600a /Al_2O_3) consecration 0.14% about 9% compare with mixed refrigerant (R290/R600A) ratio 60%/40% that about 7%.
5. The evaporator inlet temperature reduced to -20 °C in (R600a/Al_2O_3) consecration 0.14%, in (R290/R600a) ratio 60%/40% reduced to -15 °C.
6. The difference between experimental and theoretical results in vapour compression system was observed for nano refrigerant and mixed refrigerant (R290/R600a) (60/40)% in COP about 8% for nano refrigerant and 15% for mixed refrigerant. The refrigeration effect

difference between experimental and theoretical results about 6% for nano refrigerant and 12% for mixed refrigerant.

These additions to the vapour compression system have led to increased efficiency and improved performance. In the future, various enhancements may be introduced to this system. Potential extensions of the research include designing a multi-stage vapour compression system with two compressors, using nano-refrigerants, and selecting nanoparticles that can further increase system efficiency – areas that warrant further investigation. The findings of this study could influence future refrigerant system designs, making refrigeration systems more efficient and capable of achieving the low evaporator temperatures required for advanced refrigeration applications.

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