Mechanism for Improvement in Heat Pump Performance by using Nano-Refrigerants: A Review

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Abstract - The effect of Al_2O_3 nano-particles on the performance of heat pump to improve its operational efficiency was presented in this paper. In the proposed method the heat pump charged with R600a inclusive with 0.06 % vol. of Al_2O_3 and used as a nano-refrigerant. Three different nano-particles size 20 nm, 40 nm and 50 nm of Al_2O_3 have been used for the preparation of nano-lubricant in the proposed mechanism. The mechanism for improvement includes simulations modeling the heat pump components such as compressor, evaporator, condenser and an expansion valve by computer of the heat pump system by using commercial MATLAB. The results showed that the addition of nano-particles to the refrigerant will improve its characteristics of refrigeration system heat transfer and thermal properties. Also, it showed that the using nano-refrigerant in refrigeration system will work normally at all conditions. The mechanism for improvement results found that the heat pump coefficient of performance increased by 19.1%, the power consumption reduced by 21.8 % when using a mineral oil with 20 nm nano-particles size of Al_2O_3 instead of the conventional mineral oil. Finally, the refrigeration effect increased and work of compressor decreased by using a small nano-particles size of Al_2O_3.

Key words: Nano-Refrigerant, Heat pump, Coefficient of Performance, R600a, Non-Toxic, Global Warming Potential

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1. INTRODUCTION

Presently, the heat pumps used in various applications such as cooling and heating of air conditioning, hot water production, centers of computers, restaurants, public buildings, hotels, and so on. The vapour compression refrigeration systems were conducted some investigators to examine the effect of nano-particle was added in refrigerant/lubricant. Most of the investigators' results obtained a remarkable improvement in thermo-physical of the refrigerant. When the working fluid in refrigeration cycle passes through the compressor, it will mix with lubricant whose contains Nano-sized particles dissolved with it and the working fluid after leaving the compressor is called Nano-refrigerant. Using the Nano-refrigerant in the refrigeration cycle has given few advantages such as improvement of the heat transfer coefficient, reducing the power consumption in the compressor, and enhancement of the refrigeration effect in the evaporator. Many works have been conducted in the past several decades. The experimental investigation for the effect of using working fluid represented by TiO_2-R600a nano-refrigeranton on the performance of a domestic refrigerator found that the refrigerator system operated efficiently and normally and the saving of energy was about 9.6% while the review for the effect of using Nano-Refrigerant of Al_2O_3-R134a in refrigeration system showed that the addition of Al_2O_3 nano-particles leads to COP enhancement of the system by about 10.32% less energy with the concentration used [3]. The result of review is the effect of using CuO nano-particles in R134a refrigerant in the system showed that the coefficient of evaporating heat transfer increases with the increase of CuO nano-particles concentration ranged from 0.1% to 0.55 % and nano-particles size ranged from 15 to 25 NM. In domestic refrigerator, the results of enhancement of heat transfer by using the working fluid of R600a R600a/mineral with mineral oil and Al_2O_3 nano-particles, the results showed a reduction in the power consumption and the freezing capacity was higher by 11.5 % when using a mixture of nano-refrigerant instead of Polyester (POE) oil. The pure R134a and R134a with Al_2O_3 nano-particles with 20 nm size with three mass of mass fraction of 0.04%, 0.06% and 0.08% wt. used in vapour compression refrigeration system. The results showed that the refrigeration system with nano-refrigerant works safely and normally, also, the power consumption reduces by 14.71% and freezing capacity is higher while the COP increases by 28.93% at 0.06%. To reduce energy consumption in buildings, the modeling of air conditioning of direct expansion and heat pump systems can be used in developing energy saving methods. The mechanism for improvement in heat pump, types of direct expansion and validation of an artificial neural network modeling technique to predict the performance of air conditioning. In this paper, the mechanism for improvement in heat pump performances by using (R600a) refrigerant with Al_2O_3 nanoparticle was considered for enhancement. Fig 1 shows the model of heat pump test rig mechanism [7].

Fig 1 Heat Pump Test Rig Mechanism

2. LITERATURE REVIEW

Shengshan Bi [2010]: An experimental work was investigated on the nano-refrigerant. TiO_2-R600a nano-refrigerants were used in a domestic refrigerator without any system reconstruction. The refrigerator performance was then investigated using energy consumption test and freeze capacity test. The results indicate that TiO_2-R600a nano-refrigerants work normally and safely in the refrigerator. The refrigerator performance was better than the pure R600a system, with 9.6% less energy used with 0.5 g/L TiO_2-R600a nano-refrigerant. Thus, using TiO_2-R600a nano-refrigerant in domestic refrigerators is feasible [1].

D. Sendil Kumar [2012]: An experimental work was investigated on nano-refrigerant .Nano Al_2O_3-PAG oil was used as nano-refrigerant in R134a vapour compression refrigeration system . An experimental setup was designed and fabricated in the lab. The system performance was investigated using energy consumption test and freeze capacity test. The results indicate that Al_2O_3 nano-refrigerant works normally and safely in the refrigeration system. The refrigeration system performance was better than pure lubricant with R134a working fluid with 10.32% less energy used with 0.2%V of the concentration used. The results indicate that heat transfer coefficient increases with the usage of nano Al_2O_3. Thus using Al_2O_3 nano-refrigerant in refrigeration system is found to be feasible [2].

R. Reji Kumar [2013]: The performance of the refrigeration system depends upon the heat transfer capacity of the refrigerant. Normally R12, R22, R600, R600a and 134a are used as a refrigerant. This refrigerant heat transfer capacity is not so good and increase power consumption. Due to these limitation nano-fluids are enhanced with the normal lubricant and increases the heat transfer capacity and reduces the power consumption. Aluminium oxide nano-fluid is used for enhancing the heat transfer capacity of the refrigerant in the refrigeration System. In this experiment heat transfer enhancement was investigated numerically on the surface of a refrigerator by using Al_2O_3 nano-refrigerants, where nano-fluids could be a significant factor in maintaining the surface temperature within a required range. The addition of nano-particles 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. Stable nano-lubricant has been prepared for the study. 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 11.5 % when POE oil is replaced by a mixture of mineral oil and Aluminium oxide nano-particles. Thus using Aluminium oxide nanolubricant in refrigeration system is feasible [8].

Hailong Li [2015]: The nano-particles, including metals, oxides, carbides, or carbon nano-tubes, can increase the conduction and convection coefficients and consequently, enhance the heat transfer. Using nano-fluids as working fluids in the refrigeration, air conditioning and heat pump systems has attracted much attention. This work set-up a test rig to experimentally study the system performance of a heat pump with nano-fluid as refrigerant, which was prepared by mixing 5wt% TiO_2 with R22. Results show that adding the nano-particle TiO_2 didn't changed the heat absorbed in the evaporator clearly but increase the heat released in the condenser. As a results, compared to using pure R22, when using R22 + TiO2, the COP of the cooling cycle was decreased slightly, however, the COP of the heating cycle was increased significantly increased power consumption of compression [4].

Vaishali P [2017]: To improve the characteristics of the traditional refrigerants, nano-fluid is a new invention to enable vapor compression systems to take advantage of nano-particles. Recent studies shows that use of nano-particles in refrigeration systems leads to remarkable improvement in thermo-physical properties and heat transfer capabilities, thus enhances the efficiency and reliability of refrigeration and air conditioning system. Refrigerant based nano-fluids are termed as nano-refrigerants. They have the potential to enhance the heat transfer performances of refrigeration and air-conditioning systems. The present work deals with the investigation on a vapour compression refrigeration system with pure R134a and R134a with different nano-particles concentration added to it. Stable nano-lubricant has been prepared with VG68 polyolester oil for the study. Three different mass concentrations are 0.04%, 0.06% and 0.08% of Al_2O_3 nano-particles with 20 nm size has been used. The system performance was investigated using energy consumption test and freeze capacity test. The results indicate that refrigeration system with nano-refrigerant works normally and safely. It is found that the freezing capacity is higher and power consumption reduces by 14.71% and the coefficient of performance increases by 28.93%, when Al_2O_3 nano-lubricant is used with 0.06% mass fraction giving optimum results [10].

Jose M Corberan [2018]: The dual source heat pump (DSHP) is manufactured as an outdoor 'plug & play' unit, working with R32 refrigerant and including a variable speed compressor, which gives full capabilities for an efficient modulating operation. The DSHP was fully characterized in steady state conditions at the IUIIE laboratory. In order to assess its dynamic performance and to identify key control strategies to optimize its annual operation, a complete integrated model of the DSHP system in TRNSYS including the DSHP and all the other system components was developed. A first energy assessment, carried out for an office building located in the Netherlands, proves that the DSHP system would be able to reach a similar efficiency than a pure ground source heat pump (GSHP) system with half the ground source heat exchanger area needed. Therefore, the DSHP system could become a cost-effective alternative solution for heating, cooling and DHW production in buildings, as the initial investment would be significantly reduced compared to GSHPs, with similar or even higher energy efficiency [5].

3. EXPERIMENTAL SETUP

The main component in the test rig which consists of the compressor (Hermetic compressor), water cooled condenser made of copper, reversing valve, and an expansion valve (capillary tube), the cylindrical spiral coil evaporator was made of copper was completely immersed in water; the schematic diagram is shown in Fig 2. The pressure at discharge and suction of compressor, outlet of condenser and at outlet of evaporator was measured by pressure gauges. The different point's temperatures of the experimental setup were measured using T-type thermocouples. For accurate measurements, six thermocouples were used to measure the temperature. The calibration of the thermocouples was done using a mercury thermometer. The power consumed by the system was measured using a digital Wattmeter. The setup of experimental was placed on a flat stage. The room temperature varied with temperature of ambient by ±1- 3°C and the air flow speed was less than 0.3 m/s. Before charging the test rig with the refrigerant, the system was checked properly for leaks by charging the system with N_2 gas at a pressure of 250 Psi, the system was evacuated by a vacuum pump to -30 Psi. The system was charged with the refrigerant (R600a) but the compressor was filled with nano-lubricant. Four cases have been considered for this experimental study as illustrated in Table 1 knowing that the concentration of Al_2O_3 in the Nano-Refrigerant in each case of (2, 3and 4) were equal to 0.06%.

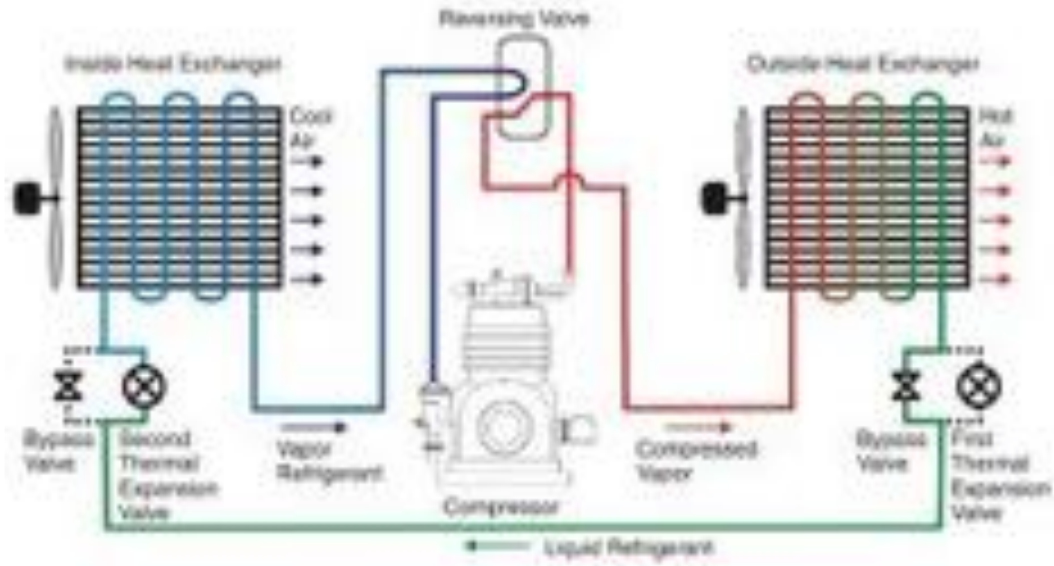

Fig 2 Schematic Diagram of Heat Pump Test Rig

Table 1 Symbol/Cases Notification

Symbol	Cases
S1	**SUNISO 3GS (mineral oil) filled hermetic compressor**
S2	**Mineral oil + 20nm nano-particles size of Al2O3**
S3	**Mineral oil + 40nm nano-particles size of Al2O3**
S4	**Mineral oil + 50nm nano-particles size of Al2O**

3.1 Data Analysis of Nano-Lubricant

The particles of Al_2O3 are commercially available spherical in shape. Three different nano-particles size 20nm, 40nm and 50nm of Al_2O3 have been used for the preparation of Nano-lubricant in the mechanism. The nano-refrigerant with 0.06% concentration of Al_2O3 and the refrigerant (R600a) were tested in the setup. The nano-particles of Al_2O3 and compressor oil mixture were prepared with aid of an ultrasonic vibrator [100 kHz, 300 W]. The mixture was remaining vibrated with an ultrasonic homogenizer for a period of not less than one hour to prevent any coagulation or deposition of particles in the mixture to obtain proper mixture homogenously. The experimental notice showed that the stable dispersion of alumina nano-particles can be kept for more than 3 days without any deposition as shown in Fig 3.

Fig 3 Variant of Nano-Lubricant Oil

For the rate of heat transfer calculation from the condenser and the evaporator, the values of enthalpies at various points were plotted on the P-h diagram for refrigerant (R600a) as shown in Fig 4, which depends upon combination of the temperature and pressure, has been used to determine enthalpy values with Cool Pack software. The important factors which affect the performance of heat pump cycle are the Coefficient of Performance (COP), Heat–Rejection Ratio (H.R.R), and Energy consumption by the compressor [9].

A. Coefficient of Performance(COP)

The coefficient of performance (also known as COP) specifies the ratio between the energy transfer of a heating pump and the total input of electrical energy. COP is a dimensionless number that expresses the efficiency of a heating system -- a pump with a higher COP transfers more heat with an equivalent energy input.

$$COP = \frac{Heat\ Removal}{Work},\ COP_{exp} = \frac{h_1 - h_4}{h_2 - h_1} \qquad 1$$

B. Heat–Rejection Ratio (H.R.R)

The heat-rejection ratio (HRR) is defined as the ratio of the rate of heat rejected at the condenser to that absorbed at the evaporator.

$$HRR = \frac{Rate\ of\ heat\ rejection\ at\ the\ condesor}{rate\ of\ heat\ absorption\ at\ the\ evaporator},\ HRR_{exp} = \frac{h_2 - h_3}{h_1 - h_4} \qquad 2$$

4. MODEL OF HEAT PUMP

In this proposed mechanism, it includes simulations modeling by computer of the heat pump system by using software MATLAB. The modeling includes the conventional heat pump as shown in Fig.4 components such as compressor, evaporator, condenser and an expansion valve.

i. Performance of Heat Pump

It is conceivable to say that the heat pump must keep a heat output (Q_{HP}) at least equal to the required thermal demand, which is dependent on the calculated radiator water inlet/outlet temperature difference and mass flow rate, as follows:

$$Q_{HP} = m_{water} cp_{water} (T_{in} - T_{out}) \qquad 3$$

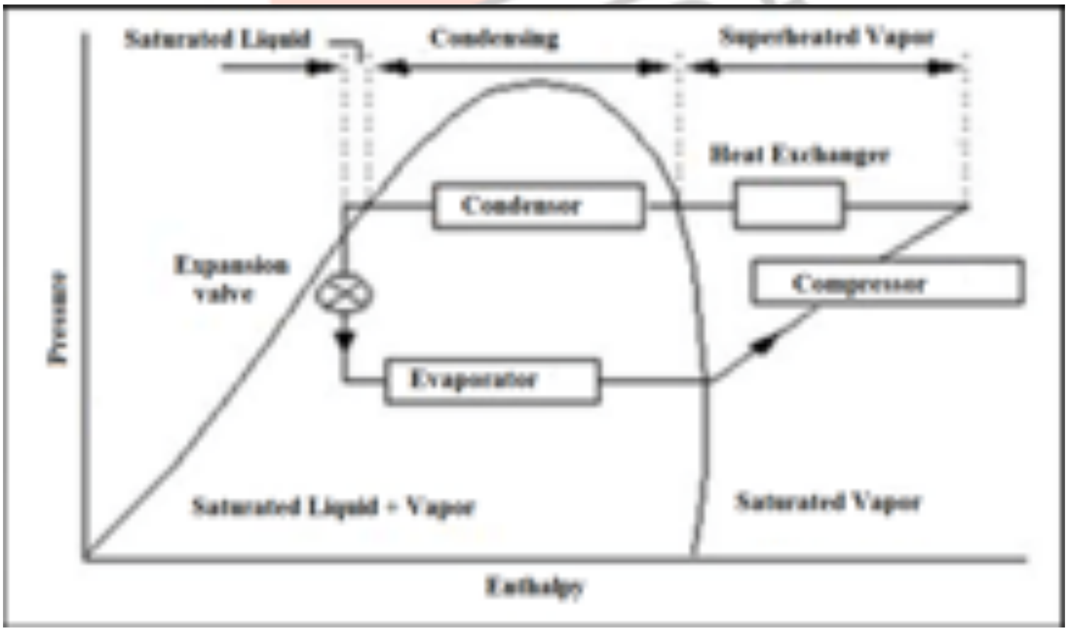

Fig 4 p - h diagram of heat pump cycle

For steady-state calculations, and considering a single-inlet, single-outlet condenser, the heat output (Q_{HP})). In this case, 600 is the mass flow rate of the working fluid; H3 and H4 are respectively, the fluid´s initial and final enthalpy [J/Kg], during the condenser phase.

ii. Performance of Compressor

In this procedure the following assumption made such as neglect the valves dynamic, there is no gas leakage. The pressures of the evaporator and condenser of the suction and discharge in addition of suction density along orifice coefficients and valves flow areas have to be known.

iii. Performance of Condenser

The performance of the condenser is largely a factor of how efficiently heat can be transferred from the steam to the cooling water. The faster that heat can be transferred, the faster the turbine exhaust steam can be condensed into liquid water. But the heat transfer in a heat exchanger can be very difficult.

iv. Performance of Evaporator

In this proposed mechanism, the evaporator of type shell and tube flooded has been employed. The modeling of evaporator is rather simple. By applying the mass conservation and energy balance to the side of refrigerant.

v. Performance of the Expansion Valve

Now, it can be supposed that the inertia effects neglected due to the valve acts as a static element with. Thus, the mass flow rate passing through the expansion device performed.

Finally, the data of R600a obtained and inputted to MATLAB as functions, by using polynomial or linear regression techniques with the compressor work and COP, all other relevant results can be obtained, as for instance the amount of energy removed/injected as (elect) or the electricity consumption given by

$$Q_{elect} = Q_{HP} - W_{comp} \quad 4$$

5. Results and Discussion

i. *Coefficient of Performance (COP):*

The values for COP that were calculated from equation 1 for cases mentioned in Table 1, which shows that the values of COP were improved when by addition of Al_2O_3 to mineral oil. The actual COP was determined using the values of the power input and the cooling load. For comparison, the theoretical values are plotted in the figure. The theoretical COP is greater than the actual COP for all cases. Also Fig 5 shows that the values of COP increases when the system was charging by the compositions of S2, S3 and S4 about 19.1%, 11.6% and 7.3% respectively in comparison with of S1. This result may be explained that when adding small of nano-particles size of Al_2O_3 to the mineral oil it will reduces the power consumption by the compressor and a sub-cooling of the nano-refrigerant in the condenser will be noticed which in turn leads to increasing of the COP. The results showed that the refrigeration system COP increased by 19.6 % when used nano-refrigerant of R600a with Al_2O_3 nano-particles instead of the conventional POE oil.

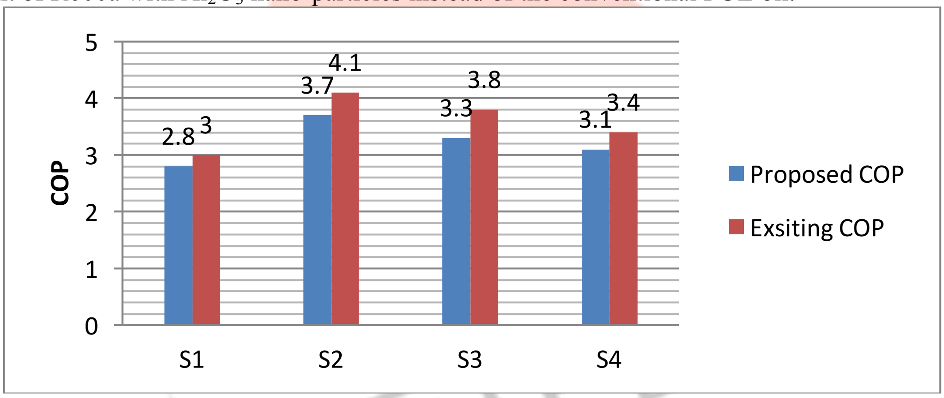

Fig 5 Comparison of COP between the actual and theoretical values

ii. Performance of Nano-particles Size on Energy Consumption by the Compressor

Fig 6 presented a comparison of the power consumption of the compressor between four cases under study, which shows a considerable reduction in power consumption when minimizes the size of the nano-lubricants. The power consumption reduction was about 21.8% when using S2 but the reduction was about 12.72% and 7.27% was observed when using S3 and S4 respectively instead of S1. Reji Kumar [4] concluded that when the nano-lubricant is used instead of conventional POE oil, the compressor power consumption reduces about 11.5% which is in a good agreement with the obtained results.

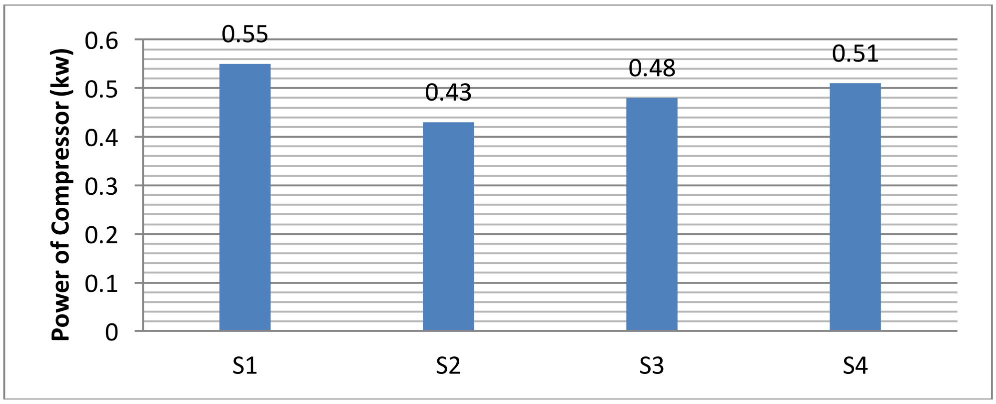

Fig 6 Comparison of compressor power consumption between the four cases

iii. Performance of Nano-particles Size on Heat–Rejection Ratio (H.R.R)

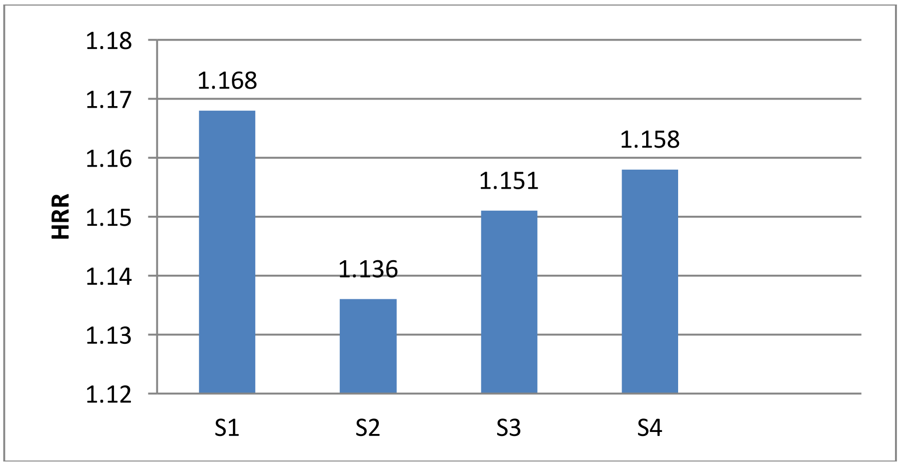

Fig 7 Comparison of HRR between the four cases

The heat rejection-ratio (H.R.R) is a term often used to relate the rate of heat flow at the condenser to that of the evaporator. Fig 7 shows that (H.R.R) decreases when used Nano-Refrigerant in the cycle. Moreover, the figure shows that using the mixtures of S2, S3 and S4 the value (H.R.R) decrease about 2.73%, 1.45% and 0.85 % respectively in comparison with of S1. Decreasing the values of (H.R.R) means that the cooling effect will increase and the work of compressor will decrease.

iv. Refrigerating Performance

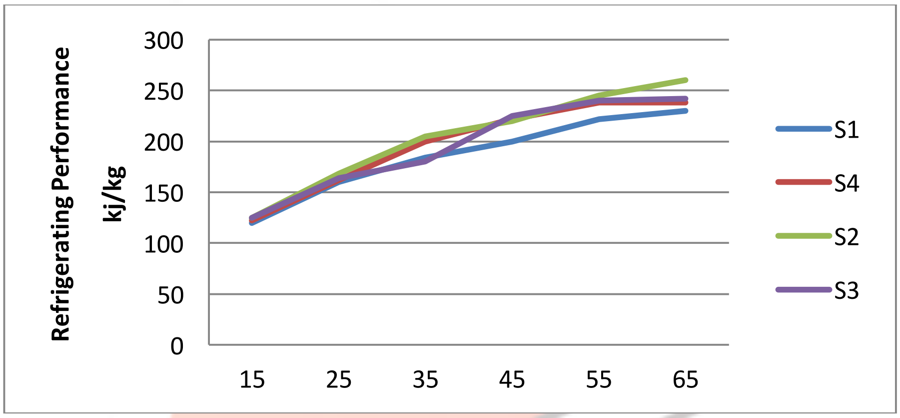

Fig 8 Performance of nano-particles size on refrigerating effect

Fig 8 shows the variations of refrigerating effect with the time. It was observed that the S2 mixture has a higher refrigerating effect than the other cases when using nano-particles in the refrigerant. Also, it is clearly shown from the figure that the refrigerating effect increases with a decrease nano-particles size of Al_2O_3 that is due to occurrence of sub-cool in the condenser. As the heat transfer rate has been enhanced and the mass flow rate of nano-refrigerant has been increased, the work of compressor decreases and the power consumption reduces which in turn enhances the heat pump performance.

v. Performance of Nano-particles Size on Work of Compressor

The variation of compressor work with compressor discharge temperature is shown in Fig 9. The figure shows that the work of compression decreases as compressor discharge temperature increases. Also, it is shown from the figure that the mixture of S2 has a lower work of compressor than the other cases. This is due to the fact that when the temperature of compressor discharge increases, the suction temperature of compressor also increases due to occurrence of sub-heat in suction line which causes increase in the mass of refrigerant circulated through the compressor per unit time hence decreases the work of compressor subsequently reduction in power consumption and performance enhancement heat pump.

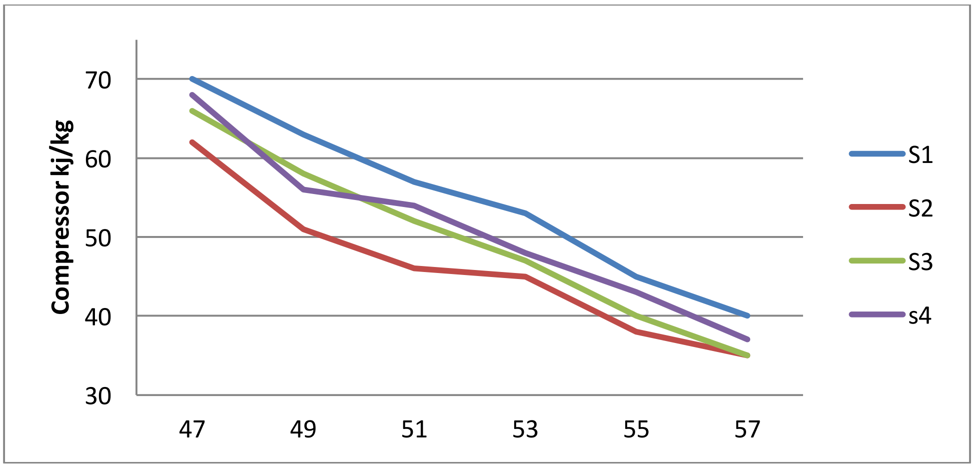

Fig 9 Performance of nano-particles size on work of compressor

vi. Performance of Nano-particles Size on the Condenser Outlet Temperatures

Fig 10 represents the relationship between the evaporator temperature and outlet condenser temperature which shows that the evaporator temperature and outlet condenser temperature decrease when used the nano-refrigerant in the cycle. Also, it is observed that the decreasing of evaporator temperature and outlet condenser temperature is more when used the S2 mixture than the other mixture cases. However, the addition of small size nano-particles in refrigerant which increase the condenser heat transfer rate thus enhances performance improvement of heat pump.

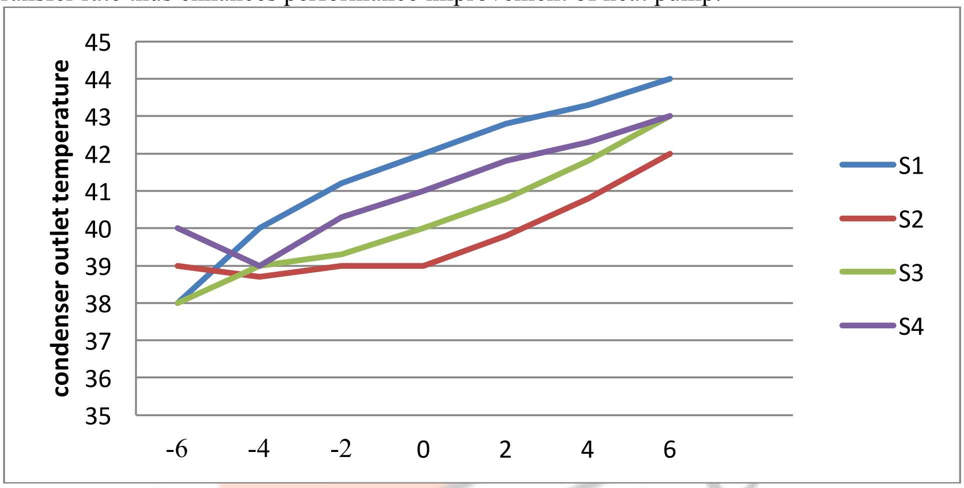

Fig 10 Condenser outlet temperature Vs. Evaporator temperature

6. CONCLUSIONS

The present study has concentrated on the effect of nano-particles size of Al_2O_3 on the performance of the heat pump for giving an indication for improvements the performance of the heat pump. The main conclusions from this work were that the refrigerating effect increases with the decrease in nano-particles size of Al2O3. Among Four cases which have been considered for this experimental study, it was found that the using of mineral oil with 20 nm nano-particles of Al_2O_3 leads to COP improvement by 19.1%, and reduces the compressor power consumption by about 21.8%, also, reduces the heat rejection by about 2.73% in comparison with the case of hermetic compressor was filled with SUNISO 3GS oil (mineral oil). Moreover, the condenser outlet and evaporator temperatures will be more decreased.

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