International Journal of Modern Manufacturing Technologies
ISSN 2067–3604, Special Issue, Vol. XI, No. 3 / 2019

EXPERIMENTAL STUDY OF THE PERFORMANCE FOR WATER CHILLER USING AL_2O_3 NANO-PARTICLE FOR REFRIGERATION UNIT

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Abstract: Heat transfer enhancement techniques such as; passive or active, are widely used in heat exchangers. The aim of present work is to study the thermal behavior in the shell and tube heat exchanger used to cool water by add Al_2O_3nano-particle to distilled water experimentally. Heat exchanger (evaporator) is a part of water refrigeration unit (1-ton capacity) which is fabricating for experimental tests. Refrigerant (R-134a) is passing through the inner tube of evaporator. While the water is pass reversely in the annular side of evaporator. The length and inner diameter of tube are 1100mm and 22mm respectively. The nano-particles of Al_2O_3 is mixed with distilled water in different concentrations such as: 0.25%, 0.35%, and 0.45%. The tests are carried out at different mass flow rates of water in the annular side such as (5, 6 and 7lpm). The results showed an optimum increment of heat transfer is 12.7 % when the concentration ratio is 0.45% and mass flow rate of nano-fluid is 5Lpm. The physical properties of nano-fluid such as thermal conductivity, density, and viscosity are increased by 1.26%, 1.4% and 3.4% respectively. Results show that the required time to cool water to certain temperature is decreased by 19% at 0.45% concentration.

Key words: nano-fluid, heat exchanger, nano- particles, evaporator.

1. INTRODUCTION

Heat transfer enhancement has been receiving a more attention since a long time ago. It is found several applications such as cooling system, heating system …etc. Heat transfer enhancement has been classified broadly in passive and active techniques. It is called nanotechnology. Nano-fluid or nano-refrigerant are used to improve the thermo physical properties. Nano-fluid represents a mixture of nano-particles and a base fluid, [1]. Coumaressin and Palaniradja, [2] studied the performance of refrigerant system using CuO-R134a. The evaporator test section was considered a double tube heat exchanger made of copper. Refrigerant flows through the annulus in counter flow. Results show that the heat transfer coefficient increases by using nano-refrigerant. Ramesh and Vivekananthan, [3] studied the enhancement of heat transfer inside a shell and tube heat exchanger using nano-fluid. The (Al_2O_3/ water) nano-fluid was contributed in enhancement of heat transfer. Reza et al., [4] investigated the heat transfer in double pipe heat exchanger using (Al_2O_3/ water) nano-fluid with different concentration of Al_2O_3. The results showed that the overall heat transfer coefficient was optimum at 0.3% concentration. Vandaarkuzhali and Elansezhian, [5] studied the performance of air conditioning system using nano-fluid. Three type of nano-particles were used which CuO, ZnO and Al_2O_3 with water. Experimental results showed COP was increased when using CuO. The mass fraction is 0.1%. Qasim et al.,[6] investigated the performance of refrigeration system using nano-refrigerant. They studied the effect of mixing R-134a with different volume of fraction of Al_2O_3 (0.01%, to 0.02%) at the COPof system. The result showed that the performance of system is increase by 30% when using nano-refrigerant with 0.02% concentration.

The aim of the present work is to study the enhancement of the heat transfer process in the evaporator using Al_2O_3 particles with water in different volumetric ratios.

2. EXPERIMENTAL TEST RIG

In order to carry out the experimental test, a laboratory refrigerant unit (1-ton capacity) is manufactured. The unit is consisting of reciprocating compressor, air cooled condenser, expansion valve, and evaporator for chilled water as shown in Figures 1 and 2.

Fig. 1. The experimental test rig

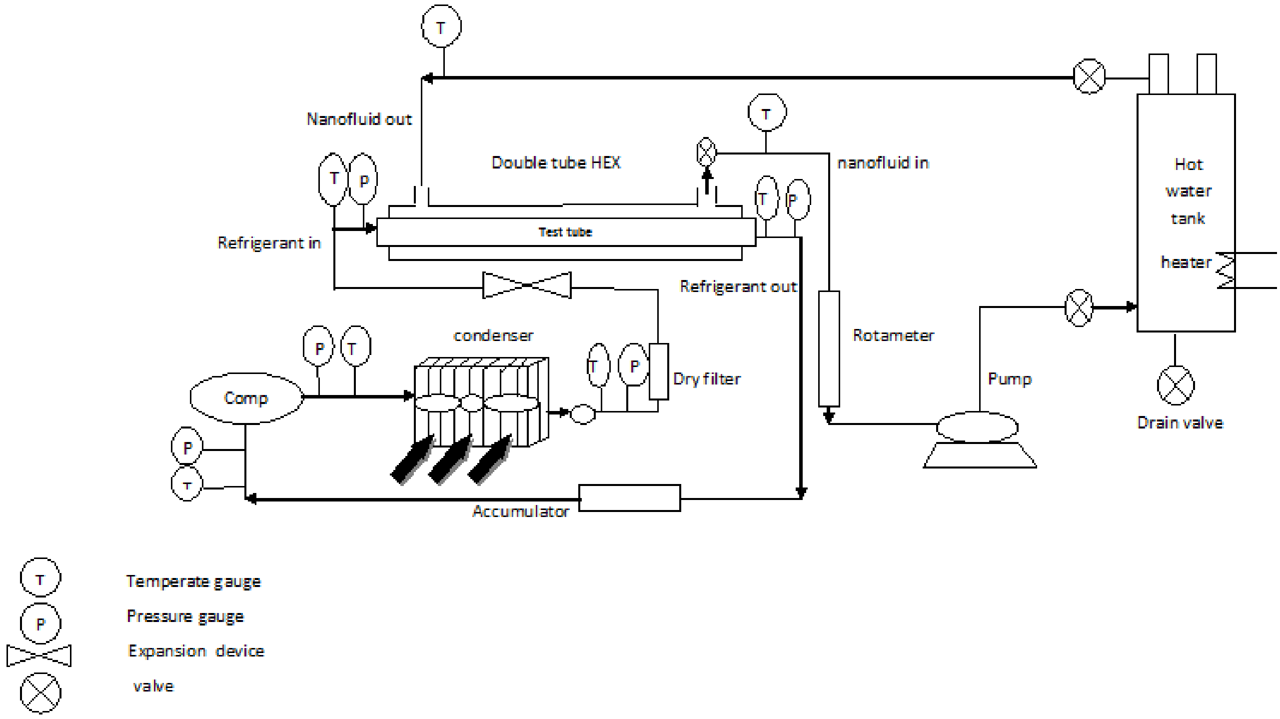

Fig. 2. Schematic diagram for the experimental test rig

R-134a is used as a refrigerant in the unit. Evaporator is shell and single tube heat exchanger as shown in Figures 3 and 4. Refrigerant is flow inside the tube while the water is flow in the annulus inversely. The performance of evaporator is tested under different mass flow rate of nano-fluid which (5, 6, 7)L/m.

Evaporator is straight horizontal shell and tube heat exchanger made of copper. The length of evaporator (test section) is 1100mm. The diameter and thickness of inner tube are 21mm and 1mm respectively. The diameter and thickness of shell are 44mm and 1mm. There are two circuits in the present work. The first circuit is for refrigerant and the second circuit for hot water. Refrigerant is passes through the tube, while water is passes through the annulus. Two thermocouple (type-K) are fixed at the inlet and outlet of annulus to measure the water temperature. Two thermocouples (type-K) are fixed at the inlet and outlet of tube to measure the refrigerant temperature. Six thermocouples are fixed along the tube to measure the refrigerant temperature gradation along the tube.

Fig. 3. Evaporator heat exchanger with insulation

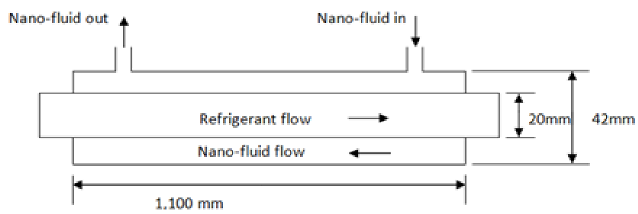

Fig. 4. The test section

3. PREPARATION OF THE (AL_2O_3- WATER) NANO-FLUID

The important property of mixture is the stability. In the present work Al_2O_3 nano-particle is mixed with base water in different volumetric concentration. The ultrasonic device is used to prepare (Al_2O_3- Water) nano-fluid. Table 1 shows the specification the device. The average diameter of Al_2O_3 particle about (20-30nm) and the mass purity is 99.5%. Table 2 shows the properties of Al_2O_3nano-particle the properties of Al_2O_3nano-particle.

Table 1. Specifications of ultrasonic vibration device

Model	JP-120ST
Ultrasonic Frequency	40 kHz
Ultrasonic Power	720 Watt (variable)
Digital Timer Control	1-30 min
Capacity	38 liter
Heating Power	800 Watt

Table 2. The properties of the (Al_2O_3) nano-particle, [7]

Density (kg/m^3)	3970
Thermal conductivity (W/m K)	40
Specific heat (J/kg K)	765

Nano-particle Al_2O_3 is mixed in three volumetric concentrations (0.25%, 0.35%, and 0.45%) with three liter of distilled water by using vibrated ultrasonic oscillator.

4. THEORETICAL ANALYSIS

The volume fraction (ϕ) of nanofluid can be estimated by the following equation (1), [6]:

$$\phi : \frac{m_n/\rho_n}{m_n/\rho_n + m_w/\rho_w} \quad (1)$$

where, w refer to nano-particle, base water respectively. The effectiveness thermal conductivity (K_{nf}) of the nano-fluid expressed by the following equation (2), [8]:

$$k_{nf} = k_f \frac{(kp + 2kf - 2\varphi(kf - kp))}{kp + 2kf + \varphi(kf - kp)} \quad (2)$$

The viscosity of nano-fluid is calculated by using the following by equation (3), [9]:

$$\mu_{n,f} = \mu_{b,f} \frac{1}{(1-\phi)^{2.5}} \quad (3)$$

where μ_{nf} is the viscosity of nano-fluid, $\mu_{b,f}$ is viscosity of water.
The specific heat capacity can be estimated by using the following equation (4), [8]:

$$(Cp)_{nf} = (1-\phi)(Cp)_w + \phi(Cp)_p \quad (4)$$

The density of nano-fluid can be calculated by the following equation (5), [10].

$$\rho_{nf} = \phi\rho_p + (1-\phi)\rho_w \quad (5)$$

The heat transfer rate of hot water (Al_2O_3 + water) nano-fluid in the annular side is calculated using, [4], following equation (6):

$$Q_{nf} = \lfloor \dot{m} C_p (T_{out} - T_{in} \rfloor_{nf} \quad (6)$$

Nusselt's number for nano-fluid in the annular side can be calculated by using Dittus and Boelter correlation [11], equation (7):

$$Nu_a = \frac{h_o D_h}{k_h} = 0.023 \mathrm{Re}^{0.8} \mathrm{Pr}_w^{0.3} \quad (7)$$

Reynolds number for nano-fluid in the annular side can be calculated by, [11], equation (8):

$$\mathrm{Re} = u\, \mathrm{Dh/v} \quad (8)$$

5. RESULTS AND DISCUSSIONS

Figure 5, demonstrated the relation between the thermal conductivity of nano-fluid with concentration of nano-particle increasing of volume concentration of nano-fluid leads to increase thermal conductivity. Results indicate enhancement of thermal conductivity by 1.2% because of high conductivity of nano-particle. This is lead to increase the heat transfer in the evaporator.
Figure 6, shows the effect of volume concentration of Al_2O_3nano-fluid on the viscosity. The viscosity increased by 4.7%. The viscosity influenced by the particle concentration of nano-particle.

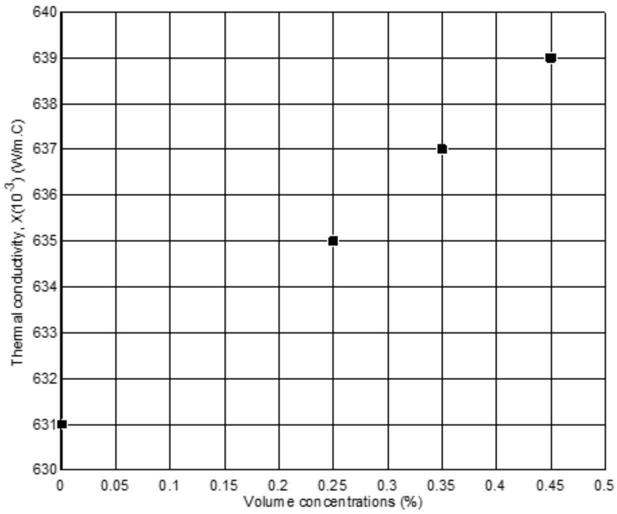

Fig. 5. Effect of nano-particle concentration on the thermal conductivity of nano-fluid

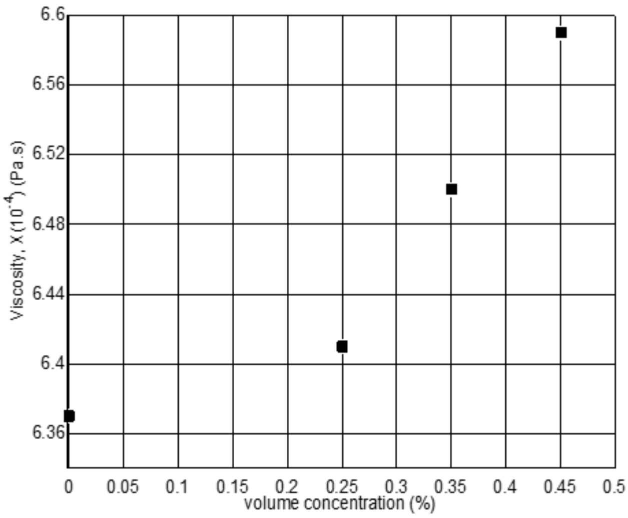

Fig. 6. Effect of nano-particle on the viscosity on nano-fluid

Figure 7, reveals that the specific heat of (Al_2O_3/water) nano-fluid decreases with addition of nano-particle. The maximum decrease in specific heat of the nano-fluid is 0.36%. This decrease is due to the lower specific heat of nano-particle.
Figure 8, illustrates the variation of density of nano-fluid it is increased by 1.36%, because of increasing

volume concentration of nano-particle, which mixed in water.

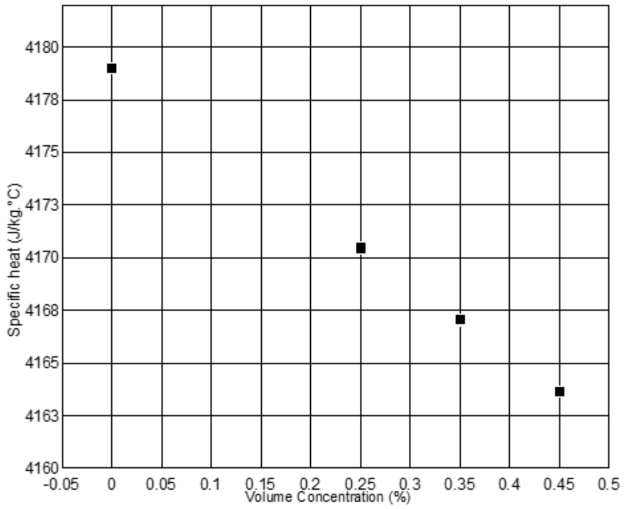

Fig. 7. Effect of nano-particle concentration on the specific heat of nano-fluid

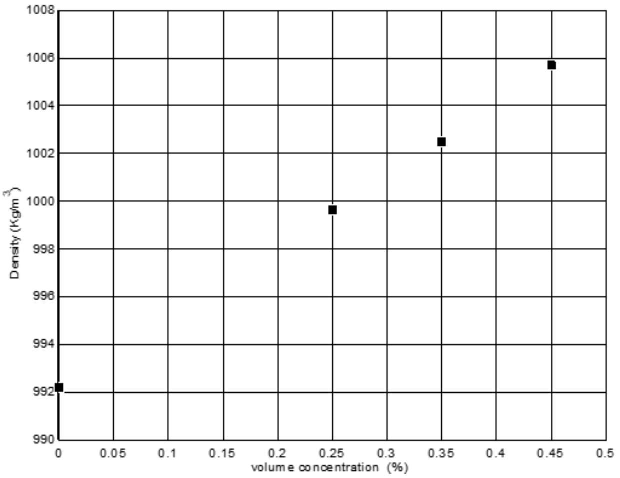

Fig. 8. Effect of nano-particle concentration on the density of nano-fluid

Figure 9, illustrates the temperature behavior inside annular side of evaporator with nano-fluid at 0.45% concentration. The heat transfer is larger compared the state without nano-particle. This enhancement because of high thermal conductivity of nano-particle leads to high thermal conductivity of nano-fluid the saving of is 23%.

Figure 10, shows that the temperature difference along the tube of refrigerant is. This is because heat absorbed from the hot nano-fluid is more due to increase the heat transfer between them.

Figure 11, shows clearly the effect volume concentration of Al_2O_3 and water mass flow rate in annular side. on the heat transfer rate between refrigerant and nano-fluid. Increasing volume concentration leads to increase the heat transfer rate because of the effect of thermal conductivity. On the other side increase mass flow rate of nano-fluid lead to decreases the heat transfer because of increase Reynolds number. The percent of enhancement in heat transfer is 12.7% for 0.45% concentration at $\dot{m}_{nf}$ 5 l/m

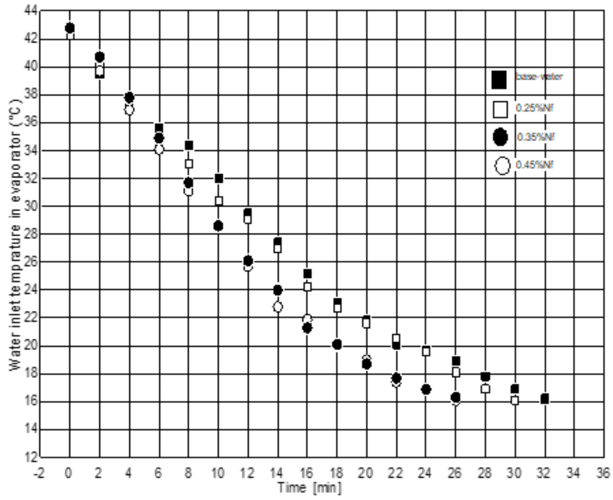

Fig. 9. Temperature –Time chart

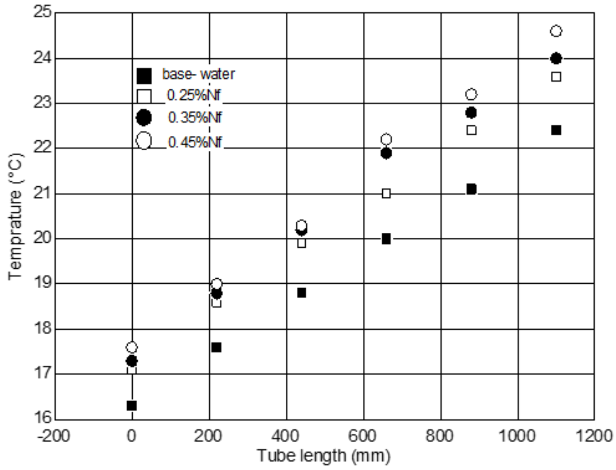

Fig. 10. Temperature distribution along tube heat exchanger refrigerant side

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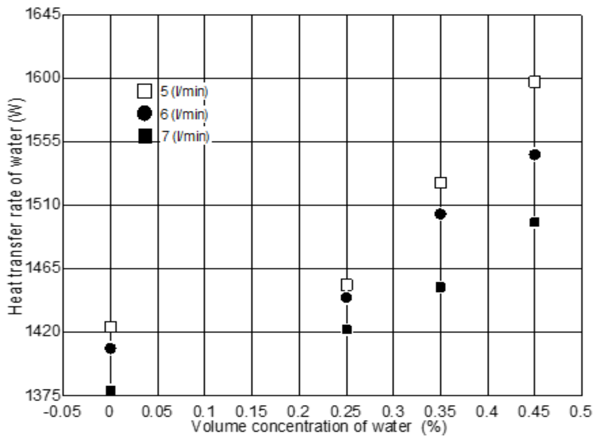

Fig. 11. Effect of volume concentration on heat transfer rate with water mass flow rate

Figure 12, shows the variation of the heat transfer coefficient with different water mass flow rate. The heat transfer is better with increasing mass flow rate, because the heat transfer between nano-fluid and refrigerant side has increased. The enhancement of the heat transfer coefficient with 0.45% nano-fluid is about (2.1%).

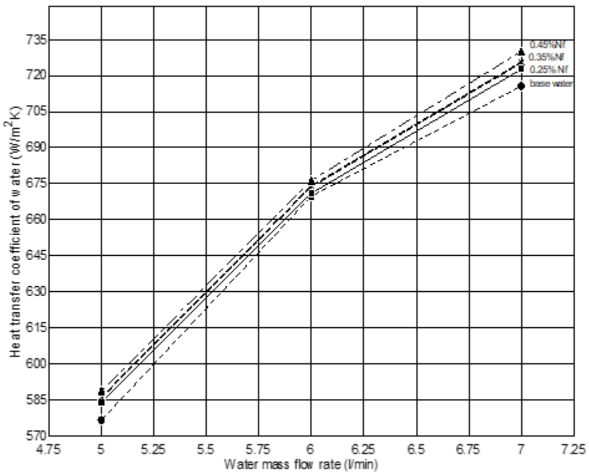

Fig. 12. Variation of heat transfer coefficient of water in annular with water mass flow rate for different volume

Figure 13, illustrated the temperature difference in the water side. The water temperature difference decreases by (24.4%) when the mass flow rate increase. that increasing mass flow rate leads to decrease the duration temperature in evaporator.

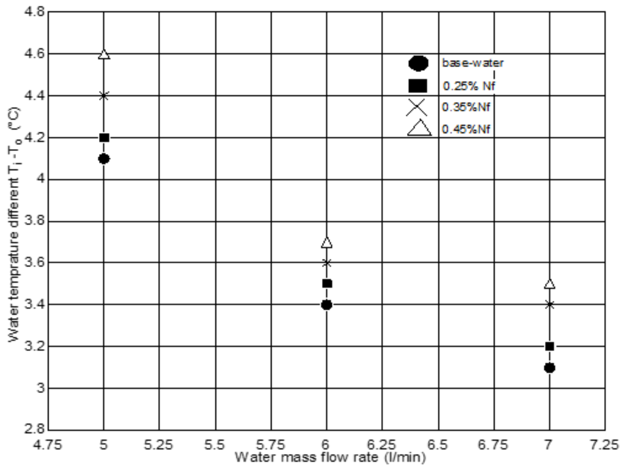

Fig. 13. Effect of water mass flow rate on the water Temperature difference with base refrigerant

6. CONCLUSIONS

The heat transfer rate of water side is significantly enhancement is about 6.2%. The thermal conductivity of nano-fluid enhancement when increase volume fraction is about 1.2%. The viscosity is increased 4.7% with 0.45% nano-fluid volume concentration. Specific heat decrease of the nano-fluid is 0.36% compare without nanofluid.The density of the nano-fluid is increased 1.36%. Then duration time when cooling the hot nano-fluid is improvement was saving 23%, with 0.45% nano-fluid volume concentration. The temperature different along evaporator heat exchanger of refrigerant side is more compared to without nano-fluid.The significantly enhancement of the heat transfer coefficient with 0.45% nano-fluid is about (2.1%).The water temperature difference decreases by (24.4%) when the mass flow rate increase.

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Received: April 14, 2019 / Accepted: December 20, 2019 / Paper available online: December 25, 2019 © International Journal of Modern Manufacturing Technologies