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Efficiency Enhancement of a Solar Collector by using ZnO Nanofluid

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Abstract--- **The increasing demand to the energy nowadays has led investigators to give attention on solar energy. In this research, the performance of a flat solar collector has been studied experimentally. It was used water and ZnO/water nanofluid as working fluid with three values of mass fractions (0.01, 0.03, 0.06%) and (0.2, 0.5, 0.8 liter per minute) flow rate. The experimental study was performed at Mosul city/Iraq, during April and May in 2020. It was showed that the outlet temperature of the fluid, heat gain, experimental efficiency, thermal losses of the solar collector were increased as increasing of the solar intensity but decreased as the volumetric flow rate increased. The using of 0.06% of ZnO/water nanofluid increase the solar collector efficiency by 12% at the maximum value of volumetric flow rate.**

Index Terms— **Flat Solar Collector, Efficiency, Nanofluid, ZnO/water**

I. INTRODUCTION

Solar energy is one of the main constituents of civilized societies and needs all social and industrial sectors. It is considered an economic source of energy because it is available and is relatively inexpensive compared to conventional fossil fuel-based energy. A large number of initiatives have been taken by countries around the world to promote scientific research and development activities on solar energy technology. In addition, the pollution caused by the burning of these materials has led the researchers to begin studding of new energy sources. The aim was to exploit the solar energy as a renewable and non-polluting energy which is free of pollutants.

Many public applications solar complexes are heat exchangers where they convert solar energy into thermal energy to take advantage of this energy in life applications. The main part of any solar system is the solar collector, which is a system that absorbs the solar radiation and converts it into heat to use for industrial applications [1-2].

Nanofluid is used in solar collectors to increase the heat transfer of the fluid which consisted of solid nanoparticles of metals (Ni, Cu and Ag) or ceramic compounds such as carbide or ceramic oxides such as Fe_2O_3 and TiO_2 suspended in water. The nanofluid applications are thermal engineering, improving heat transfer and improving the physical properties of water and thus improving the efficiency of the solar collector.

Cheng et al., 2010 [3] conducted an experimental and theoretical study of the effect of the amount of radiation falling on the oil inside the absorber tube of the solar collector with parabola, and concluded that there was an agreement between the two studies that the error rate between them does not exceed (2%) and that radiation losses do not exceed 153.7 w/m^2. Lei et al, [4-5] studied the absorber tube bending and temperature gradients by using the high frequency heating of induction to band a new borosilicate glass to Kovar alloy ends. The absorber tube thermal stress and gradients of temperature might be reduced by the using of internal finned tubes [6] and by inserting metal foams in the absorber tube [7].

Hussein et al., [8] studied the measurements of nanofluid properties. Three samples of solid nanoparticles have been suspended in water. Thermal conductivity and viscosity have been measured and validated with standard. The recommendation of nanofluid applications in heat exchanger has been conducted by [9].

Bajestan et al., 2016 [10] used nanofluid to improve heat transfer of the fluid in solar heat exchanger. They discovered innovative ways to improve heat transfer and TiO_2/water nanofluid using. The results indicated that the performance of solar heat exchanger increased by (21%) when using the titanium oxide as compared to water.

This paper is studied the performance of a flat solar collector by using water and ZnO/water nanofluid. The influence of the volume concentration (0.01, 0.03, 0.06%) and the volume flowrate (0.2, 0.5, 0.8 liter per minute) on the performance is indicated.

II. EXPERIMENTAL INVESTIGATION

2.1. PREPARATION OF NANOFLUID

The nanofluid is prepared by mixing the ZnO solid nanoparticle powder with water. This method is most commonly used in the preparation of nanofluid [11]. In this method, nanoparticles are suspended in water and the electric mixer is used to prevent the aggregation of

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nanoparticles and obtain nanofluid. This method is more economical than the other methods for producing large-scale. The nanofluid volume fractions are preparing with 0.01%, 0.03% and 0.06% respectively.

Ten liters of water were added to each concentration of nanofluid. The mass of nanoparticles was measured by using a sensitive balancing. It was noted that the ZnO/water nanofluid was significant stability along all experiments.

In the study undertaken, 30nm size diameter of ZnO solid nanoparticles dispersed in pure water at a volume concentration (0.01, 0.03, 0.06%) that evaluated the volume concentration by the Eq. (1) below [8] and the thermal properties are illustrated in Table1.

$$\emptyset = \frac{\frac{m_p}{\rho_p}}{\frac{m_f}{\rho_f}+\frac{m_p}{\rho_p}} \tag{1}$$

Table 1. Thermal properties of ZnO nanoparticles and water

Property	ZnO	Water
Density	1125 kg/m^3	1000 kg/m^3
Thermal conductivity	24 W/m.K	0.6 W/m.K
Viscosity	-	1.02 mPas

The density can be evaluated by:

$$\rho_{rf} = (1-\emptyset)\rho_f + \emptyset\rho_s \tag{2}$$

Where:

ρ_f , ρ_s : Density of fluid and solid (kg/m^3) respectively.

The thermal conductivity of nanofluid may be estimated as [11]:

$$k_{nf} = \left[\frac{k_s + (n-1)k_f - (n-1)\Phi(k_f - k_s)}{k_s + (n-1)k_f + \Phi(k_f - k_s)}\right]k_f \tag{3}$$

Where: n is the shape factor, k_s : Thermal conductivity of the solid (W/m.K), k_f : Thermal conductivity of the fluid (W/m.K), Ø: Volume fraction, it can be assumed n = 3 for spherical nanoparticles.

The specific heat of nanofluids can be evaluated as [11]:

$$c_{pnf} = \left[\frac{(1-\Phi)(\rho c_p)_f + \Phi(\rho c_p)_s}{(1-\Phi)\rho_f + \Phi\rho_s}\right] \tag{4}$$

The viscosity of nanofluids can be calculated as [19]:

$$\mu_{nf} = \left[123\Phi^2 + 7.3\Phi + 1\right] \tag{5}$$

2.2. EXPERIMENTAL METHOD

The experiment tests were performed on the flat solar collector as shown in Fig. 1. Along two months April in 2020 using pure water, nanofluid with mass factions (0.01%, 0.03% and 0.06) and three different flow rates (0.2 L / min, 0.5L / min, 0.8L/ min). The following steps must be followed before and after the device operation as follows: the appropriate place at Mosul city has been selected to setup the flat solar collector for solar radiation gain.

The flat solar collector is fabricated with 2m length, 0.7m width and 0.2m thickness. Cleaning the solar collector including the inverter and the glass covered with the absorbent tube. Thermocouples have been fixed and connected to data logger to measure temperatures. Taking reading of the temperature and volumetric flow rate that measured by the thermocouples and volumetric flow meter equipment. It was started from 9 am to 3 pm and saving to Microsoft Excel for analysis.

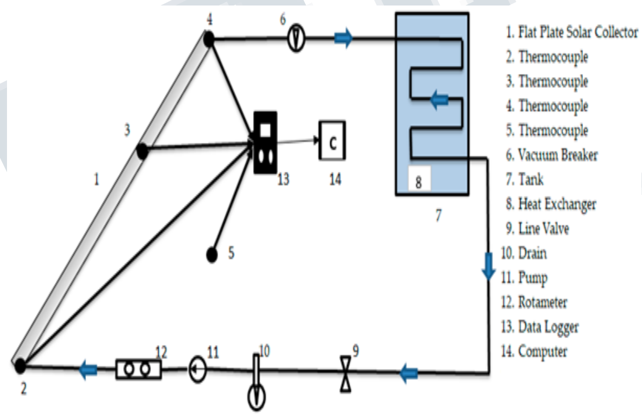

Fig. 1. Flat Plate Solar Collector

III. EFFICIENCY CALCULATIONS

The amount of solar radiation received by the collector shown Fig. 1, can be calculated as:

$$Qi = I \cdot A \tag{6}$$

When I is the solar radiation intensity in W/m^2, A is a collector surface area. A part of this radiation is reflected back to the sky, another component is absorbed by the glazing and the rest is transmitted through the glazing and reaches the absorber plate as short wave radiation.

The conversion factor illustrates the solar radiation percentage penetrating the collector transparent cover transmission and the absorbed percentage. As known, it is the product of the rate of transmission of the cover and the absorber rate of absorption.

$$Qi = I(\tau\alpha)\cdot A \tag{7}$$

The temperature of the solar collector absorbs heat is lost to the atmosphere by radiation and convection and it is getting higher than that of the surrounding. The heat loss rate (Qo) depends on the temperature of collector and the collector

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overall heat transfer coefficient (U_L).

$Qo = U_L\, A\, (Tc - Ta)$ (8)

The useful energy rate gained by the collector, can be evaluated as:

$Qu = Qi - Qo = I\tau\alpha . A - U_L A\, (Tc - Ta)$ (9)

The extraction heat rate from the flat collector can be measured by means of heat amount carried away through the collector, as:

$Qu = \dot{m}c_p\, (To - Ti\,)$ (10)

Eq. (10) shows the somewhat inconvenient due to difficult defining the average temperature of collector. When the surface of collector was at the fluid inlet temperature, it can be defined a quantity that relates the gain of actual useful energy of collector to the useful gain. It is defined as "the collector heat removal factor (FR)" which can be formulated as:

$F_R = \frac{\dot{m}c_p(T_o - T_i)}{A[I\tau\alpha - U_L(T_i - T_a)}$ (11)

The solar collector gain of useful energy is occurred during the inlet fluid temperature of the whole collector.

$Q_u = F_R\, A[\, I\tau\alpha\ -\ U_L(Ti - Ta)]$ (12)

The Hottel Whillier-Bliss Eq. (12) is a widely relationship used for measuring the gain of flat solar collector energy.

The collector efficiency (η) defined as the ratio of the useful energy gain (Qu) to the incident solar energy over a particular time period can be evaluated as:

$\eta = \frac{\int Qudt}{A \int Idt}$ (13)

The efficiency of the system can be calculated by dividing the useful energy (acquired) by the fluid of the solar collector by the total radiation intensity falling on the system multiplied by the area of the absorption plate [13].

$\eta = \frac{Qu}{AI}$ (14)

$\eta = \frac{F_R\, A[\, I\tau\alpha - U_L(Ti - Ta)}{AI}$ (15)

$\eta = F_R\ \tau\alpha\ -\ F_R U_L (\frac{Ti - Ta}{I})$ (16)

IV. RRESULTS AND DISCUSSION

Fig. 2 shows the relationship between the temperature of the pure water and the nanofluid outside the solar collector with the daylight hours and for several volumetric flowrates. It was observed that the outlet temperature of the water begins to increase with Sunrise hours until reach the highest value at midday 70°C and begin to decrease after midday and at a volume flow (0.2 L / min). When the volumetric flow rate increases to 0.5 L / min, the highest temperature will decrease to 56°C, finally the outlet temperature is 48°C at the highest flow rate (0.8 L / min).

Fig. 3 shows the outlet temperature when using nanofluid with concentrations (0.01, 0.03, 0.06%) against time. It can be noted that the outlet temperature of nanofluid with 0.06% concentration at midday is higher than other concentrations of nanofluid. This is due to the fact that by increasing the mass concentrations of nanofluid in water, the physical and thermal properties of nanofluid improve. The heat transfers of nanofluid increases and absorbs a greater amount of solar radiation and thus increases the temperature of the nanofluid.

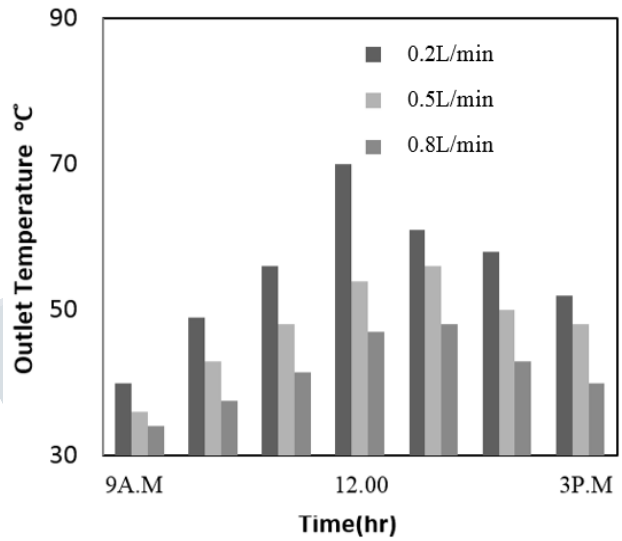

Fig. 2. Exit temperature with daylight hours for different flowrate of pure water.

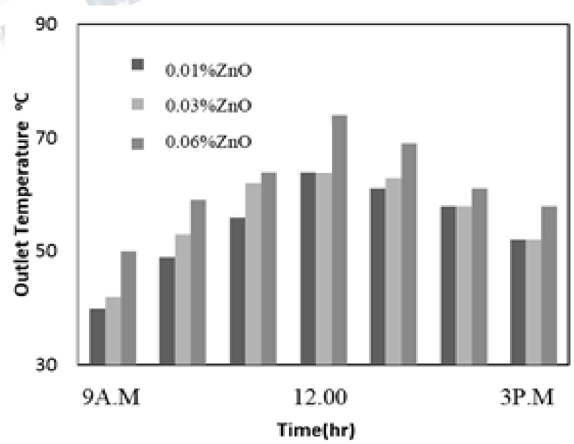

Fig. 3. Exit temperature with daylight hours for different flowrate of nanofluid.

Fig. 4 shows the useful energy obtained from the solar water collector and the volume flowrates (0.2, 0.5 and 0.8 L/min). it can be seen that the energy starts increasing with sunrise hours until it reaches its highest value at midday 439 W then reducing after midday at the highest volumetric flowrate 0.8 L / min. It was observed that the highest thermal energy obtained at midday is 421 W and 409 W at the flow rate 0.5 and 0.2 L / min respectively.

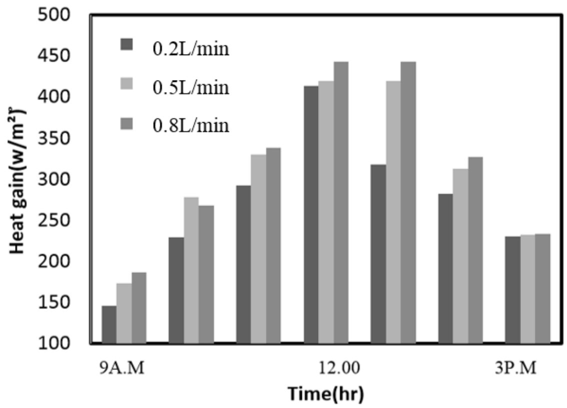

Fig. 4. The heat gains of pure water against time with different volume flowrates.

Fig. 5 indicates the useful energy of nanofluid with different concentrations. It can be noted that the maximum useful energy is 522, 515 and 503 W for 0.01, 0.03 and 0.06% of ZnO/water respectively. The same behavior of heat gains from flat solar collector when using pure water and nanofluid is increased with sunrise till midday then decreasing gradually.

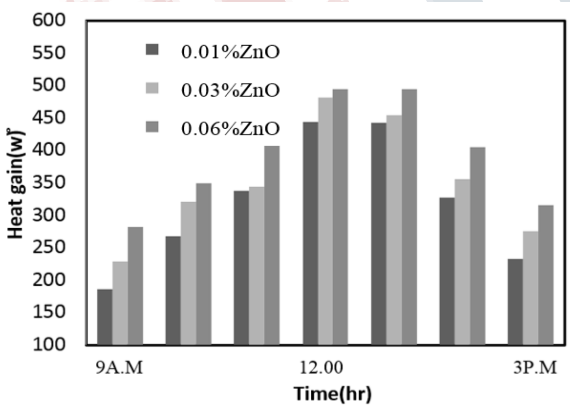

Fig. 5. The heat gains of nanofluid against time with different mass concentrations

Fig. 6 indicates the thermal efficiency of the flat solar collector using pure water and volume flowrates with daylight hours. It was observed that the thermal efficiency begins to increase with the hours of sunrise to reach its highest value at midday 57%, 52% and 49% when volume flowrate increase from 0.2, 0.5 and 0.8 L/min respectively. The reason to decrease thermal efficiency with increasing of volume flowrate is the reducing the time to heat transfer and absorbing solar radiation. After midday the thermal efficiency is decreased due to reduce solar intensity.

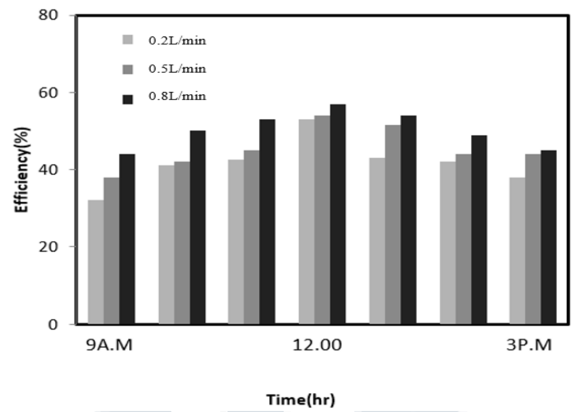

Fig. 6. The solar collector thermal efficiency using pure water and volume flowrate with time.

Fig. 7 shows the thermal efficiency of the flat solar collector using ZnO/water with mass concentrations and daylight hours. It can be noted that the thermal efficiency increases with the hours of sunrise to reach its highest value at midday 63%, 60% and 57% when mass concentrations of nanofluid increase from 0.06, 0.03 and 0.01% respectively. The reason to increase thermal efficiency with increasing of mass concentrations of nanofluid is the improving of thermal properties of nanofluid such as thermal conductivity. After midday the thermal efficiency is decreased due to reduce solar intensity.

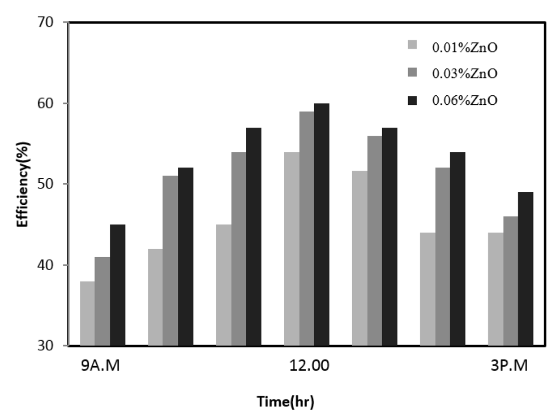

Fig. 7. The solar collector thermal efficiency using ZnO nanofluid with mass concentrations and time.

V. CONCLUSIONS

The fluid temperature outside the solar collector is directly proportional to the intensity of the solar radiation and the

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volume flowrate at daylight hours up to midday. The values of heat energy gained and heat losses are directly proportional to the intensity of solar radiation and volumetric flowrate during daylight hours up to midday. The using of pure water in the flat solar collector with different volume flowrate is increase maximum thermal efficiency from 49% to 57%. The utilizing of ZnO/water to the solar collector improves thermal efficiency by 9%, 11% and 14% when using 0.01%, 0.03 and 0.06% of the nanofluid mass concentrations respectively.

VI. NOMENCLATURE

A aperature area(m^2)
To outlet fluid temperature (^oC)
Ta ambient temperature (^oC)
Cp specific heat (J/kg.^oC)
U_L overall heat loss coefficient (W/m².^oC)
$\emptyset$ concentration ratio
I beam radiation (W/m²)
Ti inlet fluid temperature (^oC)
$\dot{m}$ mass flow rate (kg/s)
Qu useful energy (W)
F_R heat removal factor of collector
η efficiency of collector

REFERENCES

[1] Kafel Azeez , Zainab Ali Ibrahim , Adnan Mohammed Hussein, Thermal Conductivity and Viscosity Measurement of ZnO Nanoparticles Dispersing in Various Base Fluids. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 66, Issue 2, pp. 1-10 (2020).

[2] A.M. Hussein, K.V. Sharma, R.A. Bakar, K. Kadirgama. The effect of cross sectional area of tube on friction factor and heat transfer nanofluid turbulent flow. International Communications in Heat and Mass Transfer 47, 49-55, (2013).

[3] Z. Cheng, Y. He, J. Xiao, Y. Tao, R. Xu, Three-dimensional numerical study of heat transfer characteristics in the receiver tube of parabolic trough solar collector. *International Communications in Heat and Mass Transfer* 37, 782-787 (2010).

[4] D.Q. Lei, Z.F. Wang, J. Li, The analysis of residual stress in glass-to-metal seals for solar receiver tube, Mater. Des. 31, 1813–1820, (2010).

[5] D.Q. Lei, Z.F. Wang, J. Li, J.B. Li, Z.J. Wang, Experimental study of glass to metal seals for parabolic trough receivers, Renew. Energy 48: 85–91, (2012).

[6] J. Muñoz, A. Abánades, Analysis of internal helically finned tubes for parabolic trough design by CFD tools, Appl. Energy 88 (11), 4139–4149, (2011).

[7] P. Wang, D.Y. Liu, C. Xu, Numerical study of heat transfer enhancement in the receiver tube of direct steam generation with parabolic trough by inserting metal foams, Appl. Energy 102, 449–460, (2012).

[8] A.M. Hussein, R. A. Bakar, K. Kadirgama, K. V. Sharma. Experimental measurement of nanofluids thermal properties." International Journal of Automotive and Mechanical Engineering 7, 850 (2013).

[9] K. Azeez, A.F. Hameed, A. M. Hussein, Nanofluid heat transfer augmentation in a double pipe heat exchanger, AIP Conference Proceedings 2213, 020059, March (2020).

[10] E.E. Bajestan, M.C. Moghadam, H. Niazmand, W. Daungthongsuk, S. Wongwises, Experimental and numerical investigation of nanofluids heat transfer characteristics for application in solar heat exchangers. *International Journal of Heat and Mass Transfer* **92**, 1041-1052 (2016).

[11] Z.A. Ibrahim, Q.K. Jasim, A.M. Hussein. The Impact of Alumina Nanoparticles Suspended in Water Flowing in a Flat Solar Collector. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 65, Issue 1, 1-12, (2020).

[12] J. A. Duffie, W. A. Beckman, *Solar engineering of thermal processes*. (John Wiley & Sons, 2006).

[13] H. Garg, *Solar energy: fundamentals and applications*. (Tata McGraw-Hill Education, 2000).