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Case study on solar water heating for flat plate collector

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ABSTRACT

This paper describes performance solar water heating for flat plate collector. The system of thermal performance designed for dimensions 125 × 110 cm and width 25 cm, in such a way that fluid can flow from inlet to outlet through pipe with longer is 15.9 m, designed as lope square pattern, used the water as fluid flow working with two different flow rate (5.3 and 6.51 L/min). The experiments were carried out under the University of Technology, conditions of Baghdad, Iraq. The result shows that the water at flow rate 5.3 L/min heated more than the flow rate 6.51 L/min, which causes the higher efficiency and effectiveness of the collector, so the maximum temperature was (51.4 °C and 49 °C) at flow rate (5.3 L/min and 6.51 L/min) respectively. The main conclusion is that used this system to heated the water and then used in-house, building and other purposes.

1. Introduction

Solar energy is a provider of clean and green energy, which can be used to fulfill global energy needs [1,2]. The solar energy is very important which is coming from the sun as a form of the solar radiation, this can be an alternative energy source. The solar radiation can be useful for our life to the heating building, heated water in order to produce steam and used it in any way such as in industrial and domestic. The system of solar water heating is consumed and cheapest about 20% of the family total energy consumption [3]. Kabeel et al. [4] show considerable improvement in the daily solar collector efficiency is obtained with increasing the nano-particle concentration up to 11% for concentration 3% with; this increase in efficiency is bounded by ± 10% uncertainty and the outlet water temperature was increased with increasing of nano-particle concentration by 5.46% for concentration 2%. El-Said and Abou Al-Sood [5] displayed experiments for investigation of air injection into the shell side of shell-and-multi-tube heat exchanger aims to augment the thermal performance and the obtain significant impact on the heat exchanger performance enhancement. Liu et al. [6] show that the maximum value of the system efficiency are 62% under small different temperatures between ambient air temperature and the collectors' temperature. The increase difference temperature between the temperature of collectors and the water temperature increased the heat gain by collectors. Kabeel and El-Said [7] demonstrate hybrid solar desalination system consisting of a humidification dehumidification unit and single stage flashing evaporation unit and they studied hybrid desalination system give a significant operational compatibility between the air humidification dehumidification method and flash evaporation desalination. Weitbrecht et al. [8] saw that experimentally study in the water solar collector of a flat plate with laminar flow

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Nomenclature

A_{coll}	Collector area (m^2)	T_f	Mean temperature (°C)
A_{pipe}	Pipe cross section area (m^2)	T_{out}	Outlet temperature (°C)
C_p	Specific heat capacity (kJ/kg K)	V	Velocity (m/s)
I_{Rad}	Intensity of solar radiation (W/m^2)	Q_u	Useful energy gain (W)
$\dot{m}$	Mass flow rate (kg/s)	Q	Volume flow rate (m^3/s)
T_{in}	Inlet fluid temperature (°C)	R_e	Reynolds number
		η	Collector efficiency
		Ɛ	Effectiveness

condition and observed the distribution of the flow through the collector. The higher collector's efficiency factor was observed at a higher rate of water flow [8,9]. Vendramin et al. [10] shows that the maximum outlet temperature was recorded in flat plate collector was 55 °C, while total loss of the heat to feed tube solar water heating systems was 3.2 MJ/d, corresponded to 16.4% of energy collected by flat plate collector and 19.8% of energy supplied to hot water tank. Sontake and Kalamkar [11] noted that the maximum efficiency of the collector at an inclined angle of 45° from the horizontal surface [12]. Kabeel et al. [13] were enhance the heat transfer in a solar water heater by using Cu nano-particles dispersed in water for various concentrations ranging from 0% to 5%. The water flow by the gravity of the reservoir, the discharge of water selected from 0.1 to 0.2 litter per minute, with accuracy of 0.005 L. Bhowmik and Amin [3] obtained from an observation that the collector efficiency and heat transfer rate are strongly depended on solar radiation. The radiation sent out by the collector absorber plate thus maximized the efficiency of the collector. The collector efficiency is recorded without and with reflector is 51–61% respectively. Prasad et al. [14] divided the solar collector energy into two types: air-type, used air as working fluid to transfer the heat. Another type, water (hydraulic), take the water as a heat transfers fluid. They show that the coefficient of heat transfers was low and thermal efficiency was low when used air-type, while when used water-type collector having high thermal performance. The solar water heater with circulating water through the tube of aluminum was tested and designed by Mongre and Gupta [15]. The efficiency was increased by fifty-five percent by increasing the area of glazing. Hernández and Guzmán [16] studies two flat plates' collector with the coil of different material, one of them is copper and the other coil stainless steel [17]. The objective of this article is to investigate the heating of water to use in many porpoises, as well as low cost.

2. Experimental

2.1. Methodology

The collector was designed of a rectangle shape of dimension 125 × 110 cm and width 25 cm, in such a way that fluid can flows from the inlet to outlet through the pipe with longer is 15.9 m, designed as lope square pattern as shown in Fig. 1(a) and (b) shows schematic of the flat plate collector. The absorber collector was insulation to decrease the heat loss by conduction through the collector, glass wool of thickness 5 cm was used to insulate the wall of inner collector faces, this face covered by aluminum foil sheet in order to increases heat absorber by the pipe because the aluminum foil sheet is a good reflector. The absorbed collector was covered with a transparent glass of thickness 2 mm to absorb the maximum amount of incident radiation. The inlet pipe connected with flow meter device, thermocouple, and controlling valve to control the volume flow rate, as shown in Fig. 2(a), also Fig. 2(b) the outlet pipe insulation and supplier by thermocouple to measure the temperature outlet of the water as shown in Fig. 3. **Accuracy**: The water flows by the force of pump device (0.5 hp) from the mean pipe. **Measuring range**: The water flow rate was selected (0.12–0.21 L/min).

2.2. Uncertainty

The uncertainty has been analyses employing the calculations done by Holman and Gajda [18], and were given in Table 1.

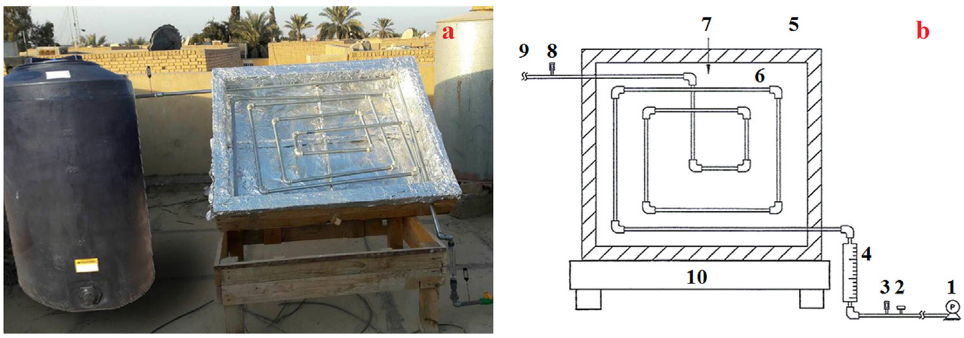

Fig. 1. (a) The rig device and (b) the schematic of rig (1 Pump, 2 Control Valve, 3 Thermocouple, 4 Flow meter, 5 Collector, 6 Pipe, 7 Aluminum Sheet, 8 Thermocouple, 9 Pipe outlet, 10 Stand).

Fig. 2. (a) Pipe at inlet and (b) pipe at outlet.

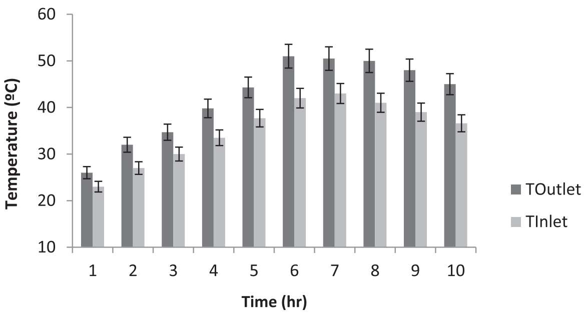

Fig. 3. Compare between inlet and outlet temperatures at flow rate 5.3 L/min.

Table 1
Uncertainty of the studied parameters.

Studied parameters	significance
Specific heat capacity (kJ/kg K)	± 0.12
Inlet fluid temperature (°C)	± 0.51
Mean temperature (°C)	± 0.51
Outlet temperature (°C)	± 0.52
Volume flow rate (m^3/s)	± 1.41
Collector efficiency	± 6.04
Effectiveness	± 8.22

3. Governing equations

In this work assumed that the flow rate of fluid and heat transfers were in steady state condition, the heat energy equation:

$$Q_u = mc_p(T_{out} - T_{in}) \tag{1}$$

$$\dot{m} = \rho Q \tag{2}$$

The collector efficiency can be determined by the equations [19]:

$$\eta = \frac{Q_u}{A_{cou} I_{Rad}} \tag{3}$$

The velocity of the water can be calculated by divided volume flow rate over the cross section of pipe:

$$V = \frac{Q}{A_{pipe}} \tag{4}$$

The mean temperature of the water:

$$T_f = \frac{T_{out} + T_{in}}{2} \quad (5)$$

Reynolds number can be calculated:

$$R_e = \frac{\rho VD}{\mu} \quad (6)$$

$$\varepsilon = \frac{T_{c,o} - T_{c,i}}{T_{c,o} - T_{c,i}} \quad (7)$$

4. Results and discussion

Renewable energy can be considered as an alternative energy source to meet the growing energy demand due to the scarcity and continuous depletion of conventional fuels. The most available source of renewable energy on earth is solar energy as the earth receives abundance of energy coming from the sun. Solar thermal collectors capture solar radiation which is then turned to thermal energy and transferred to a working fluid subsequently. Compared to other stationary collector such as flat plate solar collector (FPC), ETSCs have outstanding thermal performance due to lower heat loss, easy transportability, and quick installation. In addition, ETSCs are suitable for unfavorable climates [20–23], The collector system manufactured to study the performance of the solar heated water. All Figs. shows the value of the temperature at the inlet and the outlet during the sunny day from eight at morning to 3 pm, noted that the maximum temperatures in the half day because of radiation of the sun are stronger. the experimentally work contains two flow rates one of the 5.3 L/min but the other 6.51 L/min, the different outlet temperature at the two flow rates is shown in Fig. 3, and Fig. 4, the maximum temperatures at 5.3 and 6.51 L/min is 51.4 °C, 49 °C, respectively. This means if the flow rate increases the temperature decreases. Fig. 5, shows the average temperatures between outlet temperature at different flow rate (5.3 and 6.51 L/min), this average begin at temperature 29.2 °C at 9 am at morning and goes rising to maximum value 50.2 °C in the half day, then decreases gradually at 3 pm, this because of the radiation of the sun was also decreases. Fig. 6, shows the efficiency of the collector at the different flow rate, the Fig. 6 indicated that the efficiency at 5.3 L/min higher than the efficiency of the flow rate 6.51 L/min, this according to the flow, the slowly flow (5.3 m/L) absorbed more heat from sun than the flow (6.51 m/L). Fig. 7, shows the effectiveness of the collector at the different flow rate, the results recorded that the effectiveness of the collector at the flow rate (5.3 L/

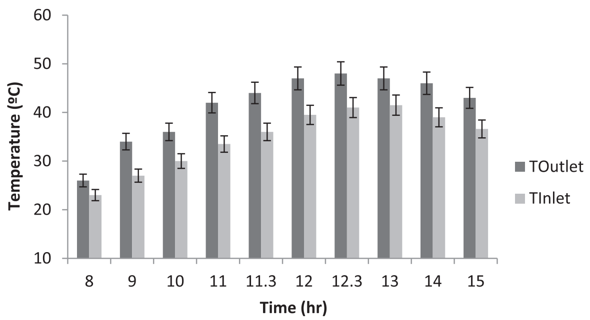

Fig. 4. Compare between inlet and outlet temperatures at flow rate 6.51 L/min.

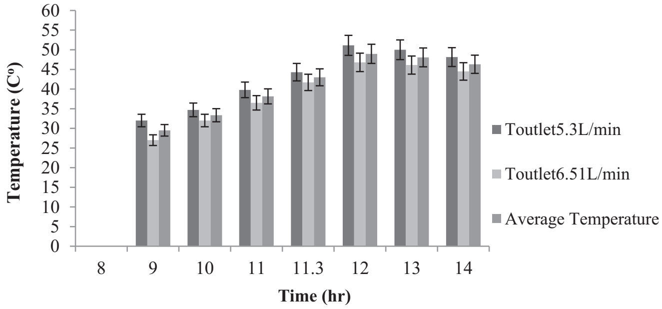

Fig. 5. Average outlet temperature at flow rate 5.3 and 6.51 l/min.

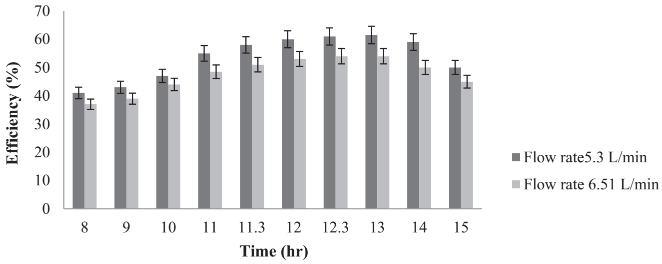

Fig. 6. Variation of the efficiency of different flow rate.

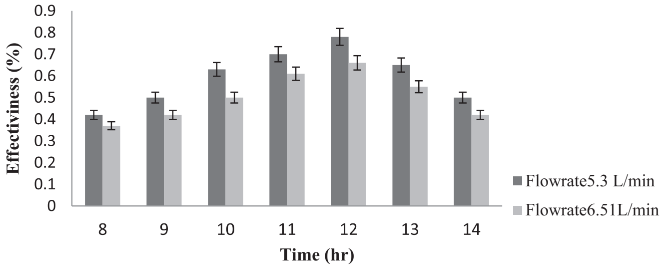

Fig. 7. Effect the flow rate on effectiveness of collector.

min) higher than the effectiveness of the collector at the flow rate (6.51 L/min), this because of the collector absorbed heat from the sun, hence increasing the temperature of the water flow in the pipe which increases the effectiveness of the collector. These results help us to exploit the sun's rays of use for heating water as well as in various uses.

5. Conclusion

This paper describes the major scenarios for solar thermal applications in Iraq by using the Solar water heating for flat plate collector. The results presented here demonstrate the water at flow rate 5.3 L/min heated more than the flow rate 6.51 L/min, because the collector observed the radiation of the sun slowly which causes the higher efficiency and effectiveness of the collector, so the maximum temperature was (51.4 and 49 °C) at flow rate (5.3 and 6.51 L/min) respectively. This system suitable for feeding anyway which needed to heating water because of its effectiveness of the collector and higher temperature.

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Competing interests

The authors declare that they have no competing interests.

References

[1] A.H. Jaaz, H.A. Hasan, K. Sopian, A.A.H. Kadhum, T.S. Gaaz, A.A. Al-Amiery, Outdoor performance analysis of a photovoltaic thermal (PVT) collector with jet impingement and compound parabolic concentrator (CPC), Materials 10 (2017) 888.
[2] A.H. Jaaz, K. Sopian, T.S. Gaaz, Study of the electrical and thermal performances of photovoltaic thermal Collector-Compound parabolic concentrated, Results Phys. (2018).
[3] H. Bhowmik, R. Amin, Efficiency improvement of flat plate solar collector using reflector, Energy Rep. 3 (2017) 119–123.
[4] A.E. Kabeel, E.M.S. El-Said, M. Abdulaziz, Thermal solar water heater with H2O-Al2O3 nano-fluid in forced convection: experimental investigation, Int. J. Ambient Energy 38 (2017) 85–93.
[5] E.M.S. El-Said, M.M.A. Abou Al-Sood, Experimental investigation of air injection effect on the performance of horizontal shell and multi-tube heat exchanger with baffles, Appl. Therm. Eng. 134 (2018) 238–247.
[6] H. Liu, W. Wang, Y. Zhao, Y. Deng, Field study of the performance for a solar water heating system with MHPA-FPCs, Energy Procedia 70 (2015) 79–86.
[7] A.E. Kabeel, E.M.S. El-Said, "A hybrid solar desalination system of air humidification dehumidification and water flashing evaporation Part I. A numerical investigation," Sixteen International Water Technology Conference, IWTC16, 2012.
[8] V. Weitbrecht, D. Lehmann, A. Richter, Flow distribution in solar collectors with laminar flow conditions, Sol. Energy 73 (2002) 433–441.
[9] S. Jaisankar, J. Ananth, S. Thulasi, S. Jayasuthakar, K. Sheeba, A comprehensive review on solar water heaters, Renew. Sustain. Energy Rev. 15 (2011) 3045–3050.

[10] A.L.G. Vendramin, C.I. Yamamoto, C.E.C. Nogueira, A.M. Lenz, S.N.S. Melegari, Analysis of the performance of a solar water heating system with flat collector, World Acad. Sci. Eng. Technol. Int. J. Mech. Aerosp. Ind. Mechatron. Manuf. Eng. 9 (2015) 386–389.
[11] V.C. Sontake, V.R. Kalamkar, Solar photovoltaic water pumping system – a comprehensive review, Renew. Sustain. Energy Rev. 59 (2016) 1038–1067.
[12] G. Notton, V. Lazarov, L. Stoyanov, Optimal sizing of a grid-connected PV system for various PV module technologies and inclinations, inverter efficiency characteristics and locations, Renew. Energy 35 (2010) 541–554.
[13] A.E. Kabeel, E.M.S. El-Said, S.A. El-Agouz, A theoretical study of Cu-H2O nano-fluid effect on heat transfer enhancement of a solar water heater, Int. J. Ambient Energy 38 (2017) 286–294.
[14] P.R. Prasad, H. Byregowda, P. Gangavati, Experiment analysis of flat plate collector and comparison of performance with tracking collector, Eur. J. Sci. Res. 40 (2010) 144–155.
[15] P.K. Mongre, B. Gupta, Experiment study of solar water heater with circulating pump and using of Aluminum tube, Int. J. Eng. Trends Technol. 3 (2013).
[16] E. Hernández, R. Guzmán, Comparison of three systems of solar water heating by thermosiphon, J. Phys. Conf. Ser. (2016) 012007.
[17] Y.F. Maydanik, Loop heat pipes, Appl. Therm. Eng. 25 (2005) 635–657.
[18] J.P. Holman, W.J. Gajda, Experimental Methods for Engineers, McGraw-Hill, 1978.
[19] B. Huang, T. Lin, W. Hung, F. Sun, Performance evaluation of solar photovoltaic/thermal systems, Sol. Energy 70 (2001) 443–448.
[20] G. Morrison, N. Tran, D. McKenzie, I. Onley, G. Harding, R. Collins, Long term performance of evacuated tubular solar water heaters in Sydney, Aust. Sol. Energy 32 (1984) 785–791.
[21] S. Kalogirou, The potential of solar industrial process heat applications, Appl. Energy 76 (2003) 337–361.
[22] R. Tang, Z. Li, H. Zhong, Q. Lan, Assessment of uncertainty in mean heat loss coefficient of all glass evacuated solar collector tube testing, Energy Convers. Manag. 47 (2006) 60–67.
[23] C. Xiao, H. Luo, R. Tang, H. Zhong, Solar thermal utilization in China, Renew. Energy 29 (2004) 1549–1556.