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EXPERIMENTAL STUDY OF NATURAL FLOW FLAT PLATE SOLAR WATER HEATER IN BASRA CITY

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A B S T R A C T

*Using solar energy for heating, cooking, desalination, electric generation and other human community requirements represents the best solution for two important world challenges, which are fossil fuel resources depletion and pollution. In this study, an experimental study for heating water by solar energy is performed at Basra city climate in Iraq. The city is located at Longitude: 47.78º and Latitude: 30.508º. The natural flow flat plate heater is directed towards the south with an angle of 30o with the horizontal. Tests for the solar water heater are implemented for five consecutive days from the month of July during the year 2021. For the present solar water heater, maximum temperature of the stored water was 48 ^{0}C, while the maximum measured temperature of the water leaving the collector is 85.9 0C The total pressure drop was calculated and it is found that the pressure drop in the collector constitutes approximately 25 % of the total pressure that causes the circulation. The maximum natural flow hot water rate is predicted to be 14*10 -4 kg/s. The maximum efficiency of the solar heater is expected to be 60 %.*

1. INTRODUCTION

Over the years, many researchers have focused their efforts on improving heat transfer (Abood et al., 2024; Abood, et al., 2023; Yaseen et al. 2024; Yaseen et al., 2022). On the other hand, the dwindling reserves of fossil fuels and the environmental pollution stemming from their combustion have spurred a quest for clean and sustainable energy alternatives (Majeed & Majeed 2022, 2024). Solar energy represents one of the most important available of renewable energy source (Majeed, 2023). The use of solar energy for the purpose of water heating is a widespread field and has been studied in many articles (Majeed et al., 2015).

(Ong, 1976) performed a theoretical model for evaluating the natural flow solar water heater. The numerical method was used for the prediction of temperature through the heating system. Validation of the theoretical model predictions with experimental results indicated a good agreement. Morrison et al. (2005) presented a numerical and experimental investigation of the evacuated tube solar water heater. A single full-scale evacuated tube with an inclination of 45o and coupled to

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a storage tank was tested. The results indicate that the natural flow circulation is sufficient to disturb the water in the storage tank and increase its temperature. (Bolaji, 2006) performed an experimental study on a natural flow solar water heater at Ado-Ekiti, Nigeria. The results indicate that the incident radiation and the flow rate through the collector have a large effect on the performance of the solar water heater. The maximum attained efficiency was 68.5 % and the corresponding water flow rate was 0.1 kg/s.m2. Also, the maximum temperature of water was 83.5 0C at an ambient temperature of 34.5^{0}C. (Al-Madani, 2006) performed an experimental study for water heater Bahrain climate. The water heater has cylindrical cross section. A cylindrical tube made from high quality glass and having length, outer diameter, and thickness of 0.8 m, 0.14 m, and 6 mm respectively was used. A pipe of copper with an inner diameter of 2 mm and painted black was inserted inside the cylindrical glass tube to serve as a collector for the incident solar energy. The test was carried in March and April 2002. The results indicate of 27 ^{0}C temperature difference for water through the water heater and 41.8 % of the efficiency. (Hammadi, 2009) performed a theoretical evaluation of flat plate water heater with natural circulation at Basrah city climate conditions. The results show that the best tilt angle for the collector according to Basra climate is about 50o. He predicted the average water temperature to be between 65 ^{0}C to 95 ^{0}C. (Hassan et al., 2023) investigated a novel solar water collector design featuring partitioned ducts that enhance thermal performance compared to conventional flat plate collectors. (Bouadila et al., 2014) performed an experimental study for a flat plate solar water heater equipped with thermal heat storage based on paraffin wax as a phase change material. Experimental tests were performed at different weather conditions and indicate that using thermal heat storage improved the efficiency of the solar water heater during the night. (Li et al., 2015) introduced a numerical simulation for the flow and heat transfer performance for an elliptical tube solar water heater with different initial temperatures. They showed that the temperature distributions in the tubes are similar, but the velocity profiles are much different. The simulation results are validated with experimental results and indicated good agreement. (Yang et al., 2017) in their article introduced an experimental investigation for a solar water heating system in Lhasa, which is located in a cold zone in China. Numerical calculations were also executed for the prediction of temperature distribution through the solar heating system. A theoretical correlation between the output temperature and the input temperature to the tank was obtained. (Swanepoel et al., 2021) discussed the potential for concentrated solar systems to generate power and pump water in rural areas with high solar irradiance. A helical coiled cavity receiver and low-cost solar dish concentrator are investigated to produce superheated steam at high pressures. According to their study, heat is captured, and temperatures and pressures are measured within the system, which results in efficient heat generation of 861 W. (Mohammed et al., 2020) studied experimentally the effect of injection small air bubbles into riser's tubes on the performance of the flat plate solar water heater. The results showed that the thermal efficiency could be enhanced by 3.5 % to 5.25 % using this method. (Bhakta & Singh, 2020) performed an experimental study on a solar water heater using parabolic concentrating system that has a perforated twisted tape inside the absorber tube. They found that the perforated twisted tape enhanced both the heat transfer and pressure drop and both of these parameters will be further enhanced by increasing the porosity of the twisted tape. (Bani Yaseen et al., 2020) experimentally studied the performance of natural flow solar water heater for Amman, Jordon climates. They proved that, the performance of solar heater is highly dependent on the mass flow rate and the intensity of the incident radiation.

In light of the urgent need to diversify energy sources and not rely on electric energy to meet the community's need for hot water for various purposes, whether in summer or winter, a prototype of a solar water heater will be tested practically to demonstrate the benefits of these systems. The system is evaluated within the conditions of Basra city to indicate the extent of success of these systems. Of course, this study will encourage the private sector in the city of Basra to produce such a system to replace the existing electrically operated heaters that consume high electrical energy.

Nomenclature

A	Area (m2).
Cp	Specific heat (J/kg.K).
H	Height of water storage tank (m).
I	Incident radiation (W/m^2)
L	Collector Length (m).
$\dot{m}$	Mass flow rate (kg/s)
P	Pressure (Pa).
Q_u	Useful heat energy collected (W).
T	Temperature (ºC).
T_∞	Ambient temperature (ºC).
x	Distance (m).
g	Gravitational acceleration (m/s2)
Greek symbols	
η	Collector Efficiency (%).
θ_o	Inclination angle of the collector
β	Thermal expansion coefficient (K-1)
Δ	Difference
ρ	Density (kg/m3)
Φ	Relative humidity (%)
Subscripts	
1,2	Denotes to collector inlet and outlet.
c	Collector.
i, o	Inlet and outlet.
f	Fluid

2. THE EXPERIMENTAL SETUP

Fig.1 demonstrate the present natural flow water heater, which consist from the steel plate, heating pipes, valves, connecting components and storage tank.

Figure 1. Images of the solar water heater

The heating pipes are fixed on the steel plate as shown schematically in Fig. 2.

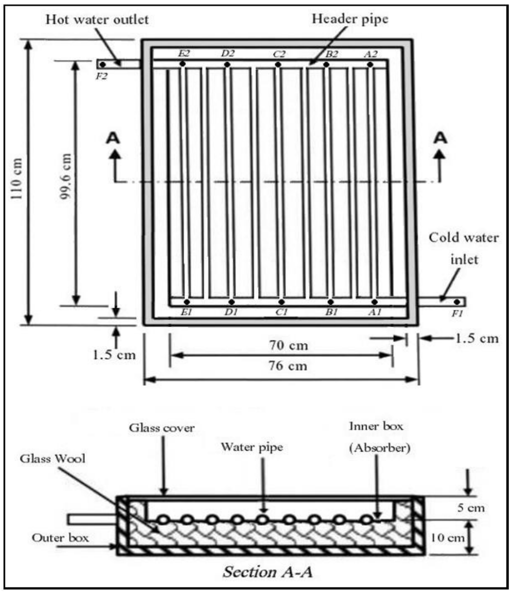

Figure 2. Schematic of the flat plate solar collect

The copper pipes are brazing on the plate to reduce the contact resistance and improve the heat conduction. The collector contains nine copper pipes; each of 94 cm long with 1.7 cm and 1.9 cm inside and outside diameters respectively. The pipes parallel with a space of 6.7 cm. The heating pipes are fixed by welding to the header pipes of 73 cm long with 2.6 cm and 2.8 cm inner and outer diameters respectively. The assembly of steel plate–copper heating pipes is put in a wooden box. The back side of the wooden box filled with glass insulation. The top of the water heater is covered by a glass of 4 mm thickness.

The final dimensions of the water heater are 110 cm in length, 76 cm wide, and 15 cm thick. The heat gain area is 0.836 m^2. The outer wooden box is fixed on an iron stand. The storage tank is positioned at 2.26 m in height. It has a capacity of 40 litters and is insulated using glass wool material.

The water heater orientation is in the position that, the water receives the maximum amount of heat from solar radiation. Optimum stationary tilt angle is 30^o towards the south at 30.51 latitude (18).

3. EXPERIMENTAL MEASUREMENTS

The locations of the temperature measuring points in the collector are shown in Fig. 2 by the black dots. Six points are for water inlet $T_{A1}, T_{B1}, T_{C1}, T_{D1}, T_{E1}, T_{F1}$ and another six points for water exit $T_{A2}, T_{B2}, T_{C2}, T_{D2}, T_{E2}, T_{F2}$. Besides, three temperature sensors are inserted vertically into the storage tank. The temperature was measured using digital thermometers for which the specification is given in Table 1. Suitable valves arranged are used at the highest point where the hot water inlet to the storage tank for measuring the flow rate by recording the time required collecting a fixed volume of water.

Table 1. Specifications of the Thermometer.

Item	Properties
Model	MTR12
Power supply	AC 230V, 50/60 Hz
Data display	Red LED display
Measurement capabilities	- 50 ~ 150 ^{0}C, Accuracy: ±2%.

4. DATA REDUCTION

The solar water heater efficiency given by (Bolaji, 2006):

$$\eta_c = \frac{Q_u}{I.A_c} \tag{1}$$

Where I is the solar intensity, A_c is collector area, and Q_u is the heat gain by the water heater, which is given by (Bolaji, 2006):

$$Q_u = \dot{m}Cp\left(T_{f2} - T_{f1}\right) \tag{2}$$

Where $\dot{m}$, is a natural water flow rate.

The operation of the natural flow water heater is shown schematically in Fig. 3. The driving force for the natural flow is the temperature difference and consequently the temperature difference between the inlet and outlet of the heating pipes. This difference for temperature and density is caused by the heat gain form the solar radiation. The frictional pressure drop, the total pressure drops (Bolaji, 2006):

$$\Delta P_t = \Delta P_1 + \Delta P_2 \tag{3}$$

Where ΔP_t, ΔP_1, ΔP_2 are the total pressure drop, pressure drop in the heating pipes and the pressure drop in the connecting tubes respectively.

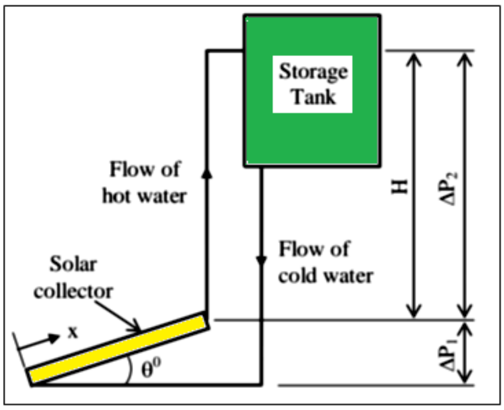

Figure 3. Effective pressure drops for solar water heater.

ΔP_1 estimated by the following relation:

$$\Delta P_1 = g.sin\theta_o \int_0^L (\rho_{f1} - \rho_x)dx \quad (4)$$

And ΔP_2 is calculated by (Bolaji, 2006):

$$\Delta P_2 = (\rho_{f1} - \rho_{f2})g.H \quad (5)$$

And the total pressure drop is calculated by:

$$\Delta P_t = gsin\theta_o \int_0^L (\rho_{f1} - \rho_x)dx + (\rho_{f1} - \rho_{f2})g.H \quad (6)$$

The variation of density is given by (Bolaji, 2006):

$$\rho(T) = \rho_o(1 - T\beta)^{-1} \quad (7)$$

Where β is the thermal expansion coefficient and ρ_o is the density at 0 °C. Eq. (6) becomes:

$$\Delta P_t = g\beta\rho_o.\begin{bmatrix} sin\theta_o \int_0^L (T(x) - T_{f1})dx + \\ H.(T_{f2} - T_{f1}) \end{bmatrix} \quad (8)$$

Using the temperature measurements, the integration in Eq. (8) is solved numerically using trapezoidal rule.

The flow rate of hot water through the cycle is calculated by using semi-empirical formula proposed by (Freegah & Al-Tabbakh, 2019).

$$\dot{m} = 189.498 * D * \mu * (T_{out}/T_{in})^{1.19} \quad (9)$$

Where D is the riser diameter, μ is the kinematic viscosity and T_{in} and T_{out} are the collector inlet and outlet temperatures in °C.

5. RESULTS AND DISCUSSION

In this section, the recorded data and the calculations obtained from the experiments performed using the solar water heater will be explained. The solar water heater tests are done for five consecutive days from 13/7/2021 to 17/7/2021 in the city of Basra. During testing, water temperatures at fifteen different points and the water mass flow rate are all measured hourly from 8:30 AM to 4:30 PM. For performance calculation, the average daily solar intensity for July was measured as 700 W/m2. This value for solar intensity was measured for the same time and location of solar water heater for solar chimney experiment for the same researcher (Rishak et al., 2021).

Fig. 4 shows the variation of storage water temperature with time and the average values for the five days of testing. The figure shows that the temperature increases gradually from 8:30 AM to 4:30 PM due to increasing the heat gain with increasing solar intensity. The attained temperatures are approximately the same for all the days except for the third day for which the temperature is lower. The decline in storage temperature is due to high wind velocity on that day which increases the heat lost from the system. The maximum temperature achieved is 48 °C.

Fig. 5 shows the variation of collector outlet temperature with time and average values for all five test days. Once again, the third day shows a different behavior with a lower temperature than its counterparts. The figure shows that there is a temperature rise from the morning to 10:30 AM, after that, the temperature drops. The main cause of this behavior is the water circulation between the collector and the storage tank. The cold water is re-interred in the collector and the hot water starts to accumulate in the storage tank. Approximately, there is a temperature rise of about 0.3 °C/min and a temperature drop of about 0.04 °C/min during the period 10:30 to 4:30 PM. The maximum measured hot water temperature is 85.9 °C and was obtained on the first, second, and fifth days.

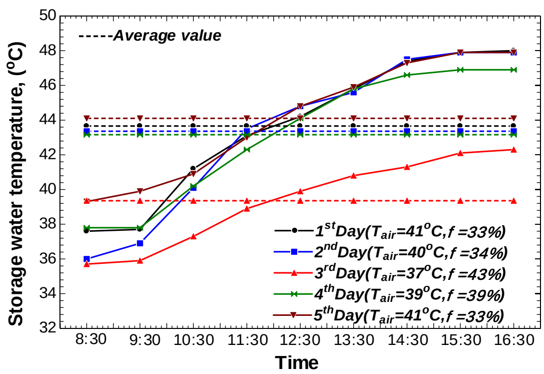

Figure 4. Variation of storage water temperature with time

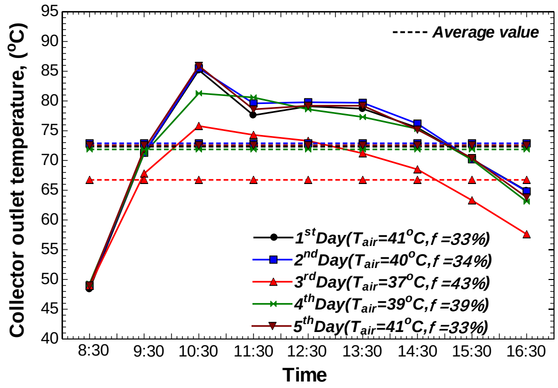

Figure 5. Variation of collector outlet temperature with time

Fig. 6 shows the variation of hot water flow rate over time. The natural circulating of hot water increases during the period 8:30 AM to 12:30 PM due to the increased buoyancy effect. After that, the flow rate decreases. Generally, the maximum flow rate occurs between 11:30 AM and 12:30 PM. The maximum average flow rate of hot water is recognized for the fourth day at 12:30 PM, which is equal to 2.56 liter per hour. The lowest flow rate is found on the third day.

Fig. 7 shows the variation of total pressure with time and the average values for all five days of the test. The results indicate that the variation has almost the same behavior for all the days. The pressure drop increases from 8:30 AM to 10:30 AM due to the increase in buoyancy effect and after that, the pressure drop starts to decrease. The maximum pressure drop is found for the second day while the minimum is for the third day. The average pressure drop is ranged from 0.34 to 0.37 kPa.

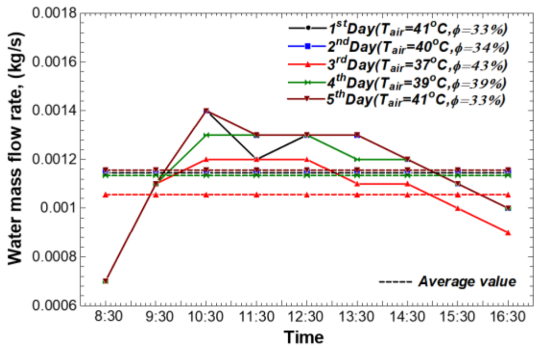

Figure 6. Variation of hot water flow rate with time

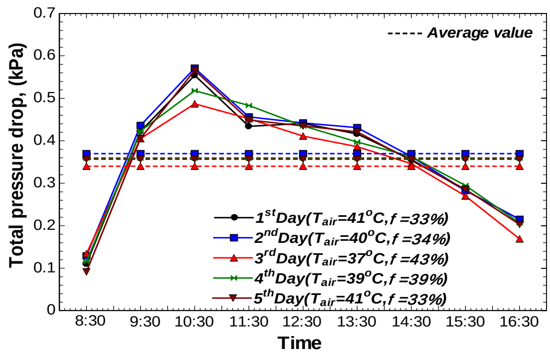

Figure 7. Variation of total pressure drop with time

Part of the pressure drop is due to the collector. Fig. 8 shows the variation of collector pressure drop with time and the average values for all five days of the test. The pressure drop of the collector increased from 8:30 AM to 10:30 AM due to increasing the heat gain and buoyancy effect, after that the pressures drop decreases. The maximum collector pressure drop occurs at 10:30 AM. It is found that the collector shares about 20 to 30 % of the total pressure drop.

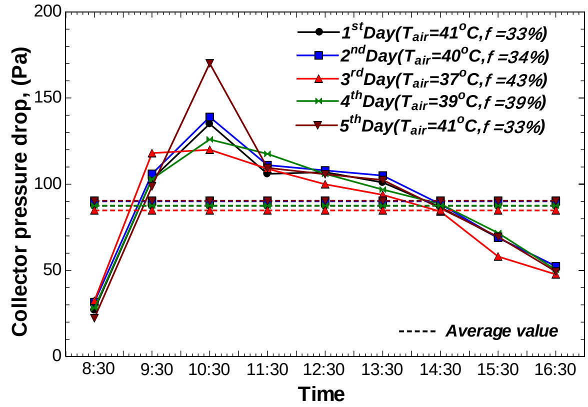

Figure 8. Variation of collector pressure drop with time

Fig. 9, shows the variation of collector efficiency with time for all five days of the test. The results show that the efficiency change behaviour is almost the same for all days except for the third day which is the lowest value. The collector efficiency increased from 8:30 AM to 12:00 PM, after that it starts to decrease. The maximum collector efficiency is recognized for the fourth day at 11:30 AM, which is equal to 60%.

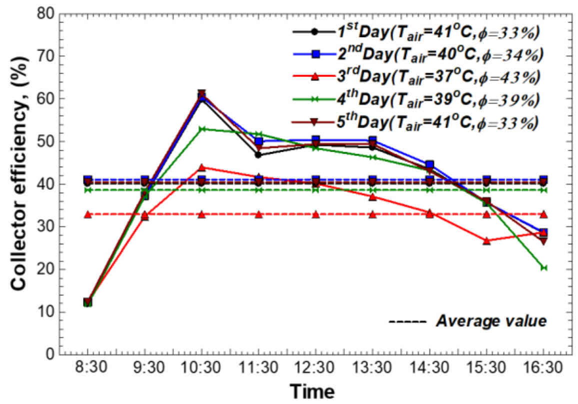

Figure 9. Variation of collector efficiency with time

6. CONCLUSION

The solar heater is fabricated and tested in Basra city conditions. The results show the possibility of using solar energy for heating water efficiently. For the present solar water heater, maximum temperature of the stored water of 48 ^{0}C, while the maximum measured temperature of the water leaving the collector is 85.9 ^{0}C. The total pressure drop was calculated and it is found that the pressure drop in the collector constitutes approximately 25 % of the total pressure that causes the circulation. The results explain that the efficiency of the collector could reach 60 %. The low efficiency due to depending on average value of solar intensity.

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