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Comparison between spiral and serpentine flow solar water heater

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Abstract

There are different designs of the flat plate collector and each one performs a different thermal performance. The present work includes the serpentine and spiral collectors. The experiment was conducted in Duhok city in Iraq. The same material and dimension were used for the serpentine and spiral collectors. The absorber plate area was 1 m^2 and the copper tube length was 7.8 m. The galvanized steel plate was used with a copper tube and a black coating to absorb the highest amount of heat. Autodesk inventor was used to designing the shape of the serpentine and spiral to be the same length. Both of the collectors gave a good performance, the spiral collector raised the water tank temperature from 32 – 56^{0}C while the serpentine collector raised the water tank temperature from 32 - 60.5^{0}C. The thermal efficiency of the serpentine collector was higher than the spiral collector. The paper displays all factors that affect the collector such as wind speed, solar radiation, ambient temperature, and used material.

Keywords: Spiral collector, Serpentine collector, Thermal efficiency, Galvanized steel sheet, Solar radiation.

1. Introduction

Nowadays, renewable energy is the best alternative to nonrenewable energy for all the countries that suffer from a financial economy. Solar energy can be used as an alternative to fossil fuels to save money and the environment. The solar collector converts solar radiation to thermal energy, heat is transferred from that thermal energy to the water, air or oil passed through the collector. It is costly to heat the water by using electricity or fuel, 20% of house electricity is consumed due to heating water [1]. 15% of china's people are using solar water heating as an alternative to electricity and fuel [2]. The storage tank and collector are the main components of the solar water heating system SWHS; the collector absorbs heat that comes from the sun while the tank stores hot water that is heated by the collector. There are two ways of circulating the fluid in the system: the first is called the active system which uses a pump or fan to circulate the fluid inside the system while the other type is called the passive system which is circulating the water without a pump or a fan, the water circulated depends on the density difference: cold water stays at the bottom while hot water moves upwards because the hot water has less density than cold water. [3] Were used the air and water to transfer the heat collected by the absorber. In the experiment, the water provided more thermal efficiency than the air. The solar collector is classified into two types, concentrating and non -concentrating collectors. A flat plate collector is a type of non -concentrating solar collector that has a simple structure and it is easy to maintain. The main components of the flat plate collector are the collector, absorber plate, and glass cover. The collector is installed on the plate inside the box while the box is covered with insulating material except for the front of the box which is covered with glass as the solar radiation reaches the collector through the glass cover. [4] Experimentally, the performance of the serpentine flat plate collector appeared, the area of the plate used in the experiment was 0.64 m^2. The copper plate and tube were used because they can absorb more heat than aluminum and steel. The experiment was going on for 8 hours, from 10 am to 6 pm in June. The capacity of the storage tank water was 60 liter and the solar irradiation was between 99-916 W/m^2. The temperature of the water was 36 ℃ which reached 45 ℃ throughout the experiment. [5] Experimentally, the performance of the serpentine flat plate collector appeared, the area of the plate used in the experiment was 2 m^2. The concrete absorber plate and copper tube were used in the experiment. The experiment was going on for 5 hours, from 11 am to 4 pm in April. The capacity of the storage tank water was 150 liter and the solar irradiation was between 650-1130 W/m^2. The temperature of the water was 44℃ and reached 69 ℃ throughout the experiment. [6] Experimentally, the performance of the spiral flat plate collector appeared, the length of the copper tube that was used in the experiment was 15 m and it was placed on the plate with an area of 0.5 m^2 area. The experiment was going on for 6 hours, from 8:30 am to 14:30 in December. The capacity of the storage tank water was 100 liter and the solar irradiation was between 525–654 W/m^2. The temperature of the water was 15℃ was reached 19℃. The maximum thermal efficiency of the collector was 35%. [7] Experimentally, the performance of the spiral flat plate collector while the system was the passive water heater system appeared. The area of the plate used in the experiment was 1 m2. The aluminum absorber plate and copper tube were used in the experiment. The experiment was going on for 5 hours, from 7 am to 6 pm in March. The capacity of the storage tank water was 55 liter and the solar irradiation was between 0-1000 W/m^2. The maximum temperature of the outlet water reached 95℃ through the experiment while the maximum efficiency of the collector was 66%.

The paper aims to compare the performance of the spiral and serpentine collector experimentally under the same weather conditions in Duhok city climate in Kurdistan of Iraq. Nowadays, the majority of people who lives in Duhok are using electricity to heat the water. The electricity is not available at all times and it is costly, due to that reason the best alternative of electricity to heat the water is the SWHS. The flat plate collector was used due to easy made and low cost than other types of solar water heaters. The steel plate absorber and the copper tube were used in the experiment. The steel plate is used because it is more available in the market and it is inexpensive compared to copper and aluminum.

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2. Materials and Methods

Two different shapes were designed for the flat plate collector FPC to compare between them. The spiral and serpentine flow were used as FPC in the experiment. The collectors were installed at an angle of 37 degrees in the north direction as shown in Figure 1.

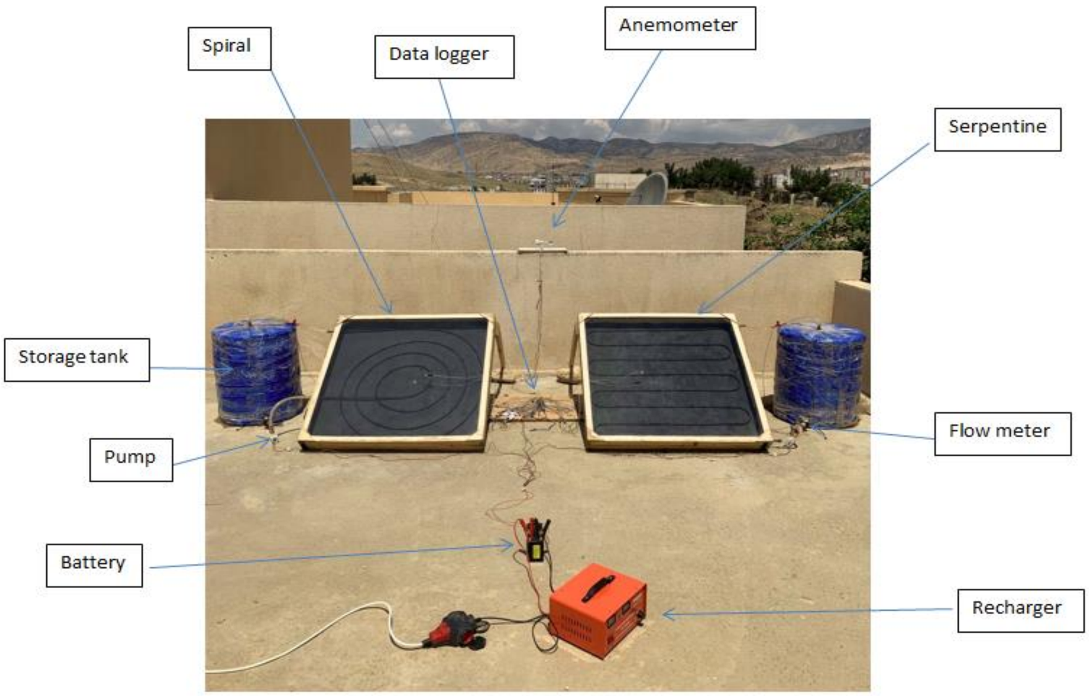

Figure (1): Solar water heating system

The 9.54 mm diameter copper tube is used because it is easy to bend. The capacity of the tank was 60 liter and the mass flow rate was 0.033 kg/s. The distance between the plate and glass cover is called an air gap, the distance between them was 8.5cm. Properties of the collector and items that were used in the experiment are shown in Table 1.

Table (1) Collector properties

Item	Dimension	Material
Absorber plate area	1 m^2	Galvanized steel
Raiser tube diameter	9.52 mm	Copper
Raiser tube length	7.8 m	
Distance between raiser tube	11 cm	
Air gap	8.5 cm	
Cover thickness	4 mm	Glass
Insulation thickness	1.7 cm	Wood

The 3 k-type thermocouples were used for each collector. WH-SP-WS01 Anemometer and SM-206 solar power meter were used in the experiment. The calibration is important to all the sensors and devices that are used in the experiment. Some of the thermocouples were neglected cause provide not accurate results. The data was collected using the Arduino mega and saved on an SD card using a data logger. The collector that was used is an active system while the pump was used to circulate the water as shown in Figure 2.

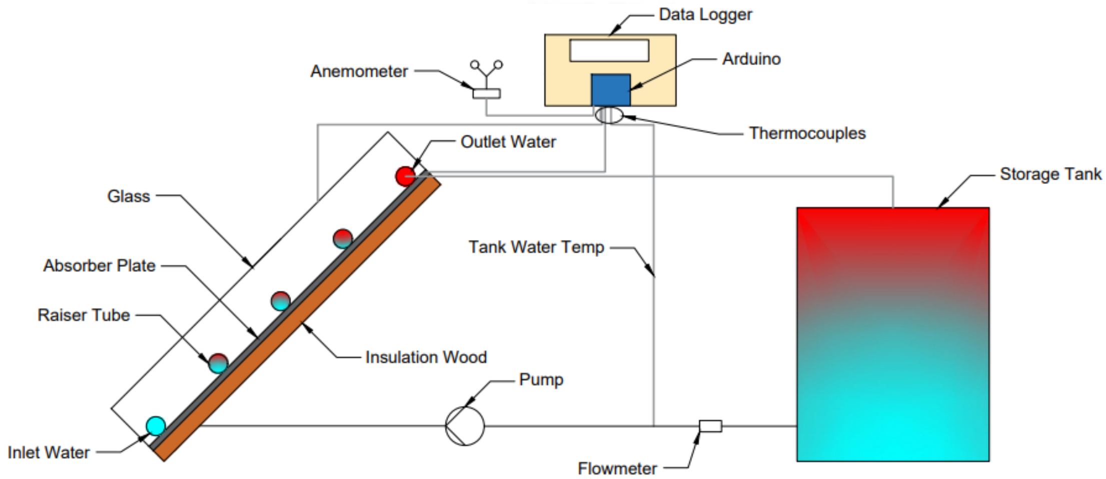

Figure (2): Schematic view of the collector

3. Mathematical Analysis

As shown in Figure (3), sun is the main source of the heat that heats the fluid in the system. The fluid temperature is increasing when solar irradiance increases. The rate of the heat in the absorber depends on the absorber area and solar irradiance, the large area of the absorber receives heat more than the small area. This heat can be measured according to Equation 1. [8]

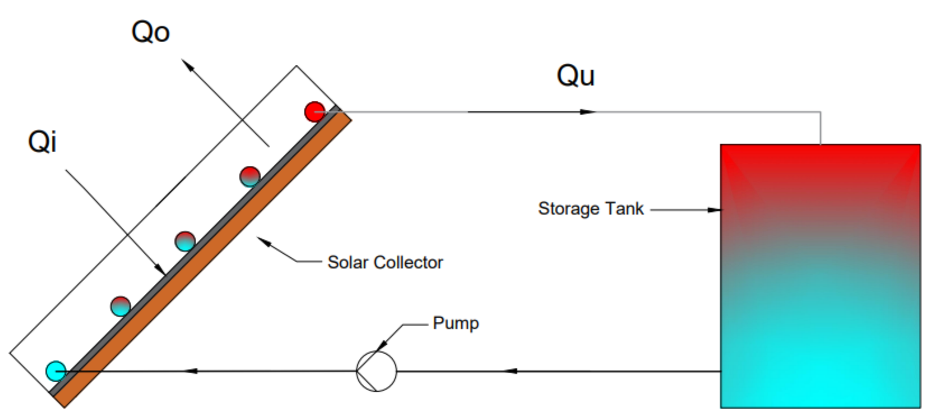

Figure (3): Thermal analysis

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$Q_i = IA$ (1)

Where:

Q_i (Solar heat that reaches the collector, w)

I (Solar Irradiance, $\frac{w}{m^2}$)

A (Area of the plate, m^2)

A glass and plate are not capable of absorbing all solar radiation, some of the heat is reflected, and due to that the transmitted heat through the glass can be denoted as τ, and the heat absorbed by the plate can be denoted as α to be added to Equation 1 as shown in Equation 2 where the value of τ = 0.89 depends on the angle of the collector and thickness of the glass while α = 0.81 depends on the plate material and color of the plate.

$Q_i = (\tau\alpha)\ IA$ (2)

The temperature of the absorber increases when the collector absorbs the solar heat, for this reason, the collector losses the heat, and are transferred from the absorber to the atmosphere by radiation and convection. This heat is called $heat\ losses\ Q_o$. The heat transfer is occurring between high temperatures of the collector Tp to the lower ambient temperature Ta according to Equation 3. [8]

$Q_o = U_L A(Tp - Ta)$ (3)

Where:

U_L (Overall heat transfer coefficient, $\frac{w}{m^2.°C}$)

Where: U_L can be calculated according to Equation 4. Where U_T, U_B, U_E need to be calculated as follows [2]

$$U_L = U_T + U_B + U_E \qquad (4)$$

Where: U_T is the top loss coefficient and can be calculated using the Equation 5. [2]

$$U_T = \left[\frac{N}{\frac{C_a}{T_p}\left[\frac{T_p - T_a}{N+f}\right]^e} + \frac{1}{h_w}\right]^{-1} + \frac{\sigma(T_p + T_a)(T_p{}^2 + T_a{}^2)}{\left[(\varepsilon_p + 0.00591Nh_w)^{-1} + \frac{[2N + f - 1 + 0.133\varepsilon_p]}{\varepsilon_g} - N\right]} \qquad (5)$$

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Where: h_w is the wind speed effect on the collector and can be calculating by using Equation 6 while and σ is Stefan's constant (σ = $5.67 \times 10^{-8}\ W/m^2K^4$). [9]

$$h_w = 2.8 + 3V \quad (6)$$

Where:

V (Wind speed, $\frac{m}{s}$)

$$C_a = 520(1 - 0.00005\beta^2) = 484$$

$$e = 0.43\left(1 + \frac{100}{T_p}\right) \quad (7)$$

$$f = (1 + 0.089h_w - 0.1166h_w\varepsilon_p)(1+0.07866N) \quad (8)$$

Where: ε_p is the effective emissivity of the plate, ε_g is the effective emissivity of the glass and N is the number of the glass cover. [2]

U_B is the bottom loss coefficient can be calculated according to Equation 9.

$$U_B = \frac{K_s}{L_s} \quad (9)$$

Where:

K_s *insulation thermal conductivity* $(0.04\ \frac{W}{m.k})$

L_s *insulation thickness* $(0.017\ m)$

U_E is the edge loss coefficient can be calculated according to Equation 10.

$$U_E = U_B\left(\frac{A_E}{A_c}\right) \quad (10)$$

Where:

A_E Is the edge area while A_c is the collector area.

Then the heat received by the fluid Q_u is measured using Equation 11. [2]

$$Q_u = Q_i - Q_o = (\tau\alpha)\ IA - U_LA(Tp - Ta) \quad (11)$$

The thermal efficiency of the collector is measured by Equation 12. [8]

$$\eta = \frac{Q_u}{Q_i} = \frac{(\tau\alpha)\ IA - U_LA(Tp - Ta)}{IA} \quad (12)$$

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These equations were used to know the thermal efficiency of each collector. The solar irradiance, plate temperature, ambient temperature, wind speed, and heat loss coefficient were needed to calculate the collector efficiency.

4. Results and Discussion

The spiral and serpentine collectors were experimentally compared on 29 May 2022. The serpentine and spiral collectors are the most common types used in flat plate collectors cause are inexpensive to design and easy to maintain. The experiment was going on for 6 hours on a sunny day. The starting water tank temperature for each collector was 32℃, and then it increased with time until it reached 56℃ for the spiral collector and reached 60.5℃ for the serpentine collector as shown in Figure 4. The serpentine collector performed better than the spiral collector because the heat loss coefficient in the serpentine collector was less than in the spiral collector. The average ambient temperature was 40℃. The water temperature rose in correlation with the rising solar radiation. The largest value of solar radiation was 942 w/m^2 at noon. The present work corresponds with [12] which used the thermal heat of the electric lamps as an alternative to solar thermal heat. The lamp produces 80% of the heat and 20% of the light therefore it is named the thermal lamp. The experiment was conducted in Egypt in 2019. The area of the collector used was 0.1 m2 and the thickness of the glass cover was 3mm. The experiment proved that the serpentine collector has better performance than the spiral collector and the efficiency of the serpentine collector is more than the spiral collector.

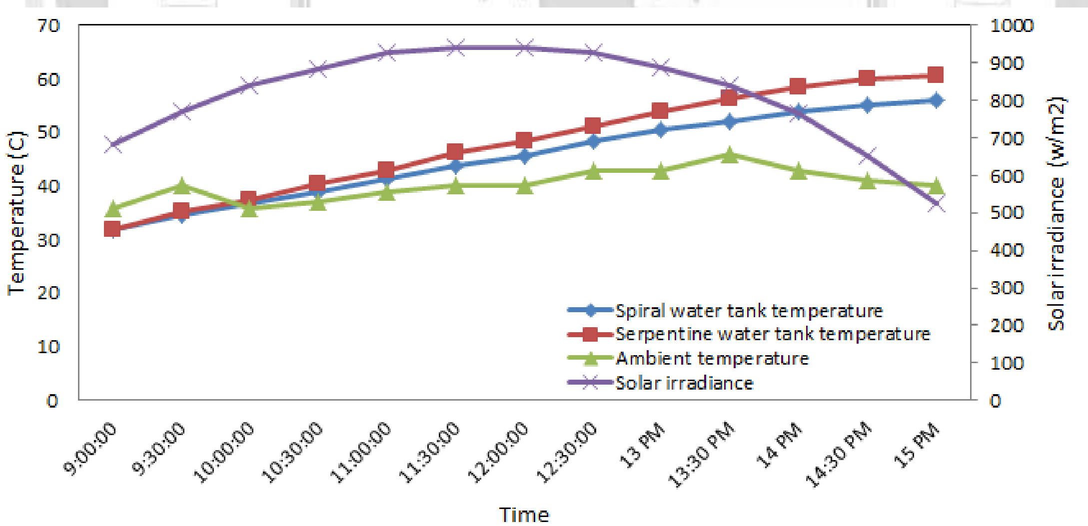

Figure (4): Change of water tank temperature and ambient temperature with solar irradiance

The serpentine collector benefited from the plate heat more than the spiral collector for that reason the water temperature in the serpentine was higher than in the spiral. The value of the plate and glass temperature is shown in Figure 5. The plate temperature in the spiral collector is more than in serpentine because the heat transfer from the plate to the fluid in the spiral collector is less than in the serpentine collector while the glass temperature of the spiral collector is close to the serpentine collector because the glass has the same thickness and the heat reflection and heat absorption of both glass covers in the collectors are close to each other. The serpentine collector benefited from solar radiation more than the spiral collector as shown in Figure 6. The maximum heat gain useful of the serpentine collector was 398 watts at 11 AM while the maximum heat gain useful of the spiral collector was 341 watts at 11 AM. However, the minimum heat gain useful of the serpentine collector was 174 watts at 15 PM while the minimum heat gain useful of the spiral collector was 169 watts at 15 PM.

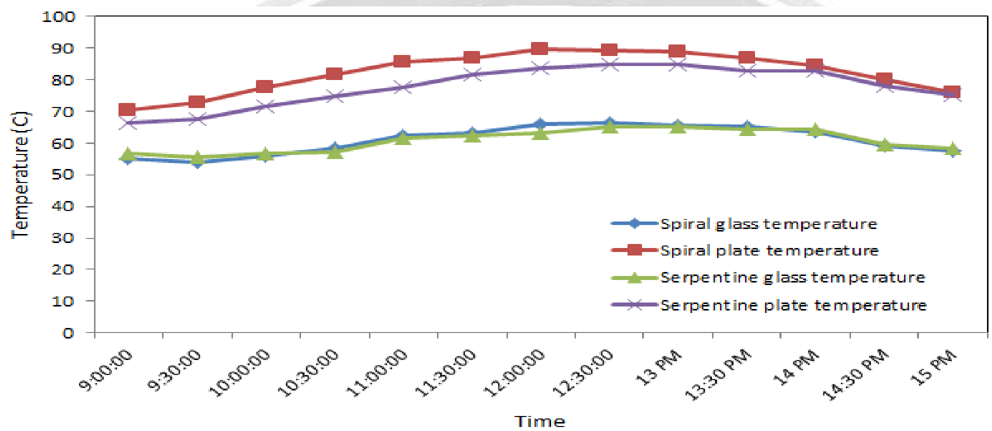

Figure (5): Comparison between the glass and plate temperature for spiral and serpentine collectors

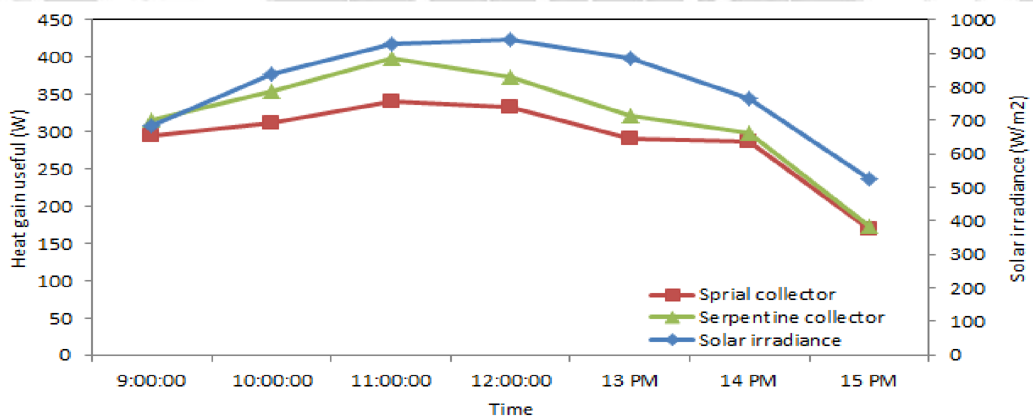

Figure (6): Heat gain useful with solar irradiance

The raiser tube absorbed the heat of the plate in serpentine more than the raiser tube in the spiral collector. The efficiency of the serpentine collector was more than the spiral collector as shown in Figure 7. The efficiency of the collector is decreased when the tank water temperature in increases. The highest value of the serpentine efficiency was 46% while spiral efficiency was 43%. The thermal efficiency of the flat plate collector depends on some items

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such as the plate absorber. The copper plate absorbs more heat than aluminum and steel plates for that reason the thermal efficiency of the copper plate is more than that of the aluminum and steel plates [10]. However, the thermal efficiency can be improved using a reflector. [11] Experimentally, the effect of the reflector on the flat plate collector appeared. The area of the collector was 1.05 m^2 while the reflector area was 1.85 m^2. The thermal efficiency of the collector was increased by 10% with the reflector.

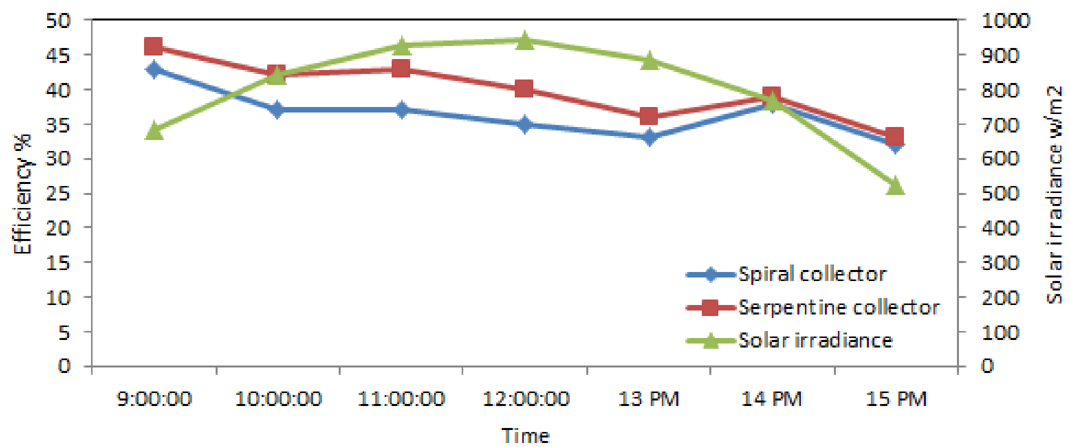

Figure (7): Thermal efficiency with solar irradiance

5. Conclusions

The spiral and serpentine solar collectors were compared under the same condition in Duhok city climate. The temperature at some different points in the collector was measured using the thermocouple, however, the wind speed and solar radiation were measured and the data were collected by the Arduino microcontroller. Wood was used as insulation for the collector while galvanized steel was used as the absorber, both of them are available in the market and it is inexpensive compared to other materials.

The following points are concluded by the obtained results.

1- The experiment evidenced that the serpentine collector was better than the spiral collector in terms of efficiency.

2- The serpentine collector reached maximum efficiency in the experiment of 46%.

3- Both of the collectors performed well which causes to increase in the water temperature to over 55 C, which can be used as an alternative to the electrical heater in residential houses.

4- The collector thermal efficiency decreases with increasing water temperature.

5- The serpentine shape is more accurate than the spiral shape to heat the water.

6- The area of the collector is suitable for use in residential houses.

7- The water temperature was increased by 29.5 ℃ in the serpentine collector for 6 hours only.

References

[1] K. Patel, P. Patel, and J. Patel, "Review of solar water heating systems," *Int. J. Adv. Eng. Technol.*, vol. 3, no. 4, pp. 146–149, 2012.

[2] M. S. Hossain, A. K. Pandey, M. A. Tunio, J. Selvaraj, K. E. Hoque, and N. A. Rahim, "Thermal and economic analysis of low-cost modified flat-plate solar water heater with parallel two-side serpentine flow," *J. Therm. Anal. Calorim.*, vol. 123, no. 1, pp. 793–806, 2016, doi: 10.1007/s10973-015-4883-7.

[3] P. R. Prasad, H. V Byregowda, and P. B. Gangavati, "Experiment analysis of flat plate collector and comparison of performance with tracking collector," *Eur. J. Sci. Res.*, vol. 40, no. 1, pp. 144–155, 2010.

[4] M. S. U. R. Mahadi, M. F. Hasan, A. Ahammed, M. T. Kibria, and S. Huque, "Construction, fabrication and performance analysis of an indigenously built serpentine type thermosyphon solar water heater," *Proc. 2014 3rd Int. Conf. Dev. Renew. Energy Technol. ICDRET 2014*, pp. 2–7, 2014, doi: 10.1109/icdret.2014.6861712.

[5] A. Sable, "Experimental and economic analysis of concrete absorber collector solar water heater with use of dimpled tube," *Resour. Technol.*, vol. 3, no. 4, pp. 483–490, 2017, doi: 10.1016/j.reffit.2017.06.001.

[6] M. R. Mohammad, D. A. Alazawi, and A. T. Mohammad, "Case study on spiral solar collector performance with lens," *AIMS Energy*, vol. 8, no. 5, pp. 859–868, 2020, doi: 10.3934/ENERGY.2020.5.859.

[7] S. Maheshwaran and K. Kalidasa Murugavel, "Experimental study on spiral flow passive solar water heater," *Appl. Sol. Energy (English Transl. Geliotekhnika)*, vol. 49, no. 2, pp. 89–92, 2013, doi: 10.3103/S0003701X13020060.

[8] M. F. Hasan, M. S. U. R. Mahadi, T. Miyazaki, S. Koyama, and K. Thu, "Exergy analysis of serpentine thermosyphon solar water heater," *Appl. Sci.*, vol. 8, no. 3, 2018, doi: 10.3390/app8030391.

[9] J. A. D. Deceased and W. A. Beckman, *Solar engineering of thermal processes*, vol. 3, no. 3. 1982.

[10] H. S. Hamood, B. M. Salim, and N. M. Abdulrazzaq, "Theoratical Analysis Of Flat Plate Solar Collector Placed In Mosul City By Using Different Absorbing Materials And Fluids," *Kufa J. Eng.*, vol. 6, no. 2, 2015.

[11] H. Bhowmik and R. Amin, "Efficiency improvement of flat plate solar collector using reflector," *Energy Reports*, vol. 3, pp. 119–123, 2017, doi: 10.1016/j.egyr.2017.08.002.

[12] M. B. Sidky, K. Haroun, N. Shukri, and K. Yacoob, "Performance Study of Different Types of Solar Water- Heaters Collectors," *ARQII Publ.*, vol. 3, no. 3, pp. 179–187, 2019, [Online]. Available: http://arqiipubl.com/ams.

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مقارنة بين سخان المياه الشمسي الحلزوني و المتعرج

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الخلاصة

هناك تصميمات مختلفة للمجمعات ذات الألواح المسطحة ولكل منها أداء حراري مختلف. يتضمن العمل الحالي مجمعات الحلزوني و المتعرج. أجريت التجربة في مدينة دهوك في العراق. تم استخدام نفس المواد والأبعاد للمجمعات . كانت مساحة اللوح الممتص 1 م ^{2} وطول الأنبوب النحاسي 7.8 م. تم استخدام الصفيحة الفولاذية المجلفنة مع أنبوب نحاسي بطلاء أسود لامتصاص أكبر قدر من الحرارة. تم استخدام مخترع أوتوديسك لتصميم شكل حلزوني و متعرج ليكون بنفس الطول. أعطى كلا المجمعين أداءً جيدًا ، حيث قام المجمع الحلزوني برفع درجة حرارة خزان المياه من 32 درجة مئوية إلى 56 درجة مئوية بينما قام المجمع المتعرج برفع درجة حرارة خزان المياه من 32 درجة مئوية إلى 60.5 درجة مئوية. كانت الكفاءة الحرارية للمجمع المتعرج أعلى من المجمع الحلزوني. يعرض الورق جميع العوامل التي تؤثر على المجمع مثل سرعة الرياح والإشعاع الشمسي ودرجة الحرارة المحيطة والمواد المستخدمة.

الكلمات الدالة: مجمع الحلزوني، مجمع المتعرج، كفاءة حرارية، ألواح فولاذية مجلفنة، إشعاع شمسي.