

An Experimental Investigation of the Efficiency of a Stationary Helical Solar Water Heater

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Abstract

The shape and geometry of a solar collector is an important factor in solar-to-thermal energy conversion. In this paper, a new stationary solar collector called helical solar collector was designed and investigated. The performance of this collector was experimentally studied using ASHRAE standard. Experiments were performed with water as a working fluid in the outdoor condition of Ahwaz, a city in the south of Iran. The findings indicate that the average of its thermal efficiency is about 53%, and that it can be used as an efficient new water heater. The experiments show that the efficiency of the helical solar water heater increases through adding the mass flow rate.



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Introduction

Due to increasing demand for energy and rising cost of fossil fuels, solar energy is considered an attractive source of green energy that can be used to heat water in domestic and industrial sectors. Solar water heating systems generally consist of a solar radiation collector, working fluid, a storage tank, a pump, a piping unit and an auxiliary heating unit^{1,2}. The most important factor in solar water heating is its efficiency. The efficiency of a solar water heating system is based on the proportion of useful energy that is received from the heated water to solar irradiance^{5,6}. Solar collectors' properties play the main role in the efficiency of solar water heating systems⁷. Scientists and engineers have been

seeking new ways to increase the performance of solar water heating systems in order to increase their performance and utility and to lower their costs. Numerous studies have investigated ways to increase the efficiency of solar collectors worldwide. Kalogirou reviewed several different types of solar thermal collectors and provided the relative thermal analysis and applications of each type^{8,12}. The efficiency value of a solar collector is largely affected by its absorbent surface¹³. The color, configuration factors and the heat transfer between the absorbent and working fluid are also important^{14,15}. The amount of heat transfer is a function of the employed working fluid, the type of contact between the absorbent and working fluid, area and the

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geometry of the absorbent and the collector^{16,17}. Many studies are carried out on heat transfer between the absorbent and working fluid and some focus on the geometry of the absorbent and the collector. These studies recommend gas-particle suspension¹⁸, fluid-film¹⁹ and metal-foam²⁰ to increase heat transfer. To maximize the overall incident radiation for a surface, solar tracking mechanisms are used, which can lead to an increase in the yearly solar radiation gain up to 1.45 times compared with optimal tilted solar collectors²¹. Since the operation of such tracking mechanisms is complicated, they are not cost-effective to be used in solar heating systems. Employing an appropriate and symmetric surface as in spherical or helical collectors makes it possible to eliminate the tracking mechanism with no obvious loss in their efficiency. The spherical solar collector has already been investigated by some researchers^{22,23}.

In this study, the efficiency of a helical solar collector with new geometry is experimentally investigated.

To obtain the efficiency of this collector, mass flow rate of the water as a working fluid, the heat transfer from the collector to the water and the solar energy received by the collector were measured.

Materials and Methods

In the present work, a novel type of stationary collector, namely, helical solar collector is proposed. It consists of a conical body, a glass cover, piping around the absorbing plate, isolated surface and working fluid that are shown in the Fig.1.

The main benefit of the helical collector is that it has symmetric sections in every side and has circular section when the incident beam radiation is normal to it at the top of collector shown in Fig.2.

This configuration enables this collector to collect incident beam radiation during the day. Other profits of this collector and the drawbacks of the existing collectors such as a flat plate solar water heater, as a common stationary solar collector, are shown in Table 1.

Table 1: Comparison between flat plate and conical solar collectors

Specification	Flat plate solar collector	Conical solar collector
Absorber area	1 m ²	1 m ²
Piping	Copper with 6.2 mm	Copper with 6.2 mm
Fixture	Metal fixture with 45 tilt angle	-
Isolation	Edge sides Bottom	Only bottom
Absorption ability of sunshine	Only upper side	Every sides
Install recommendation	According to location	Has symmetric geometry and do not need any recommendation for install
Total cost (Iran Rials)	8,030,000	7,500,000

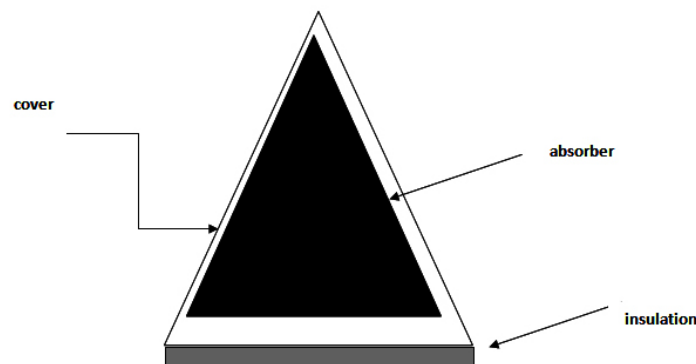


Fig. 1: The schematic draft of the conical solar collector



Fig. 2: Piping and cover install on the conical solar collector

Experimental Procedure

The schematic of the experimental is shown in Fig.4. This helical solar collector was experimentally investigated at Behbahan city, Iran (latitude is $30^{\circ} 36'$ N and longitude is $50^{\circ} 15'$ E. The relative collector position is shown in Fig.3.

The specifications of the helical solar collector used



Fig. 3: The conical solar collector used in this experiment

in this experimental test are presented in Table 2. The tilt angle of the collector is always 90° , so it is normal to the earth in every location.

The solar system is a force convection system with

Table 2: Specifications of the helical solar collector

Specification	Dimension	Unit
Diameter of absorber (conical body)	0.6	m
Absorber area	1	m ²
Absorber high (Con altitude)	1.07	m
Absorber thickness	1.5	mm
Thickness of Frame (totally glass)	6	mm
Thickness of pipe	1.1	mm
Diameter of pipe	6.2	mm
Weight	34	Kg
Thickness of Insulation (Polystyrene and wood)	20	mm

an electrical pump (6 in Fig.4). As shown in this figure, it does not have any cycles, so the system is open. Water was used as a working fluid in this collector. A flow meter (4 in Fig.4) was connected to the water tube before the electrical pump. Three K thermocouples were used to gauge the air temperature (10 in Fig.4) and the fluid temperature in the inlet (3 in Fig.4) and outlet (2 in Fig.4) of the helical collector. These thermocouples were connected to a channel data logger (TES data logger model). A TES solar meter was used to record the solar radiation. The calibration of the gauging instrument was undertaken before, during and after the experimental data gathering. An independently calibrated platinum resistance thermometer was employed to regulate the thermocouples; the flow meter was adjusted using a data logging sub-routine for water draw off from the collector into a container and measuring the mass with accuracy scales, and the solar meter using a calibrated reference solar meter with a valid calibration certificate.

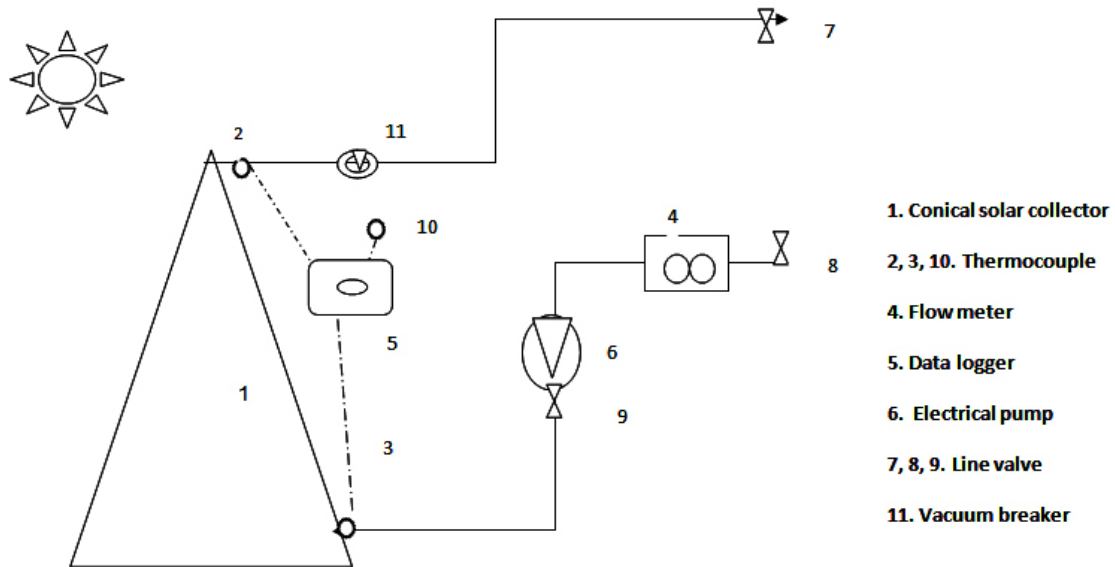


Fig. 4: Set up of the experiment

Test Method

ASHRAE Standard for testing the thermal efficiency of collectors is definitely the most widely used standard employed to test the performance of stationary solar water heater²⁴. The thermal performance of the solar collector is established by getting the values of instantaneous performance for different combinations of received radiation, ambient air and inlet fluid temperature²⁵. It necessitates experimental measurements to obtain the level of incident radiation and the amount of energy added to the working fluid circulating the collector at either steady state or quasi-steady-state conditions.

ASHRAE Standard recommends performing the experiments in various inlet fluid temperatures. After steady state conditions, the result for each test are averaged and used to derive a single point while other results are rejected. As the mass flow rate and input and output fluid temperatures of the fluid are measured, the useful energy can be obtained by means of equation (1). The useful energy can also be described on the basis of the energy taken in by the absorber and the energy lost from it as stated by equation (2).

$$Q_u = \dot{m}c_p(T_o - T_i) \quad \dots(1)$$

$$Q_u = A_c F_R [G_T(\tau\alpha) - U_L(T_i - T_a)] \quad \dots(2)$$

Where, c_p is the heat capacity of the working fluid.

The instantaneous collector efficiency relates the useful energy to the total incident radiation on the collector surface by equation (3) or (4).

$$\eta_i = \frac{Q_u}{A_c G_T} = \frac{\dot{m}c_p(T_o - T_i)}{G_T} \quad \dots(3)$$

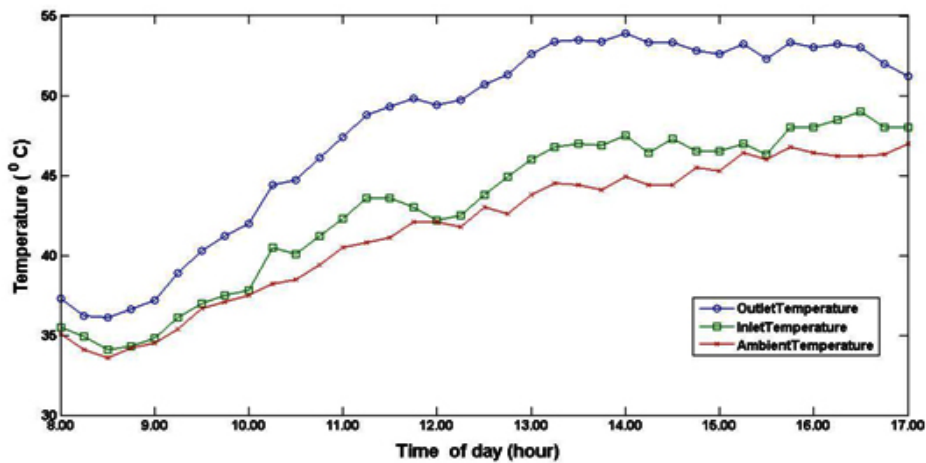
$$\eta_i = F_R(\tau\alpha) - F_R U_L \left(\frac{T_i - T_a}{G_T} \right) \quad \dots(4)$$

$F_R(\tau\alpha)$ and $F_R U_L$ are absorbed energy and energy loss parameters respectively. After testing the thermal efficiency of the solar collector, η_i can be calculated from the obtained data. Both remain unchanged when the efficiency tests are administered near the normal incidence conditions. Based on Eq. (4), if the data of efficiency tests are plotted, it will be a straight line with vertical axis as efficiency against $\frac{T_i - T_a}{G_T}$ as the horizontal axis. The intersection point of this line with the vertical axis shows the peak collector efficiency, when the inlet temperature of the collector is close to the ambient temperature. Also, at the intersection of this line with horizontal axis, stagnation point, the collector efficiency is zero and usually happens when the working fluid stops flowing through in the system.

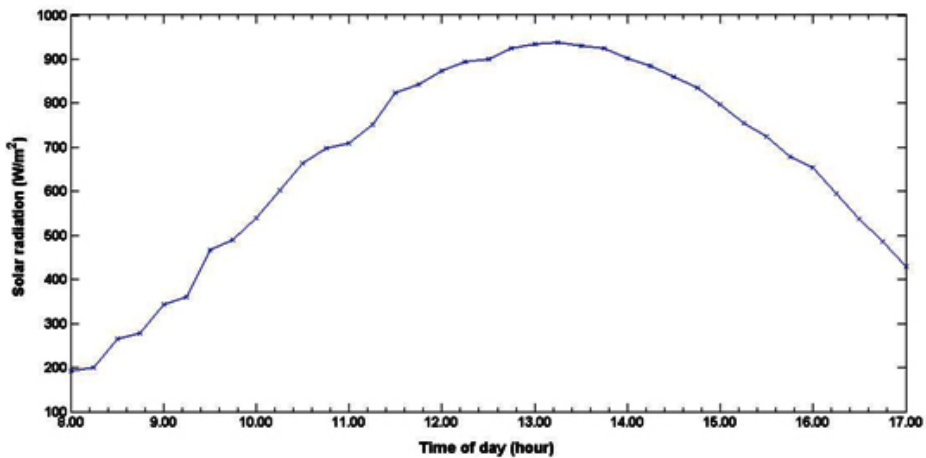
Results and Discussions

The experimental results consist of efficiency and changes in inlet-outlet temperatures in the helical solar collector. All the data were tested in a quasi-steady state condition. In each test, the highest differences in the inlet, outlet and ambient temperatures are 0.6, 0.6 and 0.5 °C, respectively and 19W/m² for solar radiation. The collector tilt angle is 90° and normal to the earth and use usual

water as working fluid. The tests were performed for many days in the latter part of summer during the day time at 8.00 to 17.00. The data were logged every 15 minutes. The experimental findings are given in the form of equations and graphs expressing the collector’s efficiency. Figure 5 illustrates typical data for working fluid at 1.1 Lit/min in one of the test days.



(a)



(b)

Fig. 5: Experimental data for 1 day. (a) Solar radiation. (b) Temperature profile

According to the experimental data and equation (3), the average efficiency of the helical solar collector in the outdoor condition of the test area was about 53%, which is suitable to use for a solar water

heating system in houses. Figure 5 shows that the difference between the inlet and outlet temperatures is high enough to use it as an appropriate solar water heater.

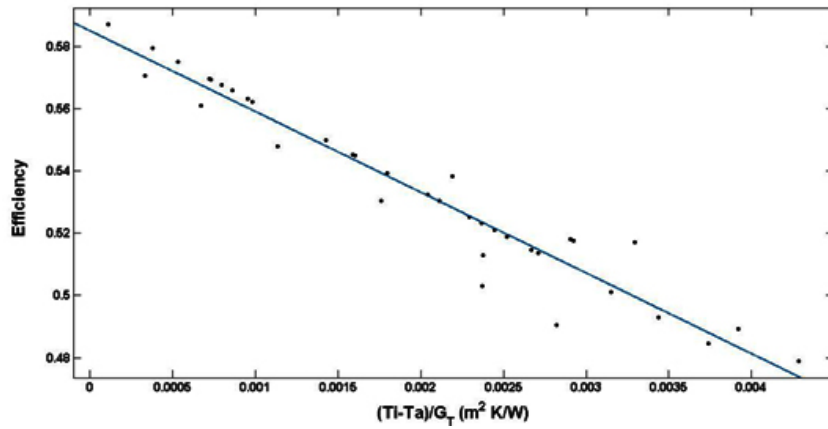


Fig. 6: The efficiency of the conical solar collector

Figure 6 shows the variation of collector efficiency versus the reduced temperature parameters, $(T_i - T_a)/G_T$ during the tests. According to equation (4) the efficiency of the helical collector decreases with increasing this parameter. Experimental results are fitted with linear equations to calculate the

characteristic parameters of this solar collector. The collector efficiency parameters, η_0 and β , are 0.585 and 0.585 respectively and the goodness parameter of the fitness, R^2 , is 0.937, which shows suitable fitting. These results are similar to previous works of Yousefi et al.^{2,4} and Goudarzi et al.⁹.

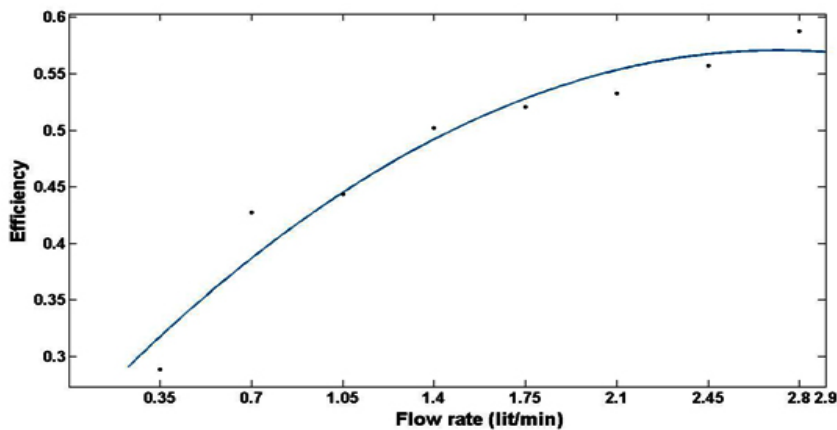


Fig. 7: The efficiency of the conical solar collector versus flow rate

Figure 7 illustrates the impact of flow rate on thermal efficiency of the conical solar collector. Based on this figure, the efficiency of the collector increases by adding to the flow rate. This trend is in line with the experimental works of Minsta et al.²⁶ and Cristofari et al.²⁷ In that they studied the effect of mass flow rate on a solar collector.

Conclusion

In this study, the efficiency and performance of a novel stationary solar collector with conical geometry was experimentally investigated. The temperature changes in the collector were experimented. The findings indicate that the average efficiency of a helical collector with 1 m² of absorber plate and

0.6 m diameter is about 53%. As shown in the diagrams, the instantaneous efficiency of the helical solar collector decreases as the ratio of temperature to incident radiation increases. The experiments showed that the difference between the inlet and outlet temperatures and the efficiency of the conical solar collector is satisfactory both in the morning and in the afternoon due to its special geometry. In

addition, the experiments showed that the efficiency of the conical solar collector increases by adding to the mass flow rate.

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