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Experimental investigation of efficiency of a novel conical solar collector

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Abstract. One of the methods to improvement of solar-to-thermal energy conversion is the design of geometry in solar collectors. In this paper, the new solar collector which is called solar conical collector has been designed and tested. The efficiency of solar conical collector was experimentally investigated by use of ASHRAE standard. Experiments were performed with water as a working fluid in the outdoor condition of Ahvaz city in the south of Iran. The results show that the average efficiency of a solar conical collector with 1m^2 area of absorber plate and 0.6m diameter of cone is about 53% and it can be used as a useful new water heater.

Keywords: Solar collector, collector testing, conical collector, efficiency, solar water heater

Nomenclature		T_i	Inlet fluid temperature of solar collector (K)
A_c	Surface area of solar collector(m^2)	T_o	Outlet fluid temperature of solar collector (K)
C_p	Heat capacity(J/Kg K)	U_L	Overall loss coefficient of solar collector(W/m^2 K)
F_R	Heat removal factor		
G_T	Global solar radiation(W/m^2)	*Greek symbols*	
$\dot{m}$	Mass flow rate(Kg/s)	$\tau\alpha$	Absorptance-transmittance product
Q_u	Rate of useful energy gained(W)	η_i	Instantaneous collector efficiency
T_a	Ambient temperature(K)		

INTRODUCTION

Solar energy is the most capable of the renewable energy sources. Due to increasing demand for energy and rising cost of fossil type fuels, solar energy is considered an attractive source of renewable energy that can be used for water heating in both homes and industry. Solar water heating systems are the cheapest and most easily affordable clean energy available. These systems generally consist of a solar radiation collector, working fluid, a storage tank, a pump, piping unit and auxiliary heating unit (Esen, and Esen, 2005; Yousefi et al., 2012).The most important factor in solar water heating is the value that called efficiency. Efficiency of a solar water heating system depends on the ratio of useful energy receive from the heated water to solar irradiance (Chen et al., 2012). Solar collector properties play main role in efficiency value (Kalogirou, 2006). Scientist and engineers are seeking new ways to increase this value in order to increase the performance and utility and also decrease the cost of system.

There are so many investigations about the increasing methods of solar collector efficiency all over the world. Kalogirou reviewed several different types of solar thermal collectors that uses commonly and do relative thermal analysis and applications of each type (Kalogirou, 2004; Tian and Zhao, 2013).

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The absorbent surface of solar collector is more effective on the efficiency value (Bogaerts and Lampert, 1983). The color, configuration factor and the heat transfer between absorbent and working fluid are important (Tripanagnostopouios et al., 2001; Orel et al., 2005). This heat transfer depends on kind of working fluid, kind of contact between absorbent and working fluid, area and geometry of absorbent and collector (Close, 1963; Parker et al., 1993; Kolb et al., 1999). Many of studies did on heat transfer between absorbent and working fluid and others focus on geometry of absorbent and collector. These studies propose using of gas-particle suspension (Bertocchi, 2004), use fluid-film (Bohn and Wang and Fend, 1988) and introduce metal-foam (Fend et al., 2004) to increase this heat transfer. For maximizing the incident global radiation for a surface, solar tracking mechanisms can be used. This can increase the yearly solar radiation gain up to 1.45 times more compared with an optimal tilted solar collector (Mousazadeh et al., 2009). Such tracking mechanisms are complicated and costly to operate and their use in solar water heating is not economically justified. Eliminating the tracking mechanism and keeping its benefits can be possible by using suitable and symmetric surface such as spherical or conical collector. Spherical solar collector has been investigated by some researcher (Samanta and Rajab Al Balushi, 1998; Pelece et al., 2008).

In this study, the efficiency of the conical collector as a solar collector with new geometry is experimentally investigated. In order to achieve the efficiency of conical collector, the water as a working fluid, pass due the collector and the heat transfer from collector to water and the solar energy received by collector is measured.

MATERIALS AND METHODS

2.1. Materials

In the present work, a novel type of stationary collector, namely, *solar conical 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 conical collector is that this collector has symmetric section in every side and has circular section when the incident beam radiation is normal to it in the top of collector, Fig. 2.

This configuration leads to conical collector be able and suitable to collect any week or powerful incident beam radiation during the day. The other profit of this collector is that it is most stable and do not need any fixture and structure to install.

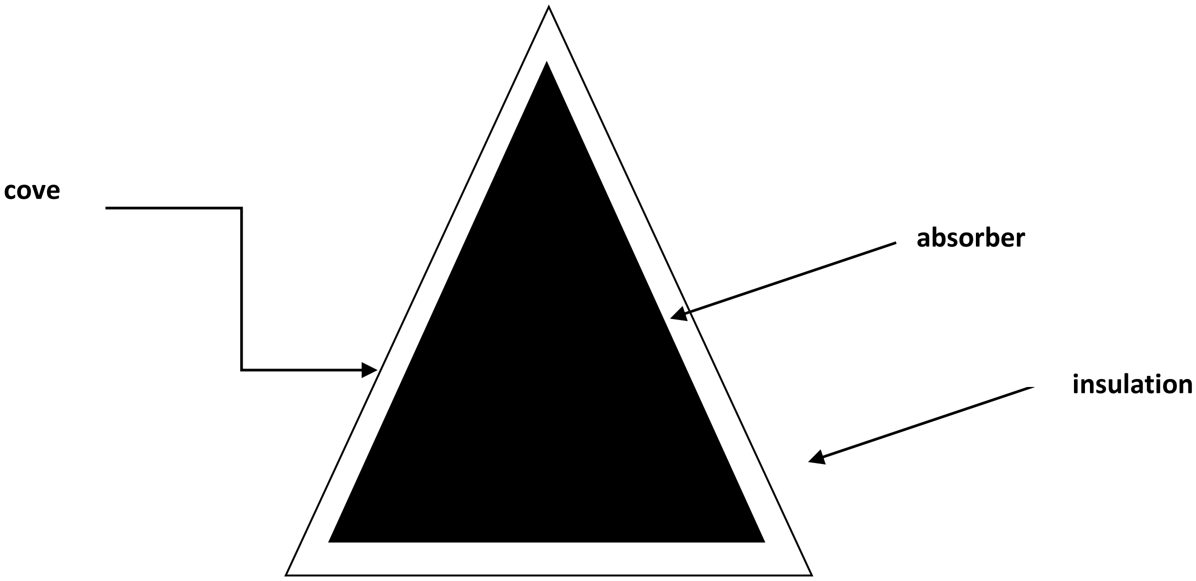


Figure 1. The schematic draft of conical solar collector.

Figure 2. Piping and cover install on conical solar collector.

2.2. Experimental procedure

The schematic of the experimental is shown in Fig. 4. The solar conical collector was experimentally investigated at the Shahid Chamran University of Ahvaz, Iran (latitude is $31^0\,19^{'}$ $16^{''}$ N and longitude is $48^0\,40^{'}\,16^{''}$ E). The relative collector position is shown in Fig. 3.

Figure 3. The conical solar collector that used in this experiment.

The specification of the solar conical collector that used in this experimental test is given in Table 1. The title angle of the conical collector is always 90^0, so it is normal to the earth in every location.

Table 1. The specification of the conical solar collector.

Specification	Dimension	Unit
Diameter of absorber (conical body)	0.6	m
Absorber area	1.0	m^2
Absorber high (Con altitude)	1.07	m
Absorber thickness	1.5	mm
Frame (totally glass)	t= 6	mm
pipe	D= 6.2, t= 1.1	mm
Weight	34	Kg
Insulation (Polystyrene and wood)	t=20	mm

The solar system is a force convection system with an electrical pump (6 in Fig. 4). As shown in this figure, the solar system has not any cycle, 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 pipe before the electrical pump. Three K thermocouple was used to measure the fluid temperature in the inlet (3 in Fig. 4) and outlet (2 in Fig. 4) of the conical collector and also the air temperature (10 in Fig. 4). These sensor were connected to a channel data logger (TES data logger model). The solar radiation was recorded by a TES solar meter. Calibration of measuring instrument was undertaken before, during and after the experimental data collection. Thermocouples were calibrated using an independently calibrated platinum resistance thermometer; flow meter using a data logging sub-routine for water draw off from the systems into a container and measuring the mass with accuracy scales, and solar meter using a calibrated reference solar meter with a valid calibration certificate.

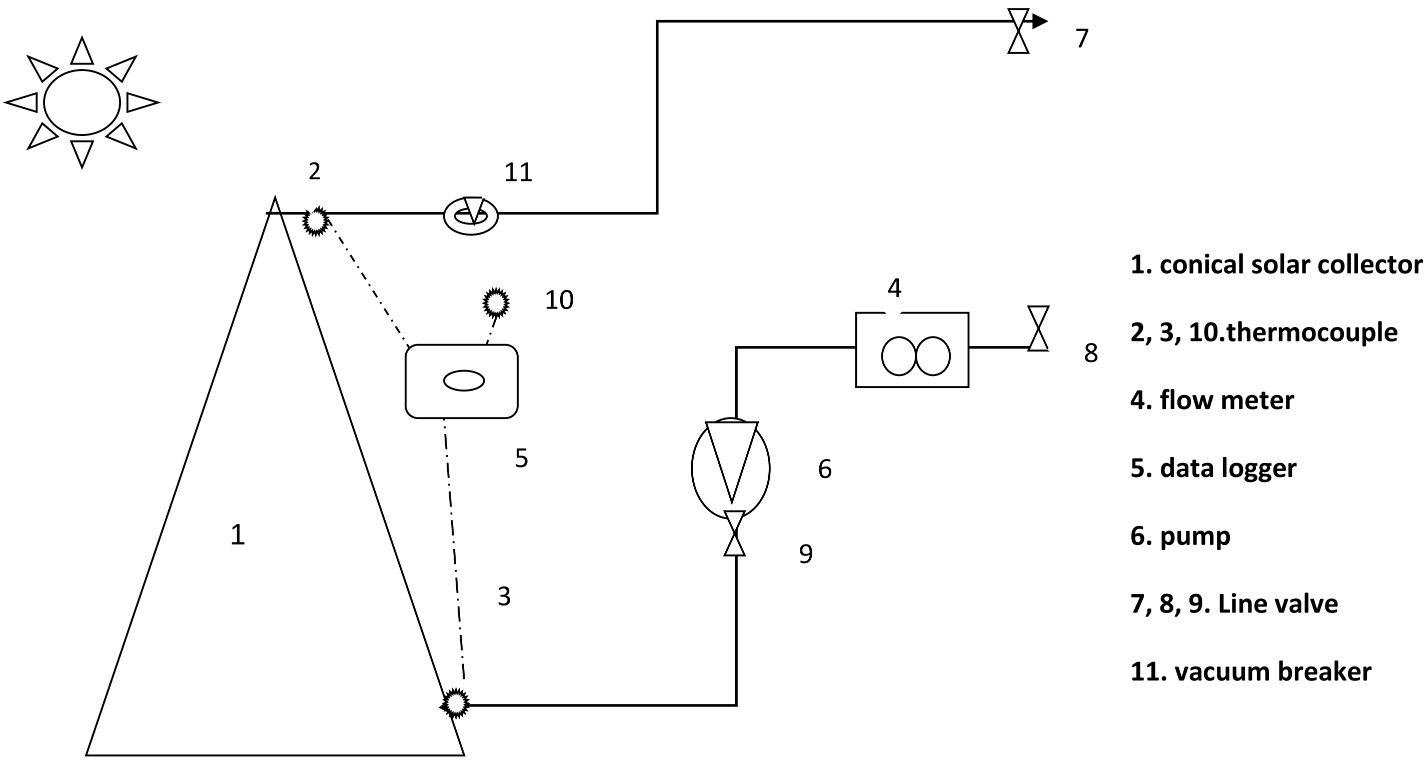


Figure 4. The schematic of the experiment.

2. 3. Testing method

ASHRAE Standard (ASHRAE Standard 93-86, 1986) for testing the thermal performance of collector is certainly the one most often used to evaluate the performance of stationary solar collectors. The thermal performance of the solar collector is determined by obtaining the values of instantaneous efficiency for different combination of incident radiation, ambient temperature and inlet fluid temperature (Duffie and Beckman, 2006). This requires experimental measurement of the rate of incident solar radiation as well as the rate of energy addition to the working fluid as it passes through the collector, all under steady state or quasi-steady-state condition s.

ASHRAE Standard (ASHRAE Standard 93-86, 1986) suggests performing the tests in various inlet temperatures. After steady state conditions, the data for each test are average and used in the analysis as a single point while other data are rejected. As the inlet and outlet fluid temperatures and mass flow rate of the water were measured, the useful energy can be calculated using equation (1). The useful energy can also be expressed in terms of the energy absorbed by the absorber and the energy lost from the absorber as given by equation (2).

$$Q_u = \dot{m}C_p(T_o - T_i) \qquad (1)$$

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

Where, C_p is the heat capacity of the water.

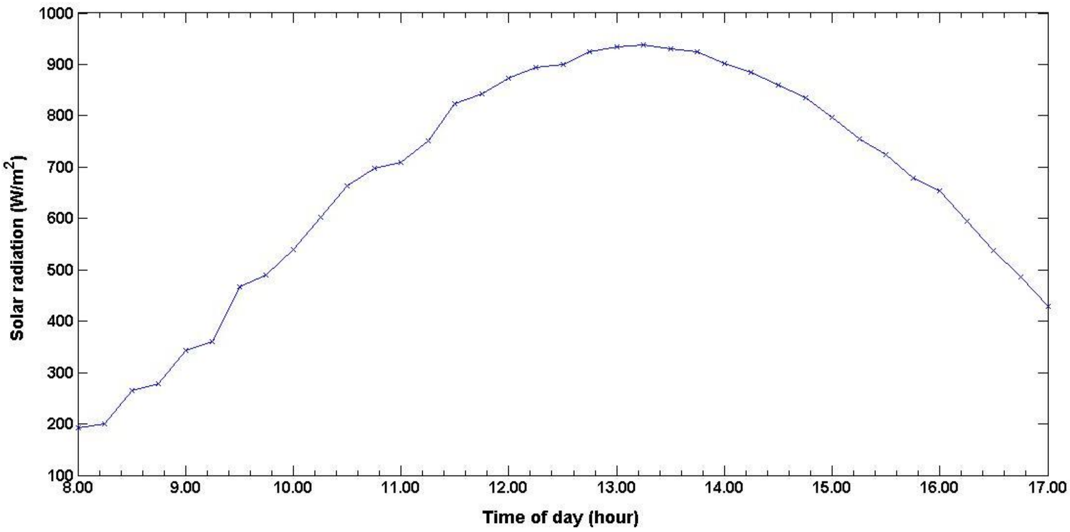
The instantaneous collector efficiency relates the useful energy to the total radiation incident on the collector surface by equation (3) or (4).

$$\eta_i = \frac{Q_u}{A_c G_T} = \frac{\dot{m}C_p(T_o - T_i)}{G_T} \qquad (3)$$

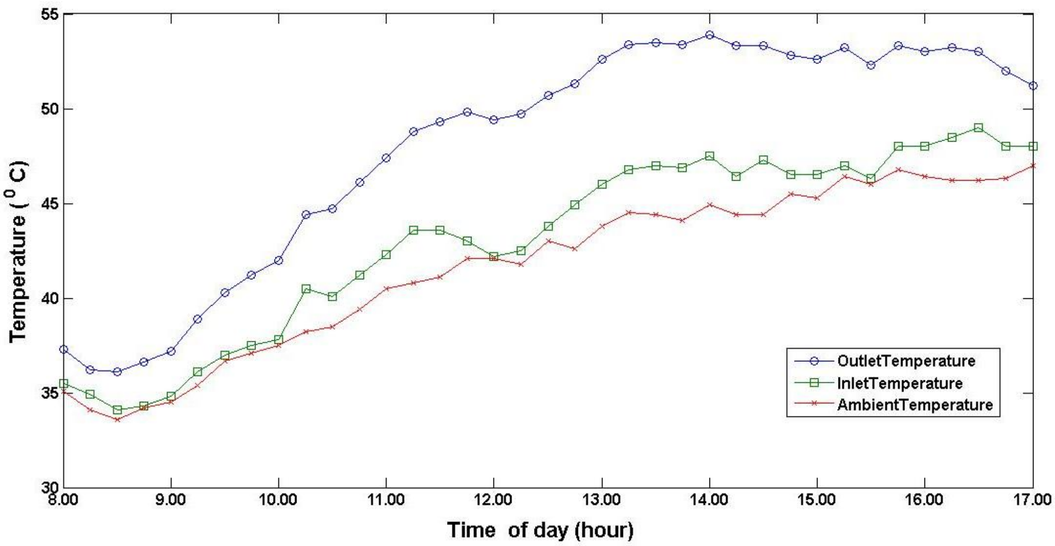
$$\eta_i = F_R(\tau\alpha) - F_R U_L\left(\frac{T_i - T_a}{G_T}\right) \qquad (4)$$

RESULTS AND DISCUSSIONS

The experimental results consist of performance and changing in inlet-outlet temperatures in the solar conical collector. All the data tested in a quasi-steady state condition. The maximum differences in inlet, outlet and ambient temperature and solar radiation in each test are 0.6, 0.6 and 0.5 ^{0}C for temperatures and 19W/m^2 for radiation respectively. The collector tilt angle is 90 ^{0} and normal to the earth and use usual water as working fluid. The tests of the collector take place for many days in the last of summer and performed during the day at time 8.00 to 17.00 o'clock. The data have logged every 15 minutes. The experimental results are presented in the form of graphs and equation that describe the collector efficiency. Figure 5 presents an example of typical recorded data for water fluid at 1.1 Lit/min in one of the test days.



(a)



(b)

Figure 5. Experimental data for 1 day**. (a)** Solar radiation. **(b)** Temperature profile.

According to the experimental data and using the equation (3), the average efficiency of the solar conical collector in the outdoor condition of test area was about 53% that is suitable for using as a water heater in house uses. Figure 5 shows that the difference between inlet and outlet temperature is enough to use as a goo solar water heater.

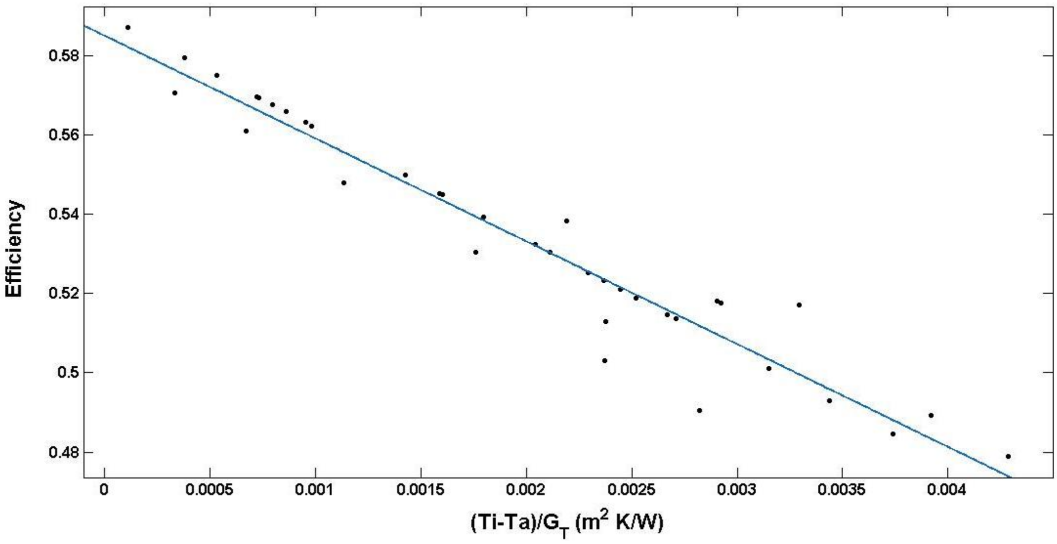


Figure 6. The efficiency of solar conical collector.

Figure 6 shows the variation of collector efficiency versus the reduced temperature parameters, $(T_i - T_a)/G_T$ during the tests. It is clear that the efficiency of the conical collector decreases with this parameter. The experimental data are fitted with linear equations to calculate the characteristic parameters of the solar conical collector. The collector efficiency parameters, $F_R U_L$ and $F_R(\tau\alpha)$, are 25.91 and 0.585 respectively and the goodness parameter of the fitness, R^2, is 0.937 that show suitable fitting.

CONCLUSION

In this research, the efficiency and performance of a novel stationary solar collector with conical geometry is experimentally investigated. The temperatures changing in the conical collector are experimentally studied. The results show that the average efficiency of a conical collector with 1 m^2 of absorber plate and 0.6 m diameter is about 53%. According to the diagram, it has been illustrated that the instantaneous efficiency of the solar conical collector decreases as the ratio of temperature to incident radiation increases. Also the experiments showed that the difference between inlet and outlet temperatures and the efficiency of solar conical collector is suitabl, because of the specially geometry of this collector.

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