HEFAT2010
7th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics
19-21 July 2010
Antalya, Turkey

TESTING THE THERMAL PERFORMANCES OF SOLAR COLLECTORS

Çağlar A.*[,1], Yamalı C.[1], Baker D.[1] and Kaftanoğlu B.[2]
*Author for correspondence
[1] Department of Mechanical Engineering, Middle East Technical University, Ankara, 06531, Turkey,
[2] Department of Manufacturing Engineering, Atılım University, Ankara, 06836, Turkey,
E-mail: acaglar@metu.edu.tr

ABSTRACT

The appropriateness of two flat-plate and one evacuated tubular solar collectors to drive an adsorption cooling cycle are investigated in the present paper. The thermal performance of the solar collectors is investigated for this reason. An experimental setup is established in accordance with EN 12975-2 standard. The collectors are tested according to this standard. The experimental setup, measurements and test procedure are described. Efficiency curves are obtained for each collector. Results show that the testing system is consistent within 6-11% when compared with certificated results. Testing results also show that the evacuated tubular collector is more suitable to drive the adsorption cooling cycle.

INTRODUCTION

Solar collectors have been increasingly used for both domestic and industrial purposes in different applications such as heating/cooling and electricity production [1,2]. The use of solar energy for cooling has a history of approximately 50 years. Adsorption cooling cycles have been developed to obtain a cooling effect without using electricity. Solar collectors are often used to drive these cycles. The ability to reach to the regeneration temperature of an adsorption cooling cycle and the collector size are important factors in the selection of an appropriate solar collector [3,4].

Depending on the purpose of the use, different types of solar collectors such as flat-plate or concentrating collector are selected. Regardless of the type, certification for solar collectors is essential for the manufacturers to sell their products confidently and the technical specifications of the collectors are guaranteed to customers with this certification. For certification, collectors must be subjected to reliability and thermal performance testing according to corresponding standards.

The thermal performance of a solar collector is determined by obtaining several instantaneous efficiency values at different collector inlet temperatures and different values of meteorological parameters such as incident radiation and ambient temperature [5]. Thermal performance testing is performed under either steady-state or quasi-dynamic weather conditions. An experimental setup is required to measure the incident radiation striking the collector, ambient temperature and fluid inlet and outlet temperatures for the collector. Moreover, an automatically or manually rotatable mechanism is needed to adjust the collector's tilt and orientation. A data-logging system is required to collect and process the data.

NOMENCLATURE

A	[m^2]	Collector Area
c_p	[J/kgC]	Constant-pressure specific heat
G	[W/m^2]	Solar global radiation
$\dot{m}$	[kg/s]	Mass flow rate of the water
T	[°C]	Temperature
t	[s]	Time
Special characters		
η	[-]	Efficiency of the collector
Subscripts		
a		Ambient
f,e		Fluid exit
f,i		Fluid inlet
m		Mean

Rojas et al. [6] studied and compared the performance of a well-designed flat-plate collector according to three different standards: ASHRAE 93; ISO9806-1; and, EN12975-2. The comparison showed that all three standards yielded similar results for the collector parameters. Sabatelli et al. [7] made a detailed sensitivity analysis that was conducted to determine the effect of uncertainties in measurements on the coefficient of the efficiency curve. The scope of the present study is to determine an appropriate solar collector supplying heat to an adsorption cooling cycle. This adsorption cooling cycle has been studied by Solmuş et al. [8]. The thermal performance and maximum available temperature of three different collectors are obtained under steady-state conditions for the choice of an appropriate collector to drive the cycle. Two of the collectors are flat-plate and the other is an evacuated tubular collector. EN 12975-2 standard "Thermal Solar Systems and Components-Solar Collectors-Part 2: Test Methods" [9] is used for the tests.

EXPERIMENTAL SETUP

A schematic view of the experimental setup is presented in Figure 1. The system components are listed in the Figure. Water is used as the heat transfer fluid and is circulated by a pump. Collectors are connected to the system with flexible pipes in order to change the collectors easily for testing. The supporting structure is designed in such a way that the tilt angle of the collector can be adjusted. The structure can also be rotated in the east-west direction to control the solar incident angle. The tank and piping are well-insulated to minimize thermal losses.

Several measurement devices are used to calculate the efficiency of the collectors. A pyranometer mounted on a plane parallel to the collector is used to measure the total (global) radiation striking the collector. An Eppley Lab Black and White type pyranometer is used. The pyranometer was calibrated by the EPLAB Company and is accurate within ±1.0 % for intensities up to 1400 W/m^2. The pyranometer was cleaned before each testing period. An electromagnetic flow meter (Krohne Optiflux 5000) with an accuracy of ±0.35% of measured value and a signal converter (IFC 100) are used to measure the volumetric flow rate of the fluid passing through the collector. A variable area type flow meter provides a redundant flow measurement to check the electromagnetic flow meter. Type T thermocouples with accuracy of ±0.5 ^{o}C are used to measure temperatures. Two thermocouples are used to measure the collector inlet and outlet temperatures of the fluid and one thermocouple is used to measure the surface air (ambient) temperature. For surface air temperature measurements, the thermocouple was positioned 2 m above the ground and placed in a Stevenson screen (a standardized well-ventilated white painted shelter). All digital measurement instruments are connected to a data acquisition (DAQ) system (Datataker DT85). Data are monitored, recorded and stored in a computer using the software (DeLogger) of the DAQ system.

Test Procedure

Tests were made during the summer season. A 15 min. test period is used for each steady-state data point. Fluid inlet temperatures varied between 39-88 ^{o}C during the tests. The mass flow rate is kept at approximately 0.02 kg/s per square meter of collector area. Data are not taken when the measured global radiation is below 700 W/m^2. All data points are for incident angles less than 20^o. Efficiencies are calculated for each data point.

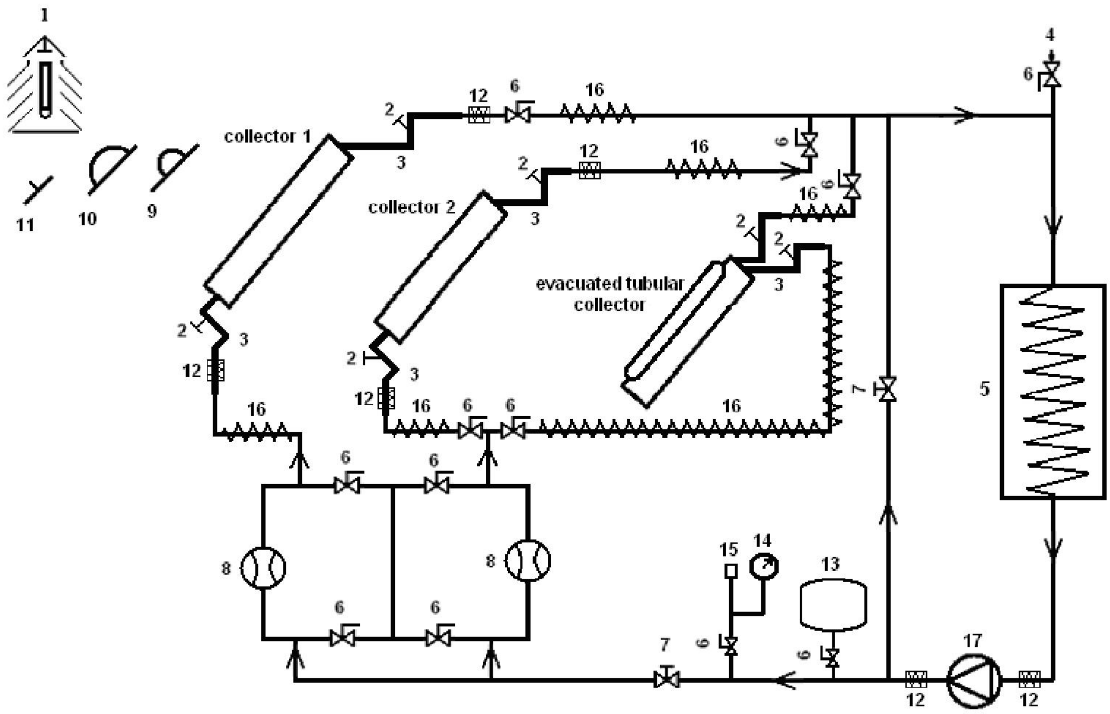

Figure 1 Schematic of the experimental setup (1. Surrounding air temperature sensor, 2. Thermocouples, 3. Insulated pipes, 4. Automatic purge valve, 5. Tank, 6. Ball valve, 7. Needle valve, 8. Flow meter, 9. Pyranometer, 10. Pyrheliometer, 11. Pointer, 12. Couplings, 13. Expansion tank, 14. Manometer, 15. Safety valve, 16. Flexible pipes, 17. Circulation pump)

The following equation is used to calculate the efficiency of the collector using data that are measured by the instruments on the experimental setup [10]:

$$\eta = \frac{\dot{m} \cdot c_p \cdot \int_{t_1}^{t_2} (T_{f,i} - T_{f,e}) \cdot dt}{A \cdot \int_{t_1}^{t_2} G \cdot dt} \qquad (1)$$

RESULTS AND DISCUSSION

Collector efficiency curves are obtained from the test results. Efficiency curves are usually defined with first or second order equations as a function of reduced temperature difference $(T_m-T_a)/G$ as follows [10]:

$$\eta = \eta_0 - a_1 \cdot \frac{T_m - T_a}{G} - a_2 \cdot \frac{(T_m - T_a)^2}{G} \qquad (2)$$

In this equation, η_o represents the efficiency when the inlet temperature is equal to the ambient temperature, and a_1 and a_2 are constants. The constants are found from the test results by utilizing the multivariate regression data analysis method in Mathcad. This analysis method is used since the equation of efficiency is not completely a second order equation and includes three independent variables, T_m, T_a, and G. The constants found can be used to calculate instantaneous collector efficiency once the temperatures T_m and T_a, and the total irradiation are known. Data points for the instantaneous efficiency of the flat-plate and evacuated tube collectors are as follows:

Flat-plate collectors (Collectors 1&2):

Figures 2 and 3 show the variation of collector efficiency with respect to a wide range of reduced temperature differences. The degradation in the efficiency occurs as expected with increasing reduced temperature difference.

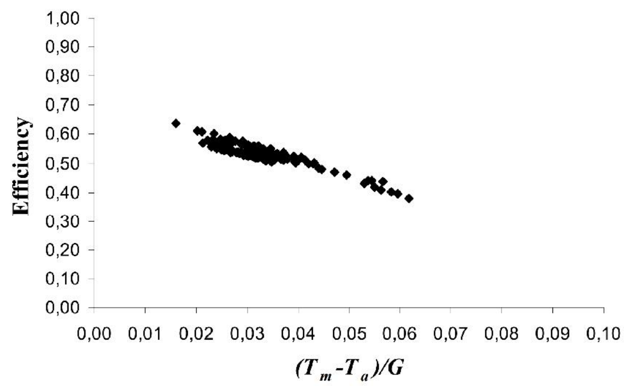

Figure 2 Efficiency of collector 1

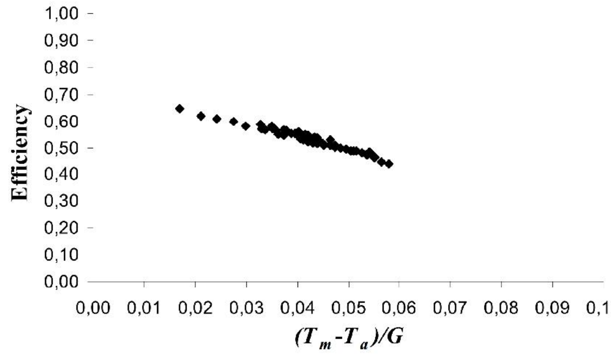

Figure 3 Efficiency of collector 2

Evacuated tubular collector:

Evacuated tubular collectors have high efficiency values and can reach high temperatures in a short time since they have very low heat transfer losses to the surroundings. They are usually manufactured to operate reliably for temperatures up to 200 °C. Figure 4 shows the variation of the efficiency of the evacuated tubular collector with respect to reduced temperature difference.

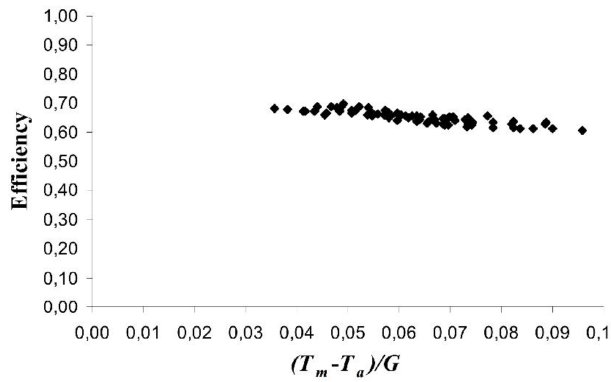

Figure 4 Efficiency of the evacuated tubular collector

Table 1 presents the coefficients of the collector efficiency equation for each of the three collectors as a consequence of processing test results. The Table also shows the maximum temperature of the collectors for two insolation levels.

Table 1 The coefficients of efficiency curves and the maximum fluid temperatures

Collector	η_o	a_1	a_2	Max. temp. G=500 W/m²	Max. temp. G=1000 W/m²
Flat-Plate 1	0.665	3.805	0.0082	75+T_a	135+T_a
Flat-Plate 2	0.735	4.715	0.0022	75+T_a	146+T_a
Evacuated Tubular	0.74	1.358	0.006	160+T_a	256+T_a

The maximum efficiency of the evacuated tubular collector is higher than the flat-plate collectors as seen in Table 1. This result is reached by means of the advantages of evacuated tubular collectors mentioned above. The differences between the evacuated tubular and flat-plate collectors are particularly dramatic when the maximum temperature is considered. The reason that the evacuated tubular collector can reach much higher temperatures than the flat-plate collectors is that the efficiency of the evacuated tubular collector decreases very slowly with increasing fluid inlet temperature resulting in a nearly horizontal curve.

The collectors were first tested by certificate authorities after their manufacture. Table 2 shows the certified results of the collectors.

Table 2 The certified results for coefficients of efficiency curves and the maximum fluid temperatures

Collector	η_o	a_1	a_2	Max. temp. G=500 W/m^2	Max. temp. G=1000 W/m^2
Flat-Plate 1	0.751	4.999	0.0000	75+T_a	150+T_a
Flat-Plate 2	0.78	3.591	0.0199	76+T_a	127+T_a
Evacuated Tubular	0.825	1.19	0.009	158+T_a	244+T_a

The efficiencies of the collectors calculated in the present study are shown to be lower than in certified results when Tables 1 and 2 are compared. The maximum efficiency constant, η_o, is seen to be lower in the present study. The difference in this constant reaches up to approximately 11% in flat-plate 1 collector. Approximately 6% and 10% degradations in this constant occurred for the flat-plate 2 and evacuated tubular collectors. However, the slopes of the efficiency curves are seen to be different for the two test results when one looks at the coefficients and the maximum fluid temperatures. Flat-plate 1 collector, for instance, has a lower a_2 value, so it has a smooth curve in the present study while the certified results display more parabolic behaviour. This implies that the efficiency decreases slower and the maximum temperature can reach higher values. In a similar manner, a slower decrease in efficiency with the fluid inlet temperature and ability to reach higher temperatures in the present study can be seen for the evacuated tubular collectors when comparing the two tables.

CONCLUSION

An existing adsorption cooling cycle is considered to be heated by a solar collector for regeneration process. Whether the collectors selected can drive the adsorption cooling cycle is investigated in term of mainly regeneration temperature. Results from two flat-plate collectors and an evacuated tubular collector tested according to EN 12975-2 standards are presented. The thermal performances of the collectors are evaluated by constructing an experimental setup. The constants of second-order efficiency equations are obtained for each collector. The evacuated tubular collector shows a higher maximum efficiency value and lower degradation in efficiency with increasing reduced temperature difference. The maximum temperatures are also calculated for two irradiation levels, 500 and 1000 W/m^2. The results indicate that an evacuated tubular collector is required for an adsorption cooling cycle with heat input at 150 ^{o}C. Evacuated tubular collectors are also more durable than the flat-plate collectors when operating at elevated temperatures around 200 ^{o}C. A comparison is also made between the present study and the certified results and the difference in collector efficiency varied between 6-11%.

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