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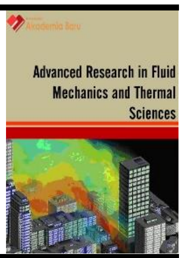

Evaluation of Solar Air Collector-Thermoelectric Hybrid System

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ABSTRACT

Solar energy is the most long-lasting, free, clean and renewable energy which cause zero-pollution to the environment. Recently, it has become a popular topic for the scientists to replace the fossil fuels as the primary sources of energy generation. To maximize the usage of solar energy, solar-thermoelectric air hybrid collector system is created and constructed, with size of 0.98m ×0.59m ×0.12m. The purpose of the combination of solar collector and thermoelectric is to collect hot air for drying purpose and generate electricity. The experiment is carried out in a laboratory with the usage of solar simulator, in which the solar intensity is fixed at 700 W/m2. The key factor which manipulating the experiment is the mass flow rate if the air flow through the hybrid system, which is set at 0.0333kg/s, 0.0385kg/s, 0.044kg/s, 0.0495kg/s, 0.055kg/s. The experiment investigation with the effect of different mass flow rate on the overall efficiency of the solar-thermoelectric air collector system is presented.

1. Introduction

In the era of development, finite resource of fossil fuels is one of the main issues for power generation in future [16]. A total of 4 million exajoules (1 exajoules = 1018 J) solar power supply to the earth annually and almost 5 X 104 EJ of it is easy to collect and convert to other energy. A total of 342 W/m2 of solar energy is collected around the earth, 30% of which are sent back to space and 70% of them (239 W/m2) are available for collection [10,14]. Therefore, in recent years, scientists have expanded their investigation in solar energy field as it is a clean, last-longing and essential energy, which is assumed to replace the fossil fuels in future [6].

Solar collector is one of the solar energy applications which collects heat energy from direct sunlight for drying and heating purpose [5,13,18]. Flat plat solar collector is the most popular type of solar collector as it can be easily installed, designed and built [9,11]. Mostly Aluminum would be the first choice for the absorber plate for the solar collector due to its high thermal conductivity properties and cheap [3,8]. To ensure the Al plate has high transmission absorption of light wave with low reflection rate, it will be painted black colour at the surface facing the sun [4]. To increase

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performance of the collector, some modification is done at the design of the plate by adding fins below it, in order to increase the total surface absorption of heat and hence increase the heat transfer within the solar collector [12,15].

Thermoelectric (TE) is a device that can transfer heat to electric through a phenomenon called Seebeck and Peltier effect [1]. In this paper, solar air collector-thermoelectric hybrid system is built in order to collect electrical and heat energy in the same time. Besides, TE also function as heat remover as it absorbs the heat from the solar collector and transfer it into electric. Hence, the energy per unit area increases and improves heat transfer rate of the solar air collector. Based on previous researches, there are only a few researches done on this hybrid system. So, the purpose of this research is to investigate the effects of thermoelectric on the thermal efficiency of a flat plate solar air collector, in the same time, to promote wider application of thermoelectric hybrid system.

2. Methodology

2.1 List of Components and Apparatus

In Figures 1 and 2 below, different sides of view of the hybrid system is shown. Thermoelectric coolers (TEC) are installed below the aluminum (Al) absorber plate. Table 1 below shows the specification of the components and apparatus used in this experiment.

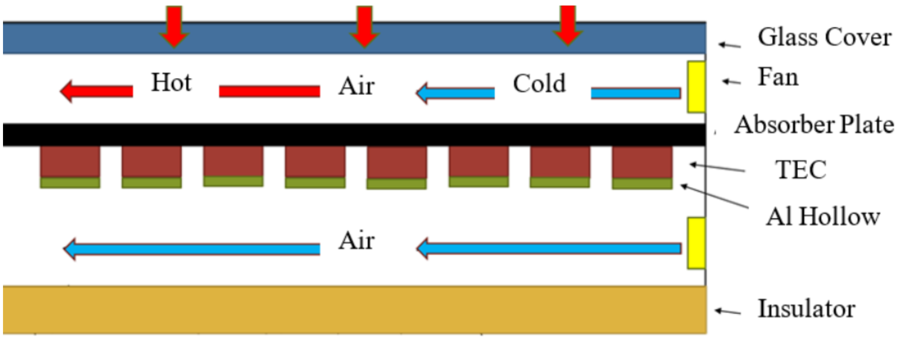

Fig. 1. The cross-sectional view of hybrid system

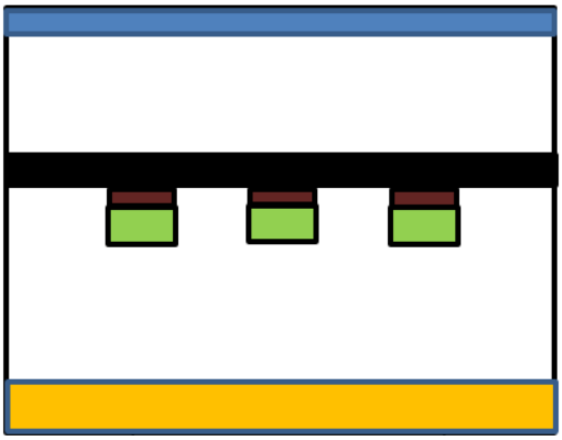

Fig. 2. The front view of hybrid system

Table 1
Specification of components and apparatus

Components and Apparatus	Specification
Solar Collector	97.5 cm x 59 cm x 12 cm
Glass Cover	97 cm x 55 cm x 0.6 cm
Al Hollow	76 cm x 5 cm
Al Absorber Plate	97.5 cm x 55cm
No. of Al Hollows	3 units
Distance between Al Hollow	7 cm
Pyrometer	EPPLEY Model 8-48
Data Logger	ADAM (Automated Data Acquisition Module)
Type of insulator	Silicon Rubber Sponge
Thermoelectric module	TEC1-12706
Thermocouple	Type K

2.2 Steps of Experiment

The experiment held in an indoor lab. Between the Al hollow and absorber plate, there are total of 36 TECs placed evenly in a row. Around the hybrid system, there are 16 thermocouples attached, which are connected to ADAM. The experiment began with adjusting the speed of fan, which was set to be 2.0 m/s, and measured by using anemometer. Next, after measuring the solar simulator by using the ADAM data logger, it was set to 700 W/m2. To obtain more accurate and precise data, before the experiment began, the fan and the solar simulator were turned on for 30 minutes for the stabilization of the system. Then it is left to run for 30 minutes before any data collection. After that, the light intensity of solar simulator, the electricity generated by the thermoelectric and the temperature of each thermocouple was recorded every 10 seconds automatically by using ADAM. The system was left to rest for another one hour after one hour run of the experiment. Before started changing the speed of fan with 1.2 m/s, 1.4 m/s, 1.6 m/s and 1.8 m/s, the experiment was repeated twice to collect the mean data.

2.3 Data Calculation

Air mass flow rate (kg/s) can be obtained from air velocity and calculated by

$$\dot{m} \quad = \rho A V_{av} \tag{1}$$

where
ρ = density of air (kg/m^3)
A = cross-section area of the output channel (m^2)
V_{av} = Average air velocity on the channel output

The thermal efficiency can be calculated by

$$\text{Thermal efficiency}, \eta_t = \frac{Useful\ Heat}{Heat\ Absorbed}$$

$$= \frac{\dot{m} C_p (T_0 - T_{i)}}{I A_c} \tag{2}$$

where
C_p = specific heat capacity of air (J/kg K)
I = light intensity (W/m^2)
$T_0 - T_i$ = temperature out – temperature in (K)
A_c = area of absorber plate (m^2)

The efficiency of the thermoelectric cooler can be calculated by

$$\eta_{tec} = \frac{Electricital\ energy\ generated}{Heat\ energy\ absorbed\ by\ hot\ surface\ of\ TEC}$$

$$\eta_{tec} = \frac{(T_h - T_c)}{Th} \frac{\sqrt{1+ZT_m - 1}}{\sqrt{1+ZT_m} + \frac{T_c}{T_h}} \quad (3)$$

where
T_m = average temperature TEG $(T_h+T_c)/2$ (°C)
Z = material quality factor
$T_h - T_c$ = temperature of hot surface – temperature of cold surface (of TEC)

According to the research, type of Tec used in the experiment is TEC1-12706, where its z-value of 2119 K^{-1} is given for the calculation of the electrical efficiency [17]. Referring to the research, the overall efficiency of the hybrid system can be calculated using the following formula [2].

$$\eta_{\text{total}} = \frac{Qu + P_e}{SA} \times 100\% \quad (4)$$

where
Qu = Useful heat (W)
P_e = Electrical power generated (W)
S = Light intensity (W/m^2)
A = Surface area of solar collector (m^2)

3. Results

3.1 Pressure Distribution

Table 2
Mass flow rate versus thermal, electrical and overall efficiency

Mass Flow Rate, $\dot{m}$ (kg/s)	Thermal Efficiency, n_t(%)	$T_{back} - T_{hollow}$, (°C)	Electrical Efficiency, n_{tec} (%)	Overall Efficiency, n_{total} (%),
0.0330	66.4	16.7	5.3	66.4
0.0385	70.2	13.9	4.4	70.2
0.0440	72.5	12.4	3.9	72.5
0.0495	73.4	10.3	3.3	73.4
0.0550	79.0	9.2	2.9	79.0

As the mass flow rate increases from 0.033 kg/s to 0.055 kg/s, the thermal efficiency increases from 66.4% to 79% due to more heat transfer from the absorber plate to the air flow inside the collector. $T_{back} - T_{hollow}$ value shows the temperature difference between cold and hot surfaces of the TEC, which is attached to the aluminium hollow and back of absorber respectively. It reaches the lowest which is 9.2 ℃ at the highest mass flow rate. This is because the rate of heat transfer from the absorber plate and Al hollow to the fluid has been increased due to the high speed of flowing air. The electrical efficiency increases with the $T_{back} – T_{hollow}$ value while the overall efficiency increases with the mass flow rate. The electricity generated falls in the range of 10.383 mW to 13.434 mW. The difference between overall and thermal efficiency is very small, which is only approximately 0.003%. Generally, mass flow rate affects overall efficiency of the hybrid system.

A comparison of overall efficiency between a flat plate solar air collector from a previous study with this hybrid system is done. According to the previous research [7] which uses flat plate solar air collector with different shape of fins has obtained maximum thermal efficiency of 51.5%, which is 27.5% lower than the hybrid system. Hence, the comparison above has shown that by adding thermoelectric cooler, the overall efficiency of the solar air collector can be increased.

4. Conclusions

A solar air collector-thermoelectric hybrid system is constructed and built. The overall efficiency and the electrical efficiency of the system reaches about 79% and 2.9%, at highest air mass flow rate, which is 0.055 kg/s. At the lowest air mass flow rate of 0.033 kg/s, the highest electricity generated, which is 13.434 mW. Higher air mass flow rate increases the thermal and overall efficiency but reduces the electrical efficiency. TEC is suitable to be used as a cooling agent of solar air collector as it can increase the heat transfer and the overall performance of the hybrid system.

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