Proceedings

Experimental Investigations of Energy and Exergy Efficiencies of an Evacuated Tube Solar Collector †

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Abstract: The main purpose of the analysis is to determine the influence of the weather and operating conditions on the energy and exergy efficiencies of an evacuated tube solar collector, heat pipe type with a mixture of water and propylene glycol (50%/50%) as a working fluid under the Polish climate conditions (the geographical coordinates for Lublin: Latitude 51°15′ N and longitude 22°34′ E), according to the experimental data. The solar collector with an aperture area of 3.6 m^2 is a main component of the solar hot water test installation located in the laboratory of the Faculty of Environmental Engineering, Lublin University of Technology. Studies have been presented for August. Based on the results, the average daily energy efficiency of the solar collector at the level of 34% (14.3–58.8%) and the average daily exergy efficiency of the solar collector at the level of 2.25% (0.86–3.75%) were established.

Keywords: solar energy; evacuated tube solar collector; energy efficiency; exergy efficiency

1. Introduction

An increase of the renewable energy sources share is one of the main priorities of the global energy policy. Solar energy can be used for applications such as: Preparation of domestic hot water; water heating in open and covered swimming pools; in farm buildings for watering animals and preparation of food, drying of agricultural products; heating of greenhouses, heating—mainly low temperature heating, usually connected to a heat pump; heating of water at 60 °C in agri-food processing plants; and desalination of sea water or discharge water, for example, from mine drainage. Conversion of solar energy into useful heat can occur in solar collectors. The most commonly used collector constructions are flat plate collectors, evacuated tube collectors, and compound parabolic collectors. By the end of 2016, evacuated tube collectors accounted for 13.7% of the total water collectors' area in Europe [1]. Flat plate solar collectors are the cheapest and have a simple design, but the problem is that they have a low thermal efficiency and low outlet temperature [2]. Evacuated tube solar collectors have higher efficiency at higher temperatures (above 80 °C) and cold climates, compared to flat plate ones [3–6]. Thermal performance of solar collectors can be determined by instantaneous or long-term energy efficiency. Energy analysis does not provide information on the occurrence of internal process losses and cannot be a sufficient criterion for energetic systems assessment. Therefore, exergy analysis that combines the first and second law of thermodynamics should be conducted [6–8]. The results of experimental studies on the effect of various parameters on both energy and exergy efficiency of evacuated solar collectors have been presented in [6,9–11], while the results of theoretical research are presented in [6,12] and results of simulation tests in [7].

2. Materials and Methods

The solar collector is a part of a solar hot-water test installation, located in Lublin (Poland). The technical parameters of the evacuated tube collector of the "heat pipe" type are as follows: Dimensions, 2040 × 1994 × 157 mm; gross area, 3.9 m^2; inside/outside diameter of the tube, 47/58 mm; insulation thickness of the manifold, 55 mm; fluid conduits diameter, 22 mm; absorber adsorption, 0.95; collector tilt, 38°; and orientation, south-east. The maximum efficiency of the tested collector for the total solar irradiance of 800 W/m^2, according to the solar collector producer's data, is equal to 0.623. In order to carry out the measurements of weather parameters, a station consisting of a pyranometer CMP6 Kipp&Zonen (I_{sol}), anemometer (v_w), and ambient temperature sensor (T_a) are used. In order to measure working fluid temperature in the collector's circulation, PT500 platinum resistance temperature sensors ($T_{f,1}$, $T_{f,2}$) were applied. Two interfaces were used to log data every five minutes and to store them. The solar installation was equipped with the LQM-III heat meter and a pump set with adjustable flow of the working fluid. A detailed description of the solar installation and the measurement system is presented in [13]. The working fluid employed is a mixture of water and propylene glycol with a concentration of 50%. Studies were carried out using a mass flow rate of 0.055 kg/s. The solar collector thermal efficiency is given by Equation (1):

$$\eta_{TH} = \frac{\dot{m}_{col} \cdot c_{p,glycol} \cdot \left(T_{f,2} - T_{f,1}\right)}{I_{sol} \cdot A_{col}} \tag{1}$$

where:
$\dot{m}_{col}$ —circulated fluid mass-flow rate, kg/s, ($\dot{m}_{col}$ = 0.055 kg/s),
$c_{p,glycol}$—fluid specific heat, J/(kg·K), ($c_{p,glycol}$ = 3880 J/(kg·K),
$T_{f,2}$—fluid outlet temperature, K,
$T_{f,1}$—fluid inlet temperature, K,
I_{sol}—total solar irradiance, W/m^2,
A_{col}—collector area, m^2, (A_{col} = 3.6 m^2).

The exergy efficiency of the collector is obtained from the following Equation (2) [6]:

$$\eta_{EX} = \frac{\dot{m}_{col} \cdot c_{p,glycol} \cdot \left[\left(T_{f,2} - T_{f,1}\right) - T_a \left(ln \frac{T_{f,2}}{T_{f,1}}\right)\right]}{I_{sol} \cdot A_{col} \left[1 - \left(\frac{T_a}{T_s}\right)\right]} \tag{2}$$

where:
T_a—ambient temperature, K,
T_s—apparent sun temperature, K, (T_s = 4500 K [6,8]).

3. Results and Discussion

In this study, the energy and exergy efficiencies evaluation of the heat pipe-evacuated tube collector were performed for one month. The highest value of the solar irradiation per day was recorded on August 4 and was at the level of 6.57 kW·h/(m^2·d), while the lowest value was recorded on August 1 and was equal to 0.97 kW·h/(m^2·d). The average solar irradiation per day for the entire month was determined as 4.68 kW·h/(m^2·d). The average values of solar irradiance for individual days ranged between 96 W/m^2 and 698 W/m^2. The average daily values of the ambient temperature reached values in the range of 18.5–27.5 °C and mean values of wind speed were in the range of 0–0.86 m/s. The unit energy yield in the solar collector was determined for individual days from 0.6 to 8 MJ/(m^2·d). Based on the results, the average daily energy efficiency of the solar collector at the level of 34% (14.3–58.8%) and the average daily exergy efficiency of the solar collector at the level of 2.25% (0.86–3.75%) were established.

4. Conclusions

Effects of various operating parameters, such as solar irradiance, ambient temperature, wind velocity, inlet mixture of water and propylene glycol temperature, and temperature difference of the fluid ($T_{f,2}$–$T_{f,1}$) on exergy and energy efficiencies of the solar collector were investigated. An increase of the difference between the working fluid inlet temperature and ambient temperature leads to a decrease in energy efficiency and an increase in exergy efficiency. The ambient temperature and the wind speed have no considerable influence on exergy and energy efficiencies. The exergy efficiency of the solar collector decreases when the wind speed increases.

Author Contributions: A.S.-O. conceived and designed the experiments; A.S.-O. and T.C. performed the experiments; A.S.-O., T.C., and K.D.-H. analyzed the data; A.S.-O. wrote the paper.

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Conflicts of Interest: The authors declare no conflict of interest.

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