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(RESEARCH ARTICLE)

Experimental investigation of the evacuated tube under Iraq weather conditions utilizing first and second law efficiency

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Abstract

This article presents the results of a field test of an evacuated-tube solar water heater and provides an analysis of those results. The first and second principles of thermodynamics were used to analyse the performance of the evacuated tube solar water heater. Between 6:00 PM and 6:00 AM before each test, the whole tank's water supply was renewed. After 24 hours of operation in the month of November, the water temperature in the tank reached 33.5 degrees Celsius. The ETSWH achieved an efficiency of 76.1% according to the first law, while the second law efficiency was 5.2%. Morning tank water temperatures averaged 33.5 degrees Celsius. The ETSWH's daily energy efficiency was 57.2%, and its exergy use efficiency was 4.48 %.

Keywords: Evacuated Tube; First law analysis; Second law analysis; Performance

1. Introduction

Due to the environmental harm caused by conventional energy and its limited supply, it is vital to gradually deploy energy-saving technology in business and integrate renewable energy sources into the energy sector. Using solar energy instead of fossil fuels would significantly cut down on both our energy needs and our contribution to dangerous air pollution. Solar insolation cannot harm the natural environment during its thermal conversion. In terms of the environment, solar thermal energy is a great choice. Solar water heaters are able to store water for later use, making them useful in both homes and businesses. This technology produces low-cost and fossil fuel-free hot water. Increase in production of this kind of energy is required to meet the needs of a developing industrial sector. Because of their low efficiency, high nighttime losses, and small storage capacities, solar heaters have room for improvement. Exergy analysis, also known as second law analysis, is helpful for energy system analysis and modeling. In recent years, it has been used in the fields of energy system design, simulation, and evaluation. It is possible to put a number on the thermodynamic flaw in the process by using exergy analysis. So, it can show how feasible it is from a thermodynamic standpoint to improve the process, but only an economic analysis can tell us whether we should. Solar water heating (SWH) systems were studied by Gunerhan and Hepbasli (2007). These systems include a tank, a flat plate solar collector, and a pump. Using models and exergy analyses, the researcher evaluated SWH setups. They also looked at how changing the temperature of the water going into the collector affected the exergy efficiency of various components in the SWH system. The best performance and design characteristics of flat plate solar water heaters were determined by Farahat et al. (2009) using exergetic augmentation. The thermal and exergetic characteristics were calculated using the simulation software. The input fluid temperature has a positive effect on the exergy efficiency. Beyond a specific fluid input temperature, exergy efficiency drops dramatically. Siuta-Olcha et al., (2021) performed a two-month long experimental evaluation of an evacuated solar collector with 24 tubes of the heat pipe type and a gross area of 3.9 m2. Lublin, Poland was the site of the test (Poland). The average thermal gain in July and August was measured at 163 and 145 W/m2, respectively, with sun irradiation at 80 and 112.8 kWh/m2. As the wind speed reached 0.86 m/s, thermal efficiency dropped by 67% and exergy efficiency dropped by 41%. The solar collector had an average monthly efficiency

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of between 45.3% and 32.9% during the course of the study period. For this work, Bracamonte et al., (2015) employed experimental setups and three-dimensional numerical simulations to examine the impact of tilt angle on the stratification effect, energy conversion efficiency, and flow patterns. To heat the water, we utilized a commercial "water in glass evacuated tube solar water heater" (WGET-SWH) with a 40-liter nominal capacity and eight evacuated tubes. Over the course of four weeks, we experimented with a variety of collector tilt angles. It is shown how the angle of the collector in a passive solar water heater affects a non-dimensional stratification index. For collector integrated passive solar water heaters, we show the effect of the tilt angle on a non-dimensional stratification index. The charging and discharging processes were not considered in this research. The effects of several degrees of tilt (10, 27, and 45) were studied using the numerical model, with the same amount of energy input. Four evacuated tube solar water heaters (ETSWH) with cylindrical absorbers in series were tested and assessed by Nitsas and Koronaki (2018) in Greek climates. When it comes to the first and second poor efficiency, input temperature is the primary influence. The intake temperature affects the effectiveness of both. When thermal efficiency drops, exergetic efficiency rises. Several experimental and computational research examined the thermal and flow characteristics of single-ended ETSWH. Natural convection circulation with a constant circumferential heat flow distribution was studied experimentally and numerically by Budihardjo et al (2007). They investigated how to employ a set of evacuated tubes attached to a diffuse reflector. They calculated the tube's internal free convection flow rate using a given formula. Energy performance monitoring of a novel household SWH system based on evacuated tube collectors was described by Hazami et al. (2013). Initially, the heat-transport mechanisms in a DSWH were modeled in detail using TRNSYS. During two months, the TRNSYS model was subjected to six days of real-world weather data (November and July 2010). In this study, the solar water heaters in Iraq are being researched to determine the performance of evacuated tubes using the first and second law analysis for Iraq's climate.

2. Experimental methodology and setup

Baiji, Salah Al-Din, Iraq, at an elevation of 118 meters, 34.97 degrees north latitude, and 43.5 degrees east longitude, served as the experimental site for the solar water heater. We used a horizontal tank that could contain 150 liters of water and a 15-evacuated tube for our experiment. There is a diameter of 58 mm and a total length of 1800 mm for each tube. Each tube has a thicker exterior glass tube and an inner tube covered with borosilicate, which lets light and heat in from the sun but keeps the heat inside. Sunlight may pass through the outer glass tube's clear surface, while the inner glass tube's opaque wall absorptance the sunlight. A water tank with a cylindrical shape and an insulating layer between its two sides. The stainless steel used for both sides helps prevent the buildup of corrosion and rust. Solar insolation up to 2000 W/m2 may be measured using a TES-132 solar power meter from the TES electrical electronic firm, which has an accuracy of 10.0 W/m2 and a precision of 0.1 W/m2.

Figure 1 Evacuated tube solar collector system

In this study, we used 12 thermocouples to measure temperatures in a variety of settings. Ten K-type thermocouples were installed in the tank's middle so that consistent temperature readings could be taken. The average was then used to determine the performance indicators. The temperature of the water at both the inlet and outlet was measured using thermocouples. To acquire a more precise readout of the ambient air temperature, a second thermocouple was employed. The test apparatus ran for one whole day. Fresh water was added to the tank at 6:00 a.m., and the experiment was stopped at the same time the following day. We drained all of the water that had been added that morning through the outflow and then refilled it at 6 o'clock in the evening with the same amount of freshwater that had been added earlier in the day. Thermal stratification inside the storage tank served to prevent the mixture of inflowing heated water with incoming cold water during withdrawals.

The thermocouples, flow meter, temperature meter, solar power meter, and water pump were all used to gather data during the trials. K-type thermocouples with 0.1°C precision was attached to the multi-channel digital temperature indicator to detect temperatures at several points throughout the system, including the water temperature, PCM temperature, and ambient temperature. A TES-132 solar power meter manufactured by the TES electrical electronic corporation with an accuracy of 10.0 W/m^2 and a precision of 0.1 W/m^2 is used for measuring solar insolation of up to 2000 W/m^2.

In this investigation, 12 thermocouples were utilized to detect the temperature at different locations. Four K-type thermocouples were inserted in the storage tank's center to collect temperature measurements on a regular basis. The performance measurement parameters were then calculated using their average. Five thermocouples were uniformly distributed across the two cylinders of the PCM enclosure to determine the average PCM temperature. Two thermocouples were used, one at the water's input and one at its exit. A second thermocouple was used in order to get an accurate reading of the surrounding air temperature.. The test rig was left operating for a whole twenty-four-hour period. The experiment started at 6:00 a.m. with the addition of fresh water to the water storage tank and ended at the same time the next day. We emptied the whole quantity of water supplied in the morning through the outlet and refilled it at 6 pm with the same amount of freshwater introduced in the morning. During withdrawals, thermal stratification inside the storage tank functioned to avoid the mixing of outflowing warm water with fresh cool water within the tank.

From 6:00 am to 6:00 pm, the thermodynamic analysis was continued with continuous monitoring of the hourly change in solar insolation, tank water temperature, and ambient temperature.

Energy stored in the water tank is determined (Chen et al. 2009; Mahfuz et al. 2014b):

$$Q_s = m_w C_{p,w}\left(T_{w,f} - T_{w,i}\right) \ldots\ldots\ldots\ldots (1)$$

To calculate how much energy was taken in by the collector, use this formula. According to research (Al-Kayiem & Lin 2014)

$$Q_c = A_c \times H_t \ldots\ldots\ldots\ldots\ldots (2)$$

where A_c is the collector area of the evacuated tubes

The efficiency of a solar water heater may be defined as the amount of energy maintained in the water tank in relation to the amount of solar energy absorbed over a certain amount of time. It means we may express the collector's effectiveness as,

$$\eta_c = \frac{Q_s}{Q_c} \times 100 \ldots\ldots\ldots (3)$$

Exergy efficiency shows how much water recovers the tank's energy. Thus, irreversibility issues diminish system exergy. Mixing between thermal layers impairs thermal stratification and ruins tank exergy storage irreversibly.

In order to calculate the exergy balance of the system under consideration, we came up with the following (Koca et al., 2008):

$$Ex_{in} = Ex_s + Ex_L + Irreversibility \ldots\ldots\ldots\ldots\ldots (5)$$

Input of exergy to collector is provided by (Petela, 2003),

$$Ex_{in} = A_c H_t \left[1 + \frac{1}{3}\left(\frac{T_o}{T_{sun}}\right)^4 - \frac{4}{3}\left(\frac{T_o}{T_{sun}}\right)\right] \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where T_o represents the temperature of the atmosphere, and T_{sun} represents the temperature of the sun's surface, which is supposed to be 5600 K.

It is possible to write the exergy that was gathered by the storage tank as (Gunerhan & Hepbasli 2007; Pandey et al. 2015),

$$E_s = m_w(E_O - E_{in}) = m_w C_{p,w}\left[\left(T_{w,f} - T_i\right) + T_o \ln\left(\frac{T_{w,f}}{T_{w,i}}\right)\right] \text{..........} (7)$$

The exergy efficiency of a home solar water heater is defined as the ratio of the additional exergy produced by the collector tank to the total exergy supplied by radiation from the sun (Gunerhan & Hepbasli 2007). The exergy efficiency may be calculated using Equations (5) through (7).

$$\psi_c = \frac{Ex_s}{Ex_{in}} \text{..................} (8)$$

3. Results

Experiments were done on ETSWH in the solar water heater (SWH). For each case, the investigations took many days. After that, thermodynamic analysis was done on the experimental days that had the same pattern of solar insolation and temperature changes in the ambient. Fig.2 shows the measurements of the temperature of the tank and solar insolation during the days of the experiment, respectively. It was observed that the solar insolation steadily rose from morning to midday while the flux intensity decreased till dusk, forming a bell-shaped curve in all circumstances. Similarly, the fluctuation in tank temperature throughout the various cases of the experiment followed a similar pattern across all cases of tests. The temperature of the tank water after 24 hours of operation yielded a value of 33.5°C.

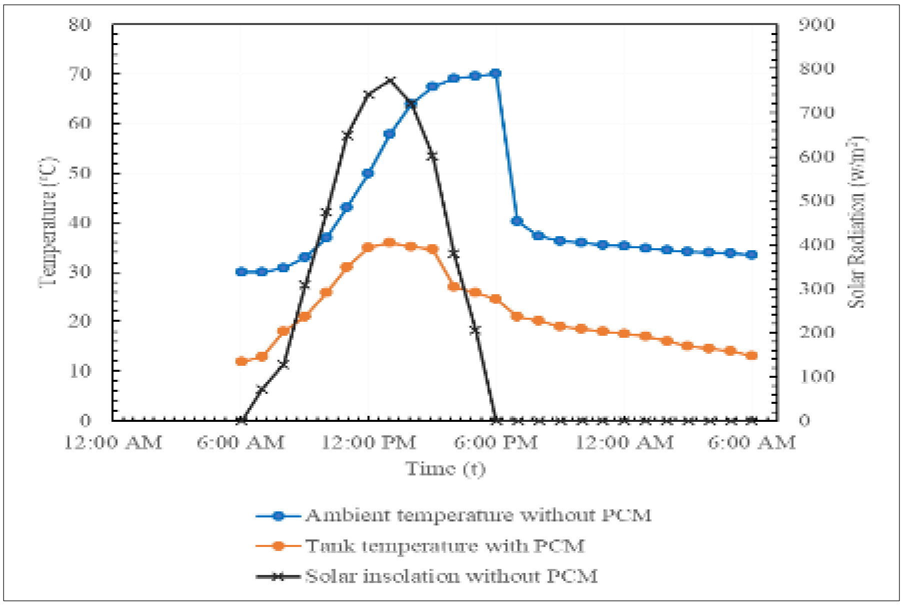

Figure 2 Temperature and solar insolation during the days of the experiment. (15/11/2022)

The ETSWH's heat energy is measured by its first law thermodynamic efficiency. solar radiation is converted into heat by the evacuated tubes, and that heat is then utilized to warm the water. Using the aforementioned equations, Fig. 2 displays the anticipated hourly thermal energy efficiency. Similar to the pattern of solar radiation seen in Fig.1, efficiency improves with increasing solar insolation until it reaches a peak about midday and then begins to fall in the late afternoon. The results show that the amount of solar insolation that reaches evacuated tubes has a significant impact on their energy efficiency. The solar collector was found to be most effective between the hours of 12 and 2 p.m., when there is a high intensity of sunlight flow. The SWH's highest recorded hourly energy efficiency was 76.1%.

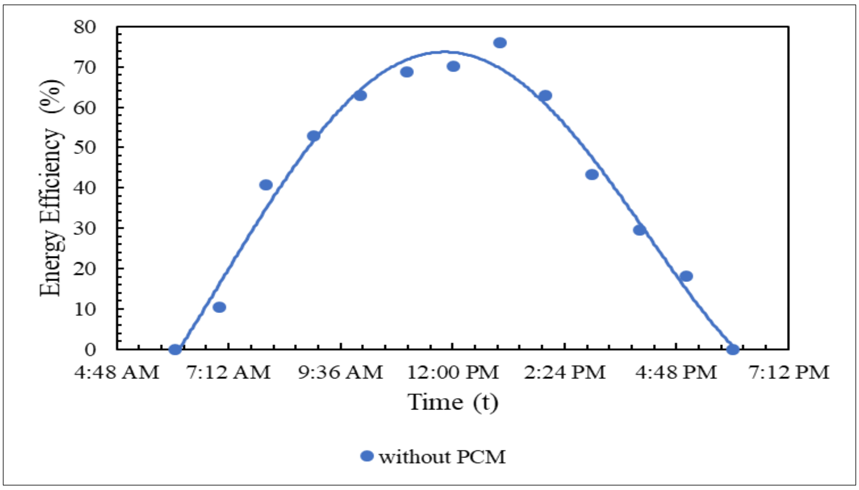

Figure 3 Hourly first law efficiency of an evacuated tube solar water heater (15/11/2022)

The second law efficiency defines the maximum efficiency that may be realistically expected from a system. As first-law efficiencies don't consider an ideal model of the system, second-law efficiency is necessary. Depending only on first-law efficiencies might provide the appearance of more efficiency than really exists in a system. So, second-law efficiencies are necessary for a more realistic depiction of a system's efficiency. Using the equations discussed in the previous sections, Fig. 4 depicts the thermodynamic efficiency of an ETSWH according to the second law. The exergy effectiveness of ETSWH over the course of an hour showed comparable variation across experiments. Contrast this trend with hourly energy efficiency graphs. Around six in the morning, the tank is refilled with cold water in preparation for a fresh set of tests. Every fresh water that enters the system must combine with the existing water to reach thermal equilibrium due to the large temperature difference. The forenoon curve's inclination reduced and seemed improper after being refilled with new water. Because of this distinction, the exergy efficiency curve looks different from the energy efficiency curve. The maximum hourly exergy efficiency for SWH was 5.2%.

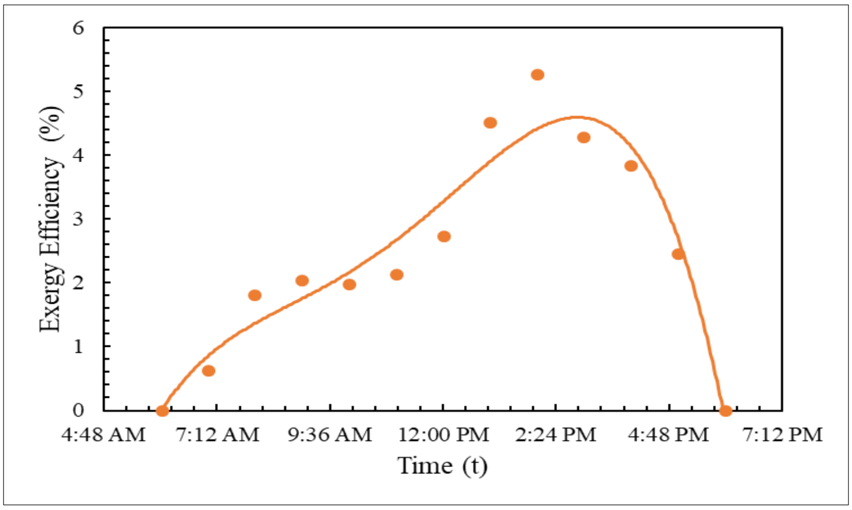

Figure 4 Hourly second law efficiency of an evacuated tube solar water heater (15/11/2022)

Fig. 5 shows the daily energy and exergy efficiencies of the experiment under the given conditions. The ETSWH used 57.2% of the energy it took in every day. These results show the system's ability to store thermal energy over the course of the day, which makes the ETSWH more energy efficient. The daily exergy efficiency of the ETSWH was determined to be 4.48%, which shows that a significant amount of energy has been lost as a result of the system's irreversibility.

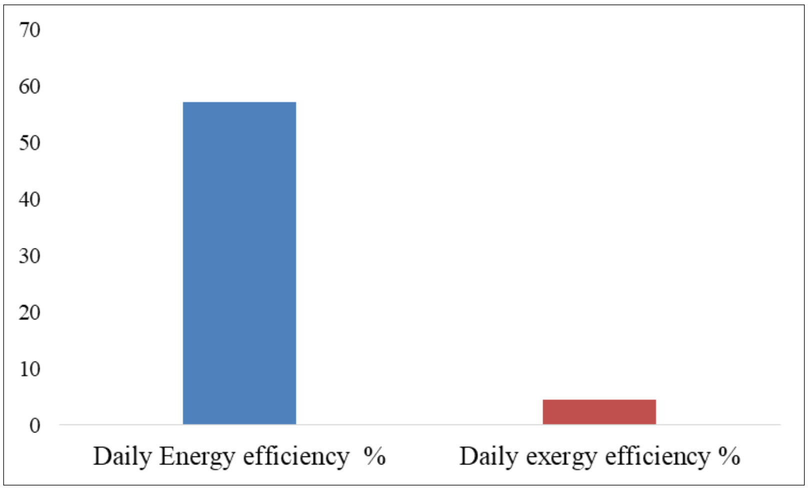

Figure 5 Daily energy and exergy efficiency of an evacuated tube solar water heater (15/11/2022)

Abbreviations

Abbreviations	
ETSWH	Evacuated tube solar water heaters
FPC	Flat plate collectors
SWH	Solar Water Heater
List of symbols	
$C_{p,w}$	Specific heat of water (kJ/kg K)
Ex_L	Exergy loss to the environment
Ex_{in}	Input evacuated tubes exergy (kJ)
Ex_s	Stored exergy (kJ)
H_t	Daily solar radiation (kJ/m^2)
Q_t	Total amount of energy stored in the water tank (kJ)
Q_c	Energy incident on the evacuated tubes (kJ)
Q_w	Energy stored by water (kJ)
T_o	Atmospheric temperature (K)
$T_{w,f}$	Final tank water temperature (K)
$T_{w,i}$	Initial tank water temperature (K)
m_w	mass of water (kg)
Greek symbols	
η_c	First law efficiency of collector (%)
ψ_c	Second law efficiency of collector (%)
Subscripts	
o	atmospheric
c	evacuated tube collector
s	Stored
f	final

i	initial
L	Loss
w	water
in	input

4. Conclusion

In this study, we examine the effectiveness of a solar water heater built using evacuated tubes. At Baiji, Salah-eddine, Iraq, an experimental setup for an evacuated tube solar water heater (ETSWH) was built and installed. The experiment was carried out by preserving the setup from 6 a.m. to 6 a.m. the next day. Each experiment started with the filling of the required quantity of fresh water at 6:00 a.m., the complete draining and replacement of the hot water with fresh water at 6:00 p.m., and the continuation of the observations until 6:00 a.m. the following morning. The study may lead to the following findings.

- The solar water heater's daily energy and exergy efficiencies were determined by system measurements. Results showed that the ETSWH was 57.2% efficient in terms of daily energy use and 4.48% efficient in terms of exergy.
- The peak performance of the solar collector occurs between noon and two in the afternoon, when the solar radiation is strongest. Energy and exergy efficiency peaked at 76.1% and 5.2, respectively, for a whole hour in the ETSWH.
- The temperature of the hot water that was accessible the next morning was recorded. Next morning, the hot water temperature was recorded at 33.5 °C due to good insulation of the system.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest.

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