JJMIE

Volume 11 Number 3, September. 2017
ISSN 1995-6665
Pages 181 -184

Jordan Journal of Mechanical and Industrial Engineering

Solar Thermal Hybrid Heating System

Ahmad Al aboushi

Faculty of Engineering and Technology, Department of Mechanical Engineering- Al Zaytoonah University of Jordan

Received Feb 10,2017 *Accepted June 15,2017*

Abstract

In the present work, a solar hybrid system is used to heat up a swimming pool to maintain it at around 30 0C around the year. The solar energy is collected using evacuated tubes collectors, within whichwater is heated up as it flows inside the tubes, before it is introduced into a heat exchanger located inside a large well-insulated storage tank, where it cools down as it looses heat to water in the tank. In winter, during cloudy days, an auxiliary system (in addition to the solar thermal system) was used to provide the required heating load. Three types of auxiliary systems were used, namely natural gas, electrical power and diesel powered boiler. In addition, an energy management system is used to optimize the percentage of the heating load to be supplied by eachauxiliary heating system.

It was found that during summer season, the heating load may be completely provided by the solar system, while during the rest of the year an auxiliary system is required to maintain the pool temperature at the desired value. Furthermore, it was found and based on current costs of electrical power, diesel fuel and natural gas in Jordan, that natural gas is the most economical source of energy to be used as an auxiliary system.

Keywords: *Hybrid solar thermal system, evacuated solar collectors, thermal solar fraction, auxiliary system*.

1. Introduction

Nowadays, the growing concern due to continuous escalation of the energy cost, environmental pollution caused by the conventional fossil-based fuels and the realization that they are non-renewable have led to the search for more environmental-friendly and renewable sources of energy. Among the various options investigated is solar energy, which has been recognized as a strong contender for the reduction in emissions emitted during the combustion of conventional fuels and for the reduction of the national energy bill.

Photovoltaic solar energy (PV) is considered one of the renewable sources of energy. Hybrid photovoltaic/thermal system in the other hand is the continuity of the photovoltaic solar energy system, it combined both systems into one system known as Hybrid photovoltaic/thermal (PV/T or PVT) solar system [1]. As reported by Zondag [2], and again by Prakash [3], the system can be segregated into two parts; the photovoltaic technology which derived from solar cell technology and convert into electricity, and thermal solar technology which derived from the thermal collector and convert the solar energy into heat. Bhargava *et al*. [4] mentioned that the hybrid system is operated solely by the solar radiation. However, and in spite of their advantages, the applicability PVT system is limited due to some drawbacks, such as:

1. Non uniform cooling;
2. Low efficiency;
3. High cost;
4. Not suitable for integration with present roof system; and
5. Needs a larger space for separate systems.

As an alternative to PVT systems, the solar hybrid heating system, which uses a conventional source of energy to provide a heating load for certain applications, such as swimming pool heating, where the heating load in addition to the collected solar energy is supplied by auxiliary system, such as anconventional diesel fuel, whose cost is continuously increasing in addition to its severe impact on the environment due to the emission of different pollutants when it is burned. Consequently, it is necessary to select the most economical auxiliary system to use it alongside with the solar system to achieve the desired thermal comfort.

Evacuated Tube Collector (ETC) has been used as a tool to make use of solar energy. Excellent presentation for ETC, together with its various applications, such as space heating, domestic hot water, solar cooling, solar desalination, cooking, is presented in Ref. [5].

The thermal performance of a prototype solar cooker based on an evacuated tube solar collector with Phase Change Material (PCM) storage unit was investigated [6]. The design has separate parts for energy collection and cooking coupled by a phase change material (PCM) storage unit. Solar energy is stored in the PCM storage unit during sunshine hours and is utilized for cooking in late evening/night time. Noon and evening cooking experiments were conducted with different loads and loading times. Cooking experiments and PCM storage processes were carried out simultaneously. It was found

* Corresponding author e-mail: A.aboushi@zuj.edu.jo.

that noon cooking did not affect the evening cooking, and evening cooking using PCM heat storage was found to be faster than noon cooking.

Experimental and numerical works on evaluating the performance of the two common types of evacuated tube solar water heaters for domestic hot-water applications was conducted by Chow *et al*. [7]. They used the single-phase open thermosyphon system and the two-phase closed thermosyphon system. It was show that the daily and annual thermal performance of the two-phase closed thermosyphon solar collector is slightly better than the single-phase open thermosyphon design. However, the payback periods of the two are relatively the same because of the higher initial costs of the two-phase closed thermosyphon collector system. In addition, they concluded that although economically they are less attractive than the flat-plate type collector system, they are suitable for applications in advanced systems with higher temperature demands.

A year round energy performance monitoring results of two solar water heaters with 4m^2 flat plate and 3 m^2 heat pipe evacuated tube collectors (ETCs) operating under the same weather conditions in Dublin, Ireland, was conducted by Ayompe [8] . The annual average collector efficiencies were 46.1% and 60.7% while the system efficiencies were 37.9% and 50.3% for the FPC and ETC, respectively. Economic analysis showed that both Solar Water Heating (SWH) systems are not economically viable while Simple Payback Periods (SPPs) varied between 13 years and 48.5 years.

Mazarrón *et al*. [9] analyzed how the required tank water temperature affects the useful energy that the system is capable of delivering, and consequently its profitability. The results show how the energy that is collected and delivered to the tank decreases with increasing the required temperature due to a lower performance of the collector and losses in the pipes. The annual system efficiency reaches average values of 66%, 64%, 61%, 56%, and 55% for required temperatures of 40 °C, 50 °C, 60 °C, 70 °C, and 80 °C. As a result, profitability decreases as temperature increases.

A heat pipe evacuated tube solar collector has been investigated by Farzad *et al*. [10], both theoretically and experimentally. The results showed a good agreement between the experiment and theory. Using the theoretical model, the effect of different parameters on the collector's energy and exergy efficiency has been investigated. It is concluded that inlet water temperature, inlet water mass flow rate, the transmittance of tubes and absorptance of the absorber surface have a direct effect on the energy and exergy efficiency of the heat pipe evacuated tube solar collector. Increasing water inlet temperature in heat pipe evacuated solar collectors leads to a decrease in heat transfer rate between the heat pipe's condenser and water.

Jordan is an energy importing country; about 96% of its needs supplied from abroad as crude oil and refined products. The special situation of Jordan and other countries in the Middle East and the present world oil price suggest that renewable energy sources, such as solar energy, can be adapted much better to the needs of the country. Solar energy is considered the largest domestic energy source and it is very attractive because it is reliable, and pollution-free. Currently, the most common fuel used for heating is heating oil, which recently has witnessed a dramatic cost increase. This necessitated researches to look for alternative sources of energy for heating purposes.

The main objective of the present work is to design, install and to test a solar heating system that may be used to heat up a swimming pool, this system may be used as a standalone or operates with an auxiliary system (hybrid system). In the case of the latter option, a control system will be used to act as an energy management system, which will optimize the contribution of auxiliary system to providethe required heating of a swimming pool.

2. Experimental Work

The main components of the experimental setup are shown in Figure (1); as indicated, the following instrumentations were used to conduct the present work:

1. Evacuated tube collectors with a total number of 85 tube, these collectors are installed on the roof of the house where the swimming pool is located. This number of the tube was selected based on initial calculations such that the collected solar heat will cover the total required heating load to maintain the pool at 30 ^{0}C during summer season;
2. Kipp and Zonen CAM Albedo meter, which is used to measure the solar incident radiation in W/m^2.
3. A national Instrument DataLogger, that is used to record and store the collected hourly solar radiation and the hourly pool temperature;
4. 30 kW.hr locally made Electric heater;
5. 30 kW.hr gas boiler (Lamborghini);
6. 50 000 Kcal Chappeeand diesel boilers, fitted with Lamborghini burner.

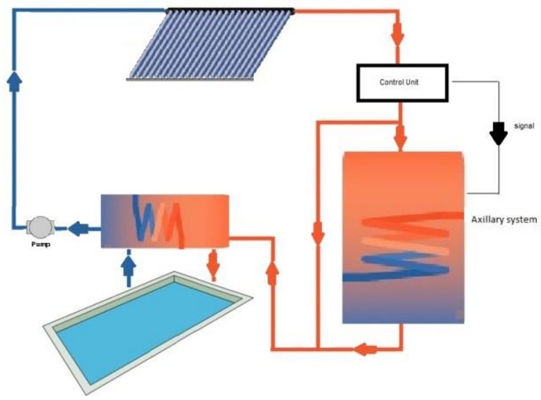

Figure 1. Experiment setup

After the installation of the above instrumentations at the site, experimental work was conducted during the summer season, including the measurements of solar incident hourly solar radiation using the albedo meter and swimming pool temperature at five different locations using thermocouples, with the measured data recorded and stored in thedata acquisition system. In addition, water inlets and outlets temperatures were recorded. All temperatures measurements were conducted using K-type thermocouples, which are connected to the data acquisition system. Preliminary conducted work during summer season indicated that the total heating load required to maintain the pool at a temperature of 30 ^{0}C was provided by the collected solar energy and hence no auxiliary system was required.

Further work was conducted in Falland winter seasons; this is to cover a year round measurements (taking into account that both spring and fall measurements are almost similar to each other). In addition to the heating load provided by solar energy, work was conducted to find out most economical auxiliary heating system (diesel fuel, electrical power and natural gas) to maintain the pool at the desired temperature all year round.

In order to optimize the percentage of the heating load to be supplied by each heating auxiliary system, a temperature controlled Energy Management System (EMS) was designed installed and used. This EMS was installed in a way to sense the evacuated tube collector outlet water temperature, such that if this value of the water outlet temperature drops below 60 ^{0}C (this corresponds to an average pool temperature of 30 ^{0}C), the auxiliary system is triggered by a signal from the energy control system in order to increase the pool water temperature to a value of 30 ^{0}C.

It is to be noted that, for each auxiliary system in operation, the experimental data collected were:

1. The hourly incident radiation;
2. the average pool temperature;
3. the energy consumed by the auxiliary system;
4. the ambient temperature;
5. the water outlet temperature from pool, which was found almost identical to the average pool temperature;
6. the inlet water temperature to the pool, which was noticed to be almost constant due the operation of the auxiliary system to maintain the pool temperature at a constant value;
7. the water inlet temperature to solar collector, which was almost of the same value of the water outlet temperature from the pool. This is due to the fact that the pipes are well insulated; and
8. the water outlet temperature from the collector, if this value drops below 60 ^{0}C, the control system triggers the auxiliary system.

The data above were collected over three days during which metrological data were almost identical and, then, average results were estimated this to ensure the repeatability of the obtained data. It is to be noted that the measurements of the above data were conducted on a daily basis during the year. Not all data will be presented here; instead, selected data will be presented and discussed in detail.

3. Results and Discussion

Hourly data were collected, stored and, then, analyzed. These data were obtained around the whole year, starting in the summer of the year of 2013 to the end of spring of the year 2014. For simplicity, only two cases will be presented and discussed in the present paper. The first one is during the summer season (the day 21st of June was selected), while the second case is selected during the winter season (17th of February). These two cases represent the hottest and the coldest days in Amman during the period of the experimental work.

4. Summer Measurements

Figure (2) shows typical hourly solar radiation data during the day of 21stof June. As indicated, the incident solar radiation increases in the morning to a maximum value during the day, beyond which it starts to decrease with time in the afternoon. The pool temperatures measurements during the months of June through September were found to slightly exceed the desired required temperature, which is 30 ^{0}C. Consequently, the solar radiation collected by the collectors was sufficient to completely heat up the swimming pool and to maintain its high temperature; no auxiliary systems were required to heat up the swimming pool during summer season.

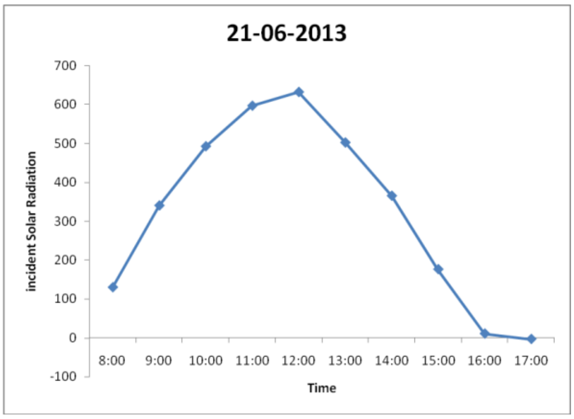

Figure 2. Hourly Solar Radiation at 21st /6/2013

5. Winter Measurements

Typical measurements for the hourly solar radiation and the temperature distribution within the pool during the day of 17th/02/2014 are shown in Figures (3) and (4), respectively. An auxiliary heating system were used to maintain the pool temperature at a desirable temperature of 30 deg. Furthermore, it was found that the total heat required to heat up the pool from 20.4 ^{o}C up to 30 ^{0}C was 2090 MJ, and the solar contribution to this heat was 197 MJ. While the auxiliary system provided 9%.

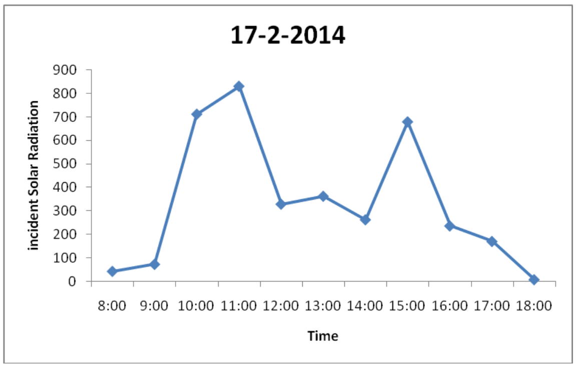

Figure 3. Hourly solar radiation on 17th/02/2014 (auxiliary system powered by natural gas)

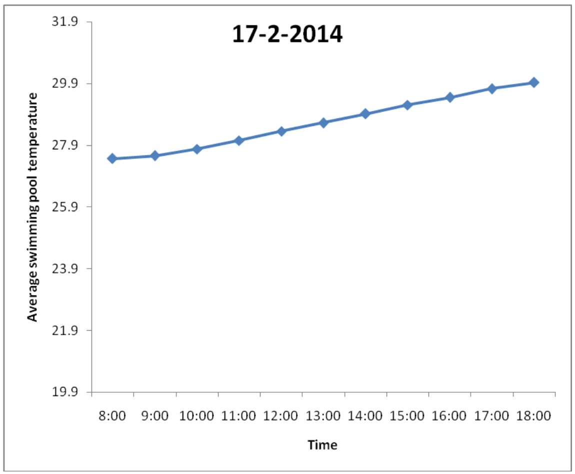

Figure 4. Temperature distribution within the pool during the day of 17th/02/2014 (auxiliary systems powered by natural gas)

6. Conclusion

Solar hybrid system was designed, installed and tested using a swimming pool. Three types of auxiliary systems were used, in addition to the solar system, namely Liquefied Petroleum Gas (LPG), electrical boiler and diesel boiler. From the present work, the following may be concluded:

1. During summer, the heating required to maintain the pool at a desirable temperature was completely covered by the solar system alone with no need to operate an auxiliary system;
2. during fall, spring and winter, an auxiliary system was required to maintain the pool at the desirable temperature which the solar system provided; and
3. based on Jordanian current energy cost, LPG was found to be the most economical auxiliary system to be used with the solar system.

Acknowledgement

The author would like to thank the Deanship of Research at Al Zaytoonah University of Jordan for financing and funding the present research work.

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