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Field measurements for solar water heaters in a mushroom plant

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Abstract

The subsidy program (2000-2017), which has been initiated by the Taiwanese government, has results in an expansion in the market for solar water heaters. The cumulative area of solar collectors installed was approximately 2.61 million square meters at the end of 2017, of which more than 93% have been installed in the domestic sector for hot water production. Industrial heat processes represent another important application for solar heating. However, the attractiveness of a SWH depends on its thermal efficiency and its economic viability. Field measurements for solar water heaters in a mushroom plant are conducted. As a pre-heating system, the thermal efficiency and the energy savings for the system depend on system design and maintenance.

Keywords: solar water heater, thermal efficiency, mushroom plant

1. Introduction

Carbon emissions are related to global warming and climate change. The issue is also major concerns worldwide. The Paris Agreement of 2016 [1] aims to maintain the increase in the global average temperature to less than 2 ℃ above pre-industrial levels. Energy production from renewable resources (wind power, photovoltaic power, solar heating etc.) is certain to be one of the major tools that will allow the target to be achieved. In 2016, the annual energy yields worldwide were more than 1740 TWh [2]. Solar heating is a mature technology. The production of hot water using solar water heaters (SWHs) is its most important application, in both the domestic and the commercial sectors [3-5]. In Taiwan, solar radiation ranges from 1,200 to 1,700 kWh/m^2/year. The Bureau of Energy of the Ministry of Economic Affairs (BEMOEA) promotes the use of solar thermal energy. Two purchase-based subsidy programs for SWHs have been implemented during the periods 1986–1991 and 2000–2017. Some regional programs have also been initiated. During the second subsidy program, the cumulative area of solar collectors that was installed was approximately 2.61 million square meters by the end of 2017 and more than 93% of these were installed in the domestic sector [6]. However, Islam et al. [7] showed that SWHs are more economically feasible for large systems. In other words, industrial heat processes represent another important application for solar heating [8-12].

Edible mushrooms are a highly nutritious food, in terms of the protein, fat, carbohydrate, fiber, minerals and vitamins that they provide [13]. Their medical properties are also recognized in oriental cultures [14]. Traditionally, they are harvested in the wild but the cultivation of some species has a long history. Synthetic logs that are composed of sawdust that is supplemented with millet and wheat bran are used to produce the highest possible yields [15]. Mushroom cultivation does not require much land, but the environmental growth factors, such as the incubation temperature and the relative humidity, affect the

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growth of edible mushrooms. Gurubel et al. [16] showed that the optimal control of temperature can result in higher production. In Taiwan, agricultural production is restricted because of the natural environment and high production costs. The Council of Agriculture is promoting Smart Production and Digital Services in the agricultural industry. The top ten leading industries, of which mushroom production is one, have been prioritized in terms of promotion. The mushroom industry is developing full environmental control, harvest automation and smart production of mushrooms in plant factories. The integration of energy-saving equipment is another target [17]. In this study, SWHs are installed as a pre-heating system in a mushroom plant to control temperature. Field measurements are conducted to verify the real performance of SWHs for an industrial heat process. The results serve as a reference for energy bureaus who wish to promote solar thermal energy.

2. Field Measurement Setup

The mushroom plant is located in Wufeng district, Taichung City (24°02'26.8"N, 120°40'42.9"E). The average daily global solar radiation is 13.85 MJ/m^2 [18]. The plant consumes approximately 13.55 m^3 of hot water per day (or 732 MJ/day). A boiler that uses low sulfur light fuel oil is used to control the ambient temperature. To conserve energy, two SWHs (forced circulation) were installed in 2014 and 2015. The areas of the glazed flat-plate solar collectors, A_{sc}, are 97.5 m^2 and 78 m^2. Six solar collectors are arranged in parallel (an array) with one inlet and one outlet to heat the cold water, and the arrays were connected in parallel. The south-facing system is installed on the tilted roof of a low-rise building (= 6°) and serves as a pre-heating system, as shown in Fig. 1. The circulation pump is switched on/off depending on temperature difference (7°C/3°C) between a water storage tank (5 tons) and the water outlet for the solar collectors. The flow rate is 0.02 kg/s-m^2. The system operates from 08:30 to 16:30. The ball valve is switched on for 8 minutes (flow rate = 0.0075 m^3/min) during a 30-minute cycle.

The thermal efficiency of a SWH depends on the daily solar radiation, the thermal performance of solar collectors and the hot water consumption [15]. The Chinese National Standard (CNS 15165-1-K8031-1) specifies an outdoor test method to determine the steady-state thermal performance of solar collectors (natural solar radiation ≥ 800 W/m^2). The plant for this study uses glazed, metallic flat-plate solar collectors (CKSW-158, Chien Kang Co. Ltd.). The thermal performance of the solar collectors is shown in Fig. 2. The collector efficiency curve shows that the intercept, $F_R(\tau\alpha)$, and the slope, F_RU_L, are 0.748 and 5.95, respectively, corresponding to useful energy collected from a solar collector and its heat loss [19].

Fig. 1. SWHs that are used to control temperature in a mushroom plant

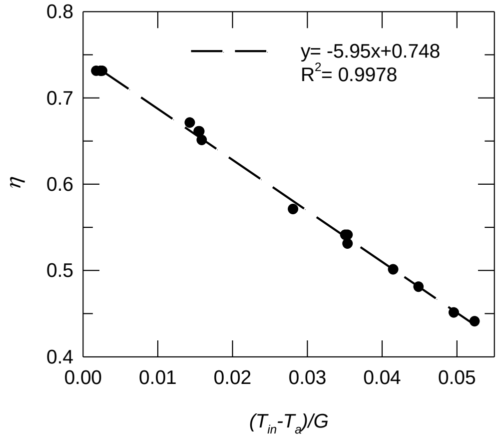

Fig. 2. The thermal performance of the solar collector

Field measurements were conducted to determine the system's performance. A precision spectral pyranometer (LI-200R, Li-Cor, Inc.) was installed to measure the inclined global solar radiation, G. Two Macnaught flow meters (M2SSP-1R, denoted as F1 and F2) were positioned along the circulation line from the bottom of the storage tank to the inlet for the collectors (circulation flow rate) and along the water supply line to the boiler (hot water consumption). Seven platinum resistance thermometers (denoted as T_a, T1–T6; 1/10 DIN Class B, Izuder Enterprise) were installed to monitor the ambient and local water temperatures. The sampling time was 10 seconds using a National Instrument's data acquisition system (cFP-AI-110 and cFP-RTD-124). During the period from May, 2016 to April, 2017, the daily efficiency, η, was calculated using the formula;

$$\eta = mC_p(T_{out} - T_{in})/(A_{sc}G) \tag{1}$$

where C_p is the specific heat; m is the mass of the water and T_{in} and T_{out} are the initial temperature in the cold water supply line and the final outlet temperature in the solar collectors, respectively.

3. Results and Discussion

Chang et al. [12] showed that the thermal efficiency of SWHs is associated with the value of G. For the initial period of operation for the system (May, 2016), a typical example of the weekly data (May 9-15, 2016) is shown in Fig. 3. The effect of the value of G (= 6.1–11.2 MJ/m^2/day) on the thermal efficiency is evident. The lowest value of η corresponds to the lowest value of G on Tuesday. As a pre-heating system, the data demonstrates that a SWH is financially viable for industrial heat processes. However, a decrease in the thermal efficiency for the system is observed for early 2017, when the thermal efficiency decreases significantly. The respective values for η for February and March, 2017, are 0.23 and 0.24, so the field piping was examined. As shown in Fig. 4, the mass flow rate decreases significantly (0-87 LPM), when a solar array is located far from the main pipe of the water inlet. In particular, a short circuit is observed for four solar arrays. Maintenance is another critical issue for the long-term operation of a SWH. Dust accumulates on the glazed surface of a SWH and reduces the thermal efficiency. As shown in Fig. 1, there are natural ventilation devices near the solar collectors. Synthetic logs that are used to cultivate mushrooms are applied onto the transparent cover of the solar collectors and regular maintenance was not performed. The hydrodynamic resistance was re-evaluated and the size of the field piping was changed in April, 2017. Fig. 5 shows variations in the mass flow rate (9-55 LPM) decreases and there is no short circuit. This results in an increase in the value of η. However, it appears that the accumulation of dust still significantly affects the system's performance.

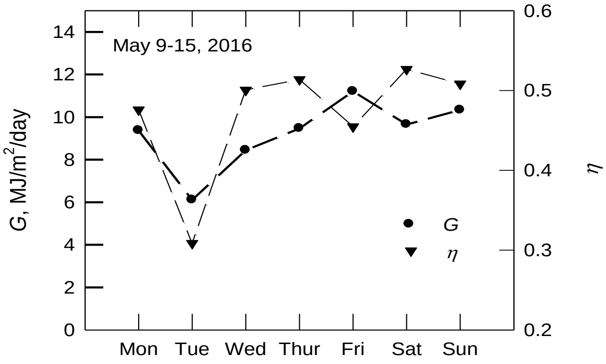

Fig. 3. Solar radiation and thermal efficiency: May 9-15, 2016

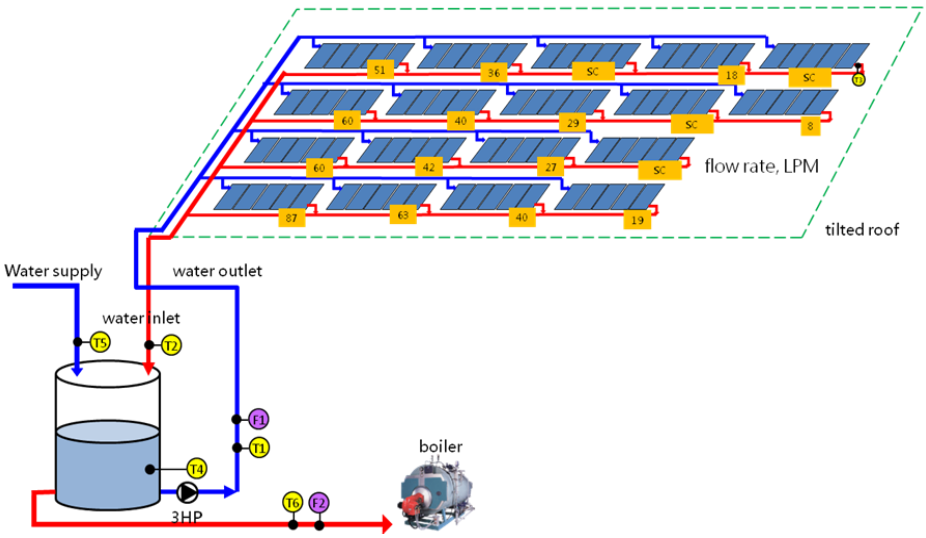

Fig. 4. The mass flow rate for the solar arrays

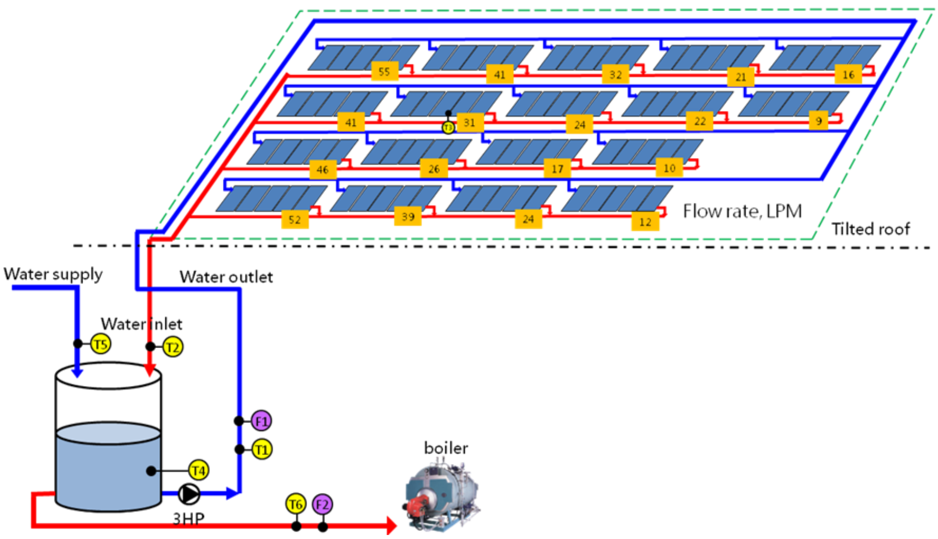

Fig. 5. The re-sized field piping on the mass flow rate for the solar arrays

4. Conclusions

Field measurements are conducted for a SWH in a mushroom plant. During initial operation, the thermal efficiency of the system was associated with the daily inclined global solar radiation. The economic viability of this pre-heating system is validated. However, dust accumulates on the transparent cover of the solar collectors and affects the system's performance significantly. Regular maintenance is required.

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Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

K. C. conducted the research; K.M. analyzed the data; W.M. wrote the paper. All authors had approved the final version.

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