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Solar Thermal Application for the Dairy Industry in Taiwan

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Abstract

Taiwan has been developing clean energy and solar heating for hot water production is a mature technology. The subsidy program (2000-2016) for solar water heaters means that the cumulative area of solar collectors installed was approximately 2.52 million square meters at the end of 2016, in which more than 93% have been installed in the domestic sector. Industrial heat processes represent an area for solar thermal application. This study presents field measurements for solar water heaters installed for sterilization in dairy industry. Global solar radiation can be correlated with the system's thermal efficiency reasonably well. As a pre-heating system, financial viability is validated.

Keywords

Solar Thermal, Solar Water Heater, Dairy Industry, Thermal Efficiency

1. Introduction

Using renewable energy is one of the major tools for reducing CO_2 emission. Mauthner *et al.* [1] reported the worldwide energy yield per annum in 2015 from wind power, solar thermal heat and photovoltaic power were 990 TWh, 375 TWh and 375 TWh, respectively. In Taiwan, the "Framework for a Sustainable Energy Policy" was announced in 2008. The "Renewable Energy Development Bill" and the "Greenhouse Gas Emission Reduction and Management Act" were also enacted in 2010 and 2015, respectively [2]. Further, production of hot water using solar water heaters (SWHs) has proven reliable and economical [3] [4] [5] [6]. A purchase-based subsidy program (2000-present) has been implemented by the Taiwanese government. The cumulative area of solar collectors installed was approximately 2.52 million square meters at the end of 2016, in which more than

93% have been installed in the domestic sector.

The real energy savings for SWHs are among the critical factors determining customer choice. Hill *et al.* [7] showed more energy savings can be obtained for larger scale SWHs. Therefore, industrial heat processes represent another area for solar thermal applications [8] [9]. In this study, the field measurement of an SWH for sterilization in dairy industry from November 2014 to April, 2016 were conducted. The system efficiency was determined and the results will be useful for promoting solar thermal application.

2. Setup for Field Measurements

To promote SWHs for industrial processes, e.g. dairy industry, it is critical to evaluate system performance and real energy savings. Field measurements for a SWH, located in Taichung City (24˚10'10"N, 120˚36'24"E), were conducted. The SWH serves as a pre-heating system for a boiler, using low sulfur light fuel oil, and is situated on the flat roof of a low-rise building, as shown in **Figure 1**. The area of the glazed solar collectors, A_{sc}, was 115.8 m^2. The solar collectors facing south were installed at a tilt angle of 30˚. Temperature set control (=5˚C) was used to the control circulation pump. For hot water supply from the SWH to the boiler, the ball valve was switched on when the vapor pressure in the boiler was less than 4 kg/cm^2 and switched off at 7 kg/cm^2.

To evaluate the system's performance, several monitoring devices were installed, as shown in **Figure 2**. A precision spectral pyranometer (PSP, Eppley Laboratory, Inc.) measured the incident solar radiation, *G*. Eight platinum resistance thermometers (denoted as T_a, T0 - T7; 1/10 DIN Class B, Izuder Enterprise) were installed to monitor the ambient and water temperatures. Two Macnaught flow meters (M2SSP-1R, denoted as F1 and F2) were positioned along the cold/hot water supply lines. Data was sampled every 10-s using a National Instrument's data acquisition system (cFP-AI-110 and cFP-RTD-124).

Figure 1. Solar water heater for sterilization.

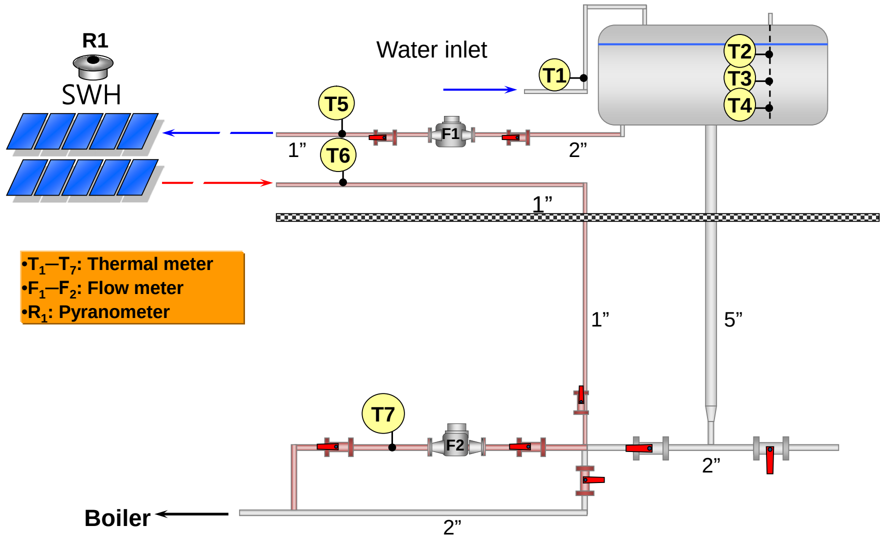

Figure 2. A schematic drawing of the monitoring devices

Certification for a solar collector is mandatory when filing for rebates in the current subsidy program. The Chinese National Standards (CNS 15165-1-K8031-1) specifies an outdoor test method to determine steady-state thermal performance of solar collectors, η, using the following formula.

$$\eta = F_R(\tau\alpha) - F_R U_L \frac{(T_{in} - T_a)}{I_g} \quad (1)$$

where T_{in} and T_a correspond to initial temperature in the cold water supply line and ambient temperature, respectively. In **Figure 3**, The useful energy collected from the solar collector, $F_R U_L$, and its heat loss, $F_R(\tau\alpha)$, are 0.7507 and 4.3357, respectively.

For the system, the daily efficiency, η_s, was calculated using the following formula.

$$\eta = \Sigma\{\dot{m} C_p (T_{out} - T_{in}) / (A_{sc} G)\} \quad (2)$$

C_p: specific heat; MJ/(kg˚C)

$\dot{m}$: water mass flow; kg/s

T_{out}: final outlet temperature in the solar collectors; ˚C

3. Results and Discussion

The daily solar radiation per square meter, ΣG, affects the system's thermal efficiency. In **Figure 4**, it shows there is abundant solar radiation in the field measurement location. The value of ΣG is more than 10 MJ/m^2 for 71.74% days. On working days, the effect of ΣG on the value of η_s for the SWH is shown in **Figure 5**. Although the data are scattered, the correlation between ΣG and η_s is evident. A higher value of ΣG results in an increase in the system's thermal efficiency (or higher solar gain). The average value of η_s is 0.521, which is greater than that observed for a SWH installed in a dormitory (η_s = 0.3 - 0.45) [10].

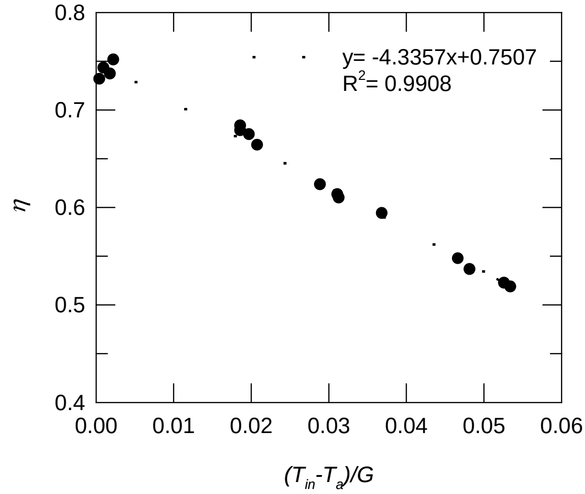

Figure 3. Thermal performance of the solar collector.

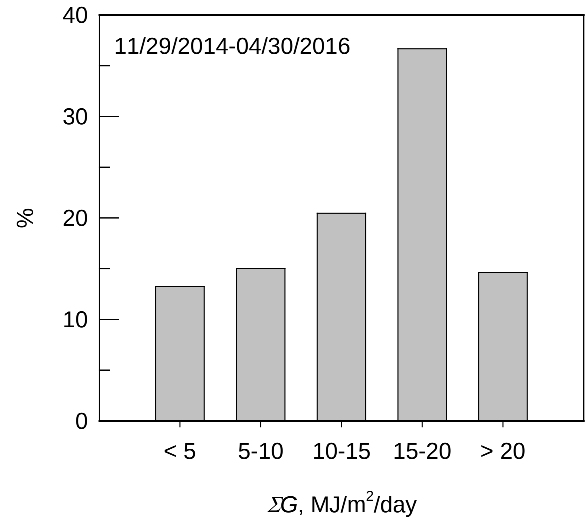

Figure 4. The daily solar radiation per square meter.

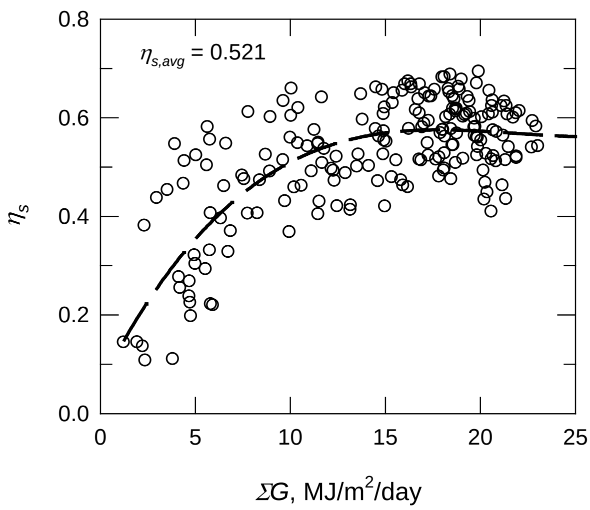

Figure 5. Effect of ΣG on the value of η for the SWHs (working days).

This demonstrates a SWH as a pre-heating system for industrial use is promising for greater energy savings.

Hot water consumption patterns have a significantly effect on the system's thermal efficiency and financial viability. In this program, the figure is 645 m^3/month and the annual energy savings are 243,751 MJ. For the boiler, the heating value is 40.19 MJ/L and the combustion efficiency is taken as 0.875. The substituted fuel savings are estimated to be 0.14 million NT$/year (1 USD ≈ 31 NT$). Further, the capital cost is approximately 0.95 million NT$ and the direct subsidy by the BEMOEA is approximately 0.26 million NT$. The payback period is estimated to be 4.8 years. Notably the maintenance cost is not considered. Since the expected service period for SWHs in Taiwan is more than 15 years, this program demonstrates the financial viability of SWHs for sterilization in dairy industry.

4. Conclusion

Load pattern is one of the dominant factors for the energy savings of SWHs. As a pre-heating system, the field measurement in this study validates there is better system performance for solar thermal application in industrial processes. A simple cost-to-benefit analysis also demonstrates its financial viability. The results can be used as a reference for the BEMOEA promoting solar thermal applications in Taiwan and other countries.

Acknowledgements

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