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EXPERIMENTAL STUDY ON THE PERFORMANCE OF THERMOSYPHON SOLAR WATER HEATER IN AREQUIPA, PERU

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ABSTRACT

An experimental device was design and built to evaluate the performance of a solar water heating system. Flat-plate solar collectors system were studied considering parallel configuration. Temperature sensors (k type thermocouple), a differential pressure transducer, a turbine type flow meter, and a pyranometer (global solar irradiance) were installed at strategic points for continuous monitoring. The studied parameters were: temperature at the inlet and outlet of the solar collectors and of the tank, heat absorbed by water, pressure drop and mass flow of water. The result shows the performance of the solar collectors system in specific conditions of the Arequipa city in Peru.

INTRODUCTION

With the advance of technology and the depletion of energy resources, the need to use renewable resources increases. For this reason, it is sought to improve the management and utilization of renewable resources in order to diminish the environmental impact and emissions of greenhouse gases responsible for climate change. This encourages the appropriate use of solar thermal energy.

Solar energy is the energy from the sun, which is presented as an endless source. Solar energy can be transformed into thermal or electrical energy by using solar collectors or photovoltaic panels, respectively. Besides, solar energy offers important advantages over other energy sources, emphasizing its free availability and pollution-free nature [1]. In Arequipa, nowadays the solar energy is mainly used to heat water using solar collectors. These are devices used to transform solar radiation into thermal energy that is absorbed by the water in solar water heating systems. Basically, there are two types of solar collectors: concentrating collectors and flat plate collectors. The last one has the advantage of using a fixed orientation and both direct and diffuse sunlight [2], being its main feature, its ability to work with temperatures below the boiling temperature. [3].

The Peruvian territory has a great potential for harnessing solar energy thanks to its geographical and climatological characteristics [4]. In most of the localities, solar radiation is high and uniform throughout the year, compared with other countries, which makes attractive its use [5]. The area of greatest solar energy potential of the Peruvian territory is mainly the south coast, which has radiation of 6.0 to 6.5 kWh/m2, followed by the highlands which have from 5.5 to 6.5 kW h/m2 of solar radiation [6] and finally, the zone of low values of solar energy: the jungle, which registers values from 4.5 to 5.0 kWh/m2 near the Equator [7].

In the last years, in the southern regions of Peru people have been taking advantage of this source of energy with solar dryers, processing various agricultural products (oregano, corn, tomato, hot pepper, etc.), solar cookers and solar heaters. In the region of Arequipa, which is one of the zones with highest incidence of solar radiation, approximately 38,000 solar heaters have been installed for domestic use, which are an annual equivalent to 61.17 MWh of electrical energy and save approximately U.S. $ 7.4 x 106 for users [8].

The objective of this study is to evaluate the performance of a solar water heating system of a small size in the city of Arequipa, Peru.

EXPERIMENTAL MODEL AND PROCEDURE

The experimental tests were done in a solar water heating system, which consists of a set of flat plate solar collectors and a storage tank (Fig. 1). The solar collectors studied are mainly designed and used for domestic activities

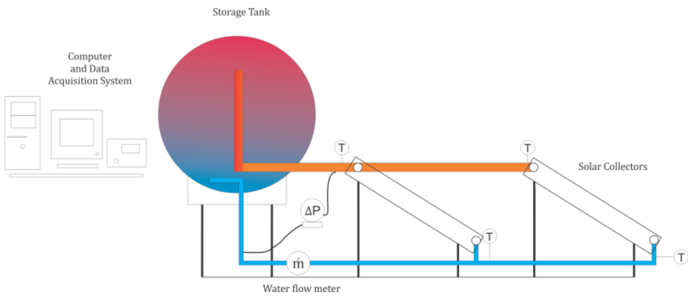

Fig.1. Solar water heating system

Figure 2 shows the distribution of the collectors. Ten collectors oriented to magnetic north were distributed in parallel (two rows of five collectors).

Fig. 2. Experimental devise

The Flat plate collectors used were built by copper tubes of 8mm diameter (grid). On the top of tubes was placed an aluminum of 1mm thickness (flat plate) to improve the absorption area. The grid tubes attached to the aluminum plate was placed in an aluminum box with a top cover glass of 3mm thickness. Expanded polystyrene was placed between the grid and the box to prevent heat leakage.

The dimensions of the collectors are 2m x 1m (length x width). The inclination respect to the ground is 15º. The storage tank is stainless steel of 3 mm thickness and 650 liters of capacity coated with expanded polystyrene and a galvanized steel casing of 1 mm thickness.

A turbine flowmeter FlowStat VCB-15-B-ES model was installed at the oulet of the tank (Fig. 1).The incident solar radiation was measured using a pyranometer Campbell Scientific Inc. CS 300 model. A differential pressure transducer Autrol ATP3100 model was installed to measuring the pressure drop in the collectors. Temperature sensors (k type thermocouple), were installed at the inlet and outlet of each collector and at the inlet and outlet of the storage tank for continuous temperature monitoring. (Fig. 1 y Fig. 3). All the signals emitted by the measurement instruments, were acquired by the Data Acquisition System, which sent them to a personal computer (PC) through an RS-232 port, for its later processing and analysis. The software used for the data acquisition was HP BenchLink Data Logger, which has a Windows type interface easy to configure and manage. For the acquisition of signals from the electronic scale, LabVIEW® was used. This software had also a Windows type interface, which allowed it easy management. The data was also obtained through an RS-232 connection between the scale and a laptop (Fig. 1).

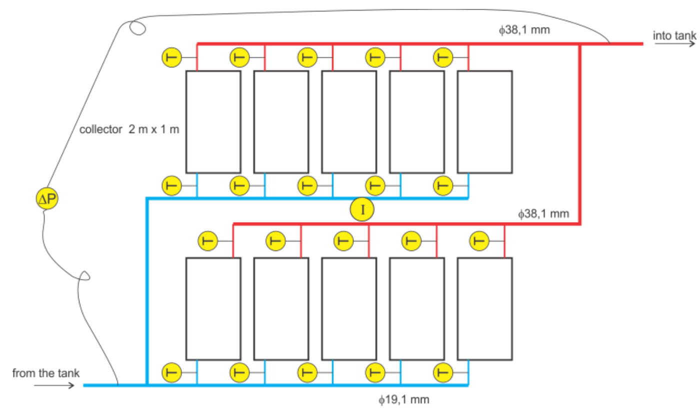

Fig. 3. Details of experimental divise

The uncertainties studied are shown in Table 1.

Table 1. Uncertainties studied.

property	uncertainties
Temperature, °C	± 0,2 °C
global solar irradiance, W/m^2	5 %
Pressure drop, pa	2 %
water mass flow, kg/s	5 %

The studied parameters are: temperature at the inlet and outlet of the solar collectors and of the tank, pressure drop in the collectors, heat absorbed by water and mass flow. The result shows the performance of the solar collectors system in specific conditions of the Arequipa city in Peru.

RESULTS AND DISCUSSION

The variation of temperatures of different locations during a day is shown in Fig. 4. The measured global solar irradiation is also shown in Fig 4. It can be seen that the temperature at the inlet of the solar collectors is different from the outlet temperature. Can also be seen that the increase of solar irradiation causes the increase of the outlet temperature. Also, the decreasing of solar irradiation causes the decreasing of the outlet temperature. This decreasing has a lower slope curve, which is due to the thermal inertia of the system.

The maximum outlet temperature occurs at noon when it reaches 85ºC. On this day the maximum incident energy is 1200 W/m2. After 13:00, incident radiation starts dropping, nevertheless the outlet temperature continues around 80ºC for an hour and thirty minutes more.

A comparison with the temperature curves of the solar collector system reported by Riahi *et al* [9] confirms current measurements. They reported that maximum temperature occurred at 14:00 and it was 80ºC which is consistent with the curve shown in Fig. 3.

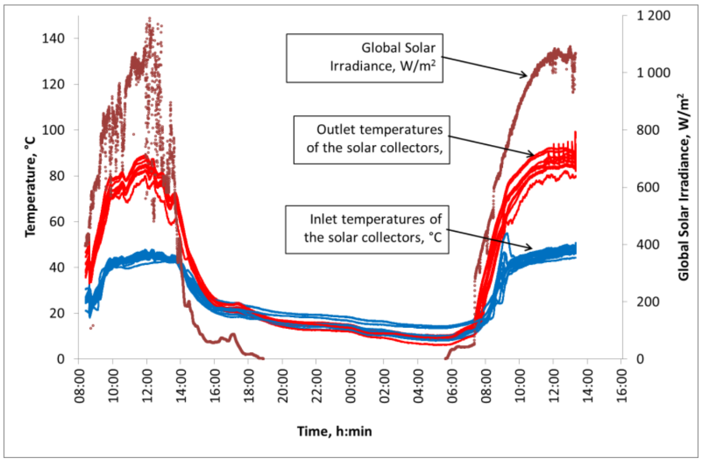

Fig. 4. Global Solar Irradiance and variation of temperatures

The average of the difference between the inlet and outlet temperatures of the collectors is calculated to evaluate the performance of the system (Fig. 5). This average represent all the differences of temperature with an uncertanty of 4%.

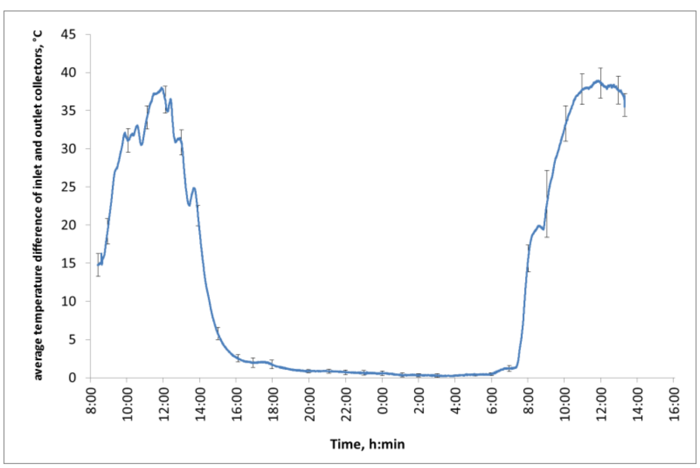

Fig. 5. Average of the difference between the inlet and outlet temperatures of the collectors.

Figure 6 shows the variation of the water temperature at the inlet and outlet of the tank. An important thing to be stressed is the temperature inversion at night so it is presumed that there is a loss of heat by radiation from the collectors to the external environment.

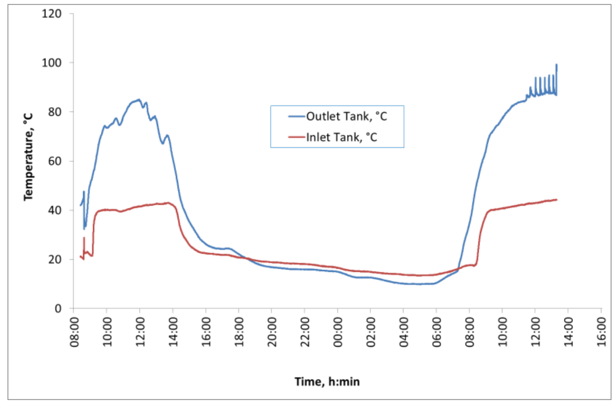

Fig. 6. Variation of the water temperature at the inlet and outlet of the tank

Figure 7 shows the mass flow rate and the pressure drop in the system. As can be seen, at noon of day 1 the mass flow rate reaches its peak value around 0.0018 kg/s. The mass flow rate decreases as a consequence of decreasing of solar irradiation. The maximum mass flow reported by Zerrouki *et al* [10] was 8.5g/s (0.0085 kg/s) at 13:30 which in terms of time of occurrence corresponds to the time obtained in the current study. The results obtained by Riahi *et al* [9] indicate that the maximum mass flow rate was reported at noon and it was 16.5 g/s (0.0165 kg /s), a value close to that obtained in this study.

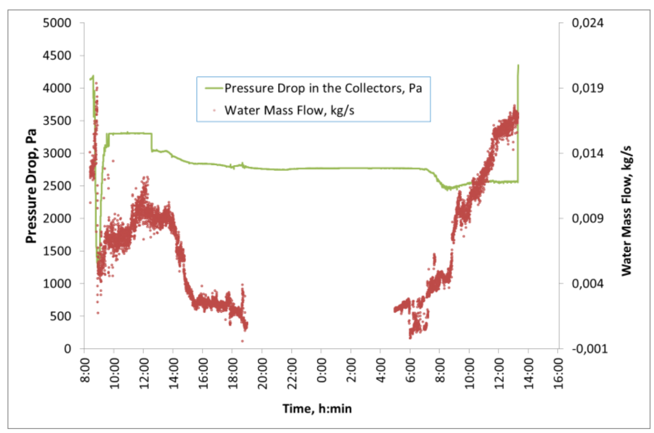

Fig. 7. Flujo másico y caída de presión

Referring to the pressure drop, can be seen in Fig. 7 that the average pressure drop is 3kPa. Considering that the internal pressure of the network is 200kPa, the pressure drop in the collectors can be considered less than 5%.

Figure 8 shows the thermal efficiency of the solar collectors system, it has been calculated considering:

$$\eta_{thermal} = \frac{\dot{Q}_{water}}{\dot{I}_{sun}} \quad (1)$$

Where,

$\eta_{thermal} =$ The thermal Efficiency of the solar collectors system, [W/W]

$\dot{Q}_{water} =$ Useful energy gain or heat absorbed by water, [W]

$\dot{I}_{sun} =$ Intensity of solar Irradiance, [W]

Where,

$$\dot{Q}_{water} = \dot{m} \cdot Cp_{water} \cdot \Delta T \quad (2)$$

$$\dot{I}_{sun} = I \cdot A \quad (3)$$

Where,

$\dot{Q}_{water} =$ Useful energy gain or heat absorbed by water, [W]

$\dot{m} =$ Mass flow, [kg/s]

$Cp_{water} =$ Specific heat of water, [kJ/kg·K]

$\Delta T =$ Average of the difference between the inlet and outlet temperatures of the collectors, [°C]

I_{sun} Intensity of solar Irradiance, [W/m^2]

A = Absorption area or collector area [m^2]

As can be seen, efficiency varies with the solar radiation and the heat absorbed by water. The efficiency ranges between 5% and 15%. At 18:00, the efficiency rises sharply (apparently), this effect is due to the abrupt decrease of solar irradiance, though, there is a mass flow rate as a consequence of the thermal inertia of the system. The decreasing of solar irradiance raises the efficiency to very high values which do not represent the true performance of the solar collectors system.

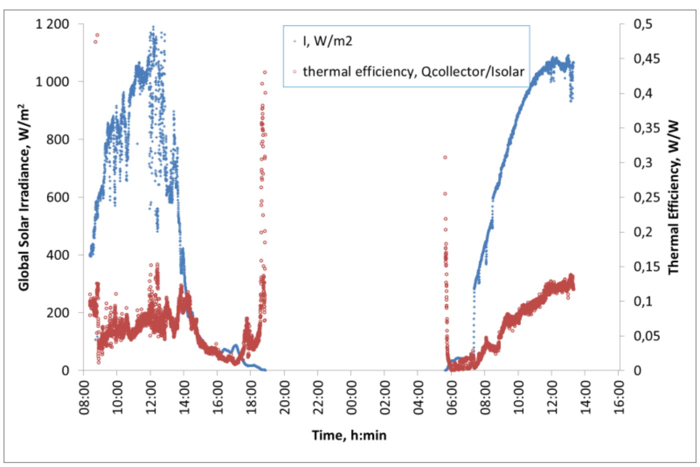

Fig. 8. Global Solar Irradiance and Thermal Efficiency

CONCLUSIONS

Experiments were realized in a solar collectors system to study the natural circulation of water (performance of thermosyphon effect). The temperature at the inlet and outlet of the solar collectors and of the tank, the heat absorbed by water, the pressure drop in the collectors and the mass flow of water were studied to know its influence in the performance of the solar water heating system in specific conditions of the Arequipa city in Peru.

The pressure drop in the collectors at the time of maximum irradiation can be considered less than 5%. This is due to the diameter of the tubes of the grid.

The maximum temperature observed at the outlet of the collectors is 80 °C, this temperature is reached at noon, that is coincident with the maximum value of system efficiency (15%).

The mass flow rate reached at the time of maximum intensity of solar irradiance was 0.0165kg/s, it means that the thermal efficiency of the solar collectors system compares well with the data reported by other researchers for relatively similar systems.

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