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EXPERIMENTAL STUDY ON THE PERFORMANCE OF A SOLAR WATER HEATING SYSTEM WITH FORCED CIRCULATION AND SERIAL / PARALLEL CONFIGURATION

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Abstract. *An experimental device was design and built to evaluate the performance of a solar water heating system. A flat-plate solar collectors system composed by 10 collectors was studied considering parallel and serial configuration. The performance of the solar water heating system was studied considering different mass flow rates of water. 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 Arequipa city in Peru.*

Keywords: *water heating system, flat-plate solar collector, serial and parallel configuration.*

1. 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 using solar collectors or photovoltaic panels, respectively. Besides, solar energy offers important advantages over other energy sources, emphasizing its free availability and its pollution-free nature (Rodríguez, 2009). 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 (CEUTA, 2008), being its main feature, its ability to work with temperatures below the boiling temperature (Struckmann, 2008). The Peruvian territory has a great potential for harnessing solar energy thanks to its geographical and climatological characteristics (Ministerio de Energía y Minas, 2001). In most of the localities, solar radiation is high and uniform throughout the year, compared with other countries, which makes attractive its use (Horn, 2006). 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 $kW{\cdot}h/m^2$, followed by the highlands which have from 5.5 to 6.5 $kW{\cdot}h/m^2$ of solar radiation (Proyecto PER/98/G31, 2003) and finally, the zone of low values of solar energy is the jungle, which registers values from 4.5 to 5.0 $kW{\cdot}h/m^2$ near the Equator (Ministerio de Energía y Minas, 2001). 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 MW·h of electrical energy and save approximately US$. $7.4x10^6$ for users (Gerencia Regional de Energía y Minas-Arequipa, 2002). The objective of this study is to evaluate the performance of a specific solar water heating system installed 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.

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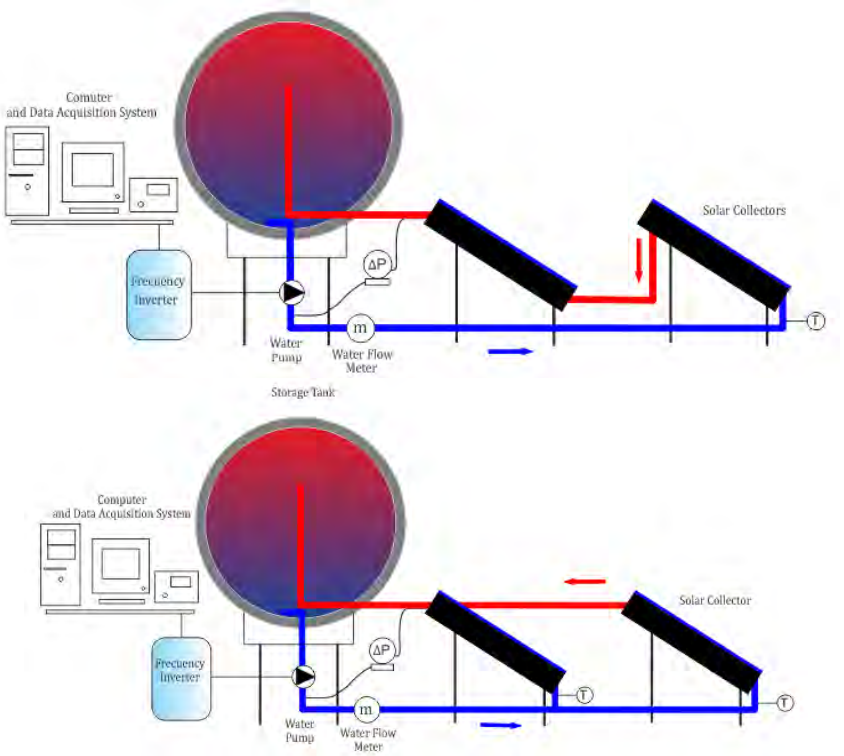

Fig.1. Solar water heating system distributions

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

Fig. 2. Experimental device

The Flat plate collectors used were built by copper tubes of 8mm diameter (grid). On the top of tubes was placed 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.

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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. 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 and 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.

Figure 3 shows serial configuration of the collectors and Figure 4 shows parallel configuration of the collectors.

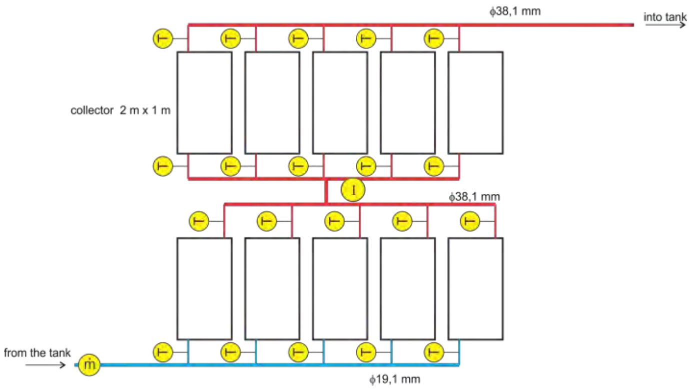

Fig. 3. Details of experimental device, serial configuration.

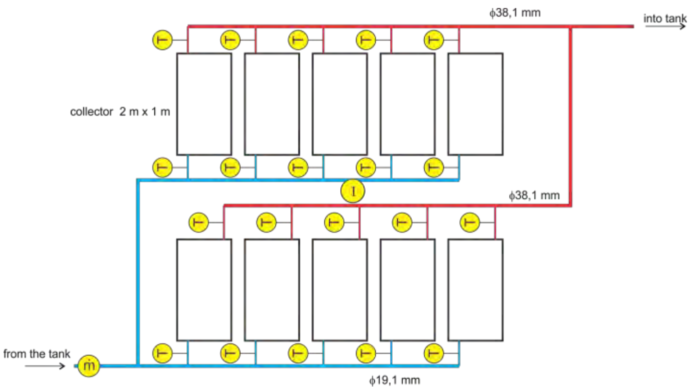

Fig. 4. Details of experimental device, parallel configuration.

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 were: thermal efficiency, temperature at the storage tank for each test with parallel and serial configuration of the collectors, and the temperature at the storage tank for different mass flow rates. The result shows the performance of the solar collectors system in specific conditions of the Arequipa city in Peru.

RESULTS AND DISCUSSION

Natural convection tests were realized in serial and parallel configuration (Fig. 3 and Fig. 4). Figure 5 shows the thermal efficiency of natural convection over a period of 7 hours of testing. It shows that the efficiency of parallel

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configuration is higher than serial configuration, and after 12 h both efficiencies have similar values. The maximum efficiency achieved in parallel configuration was about 30% and in serial configuration 18%. The water heating process is less efficient in serial configuration because of the pressure losses; in this configuration the water has to travel farther to reach the storage tank.

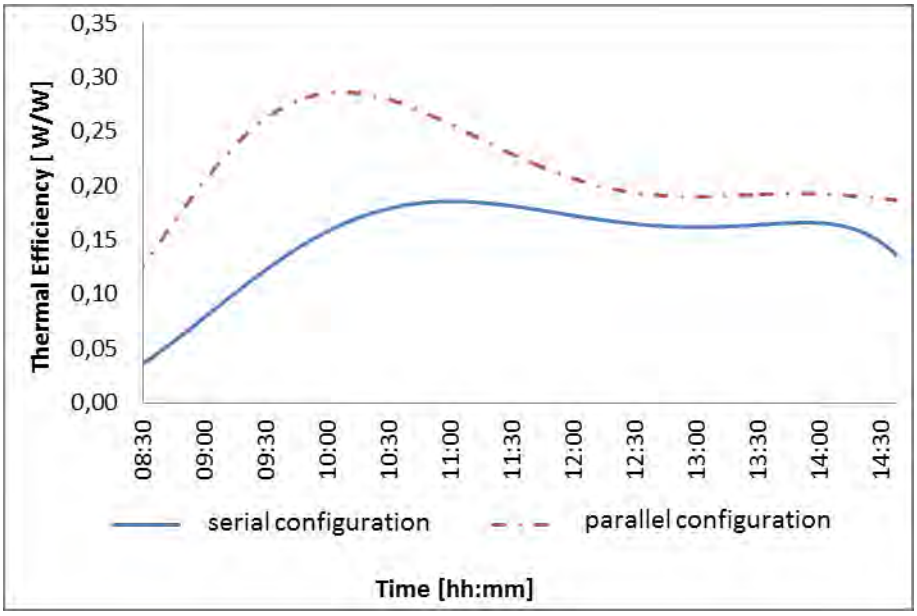

Fig. 5. Thermal efficiency in natural convection vs. time.

Figure 6 shows the thermal efficiency of differents mass flow rates in serial/parallel configuration tests. In this figure, we can see that thermal efficiency is higher for small flows, however, natural convection test always shows a higher efficiency.

At the beginning of the experiment, the tests with forced mass flow rate show higher thermal efficiency than natural convection tests, but after 10 h, thermal efficiency of natural convection tests outstrips the thermal efficiency of the tests with forced mass flow rates.

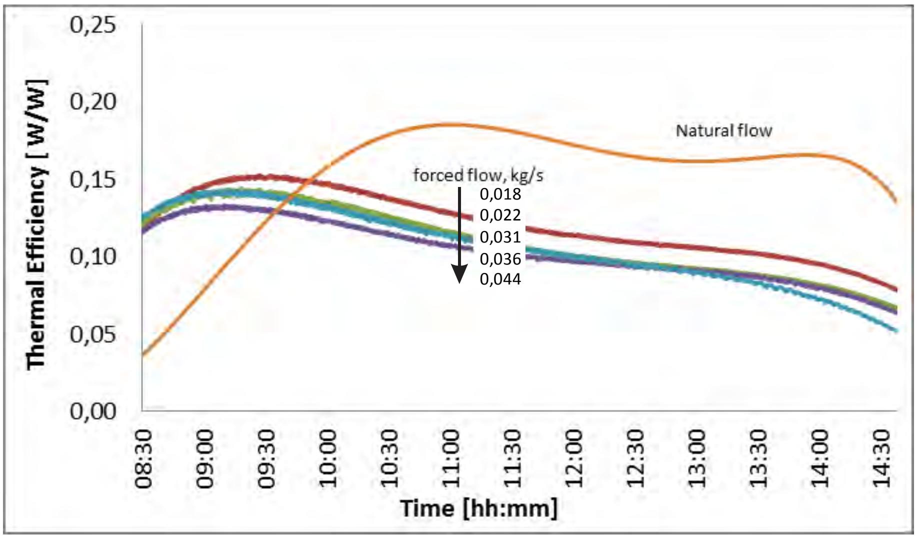

Fig. 6. Thermal efficiency in forced flow vs. time.

Figure 7 shows the average temperature in the storage tank for different mass flow rates in serial configuration tests. The temperature in the storage tank is higher with lower mass flow rate. It corroborate the thermal efficiency values of Fig. 6.

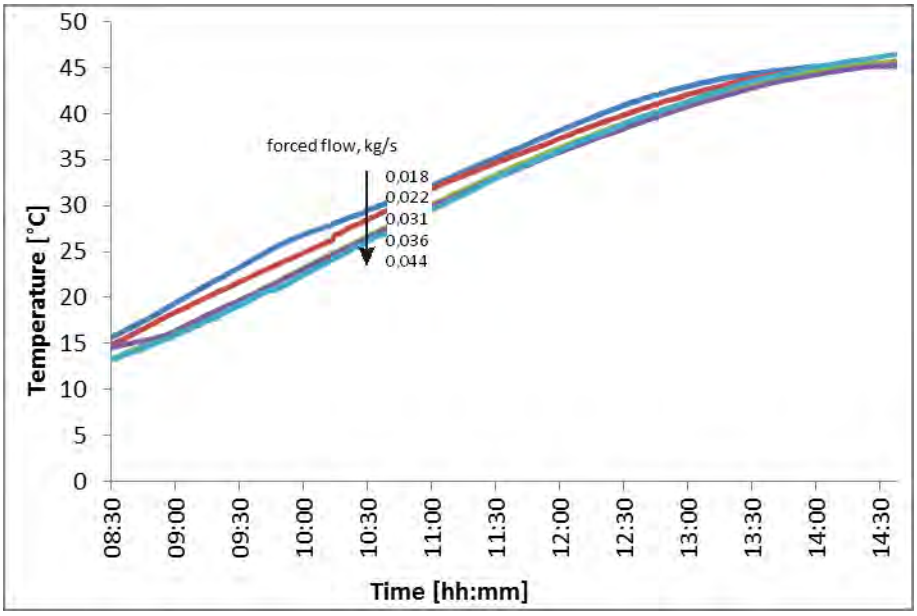

Fig. 7. Tank temperature in forced flow vs. time.

Figure 8 shows heat losses in the storage tank during night hours, this figure refers to the natural convection test with serial configuration. It notes that since 16 h to 8 h of the following day, the temperature inside the storage tank drops about 10°C, representing 20% of the energy stored during daylight hours. This phenomenon is mainly due to the losses produced by the thermal insulation of the tank.

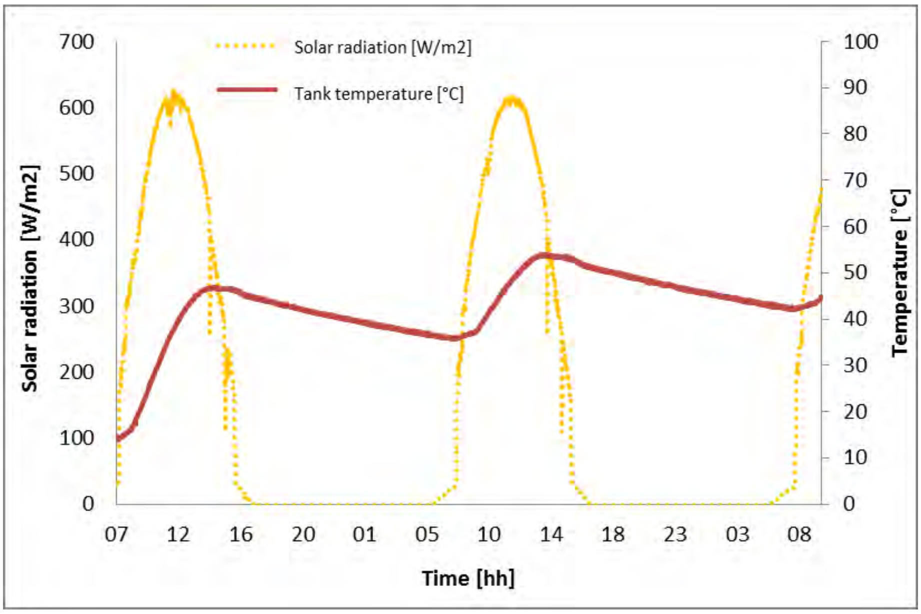

Fig. 8. Night heat loss in the tank vs. time.

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4. RESPONSIBILITY NOTICE

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