Comparison of two temperature control techniques in a forced water heater solar system

E Hernández1, R E Guzmán1, A Santos1 and E Cordoba1
1 Universidad Pontificia Bolivariana, Floridablanca, Colombia

E-mail: emil.hernandez@upb.edu.co

Abstract. A study on the performance of a forced solar heating system in which a comparative analysis of two control strategies, including the classic on-off control and PID control is presented. From the experimental results it was found that the two control strategies show a similar behavior in the solar heating system forced an approximate settling time of 60 min and over-elongation 2°C for the two control strategies. Furthermore, the maximum temperature in the storage tank was 46°C and the maximum efficiency of flat plate collector was 76.7% given that this efficiency is the ratio of the energy of the radiation on the collector and the energy used to heat water. The efficiency obtained is a fact well accepted because the business efficiencies of flat plate collectors are approximately 70%.

1. Introduction
Automatic control has played an important role in the advancement of engineering and science. Given the development in control systems, for space vehicles, guided missiles and robots, this has become an integral part of modern industrial processes and manufacturing. For example, automatic control is fundamental for the control of pressure, temperature, humidity, viscosity, level and flow in the process control industries, to improve productivity and simplify the work of many repetitive and routine manual operations, making it attractive to achieve optimum performance of the systems [1-2]. On the other hand, solar collectors are devices that are used to heat water, for heating systems and swimming pools, and can be used both at home and industrial level. Because they are equipment of easy acquisition thanks to its technical - economic relation.

It is composed of a solar radiation absorbing plate that is responsible for transferring the thermal energy to the circulating fluid through a coil, a transparent cover and a metal box isolated on the sides and the bottom, where the elements previously described [3,4].

In the following work we use a forced solar heating system with a flat plate collector, as shown in Figure 1, Figure 2 and Figure 3, in order to find the curves of radiation vs efficiency, according to the solar rays that effect the collector surface, the parameters obtained were compared with similar studies carried out by the company CENSOLAR (Solar Energy Studies Center) [5-8].
2. Theory
Numerous investigations have been carried out on thermosiphon solar water heaters with flat plate collectors. Runsheng Tang et al. [9], carried out a theoretical and experimental study on a solar water heater thermosyphon and concluded that for a given temperature in the tank, the outlet temperature in the system with a vertical cylindrical tank was slightly larger than a horizontal cylindrical tank.

Soteris A. Kalogirou [10], showed, through a simulation, that the best performance system is obtained with small pipe diameters in the collector with a range of 15mm-35mm with similar efficiencies, therefore the decision depends on the costs. It also determined that the optimum slope of the collectors is the latitude plus 10°, although a smaller slope does not significantly affect the performance, and the optimum distance between the top of the collector and the bottom of the tank is 15cm. The useful energy that is obtained in a solar collector, can be determined with equation (1).

\[ Q_{util} = mC_p(t_s - t_e) \] (1)

Where \( m \)=mass flow, \( C_p \)=Specific water heat, \( t_s \)=Output temperature, \( t_e \)=Inlet temperature. The performance of the solar collector depends on the useful energy and the solar radiation, according to equation (2).
\[ \eta = \frac{Q_{\text{util}}}{(S \times I)} \tag{2} \]

Where: \( I \) = Intensity of solar radiation in W/m\(^2\) and \( S \) = Catchment area in m\(^2\). The useful energy can be calculated as the difference between the energy that is captured and that which is lost for thermal reasons. The energy absorbed can be expressed according to equation (3).

\[ Q_{\text{abs}} = a \times I \times S \tag{3} \]

Where \( a \) = Coefficient of losses. Thermal losses are proportional to the collector surface and the temperature difference between the absorber and the environment, according to equation (4).

\[ Q_{\text{per}} = b(t_m - t_a)S \tag{4} \]

\[ t_m = \frac{(t_e + t_s)}{2} \tag{5} \]

The performance is expressed according to equation (6).

\[ \eta = \frac{Q_{\text{util}}}{(I \times S)} = \frac{(Q_{\text{abs}} - Q_{\text{per}})}{(I \times S)} = a - b(t_m - t_a)/I \tag{6} \]

\[ \eta = 0.83 - 6.8(t_m - t_a)/I \tag{7} \]

The values of the constants for flat plate collectors can be taken as [11-12]:

\[ a = 0.83 \text{ and } b = 6.8 \tag{8} \]

3. Methodology

The forced system consists of a solar collector, an accumulator tank with heat exchanger, with a capacity of 150 litres, a centrifugal pump of magnetic drive and an aeration tank. All of this is coupled, as shown in Figure 2, in which the installation is presented. The dimensions of the tank and the manifold were made according to the recommendations of the company Censolar for forced systems installations.

The thermal performance test of the collector was carried out considering equation (9) for which FR \( \tau = \) constant and FR \( U = m = \) constant can be assumed [3]. The equation of this characteristic curve of the collector can be assimilated quite accurately to that of a line in which the variable on the abscissa axis is \((t_m - t_a)/I\) and whose slope is FRU. For a c.p.p. Of average type can be approximated \( a=0.83 \) and \( m=6.8 \), obtaining the equation (9).

\[ \eta = 0.83 - 6.8(t_m - t_a)/I \tag{9} \]

In equation (9), if \( x = (t_m - t_a)/I \) is obtained

\[ \eta = 0.83 - 6.8x \tag{10} \]

The value of \( I(\text{w/m}^2) \) radiation was measured with a Kipp & Zonen CM3 pyranometer and the temperatures with thermocouples type k located at the ends of the collector, the results are shown in Figure 4, where the maximum efficiency obtained was 76.7% [13].

Figure 5 shows the behaviour of the two control strategies in which for the on-off case a set point of 30°C and a hysteresis of 1.5°C are used, for the PID case the values of the parameters with the auto-tuning function of the controller \( P=2.9, I=342 \) and \( D=71 \). An approximate settling time of 60 minutes and over-elongation of 2°C can be observed for the two control strategies [14].
4. Conclusions

A forced solar water heating system is designed, constructed and evaluated with a flat plate manifold. This equipment is operated by a centrifugal pump of 12V, has a storage capacity of water of 150 litres, which can be used to supply hot water.

According to the experimental results, it is observed that the collector reaches a maximum efficiency of 76.7% and a maximum temperature of 46°C in the storage tank.

It was found that the forced flow system allows the storage tank to be positioned below the collector level, which is an advantage when compared to the thermosyphon system where the storage tank must be above the collector.

With an average flow rate of 0.3gpm the pump provides sufficient mass flow to the water to extract the heat from the manifold and deliver it to the coil quickly and steadily, raising the water temperature to a maximum of 50°C.

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