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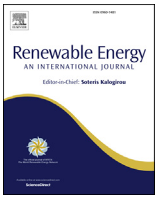

The pulsed-flow design: A new low-cost solar collector

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ABSTRACT

A new pulsed-flow design of hose-based solar collector is presented, which uses a long hose connected to district-grid water in the same way that the basic hose design does. But on contrary that this last, here the exit is not connected directly to consumption and instead the hot water flow is controlled by a thermostat that purges the hose to an insulated tank every time it reaches the desired temperature. So, this water-pond collector works close its maximum efficiency along the day and minimizes nocturnal cooling effect, improving noticeably the performance of the original hose design. As was demonstrated by thermal modeling, this new pulsed-flow design could satisfy the domestic demand of sanitary hot water even in high-latitude locations and furthermore, its performance could be noticeably improved by adding a smart microcontroller. The economic analysis shows this design could be highly competitive applied to large hot-water demands and relatively good for single family demands.

1. Introduction

It is well known that a small vacuum-tube solar collector can satisfy the family demand of hot water around worldwide. This design is suitable for cold high-latitudes developed countries that represent more than two-thirds of worldwide market. On the other hand the scenario is quite different in developing countries in which prices usually increases markedly due to extra costs like freight, technician's installation and insurances that are all very high in countries with low population density and small solar markets. Certainly in this case there are barriers not solved for the vacuum-tube technology and its complexity. However, recently has been proposed a simple solar collector based on a long hose, intended to solve this challenge by offering a low-cost home-made system [1]. It consists in a single black LDPE hose wrapped by transparent air-packed polyethylene film, which is connected directly between district water grid and consumption, as Fig. 1 illustrates. This way, by choosing a large-diameter long hose a good flow is provided to consumption meanwhile the full water inventory is simultaneously heated within the hose. Despite its simplicity, this collector achieves good diurnal efficiencies according to both, their large solar area and water-pond characteristics. The water pond scheme obtains higher efficiencies relates to conventional natural-convection scheme in which a few liters is overheated into the collecting unit, as it was used by previous designs of water-pond roofs [2–4]. This key behavior will be presented briefly here; a full discussion was previously provided [1].

1.1. Thermal analysis of the water-pond solar collector

Thermal efficiency (η) of any solar collector can be approximated by a linear function:

$$\eta = a0 - a1\,\frac{(Tm - Ta)}{I_n} \tag{1}$$

where a_0 is the optical efficiency, a_1 (W/m^2 °C) is the heat-losses coefficient, I_n is the normal flux of solar irradiance (W/m^2) and T_a is the ambient temperature. The mean temperature (T_m) in a flat collector is the average between the cold inlet (T_c) and the hot exit (T_h) temperatures, and this difference $\Delta T = T_h - T_c$ easily rises 40 °C during the day since natural convection is the unique driven force on the cooling circuit [5–7]. For illustrative purpose, let us considered a collector working at ΔT = 40 °C and T_a = 20 °C in which the tank water is heated to 30 °C, and so, T_c = 30 °C. Hence, a set of: T_h = 70 °C, T_m = 50 °C and T_m–T_a = 30 °C is obtained. On the other hand, a water-pond collector working on the same condition has: T_c=T_h=T_m = 30 °C and thus T_m–T_a = 10 °C, a third of the previous one. Hence, according to Eq. (1) the efficiency of the water-pond collector is noticeable higher than the flat one of

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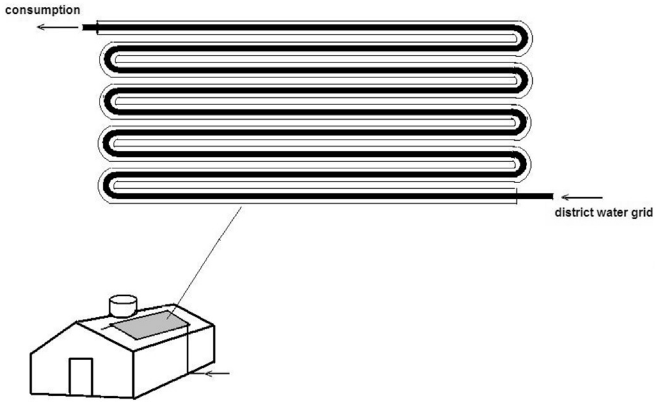

Fig. 1. Schematic drawing of the basic hose collector.

similar quality (that is, having same a_1 and a_0) since its heat losses is a third than the standard collector's ones.

The thermal performance of this hose-based collector working on a temperate maritime-climate location (Buenos Aires, 35° south latitude) was recently studied [8]. It was designed by using new transparent materials as thermal insulation [9–11]. It was observed that a 1.5″ LDPE hose (double-wrapped with double air-packed polyethylene film, being so $a_0 = 0.8$ and $a_1 = 14$ W/m^2 °C) could satisfy the diurnal household demand of sanitary water most part of year. This behavior is illustrates in Figs. 2 and 3 showing the daily evolution of the collector's (mounted onto a 30° inclined roof) temperature and efficiency for different seasonal conditions (see Table 1). From here, three clearly different behaviors can be observed:

a) Temperature increases sharply from sunrise to noon, and reaches useful levels at early morning accordingly to high efficiencies obtained during this period, in which they are close to its maximum (a_0) value.
b) Temperature barely keeps its level from noon to sunset following a sum-zero process in which small (positive and negative) efficiencies are observed. In this case and on contrary than previous one, the high temperatures reached cause a noticeable decreasing on efficiency.
c) Temperature decreases very sharp during the night. Here, the large area of hose becomes a major disadvantage of this system that works clearly worse than a conventional collector using an isolated tank.

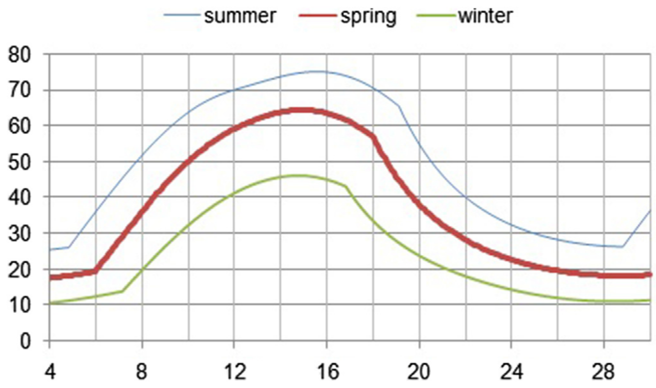

Fig. 2. Daily evolution of temperature (°C) on a 1.5″ hose collector during winter, spring and summer cases (see Table 1) for average conditions in Buenos Aires (35°S); time of day (in hours) on the X axis.

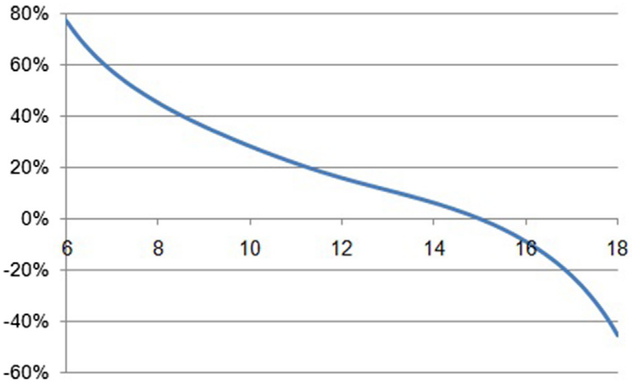

Fig. 3. Daily evolution of collector's efficiency (Eq. (1)) for the previous spring case.

Table 1
Climatic parameters for Buenos Aires (35°S) [12].

Date/Season	G'' (kWh/m^2)	I_n (W/m^2)	T_a (°C)
1st January/Summer	6.5	745	30 ± 5
21 Sept./Spring	4.5	720	22 ± 5
1st July/Winter	2.0	600	15 ± 5

Summarizing, we can conclude that the water-pond collector works very well during mornings and poorly during afternoon, but decidedly it has bad performance during nights. Furthermore, this system cannot storage any plus of energy absorbed during sunny days in order to be used on next cloudy days, since the energy gained during the day is always losses during night. These behaviors are maybe the reasons why this kind of collectors (extensively proposed by solar enthusiasts) has been ignored for scientists. However and as was proposed recently, this concept can be enhanced by using a "mixed" system assembled with a thinner hose in parallel with a thicker one [8] or by using a very thick vertical tube with reinforced insulation [13]. This way, this collector works reasonable in tropical and templates climates, but not at all in cold high-latitude locations or/and when the nocturnal demand is the predominant one. Indeed, these are unsolved challenges for every low-cost collector, but now we are intending to solve this lack by means of this new pulsed-flow design.

2. The pulsed-flow collector

2.1. Conceptual design

This new design proposes two major modifications to the basic hose collector:

1) An automatic temperature-controlled on/off valve is added at exit, like a bimetallic thermostat. So, every time the water within hose reaches the desired pre-set temperature (typically between 35 °C and 45 °C), this valve is opened and the hot water flows out the system until the "cold front" from inlet comes to exit. So, the valve is closed and then a new warming cycle begins.
2) The hose exit is connected to a thermally isolated storage tank, working as an intermediate buffer between collector and consumption. On the contrary that on a standard collector working on a free-convection loop, this tank does not need to be mounted outside onto the roof and so, its insulation can be built noticeably cheaper.

This way a pulse-flow system is obtained, in which the district-