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Numerical and experimental investigation of thermosyphon solar water heater

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ABSTRACT

A glassed flat plate collector with selective black chrome coated absorber and a low wall conductance horizontal storage are combined in order to set up a high performance thermosyphon system. Each component is tested separately before testing the complete system in spring days. During the test period, effect of different inlet water temperatures on the collector performance is studied and results have shown that the collector can reach a high efficiency and high outlet water temperature even for elevated inlet water temperatures. Subsequently, long term system performance is estimated by using a developed numerical model. The proposed model, accurate and gave a good agreement with experimental results, allowed to describe the heat transfer in the storage. It has shown also that the long-term performances are strongly influenced by losses from the storage than losses from the collector.

1. Introduction

Solar water heater is one of the most successful solar technologies. Nowadays, world's demand of energy has dramatically increased; furthermore, process to collect hot water by solar radiation is yet expensive. Most solar water heater designs used for single family are the closed and opened solar water heating systems. These two systems are categorized into two groups: forced circulation and natural convection. The advantages of thermosyphon systems are that they do not rely on pumps and controllers, are more reliable, and have a longer life than forced circulation systems [1]. Thermosyphonic systems are studied intensively by many researches [2–10]. Hasan [11] studied the effect of the hot water storage tank volume and configuration on system efficiency and he concluded that there is no difference between the performances of vertical and horizontal storage tank systems, and concluded that the efficiency of a SWH system can be increased by using a larger hot water storage tank or smaller collectors area.

The technical performance and reliability of solar systems are key parameters that can significantly vary the production of thermal energy and thus the cost effectiveness. The two main parameters, to get a reliable system, are the storage insulation and the collector performances. A very good insulated storage and a highly efficient collector leads to a profitable system in all months of the year and mainly in the countries having good sunshine climate. Tunisia is one of these countries which characterized by a temperate and an abundant sunshine for the most periods of the year. A typical flat plate solar collector consists of an absorber in an insulated box with transparent cover sheets (glazing). The absorber is usually made of a metal sheet characterized by a high thermal conductivity with attached or integrated tubes. For the collectors having high performances, its absorbers surfaces are coated with a special selective material to maximize radiant energy absorption while minimizing radiant energy emission. The best selective absorbers present selectivity values over 10, denoting higher sunlight energy absorption and lower thermal energy losses. The insulated box reduces heat losses from the back and sides of the collector. The flat plate collector of selective absorber coated with black chrome is one of best collectors used for heating water. For the complete system, the storage must be insulated with very low thermal conductivity materials. Black chrome for selective absorbers and collector efficiency vs. coating properties are studied in [12–17]. Kalogirou et al. [18] introduced in their study, performance of solar systems employing collectors with colored absorber, that the flat plate collectors of highly selective coatings can reach stagnation temperatures of more than 200 °C and they showed that the colored collectors present lower efficiency than the typical black type collectors. Tripanagnostopoulos et al. [19] studied the solar collectors with colored absorbers and they concluded that selective colored absorbers are efficient in wider range of operating temperatures than absorbers with color paints of high emissivity.

Recently, the International Energy Agency issued a Technology Roadmap for Solar Heating and Cooling [20] which estimates the potential for domestic hot water in Africa and the Middle East in the range of 2 Ej/year.

For the long term calculation, a number of computer software programs have been developed concerning the modeling and

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simulation of thermal systems. The minimum energy requirement is generally calculated using appropriate software packages (e.g., F-Chart, Transys, T*Sol and Solo) and based on monthly or daily means of climatic data, and the mean storage temperature. Many theoretical models are currently available for the estimation of the thermal stratification within storage tanks, and among the used models, is the one dimensional model.

Khalifa and Mehdi [21] studied the verification of the one dimensional heat flow in a horizontal thermosyphon storage tank and they concluded that the heat flow in the tank may be considered one dimensional. Moreover, computer programs are more accurate with smaller time steps. Huang and Hsieh [22] studied the effect of computation time step on temperature distribution with five tank sections choosing 6, 10, 15 and 20 min time steps, and results have shown a good agreement with the experiments. They claimed that the computation time step in simulation can be as large as 15 min with good accuracy even for the worst cases; thus it can save a significant amount of computation time.

In this paper, our main objective is to build a high performance solar collector coupled with good insulated storage tank for use in domestic hot water as well as for industrial energy. The storage, of 200 l insulated with polyurethane foam, is located horizontally above a flat plate collector of 1.93 m^2 aperture area having a selective absorber coated with black chrome.

Long-term prediction of the proposed system will be performed thanks to a numerical model developed in this study. The developed model describes the energy flows within the storage based on a differential equations solution method and the technical characteristics of the proposed system. It yields the hourly, daily, monthly and annual performances.

The experimental work is achieved in spring to identify the system efficiency in days characterized by the soft climatic weather. Tests are achieved in the Laboratory of Thermal Processes (L.P.T) in Borj Cedria, Tunis, Tunisia. Numerical results expected are the system drawn water temperature energy, efficiency and system performance. Results are validated with the experimental measurements and they have shown that the model can provide accurate results.

2. System description and test procedure

2.1. System description

The experiment is designed to investigate the system performances. Before coupling the collector with the storage, each component is tested separately. In the First days, the collector outputs are obtained. In the next days, the storage loss coefficient is determined. Then, the complete system performance is studied. Fig. 1.1 illustrates the schematic of the amenities used in the experiment. The pyranometer of type KIPP & Zonen CM11, to measure solar radiation, is placed near the top of the solar collector at the same inclination and azimuth of the solar plan. Water temperatures are measured using RTD (Pt100) sensors having the greatest temperature stability and characterized by a good linearity with a sensitiveness ±0.1% °C. Two sensors placed at the inlet and outlet of the collector to measure inlet and outlet fluid temperatures, and another used to determine the draw-off fluid temperature from the tank. The sensor for measuring the ambient temperature is placed at a height of 1.25 m from the surface of the test site. The wind speed is measured by a cup anemometer consisted of three hemispherical cups each mounted on one end of horizontal arms, which in turn were mounted at equal angles to each other on a vertical shaft. The water flow rate is measured by a Flow Meter, of float type, that is installed in the system in the outlet of hot water. The measurements are performed using a Data acquisition type Agilent 34970A.

The collector is titled of 38° to horizontal surface and oriented to the south. It is a selective collector, which has dimensions of $1.98 \times 1.041 \times 0.09$ [m] with one glass cover of thickness of 4 mm, an aperture area of 1.93 m^2 and 10 risers with inner diameter of 12 mm and outer diameter of 14 mm. The absorber thickness δ, absorptance $\alpha_{p,}$ emittance ε_p and absorption-transmittance $\tau\alpha$ are 12.10^{-3} mm, 0.95, 0.1 and 0.86, respectively. The bottom and edges thickness of the collector are 40 mm with thermal conductivity k of 0.035 W/m K.

The horizontal cylindrical water storage tank, of 200 l, is insulated by 4 cm of injected polyurethane foam with density of 40 kg/m^3. The polyurethane foam is one of the best insulating materials, having a very low thermal conductivity. The polyurethane thermal conductivity k is in the range of 0.02–0.035 for temperatures below 100 °C [23]. The storage inner area and insulation thickness are 2.1 m^2 and 5 cm, respectively.

2.2. Test procedure

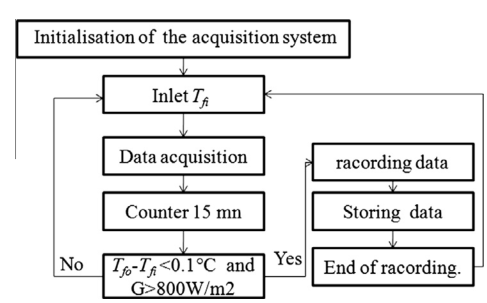
2.2.1. Collector performances test

A test sequence contains a number of consecutive days of measurements are carried out. Various inlet water temperatures are inserted to acquire information about the collector performance. The experiments were conducted in the months of April and May and the outputs (outlet water temperatures, instantaneous efficiencies, solar radiation and ambient temperature) were recorded.

The program used for this test is the HP-VEE; it is designed according to the standards for testing solar collectors following the flow chart below and is as follows:

(i) When the program starts, the data logger initializes the different probes, anemometer, flow meter and the pyranometer at a measurement frequency of 10 s.
(ii) After assigning the set point temperature, the program always takes the final values given by the data logger and the measures of the difference ($T_{fo} - T_{fi}$) should not exceed 0.1 °C and the sunshine G must be greater to 800 W/m^2.
(iii) Once the gap is stable during 15 min, the program proceeds to the recording of data acquired for 90 successive values and stop recording automatically.

The procedure is as follows:



The program automatically opens an excel file; this file shows instantaneous values as ambient temperature T_a; collector inlet, outlet, difference and mean water temperature; solar radiation G (W/m^2), the collector efficiency.

2.2.2. Storage loss test sequence

This sequence intends to identify the overall store losses. The store overnight heat loss coefficient is obtained in an independent test where the system with a hot storage tank is left to cool down