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Construction and Comparison of the Efficiency of Water Heating Systems using low Cost Solar Collectors

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Abstract

This work describes the manufacture of two solar water heating (SWH) systems, one using polyvinyl chloride (PVC) pipes and the other using PVC plates, both with approximately the same area of collecting solar thermal energy. The aim is to analyze their efficiencies and discuss physical concepts and their practical applications. Both SWH collectors were placed side by side under the sun, such that they were submitted to the same climatic conditions. This work also draws attention to the importance of using solar radiation[1] as an alternative and sustainable source of energy for water heating.

Key words

solar energy, water heating system, low cost solar collector.

1. Introduction

This work aims to discuss the physical concepts of the solar thermal energy[1,2] applied to SWH[3], using the manufacturing process, characterization and analyses of two different basic SWH systems of solar panels manufactured with polyvinyl chloride (PVC). The results obtained from both systems are compared to each other in order determine the best arrangement. The devices studied here could be used to heat water for buildings, hotels and industries.

2. Solar Energy

2.1 Utilization of Solar Energy

The sun radiates annually approximately 10,000 times the energy consumed by the world population during the same time period. However, the solar energy that arrives in our planet is still little used. In addition, it is not uniformly distributed over the planet surface[2.] The sun light distribution depends on the latitude, the season and the atmospheric conditions, such as cloudiness and relative humidity of air. On average, the region between the tropics receives a portion of solar energy larger than the others regions. Brazil has large part of its surface in that range, which goes from the city of Rio de Janeiro to the north of the country. Thus, it owns a huge potential of solar energy.

Many technologies have been employed to transform the sun energy into other source of energy[4]. The thermal collectors can be used to heat residential water and the photovoltaic solar cells to generate electric power[5,6].

2.2 Solar Radiation on the Thermal Collector

The solar radiation incident on the solar thermal collectors is decomposed into two components: (a) the direct solar radiation (G_B), defined as the fraction of the solar irradiation that passes through the terrestrial atmosphere without undergoing any change in its original direction, and (b) the diffuse solar radiation (G_D), which refers to the component of solar radiation that passes through the atmosphere, but is scattered by aerosol, dust or even reflected by constituent elements of the atmosphere. The part of radiation that reaches the collector coming from emission and reflection of its neighborhood structure, such as the vegetation and buildings are also included in the diffuse solar radiation component, being commonly named albedo.

Thus, we define the instantaneous solar radiation G reaching the interested plane (in W/m^2), as the sum of its direct and diffuse components:

$$G = G_D + G_B, \qquad (1)$$

where the labels B and D are relative to direct and diffuse components of the solar radiation, respectively.

The integration of solar radiation in the predetermined period of time supplies the received energy per unit of area in this same time interval (hours or days):

$$I = \int_{t1}^{t2} G dt, \qquad (2)$$

where the integration limits t_1 and t_2 defines the desired time interval.

The collectors are usually installed on the roof of houses and buildings. Depending on the volume of water to be used, the consumption of one house may require the installation of several square meters of collectors. To supply hot water for a typical residence (one or two rooms), it is necessary approximately $4m^2$ of collectors[5].

It is noteworthy mention that there are several types of SWH collectors. In this work we investigated SWH systems using flat and open types of solar thermal collectors.

2.3 Applications of Solar Thermal Energy for SWH

One of the most popular applications of solar energy is water heating for homes, hotels and industry. This is a direct application of solar energy and its operation is based in relatively simple physical principles[7] such as the natural convection and the greenhouse effect.

2.3.1 SWH System

A SWH system can be divided into three basic subsystems:

a) Captation: composed by solar collectors (where the working fluid circulates), the collectors, batteries and the thermal reservoir connecting pipes and in the case of larger installations, the hydraulic pump;

b) Accumulation: its main component is the thermal reservoir, plus a complementary source of energy, such as electricity and gas, that will ensure the auxiliary heating during rainy periods or low insolation, or when there is an eventual increase of the consumption of hot water, and

c) Consumption: comprises all hydraulic distribution between the thermal reservoir and the point of consumption. It is also known as the secondary circuit of the installation.

2.4 Heating System Used in this Work

In this work, two SWH systems were built using open collectors with the same external area for solar insolation. The first system uses only pipes and the second one uses plates, both with natural circulation of water, called thermosyphon (Figure 1 and 2). Its working principle is based on the density difference between the hot water, which is heated by solar radiation incident on the collector, and the cold water that is present in the reservoir. For that purpose, it is necessary that the collectors be positioned with a minimum slope and that the reservoir be installed at a certain height above the collectors. It is important to note that they do not need circulation pumps. They are economical when taking into account their cost and maintenance, even with efficiency smaller than those using forced circulation, being quite suitable for small systems. For the captation sub-system it was used the so called "open collectors" [6, 7], since they do not have transparent cover nor thermal insulation.[8] These systems exhibit good performance under low temperatures, decreasing significantly for high temperatures.

3. Materials and Methods

The kits that will be presented here are composed of two systems of water heating, using PVC pipes and rectangular plates solar collectors. They were produced with materials available in ordinary construction stores. During the manufacture of the collectors some special care must be taking concerning the handling of cutting tools, such as saws, nails and knifes.

The water heating systems are composed of a collector, which allows the captation of the solar thermal energy, and a reservoir, used for storing the heated water. Two thermocouples were placed one in the top and the other in the bottom of the reservoir, separated by 10 cm, in order to determine the temperature variations between the upper and lower layers of the water inside the reservoir.

3.1 Heating system using PVC pipe collector

3.1.1 Used materials

Table 1 displays the list of materials adopted in the fabrication of the SWH system made with PVC pipes. All the materials are easily found in ordinary construction stories.

Table 1: Materials used for the fabrication of the PVC pipe collector.

PVC pipe of 1/2"	Plastic adhesive Araldite 10 MIN
T adapters of 1/2''	Matte black ink (Coral)
Knee adapters 90° of 1/2 "	Reservoir of styrofoam of 12 liters
Cap adapters of 1/2''	Adhesive for PVC
Threaded adapter for water tank 1/2 "	

3.1.2 Assembly Description

It was used 24 pieces of PVC tubing (1/2)" with 60 cm length, which were connected with T-type adapters (Figure 1*a*). They were then connected to each other by appropriated connectors (Figure 1*b* and 1*c*). In the ends of the collector, 4 adapters were placed, being two caps and two knees, connected to a 100cm tube (Figure 1*c*). A bigger tube was connected to the knee adapter of the bottom of the collector. It was then connected to the styrofoam water reservoir by a 18cm tube through the screwed pipe (Figure 1*d*). The same procedure was used for the upper connection of the collector, but connecting it to the top part of the reservoir, as displayed in the complete system, Figure 1e.

Figure 1: Set up of the collector made with pipes.

3.2 Materials Used in the PVC Plates Collector

3.2.1 Used materials

Table 2 displays the list of materials adopted in the fabrication of the SWH system made with PVC plates.

Table 2: Materials used for the fabrication of the PVC plate collector.

PVC plates for shelving of 20x60 cm	Adapters for water tank of 1"
PVC pipe of 1"	Plastic adhesive Araldite (10 min.)
Cap adapters of 1"	Reservoir of 12 liters
Adapters glove of 1"	Matte black ink
Adapter and knee 90° of 1"	

3.2.2 Assembly Description

A tube of 65.5 cm length was fixed with a press type walrus (Fig. 2*a*) in order to make slits for the insertion of the rectangular PVC plates (Fig. 2*b*). Then, the collector was connected to the reservoir using 100cm and 40cm tubes (Figures 2*c* and 2*d*). After that, the connections were sealed, leaked tested and painted with matte black oily ink. The complete system is shown in the Figure 2e.

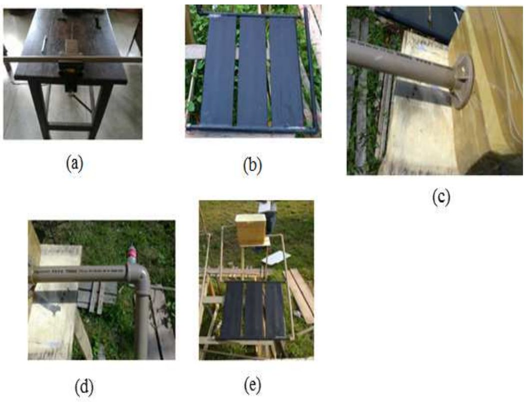

Figure 2: Set up of the SWH kit made with PVC plates.

4. Results and Discussion

During the period from December 16th to 20th, 2011, the temperature of the reservoirs were collected "online", daily, without interruption, using the *LogChart II* software[9]. The data were registered every minute by the program. It is noteworthy noting that the used system does not allow the renewal of water, *i.e.*, it was kept the same amount of water throughout the period of collection of the temperature.

The result of the temperature measurements over the mentioned period can be visualized in Figures 3 and 4. They show the variation of the temperature in the reservoirs for the PVC pipe and PVC plates heating systems, respectively.

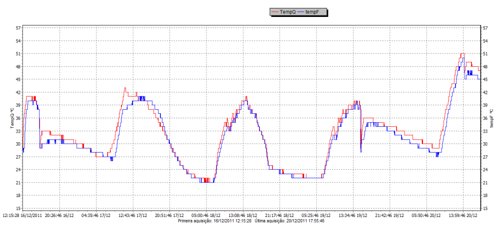

Figure 3: Temperature in the reservoir, as a function of time, for the PVC pipe collector.

Comparing the Figure 3 with the Figure 4, one notices some strong unstable fluctuations in the behavior of the temperature of the reservoir that utilizes the tube collector (Figure 1) caused by winds in relation to that using plate collector (Figure 2). It is likely related to factors ranging from the data acquisition by the program to causes related to ventilation, due to the configuration of the area of the pipe collector. In this case, it is composed of a sum of cylindrical areas spaced apart between themselves, enabling the circulation of air currents through them. Also, it needs to be considered the absorption and emission of thermal energy by the water that circulates the tubes, since if flows more quickly in the cylindrical tubes.

It is also verified that the temperatures reached during the acquisition period varied from 21°C to 51°C, for the system containing the tube collector and from 26°C to 43°C, for the system containing the plate collector. The maximum and minimum environmental temperatures where the collectors were placed were respectively 22°C and 30°C.

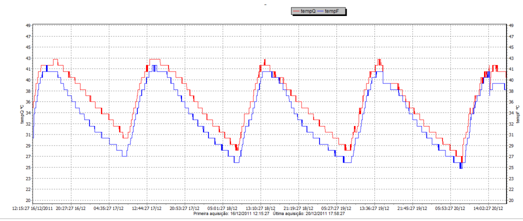

Figure 4: Temperature in the reservoir, as a function of time, for the PVC plate collector.

5. Conclusion

Both SWH systems were efficient to increase the water temperature in the reservoir, compared to what it would be obtained without the collectors. It was also verified that the plate collector was more stable and more efficient than the pipe collector considering that the temperature decay was smaller in the plate based system as compared to the system with tube collector.

The strong temperature fluctuations observed in the SWH system with the tube collector must be associated with external ventilation that increases during the period of decay of the temperature at night. This is a fast process, because of the cylindrical geometry of the pipes, which makes the cooling process more efficient than using rectangular plate geometry.

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References

1. S. Jebaraj, S. Iniyan, A review of energy models, Renewable and Sustainable Energy Reviews, 10 (2006) pp. 281–311.

2. M. D'Antoni, O. Saro, Massive Solar-Thermal Collectors: A critical literature review, Renewable and Sustainable Energy Reviews, 16 (2012) pp. 3666– 3679.

3. M. Srinivas, Domestic solar hot water systems: Developments, evaluations and essentials for "viability" with a special reference to India, Renewable and Sustainable Energy Reviews, 15 (2011) pp. 3850–3861.

4. V.V. Tyagi, S.C. Kaushik, S.K. Tyagi, Advancement in solar photovoltaic/thermal (PV/T) hybrid collector technology, Renewable and Sustainable Energy Reviews, 16 (2012) pp. 1383– 1398.

5. X. Zhang, X. Zhao, S. Smith, J. Xu, X.Yu, Review of R&D progress and practical application of the solar photovoltaic/thermal (PV/T) technologies, Renewable and Sustainable Energy Reviews, 16 (2012) pp. 599– 617.

6. R.Kumar, M. A. Rosen, A critical review of photovoltaic–thermal solar collectors for air heating, Applied Energy, 88 (2011) pp. 3603–3614.

7. T. Khatib, A. Mohamed, K. Sopian, A review of solar energy modeling techniques, Renewable and Sustainable Energy Reviews, 16 (2012) pp. 2864– 2869.

8. S. Sinha and G. N. Tiwari, Theoretical Evaluation of Commecial Solar Hot Water System for Constant Delivery Temperature, Energy Conversion and Management, Vol. 33, No. 2 (1992) pp. 125-133.

9.http://www.chart.state.md.us/downloads/readingroom/chart_ii_documents/chartiisoftwaredevelopmentguide10final013003.pdf