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SOLAR WATER HEATING SYSTEM USING MIXED ABSORBING GRID

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Abstract. *This is a study of a solar water heating system for residential use which comprises of an alternative solar collector and an alternative thermal reservoir made of thermal EPS box. The absorbing grid solar collector consists of PVC pipes connected in series-parallel, forming a mixed grid. The solar collector works in a thermosyphon system. There is also an examination of the manufacturing processes and assembly of the heating system and testing to determine the feasibility of the proposed system. The heating system was tested in two distinct configurations: the first involved using an alternative collector with just a cover glass; and the second had two overlapping coverage glasses. Thus the capacity of the system to provide residential water heating for the bathing was demonstrated in both tested configurations.*

Keywords: *Solar energy, Solar collector, Thermosyphon, Residential hot water.*

1. INTRODUCTION

In the last few years, several countries have begun to look more closely at alternative sources of energy to fossil fuels to form the national energy matrix. A valuable source of energy is the solar power, which is able to produce electricity or water heating.

Solar power can be transformed into electrical energy by means of a direct transformation, which is performed by installing photovoltaic panels, or by an indirect transformation, which is carried out through concentrators. Heating water can be obtained by using solar collectors. Each solar collector for heating water can reach a different temperature and may have a different application.

Brazil has an average solar potential of approximately 600 W/m², and can reach peaks of up to 1000 W/m². This form of energy conversion has a great potential and should be more widely used.

Residential water heating systems still use mostly electric showers; approximately 73% of Brazilian homes depend on this equipment as a means of heating water for bathing. The electricity used in these showers does not always originate from a clean source of energy. Solar energy collectors are an alternative to the conventional electric power system.

Santos (2008) and Tomé (2014) stated that in Brazil, 23% of residential electricity consumption is used for heating water. It was also mentioned that, in extreme cases, the overload caused at peak times can be due to water heating equipment and can cause interruptions to the electricity supply.

Data from the National Energy Balance of 2013 show that one third of the energy generated at Itaipu is used to operate electric showers at peak times, while Brazil has radiation to heat water for most of the year.

All these data suggest the importance of replacing the current energy system with a solar source for hot water, mainly to reduce the consumption of conventional energy, and thus relieve the pressure on the Brazilian energy matrix.

The main objective of this work is to investigate the thermal and economic viability of a solar water heating system by using a collector constructed from PVC plates. The Boiler is also alternative and cheap. Another goal is to verify the relation between the isolation gains and losses of incident radiation between the collector with one glass, and the same collector with two glasses.

The proposed system is designed to obtain hot water for bathing by replacing the electric shower head.

2. MATERIALS AND METHODS

An alternative collector was built to analyze the feasibility of using low cost materials with easy access to water heating, and also check the influence of a second glass in the heating system; this made it possible to test both configurations.

Both collectors were assembled from a box built with PVC plates with the following dimensions: 1.45 m (length) x 0.95 m (width) x 0.07 m (height), and with a thickness of 0.003 m, and a total collector surface area of 1.38 m².

Since the PVC is unable to withstand the internal temperature of the collector, a steel sheet was used for internal coating, which was attached to the PVC by rivets. A layer of black spray paint was applied to the steel sheet for better absorption of solar radiation.

The water circulation system chosen was the mixed (parallel and series). A rip was torn through the PVC plate, with the aid of a drill and a saw, to fix it to the collector. A polyester resin was used to seal the gaps.

Figure 1 shows the collector while it was being built during the period that involved fixing the absorbing grid and the internal painting of the collector.

Figure 1. Solar collector during its manufacturing process.

An expanded polystyrene box (Styrofoam) of 150 liters of capacity was used as an alternative thermal reservoir; this had previously been fitted with points for installing a shower, a buoy and feed points (heated water from the collector) and return (water will be heated by the collector). The water temperature of the Boiler was subjected to monitoring in its integer, and showed satisfactory temperature conservation of the fluid, with a loss of just 4.0 ºC for 24 hours.

In conducting the thermal analysis, each collector was measured and compared: this included thermal efficiency, inlet temperatures (water coming from the collector) and exit temperatures (water conducted to the collector) in the thermal reservoir as well as the temperatures of the fluid within the thermal reservoir at various points (bottom, ¼ from the bottom to surface, ½ of the Boiler, ¾ from the bottom to surface and the surface). All these temperatures were measured with the aid of a thermocouple of Cromel-alumel coupled to a digital thermometer Intrutherm™ TH-060.

The tests were performed with both configurations, using the same thermal reservoir and the same angle of inclination (15º pointing to the north). In the first test, only a glass plate was used that was placed on the mesh tube. Then, a second glass plate was placed in the second test.

Based on the procedure performed by Souza (2007) and Souza (2010), all the tests were conducted on days with good solar conditions, high rates of direct solar radiation and low cloud cover to enable a realistic comparison between the different days. The tests were performed during the period 10h - 15h, at intervals of 30 minutes, on the following days - 12/02/2014 and 12/18/2014. Figure 2 shows the collector during a testing day.

Figure 2. Solar collector in the test.

As used by Souza (2009) and Lopo (2010), the thermal efficiency (η_T) of the collector was evaluated by Eq. (1).

$$\eta_t = \frac{P_u}{A.I} \tag{1}$$

Where P_u is the power delivered to the working fluid in W; the parameter I is the global solar radiation in W/m²; and the parameter A is the useful area collector in m².

The solar radiation data were collected with the aid of 5.93 WeatherLink® program, which is able to record various quantities as a function of time through a meteorological device that is centrally located in weather LMHES / UFRN.

The useful power delivered to the working fluid (P_u) can be calculated through Eq. (2).

$$P_u = \dot{m}.c_p.\Delta T \tag{2}$$

Where $\dot{m}$ is the mass flow rate of the system in kg/s; c_p is the specific heat of the water, which is approximately 4,186 kJ/(kg.K); and ΔT is the difference of temperature between the inlet and outlet of the fluid in the heating system, in °C.

The mass flow rate was determined by measuring the ratio of the volume of water (150 liters), times the density of water (1000 kg/m³) divided by the total assay time (five hours). Therewith, was used a mass flow rate value of 1/120 kg/s.

3. RESULTS AND DISCUSSION

Table 1 and Table 2 shows the data obtained for the inlet and outlet temperatures of the tank (T_i and T_o, respectively), the beam solar radiation (I) at the moment of the test and the collector efficiency (η_t). The measurements were taken at half hourly intervals; however the average efficiency was calculated at the interval of one hour, so that the collector efficiency could be compared with a single glass.

Table 1. Thermal efficiency of the solar collector with a single glass.

Hour	T_i (°C)	T_o (°C)	ΔT (°C)	I (kW/m²)	ηt (%)
10:00 - 11:00	41.6	28.5	13.1	0.941	35.1
11:00 - 12:00	43.8	30.6	13.2	0.910	36.6
12:00 - 13:00	44.5	33.6	10.9	0.846	32.5
13:00 - 14:00	43.3	34.5	8.8	0.751	29.6
14:00 - 15:00	40.1	35.9	4.2	0.428	24.8
Average	42.7	32.6	10.0	0.775	32.7

Table 2. Thermal efficiency of the solar collector with two glasses.

Hour	T_i (ºC)	T_o (ºC)	ΔT (ºC)	I (kW/m^2)	η_t (%)
10:00 - 11:00	43.9	29.0	14.9	0.901	41.7
11:00 - 12:00	45.8	30.7	15.1	0.927	41.1
12:00 - 13:00	46.4	31.5	14.9	0.885	42.5
13:00 - 14:00	46.3	33.4	12.9	0.858	38.0
14:00 - 15:00	45.9	36.3	9.6	0.729	33.2
Average	45.7	32.2	13.5	0.860	39.6

Figure 3 shows a comparison between the results of the collectors' performance on different days. It should be noted that the global average insolation during the interval 10h and 15h are similar between the two days of the tests, and thus makes it possible to compare their thermal efficiencies.

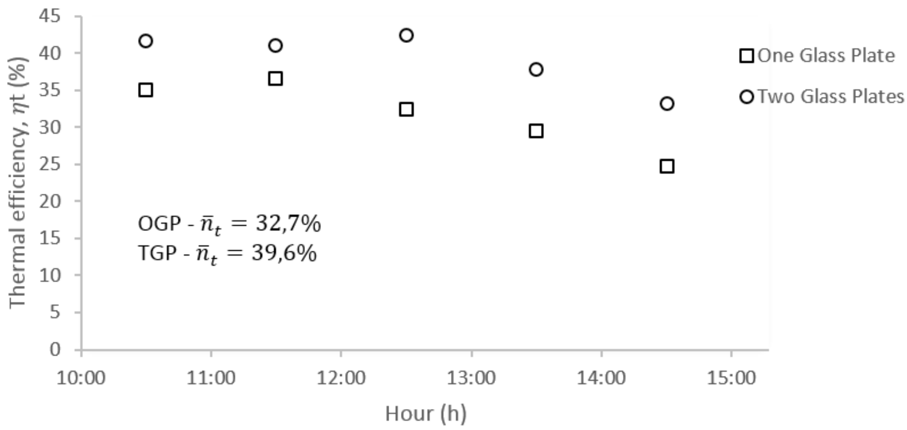

Figure 3. Comparison between the thermal efficiency of the collectors.

Figure 3 shows that the solar collector with two glass plates has a global average efficiency greater than the solar collector with only one glass plate.

Collectors can also be compared by the temperature data at the thermal reservoir. Figure 4 and 5 show the temperature data for each point within the reservoir.

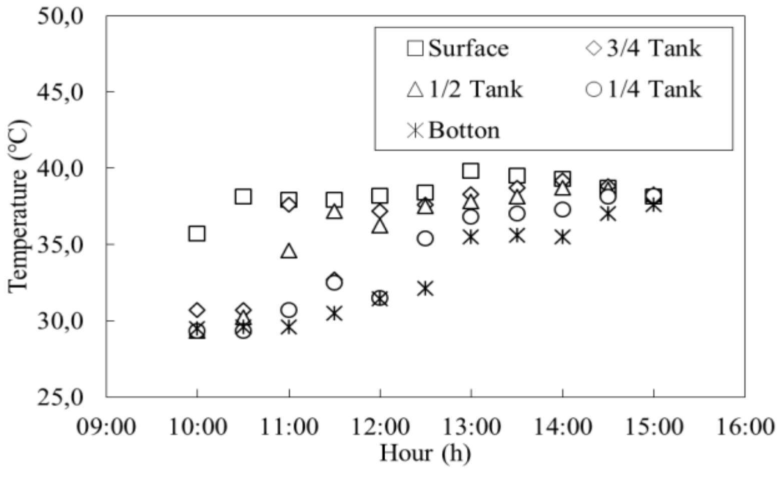

Figure 4. Temperature at each tank level versus time of day for the collector with a single glass.

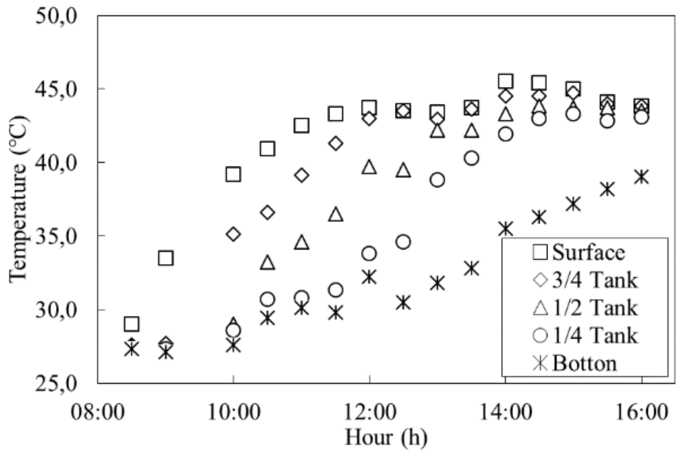

Figure 5. Temperature at each tank level versus time of day for the collector with two glasses.

It is clear that the collector with two glass plates reaches higher temperatures (45.5 °C for the collector with two glasses and 39.5 °C for the collector with a single glass) at a higher rate than the collector with only a plate (5,0 °C/h for the collector with two plates and 3.6 °C/h for the single glass). However, the solar collector with a single glass generates a temperature gradient that is more uniform inside the tank than the collector with two glasses.

Other data that should be highlighted is the water temperature in the reservoir at the end of testing when a stir enables all the water to mix and reach a uniform temperature. In the case of the collector with a single glass, the temperature after mixing was 39.3 °C and for the collector with two glasses, the temperature after mixing was 43.1 °C.

4. CONCLUSION

Both configurations tested for the solar collector proved feasible for producing water heating. The configuration with two glasses was more thermally efficient. The setting with a single glass is more cost-efficient. The configuration with two glasses had a lower thermal loss, with this effect overcoming the loss of energy absorbed by the collector grid. It was concluded that at least one other collector would be needed in the system to provide an adequate volume of water for a family of four people.

5. FURTHER WORK

Further studies would be of value to determine the thermal losses of each collector and quantify the energy difference between the two configurations tested. This should involve testing the two settings simultaneously to enable a more real comparative analysis, as well as test these collectors for various solar conditions.

6. REFERENCES

Lopo, A.B. *Análise do desempenho térmico de um sistema de aquecimento solar de baixo custo*, Dissertação de Mestrado, UFRN, 2010.

Santos, N.R.G. *Projeto, construção e análise de desempenho de coletores solares alternativos utilizando garrafas pet*, Dissertação de Mestrado, UFRN, 2008.

Souza, L.G.M., et al. *Alternative solar energy water heating system*, COBEM – International Congress of Mechanical Engineering, Brasília - 2007.

Souza, L.G.M., et al. *Heating system using alternative solar collector built with fibercement tiles*, COBEM – International Congress of Mechanical Engineering, Gramado – 2009.

Souza, L.G.M., et al. *Water Heating solar system using collector with polycarbonate absorber surface*, ENCIT – Brazilian Congress of Thermal Sciences and Engineering, Uberlândia – 2010.

Tomé, M.C. *Análise do impacto do chuveiro elétrico em redes de distribuição no contexto da tarifa horosazonal*. Dissertação de mestrado, UNICAMP, São Paulo, 2014.

7. RESPONSIBILITY NOTICE