HEATING SYSTEM USING ALTERNATIVE SOLAR COLLECTOR BUILT WITH FIBERCEMENT TILES

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Abstract. *Its presented an alternative solar collector constructed with two fibercement tiles, with their concavities filled with PVC tubes connected in parallel, forming an absorber grid. Between the two tiles was placed a layer of EPS powder (expanded polystyrene), for the reduction of thermal losses through the bottom of the collector. The heating system is formed by the collector and storage tank, also alternative, constructed from a polyethylene reservoir used to storage water. The system operates in thermosyphon regimen and will be tested in two configurations: with and without coverage. It isn't used glass for the transparent cover of the collector. It will be used a transparent cover of PET bottles. The heating system presents simple processes of manufacture and assembly and its main characteristic is its low cost. This system will be used to produce hot water for home bath, taking advantage of the use of its coverage area. It will be presented results of tests for the two presented configurations. It will also be demonstrated the thermal, economic and material viability of the proposed heating system.*

Keywords*: alternative solar collector, heating system, recyclable materials, low cost.*

1. INTRODUCTION

The most pessimistic forecasts of the ambient scientists are becoming reality and, then it becomes essential to substitute fossil sources for clean and abundant source of energies.

The solar water heating, the indirect generation of electric energy through the use of solar concentrators and the direct conversion of the solar energy in electric energy through the use of the photovoltaic's cells represents viable applications extremely and its uses have grown exponentially in the whole world, mainly in the more developed countries.

Brazil is a leading country in relation to the available solar potential, and the northeast region presents an average potential around 600W/m ², reaching peaks around 1000W/m². This potential places the northeast region as an extremely viable region for the implantation of any solar installations, for lots of applications. (www.inpe.br)

According to National Energy Rocking (BEN) of 2007, 45% of the consumption of electric energy in Brazil is directed for the sector of constructions, having been 80% correspondent to the companies and residences and 20% to the public administration, with ciphers reaching 13.8% of the brute internal product of the country (Gomes, 2008).

The residential sector answers for 23% of the national consumption of energy and the consumption of the electric shower is one of the biggest in a residence, corresponding 25%, losing only for the refrigerator/freezer that corresponds to 30%. Its use reaches the schedule of peak from 6pm to 7pm, corresponding to 8.5% of the national demand of energy in this schedule (Costa, 2007).

This data points the importance of the alternative energies with respect to the water heating destined to the bath in substitution to the electric shower bath to propitiate the reduction of the consumption of electric energy, bringing relief to the Brazilian energy matrix.

This work presents the thermal and economic viabilities of a system of water solar heating that uses a collector manufactured with the use of used asbestos-cement roofing tiles in coverings of residences. The main innovation of the work is the use of a composed transparent covering with PET bottles, in substitution to the conventionally used transparent glass. This collector could be used to constitute the roof of a residence, being provided the heating of the water to be consumed by its inhabitants. An alternative thermal reservoir of little cost that the inox or copper reservoirs is also presented

Average results are presented for two configurations: with and without transparent coverage, in a system composed of a solar collector and thermal reservoir, working in regimen of thermosyphon, with absorber grid formed by six tubes in parallel.

2. BIBLIOGRAPHIC REVIEW

To promote the heating of water for the bath are used conventional and alternative collectors.

The conventional collectors consist of a box in aluminum profile or glass fiber, thermal insulation of glass wool, absorber plate of aluminum; absorber grid formed by copper tubes and a glass transparent cover. Working in thermosyphon or using a continuous flow pump for the movement of the working fluid.

The collectors are usually made of alternative materials to lower cost and have as main purpose the socialization of water solar heating. Several generations of alternative collectors using plastic absorbers tubes have been developed and tested in LMHES/UFRN. The main objective of the study of such collectors is to reduce the manufacturing cost, searching for the socialization of its use in heating solar systems for domestic and industrial water. With this objective, several studies were developed, demonstrating that the low cost solar plastic collectors have been studied since the 70s (Souza, 2002).

Souza (2004) studied and compared two types of collectors, an alternative and a conventional, demonstrating the competitiveness of alternative collector with absorber grid consisting of multiple PVC tubes in relation the conventional collector with copper tube.

Souza (2005) studied an alternative collector consists of three elements: box, absorber grid and glass. The box was manufactured in composite material and the absorber grid was composed of multiple PVC tubes connected in parallel, using a configuration that allowed the reduction of space between the tubes. It was shown the thermal, economic and material viabilities of the proposed solar collector.

Souza (2006) studied a low-cost alternative heating solar system composed for a solar collector and an alternative thermal reservoir. The collector had an absorber grid formed by PVC tubes and the thermal reservoir was made from a polyethylene drum of 200 liters, used for water storage and/or waste, covered with a composite material made of gypsum base, ground EPS and water. It was shown the thermal, economic and material viabilities of the system studied.

Souza (2007) studied an alternative heating system consisting of a collector with absorber grid tubes of PVC connected in parallel through the PVC tees of same diameter and an alternative heat reservoir built from a drum coated with a polyethylene cylinder made in glass fiber. It was shown the thermal, economic and material viability of the system under study.

Another alternative heating system at low cost with the objective of socializing the solar water heating was developed and built in the Technology Business Incubator Center - CIETEC / SP in 1999 and received the name of Low Cost Solar Collector ASBC. The ASBC has collectors similar to those used in swimming pools, not having, therefore, transparent cover. This system for a four-person family is composed of three PVC collector plates of 0.91 meters interconnected and painted in black and a reservoir of volume equal to 170 liters. Each plate collector consists of a PVC brick profile lining with PVC pipes attached to their ends (Varella, 2004).

An alternative collector was developed and built in 2004, by the Society of the Sun, a São Paulo ONG, using PET bottles and milk TETRA PAK packages. This collector is composed of 80 PET bottles and has an absorber grid formed by eight pipes of on PVC in parallel. Tests carried through with the ASBC and the collector of PET showed that the more efficient ASBC is 17.2% (Santos, 2008).

Santos (2008) presented an alternative solar system for collecting water heating consisting of one or two alternative collectors and an also alternative water storage reservoir, whose main purpose was to socialize the use of the energy, mainly to be used by low income populations. The collectors had been constructed from the use of PET bottles, cans of beers and soda and pipes of PVC of ½" Such collectors were formed by only three elements: bottle pet, cans and absorber pipes. It was demonstrated the thermal, economic and of materials viabilities of the studied collectors.

Souza et al. (2008) had studied a new configuration for the absorber grid of an alternative collector with absorber surface formed by PVC pipes, making a mixing grid series-parallel objectifying an increase of the temperature of the water, to propitiate the attainment of a bigger temperature of the water in the interior of the thermal reservoir.

3. MATERIALS AND METHODS

The solar collector developed is formed by two asbestos-cement roofing tiles of 2.44 x 0.50m, with thickness of 0.4mm, having enters the two overlapping roofing tiles an isolating layer of triturated EPS. The absorber grid is composed for six pipes of PVC of 20mm of external diameter, in parallel through connections in T of the same material. It functions in regimen of thermosyphon, with a volume of warm water of 150 liters. Its area corresponds to 1,40 m ².

The superior asbestos-cement roofing tile and the absorber tubes had been painted of black color for a better absorption of the solar radiation global incident. Covering is made of cut PET bottles that assume the transparent format of roofing tile. Figure 1 show the considered collector constructed.

The processes of manufacture and assembly of the collector are constituted by the following stages:

1. Cutting of the PVC pipes;
2. Linking of the tubes to the PVC connections for the formation of the absorber grid through PVC glue;

3. Confection of the separation element between the two asbestos-cement roofing tiles – it was used composite with gypsum, triturated EPS, scraps of tire, cement, sand and water, getting itself a wall of separation of 5.0 cm;
4. Setting of the roofing tiles the separation structure through the use of screws;
5. Introduction of triturated EPS between the two roofing tiles;
6. Rank of foam in the lateral spaces between the roofing tiles for preservation of the thermal insulator;
7. Painting of the superior roofing tile and absorber tubes;
8. Setting of the absorber grid in the superior roofing tile;
9. Coupling in the grid of the entrance and exit tubes of the water in the collector;
10. Confection of the transparent covering using PET bottles;
11. Setting of the segments of PET bottles to the superior roofing tile using contact glue;
12. Linking of the entrance and exit tubes of the collector to the alternative thermal reservoir;

Figure 1. Alternative solar collector in study

The alternative thermal reservoir of 150 liters was confectioned from an element base, a polyethylene drum of 200 liters. The reservoir was opened in its superior cover and was placed in the interior of a drum confectioned in fiber glass with thickness around 5,0 mm. The cover of the reservoir was constructed in fiber glass. In the space between the two basic elements, fiber cylinder and polyethylene drum were placed triturated EPS. Figure 2 shows the constructed thermal reservoir.

Figure 2. Alternative thermal reservoir.

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The heating system functions in regimen of thermosyphon for a volume of 150 liters of and was tested for the diagnosis of its thermal efficiency, being measured the parameters that characterizes it and are necessary for the analysis of its thermal performance, (Duffie, 1991, Souza, 2008).The collector was inclined of 15,5°S. To determine the flow rate it was considered that all the water in the reservoir circulated by the collector, corresponding therefore to relation between the volume of the reservoir (150liters) and time to test the system (seven hours). The alternative heating solar system is presented in Fig. (3).

It was measured the temperature of entrance and exit of the fluid of the collector, the temperature of the water contained in the reservoir at various points (lower, ¼, ½, ¾ and upper), ambient temperature and global solar radiation. Also was measured the necessary time for uniformization of the temperature of the fluid mass in the thermal reservoir.

As temperatures of entrance and exit of the fluid had been measured in the period between 8am and 3pm, in intervals of 30 minutes; the temperature of the collector and absorber tubes had been measured from 15 to 15 minutes between 11am and pm, period of maximum and constant radiation, where it is evaluated maximum loss presented by the collector; the temperature of the fluid mass was measured after the seven hours of functioning. The tests had been carried through in days with good solar conditions; high indices of direct and global radiation solar and low cloudiness to allow a more real comparative analysis between the test days.

To test the thermal efficiency of the thermal reservoir, it was filled and was established a connection between it and the considered collector. After one day of functioning of the heating system, at 3pm, it was measured the temperature of the water contained in the reservoir, correspondent to 45°C and closed its communication with the collector, preventing the thermal exchange between the reservoir and the collector during the night.

A thermocouple of chromel-alumel was placed in the interior of the considered alternative thermal reservoir to measure the temperature of the water, another one in the external surface for the same measuring and another one to measure the ambient temperature. The test consisted of measuring these temperatures, at each hour, during all the night to quantify the drop of temperature in the water mass contained in the reservoir. The temperatures had been measured using a digital thermometer.

O global coefficient of thermal loss (U_{loss}) was determined through the parameters of the Equations (1) (4).

$$P_{abs} = \tau_v . \alpha_p . \mathrm{I.A} \tag{1}$$

Where:

$P_{abs.}$ - absorbed power for the collector (W)

τ_v - coverage transparent transmissivity;

α_p - absortivity of tube painted in black

I - global solar radiation (W/m²)

A – collector area (m²)

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

Where;

P_u - power transferred to the working fluid (W);

$\dot{m}$ - mass outflow (Kg/s);
c_p - specific heat of the fluid – J/Kg.°C)
Δ**T** - difference of temperature of the fluid in the system (°C)

$$P_p = P_{abs} - P_u \qquad (3)$$

Where:

$P_{abs.}$ - absorbed power for the collector (°C)
$P_{p.}$ - lost power (W)

$$U_{loss} = \frac{P_p}{A.(T_{pm} - T_a)} \qquad (4)$$

Where:
U_{loss} - global coefficient of thermal loss (W/m². °C);
T_{pm} - plate average temperature – (°C);
T_a - ambient temperature – (°C).

The thermal efficiency of the water solar heating system was determined through the parameters of the Equation (5).

$$\eta_t = \frac{P_u}{A.I} \qquad (5)$$

Figure 3. System of heating in test.

4. RESULTS AND DISCUSSIONS

Tables 1, 2 and 3 present the general average result in three days of tests and Figure 4 shows the behavior assumed for the measured thermal parameters.

Table 1. Average results for three days of tests – configuration without coverage transparent.

TEST DAYS	ΔT (°C)	I (KW/m²)	ηt (%)	T_{LOWER} (°C)	$T_{1/4}$ (°C)	$T_{1/2}$ (°C)	$T_{3/4}$ (°C)	T_{UPPER} (°C)
DAY 1	7,6	0,70	21,7	34,1	37,0	38,7	39,7	40,7
DAY 2	7,4	0,68	21,8	33,8	36,8	38,2	39,4	40,5
DAY 3	7,3	0,68	21,5	33,6	36,4	37,7	39,0	40,2
AVERAGE	7,4	0,69	21,7	33,8	36,7	38,2	38,9	40,5

Table 2. Average results for three days of tests – configuration with transparent coverage.

TEST DAYS	ΔT (°C)	I (KW/m²)	ηt (%)	T_{LOWER} (°C)	$T_{1/4}$ (°C)	$T_{1/2}$ (°C)	$T_{3/4}$ (°C)	T_{UPPER} (°C)
DAY 1	8,8	0,71	24,8	39,2	41,5	42,6	43,1	43,8
DAY 2	8,6	0,70	24,6	38,2	40,9	42,4	43,5	43,5
DAY 3	8,8	0,71	24,8	39,3	41,2	42,5	43,7	43,7
AVERAGE	8,7	0,71	24,5	38,9	41,2	42,5	43,4	43,7

Table 3. Average results for three days of tests for the two configurations studied.

CONFIGURATIONS TYPE	ΔT (°C)	I (KW/m²)	ηt (%)	T_{LOWER} (°C)	$T_{1/4}$ (°C)	$T_{1/2}$ (°C)	$T_{3/4}$ (°C)	T_{UPPER} (°C)
WITH COVERAGE	8,7	0,71	24,5	38,9	41,2	42,5	43,4	43,7
WITHOUT COVERAGE	7,4	0,69	21,4	36,4	36,7	38,2	38,9	40,5

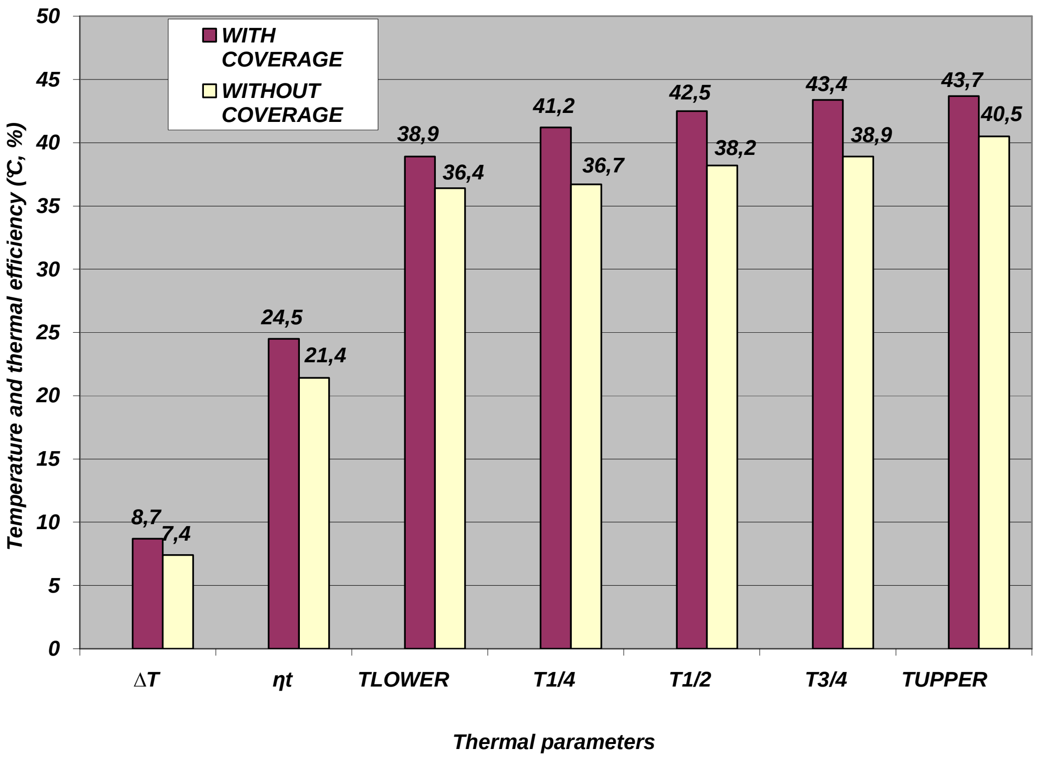

Figure 4. Behavior assumed for the measured thermal parameters.

The average efficiency of the collector for the best configuration was around 25%, slightly below the majority of alternative collectors, with thermal efficiency around 30 to 35%.

The difference in thermal efficiency between the two settings was around 14.5%. In respect of the temperature gradient there was a difference of 17.6%. The configuration with coverage was more efficient than the other without coverage. This is due to a decrease in the exchange between collector and thermal environment, provided by the transparent cover.

The variation of solar radiation was 3.0%, which shows solar conditions almost identical to the tested days, a necessary condition for a comparative analysis.

With respect to the temperature of the heated water, was observed that there was a significant uniformity, and the levels were higher than the temperature required for the bath. After the seven hours of testing are water was mixed in the tank resulting in a temperature of 38.8 ° C for the configuration without cover and 42.4 ° C to another configuration. In this case the supremacy of the configuration with coverage was 9.2%.

Despite the significant levels of temperature and relative uniformity of the water, these parameters can be optimized through the use of two modules, with four tiles and 10 absorber tubes.

The heat loss of the system can be evaluated by calculating the absorbed, useful and lost power, whose values are shown below. The values of parameters used for determining the overall heat loss coefficient were measured in the range between 11:30am and 12:30pm, period of constant radiation at a day of appropriate solar conditions. Table 4 shows the values of the parameters of heat loss for both configurations studied.

Table 4. Values of the parameters of heat loss for both configurations studied.

CONFIGURATIONS TYPES	$P_{ABSORBER}$ (W)	P_{USEFUL} (W)	P_{LOSSED} (W)	U_{LOSS}
WITH COVERAGE	552,8	276,4	276,4	45,0
WITHOUT COVERAGE	691,0	225,0	466,0	*16,5*

The heat loss of the collector for the configuration without coverage was 67.0% in relation to the absorbed energy, while the net power was 33.0%. This amount of heat loss is quite significant compared to conventional collectors, but not impossible to obtain hot water bath for low income households. The value of Uloss was much higher than that obtained for conventional collectors, which was expected.

The heat loss of the collector for the configuration with coverage has decreased significantly, corresponding to 50.0%% for the energy absorbed, the percentage of net power. Regarding the overall coefficient of heat loss reduction was approximately 64%, in spite of still greater magnitude that the coefficient on the conventional collectors market. This demonstrates the influence of the transparent cover placed on top of the collector. This loss can be reduced through a specific study to determine the thickness of the insulating layer and a better sealing of the collector.

The results of the test to evaluate the thermal efficiency of the alternative thermal reservoir are presented in Table 4.

Table 4. Results of the test with the alternative thermal reservoir.

TIME (HOUR	T_{WATER} (°C)	$T_{AMBIENT}$ (°C)	T_{UPPER} reservoir(°C)	T_{HALF} reservoir (°C)	T_{LOWER} reservoir (°C)
16:00	45,3	27,0	28,0	28,3	28,5
18:00	45,0	26,0	27,0	27,5	28
20:00	44,2	25,5	25,1	25,6	26,2
22:00	43,5	25,0	25,1	25,6	25,6
00:00	42,9	25,0	25,1	25,2	25,6
02:00	42,5	24,9	24,9	25,5	25,6
04:00	41,8	25,0	25,0	25,4	25,5
06:00	40,9	27,7	28,0	30,4	28,7
07:00	40,6	28,4	28,8	29,6	28,4
09:00	40,1	31,8	36,0	36,8	32,3
11:00	40,1	31,9	38,5	35,5	33,7
12:00	40,1	32,0	38	35,5	34,0
14:00	40,4	32,4	38,2	36,0	35,0
16:00	40,7	30,0	35,0	33,0	32,0

The shown data demonstrates the good thermal efficiency of the considered alternative thermal reservoir. It had a temperature drop, during the 24 hours, corresponding to 4,7°C This fall of temperature is inside of the average pointed for literature with respect to conventional thermal reservoirs, of copper or inox, that they present values around 5°C for the tested level of temperature. It is standed out, still, the price of the considered component, very lesser for the alternative reservoir than for the conventional reservoirs.

The temperature of the external surface of the reservoir was well next to the ambient temperature during all the night reflecting a low thermal loss by the side of the reservoir. The temperature of the reservoir reached values above of the ambient temperature for the period where the reservoir started to be warmed by the global solar radiation absorbed by the same, once that it was painted in black ink. Therefore, the most significant loss occurred in the inferior part and/or cover of the reservoir.

The mechanical resistance test of the considered alternative reservoir did not verified damages to its structure, demonstrating its capability to support the corresponding weight to the volume of water contained in the reservoir. It didn't presented occurrence of emptying, what certifies its good gasket, also obtained through polyester resin.

Souza (2002) studied the degradation of PVC tubes exposed to the sun; demonstrating that a collector with absorber surface formed by PVC tubes presents life exceeding ten years.

The other element of the collector, fibercement, has a useful life well over that time. It is shown therefore that the life of the collector would be more than 10 years, which demonstrates its economic viability.

The cost of manufacture of the collector was around U$30.00 and the thermal reservoir had a cost around U$100.00 Therefore, the total cost of the heating system was inferior to U$150.00, what it represents a sufficiently inferior cost to the necessary one for the manufacture of a conventional heating system. It is standed out that the studied collector is made to be used by low income populations, not being competitive with the conventional system. However, it presents viability to be used for the considered end.

5. CONCLUSIONS

1. The studied collector presents viability of use for the considered end;
2. The collector presents easy processes of manufacture and assembly;
3. The configuration with transparent cover was much more efficient by having a lower heat loss
4. The heating system presents low thermal efficiency, however it revealed capable to provide hot water for the bath of a family with four people in the studied area;
5. The thermal loss of the collector is much higher than the relative one to the conventional collectors, as expected;
6. The most important characteristic of the considered heating system is its low cost;
7. The studied heating solar system can contribute to increase the use of the solar water heating for low income communities, being socialized the use of solar energy.

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