ALTERNATIVE SOLAR ENERGYWATER HEATING SYSTEM

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Abstract. A solar alternative system for water heating is presented. It's composed of a low cost alternative collector and an alternative thermal reservoir for hot water storing. The collector box was confectioned in composite material and uses absorption coils formed of PVC tubes. The reservoir for hot water storage was confectioned of a plastic polyethylene drum used for water storage, coated with a fiber glass confectioned cylinder. The function principle of the system is the same of the conventionally one. Its regimen of work is the thermosiphon for a volume of 250 liters of water. The main characteristic of the system in the considered study is its low cost, allowing a larger socialization of the solar energy use. It will be demonstrated the thermal, economic and of materials viabilities of the considered heating system, and its competitiveness in relation to the commercially available collectors. Relative aspects will be boarded such as the PVC tubes susceptibility of thermal degradation and for UV.

***Keywords**: alternative solar collector, thermal degradation, PVC tubes, low cost.*

1. INTRODUCTION

Having knowledge that 42% of the consumption of electric energy in Brazil are directed for the sector of building, being 84.1% correspondent the companies and residences and 15.9% the public administration, with ciphers reaching 13.8% of the of the income of the country and the residential sector corresponds to 25% of the national energy consumption and the electric shower consumption is bigger in a residence, corresponding to 25% and its use reaches the schedule of peak from 6pm to 7pm, corresponding to 8.5% of the national energy demand, it's perceived the importance of the study of renewed alternative sources to substitute the electric shower in the hot water production for residential ends (Souza, 2004).

The devices used for the hot water production through the solar energy are the low concentration collectors, divided in two groups, the conventional and the alternative. Such collectors generally are constituted by copper absorber tubes, absorber aluminum copper plate, glass cover and woolen glass thermal isolation and absorb grid with configuration in parallel.

The heating systems generally are constituted of more than a collector, generally in parallel, working in regimen of thermosiphon or forced flow; for a thermal reservoir generally of copper or inox and tubes for the conduction of heat, generally of CPVC. Such systems have high initial cost not being accessible to the majority of the population.

This work also presents the thermal, economic and of materials viabilities of a heating solar system composed of an alternative collector constructed of a composite material based of gypsum, dusted EPS and water, that uses PVC absorb tubes, working in thermosiphon regimen and a boarding relative of the degradation processes to the use of tubes PVC as absorber elements of radiation (Souza, 2000-2002).

Such collector has as main innovation the possibility of its construction using only three elements, which are: the box, the absorber grid and the glass covering. The absorber grid is constituted of 12 PVC tubes of ¾" in parallel through the use of connector tubes of the same material. The thermal insulator of the collectors is the same composite with it was manufactured, preventing, therefore, the use of the wool of glass, harmful to the health of who handles it.

2. LITERATURES REVISION

Alternative collectors are those that differ in constituent geometry, materials and elements in relation to the used ones in the conventional collectors confection. The main objective of the study of alternative collectors is the reduction of the manufacture cost once the cost of the same ones represents 50% of the total cost of investment for acquisition of a water heating solar system. Exactly having long useful life, the heating solar systems require high initial investment, this explain the low tax of growth in the use of solar systems for water heating in the world. The development of research is essential, looking for systems with less cost and with significant thermal performance (Cristofari, 2002).

With these purposes, innumerable works have been developed in the whole world, demonstrating that the plastic solar collectors of low cost present ample viability of use. Souza (2000, 2002, 2004, 2006) showed the thermal, economic and of materials viabilities of water solar heating systems and analyzed also the inherent degradations to the use of the PVC when submitted to the solar radiation and the heat.

Literature shows that the susceptibility to thermal consuming of PVC is accented when the attainment of levels of temperature above of 60°C in its surface. The UV degradation also represents a restriction to the use of solar collectors with PVC absorber tubes, once radiations with this wave length affect the tubes mechanical integrity. (Souza, 2004).

The conventionally thermal reservoirs used in heating systems, generally are manufactured in stainless steel, and are covered by steel carbon, for varied volumes. They can be horizontal or vertical, being constituted of two cylindrical surfaces, an internal and an external one, having between the same ones, a thermal isolation, generally glass wool; of high and low pressures, being low pressure the most economic.

The alternative thermal reservoirs are very little cited in literature, being generally confectioned in rigid plastic or fiber glass. For being the most expensive constituent element of a water heating solar system (reaching values around R$1.000, 00 for a volume of 200 liters, that is used in the residential installations of small size) researches are essential to the use of alternative materials for the reduction of its cost. Such materials however have that to endow the thermal drum with low thermal conductivity characteristic of an efficient thermal insulator, essential for the reduction of the warm water thermal loss, mainly for night and early in the morning, periods of absence or low level of global solar radiation.

Souza (2003) constructed and studied an alternative thermal reservoir for a system of solar water heating with the characteristics of significant thermal performance, low cost, good aesthetic and reduced weight. The materials used for its manufacture had been: two levels of wood forming the internal and external cylinders; wood of 15mm for the bottom and cover; glass fiber blankets for covering the internal and external surfaces, as well as the deeper one and the cover; placed thermal EPS (expanded polystyrene) as isolator between the internal surfaces and external ones of the tank. The composite passed through a process of manual lamination, using polyester resin. Its volume corresponds to 250 liters.

The results of the thermal tests had shown the viability of use of the alternative reservoir, of very inferior cost to the available conventional reservoirs in the market of copper or inox, with cost at about R$ 400,00, what represents less than the half of the values charged for such conventional tanks. The level of thermal loss was very next to the limited literature parameter, about 5ºC of loss for a time of 24-hour, to a level of temperature of 45ºC. Souza (2004) constructed and tested another alternative reservoir that consisted of composite material involving a polyethylene drum of 200 liters, with thickness of 50mm. The thermal efficiency of the alternative drum was next to the presented previously, however it presented a large weight.

Researching forms of attainment of a low cost heating system are important. This researching of alternative systems to make viable the use of solar energy and its considered end to become it accessible for a bigger parcel of the population are being done in the scope of the Laboratory of Solar Energy of the Federal University of Rio Grande do Norte. Amongst the studied collectors are the collectors: parallel tubes forming a coil; in labyrinth, of parallel plates (sandwich type), formed of units of heating consisted of glass bulbs (carcasses of fluorescent light bulbs having in its interior PVC tubes).

3. MATERIALS AND METHODS

The heating system considered is composed of a collector with absorber grid formed by PVC tubes, in parallel and of a hot water storage tank. The follow one describes the main characteristics of the collector, the main element of the heating system and its processes of manufacture and assembly.

The absorber grid of the collector is formed by linked in T 24 connections of ¾" PVC tubes forming the entrance and exit tubing and establishing connection between the 12 absorber tubes of the same material and diameter. The box is confectioned in ceramic matrix composite formed by the mixture of gypsum, dusted EPS and water, and present corresponding external dimensions of L = 2.10m, B = 0.94m and H = 0.17m, with internal area of Ai = 1.66m². It is re-covered by a transparent plain glass blade of corresponding thickness of 3mm. It is formed, therefore, for only three elements, differently of the conventional collectors with five, which they are: box, absorber grid and glass.

The manufacture process of the alternative collector that composes the heating system presents the following stages:

1. Mold construction;
2. Application of the oil in all the mold internal parts;
3. Preparation of the composite using the following ratios: 1.0 Gypsum + 1.0 EPS + 0.30 water in volume;
4. Fulfilling with composite the space between the internal and external laterals and above the internal box cover;
5. Drying box by direct exposition to the solar radiation;
6. Assembly of the box in a metallic structure;
6. Waterproofing of the box by implicating one glue mixture of wood, cement and sugar;
7. Opening the two punctures for the rank of the entrance tubing and water exit of the collector;
8. Painting the box.

After the confection of the box the next step is the assembly of the absorber grid and the collector that followed the following steps:

1. Cut of the PVC tubes;

2. Junction of the connection in T of PVC through the appropriate glue use;
3. Coupling of the absorber tubes in the connections in T using one PVC special glue;
4. Test of hindrance of the absorber grid;
5. Painting of the absorber grid;
6. Placing of the absorber grid in the box of the collector;
8. Placing of the transparent plain glass covering of 3mm of thickness;
9. Placing of the collector in a metallic structure;
10. Painting of the metallic structure.

The heating system functions in regimen of thermosiphon, for a volume of water of 200 liters and was tested to evaluate its thermal efficiency, being raised parameters that characterize it, necessary for the analysis of its thermal performance, as well as the susceptibility of the absorber tubes to reach the critical level for the beginning of the thermal degradation of the PVC tubes, around 60°C. It was measured the temperature of entrance and exit of the collectors fluid, the internal and external temperatures of the collectors, the temperature of the external surface of the absorber tubes, the temperature of the water contained in the reservoir, the ambient temperature and the global solar radiation. Also the necessary time for uniformization of the temperature of the mass was measured.

Also the autonomy of the system was evaluated in relation to the number of days the system will be able to propitiate hot water in the ideal temperature for bath to a residence with four people. The baths were simulated from 7:00am, 12pm and 8pm, leaving 50 liters in the thermal reservoir, which corresponds to the 2/3 of its height. It is standed out the simulation of the baths is more critical than what it happens in the reality, therefore occurred without mixture of the hot water of the drum with the cold water of the net. One another carried through test was to evaluate the thermal loss of the drum through the measurement of the mass of water contained in the reservoir temperature decrease and its external temperature.

The temperatures of entrance and exit of the fluid had been measured in the period between 8am and 3pm, in intervals of 30 minutes; the temperatures of the collector and absorber tubes had been measured in intervals of 15 minutes between 11am and 1pm; the temperature of the fluid mass was measured after eight hours of functioning. The proposed heating system with an alternative collector is shown in the Fig. (1).

Figure 1. Water heating alternative solar system proposed.

The parameters that characterize the thermal efficiency of a solar collector are the thermal efficiency and the loss global coefficient. For the determination of the loss global coefficient was used Eq.(1). Also had been determined the absorbed heat (Q_{abs}) by the system, the useful heat transferred to the fluid (Q_{useful}) and the system lost heat (Q_{loss}), determined for the equations (2), (3) e (4), shown to follow. Eqs.(5), will be used for the determination of the thermal efficiency (DUFFIE&BECKMAN, 1991, Bezerra, 2001, Censolar, Gil, 2001).

$$U_{loss} = \frac{(\tau_v.\alpha_p - \eta_t) I}{(T_{pm} - T_a)} \tag{1}$$

Where:

τ_v = glass transmissivity (%)

α_p = plate absortivity (%).
η_t = thermal efficiency (%).
T_{pm} = plate average temperature (^oC).
T_a = environment temperature (^oC).

$$Q_{abs} = \tau_v.\alpha_p.\mathrm{I.A} \tag{2}$$

$$Q_u = \dot{m}.c_p.\Delta\mathrm{T} \tag{3}$$

where:

$\dot{m} = \rho.$**Q =** mass outflow;

c_p = specific heat the constant pressure

$\Delta\mathrm{T}$ = gradient of temperature of the fluid in the collector

$$Q_p = Q_{abs} - Q_u \tag{4}$$

$$\eta_t = \frac{Q_u}{\mathrm{A.I}} \tag{5}$$

Where:

Q_u = useful total energy transferred to the work fluid, in kW.

I = global solar radiation, in kW/m^2.

A = = collector area, in m^2.

$\dot{m}$ = mass outflow, in kg/s.

c_p = specific heat of the water, in KJ/kg ^oC.

ΔT = temperature gradient between entrance and exit water, in °C.

With the values of the parameters above related the thermal efficiency the collector it can be express for the equation (6).

$$\eta_t = \frac{0.021.\Delta T}{\mathrm{I}} \tag{6}$$

4. RESULTS AND DISCUSSIONS

Table 1 show to the data of effected test of 1º day with the alternative heating system in study, formed of the alternative collector and thermal reservoir for hot water storing.

Table 1. 1º day data of test.

TIME (HOUR)	$T_{ENTRANCE}$ (°C)	T_{EXIT} (°C)	ΔT (°C)	I (KW/m²)	η_t (%)
8:00 - 9:00	30.0	40.0	10.0	0,65	0,28
9:00 -10:00	32.0	47.0	15.0	0,7	0,39
10:00 -11:00	34.0	49.0	15.0	0,75	0,36
11:00 -12:00	36.0	51.0	15.0	0,8	0,34
12:00 -13:00	38.0	51.0	13.0	0,78	0,30
13:00 -14:00	40.0	51.0	11.0	0,7	0,28
14:00 -15:00	42.0	50.0	8.0	0,65	0,22
AVERAGE	**35.9**	**48.4**	**12.5**	**0.72**	**0.31**

The data of the table shows that the values of the reached temperature gradient with the collector had been significant, considering the fact the system has only 1,6 m² of exposition area to the incident global solar radiation, making possible the return of the water to the thermal drum with temperatures always superior to the ideal temperature for bath, between 36.0 and 38.0°C. The significant tax of heating speed can be perceived demonstrating that all the water volume of the alternative thermal reservoir was warm in levels above of those required for the bath.

The values of thermal efficiency had been compatible with the shown in literature for alternative collector, although they are inferior to the corresponding values to the conventional plain collectors, because they present superior thermal loss. The average ambient temperature in the test site was of 31.0°C and the average radiation in the period of the test was inside the average foreseen for the Brazilian Northeast, for the period of the year where the assay occurred, in 09.03, around 700W/m².

To evaluate the heating speed of the contained liquid mass in the drum it was measured its temperature in the bottom, at ¼, at ½, at ¾ and in its superior part, for a corresponding warm up time to a day, which values meet shown in Table 2.

Table 2. 1º day data of test .

TIME (HOUR)	T_{botton}	$T_{1/4}$	$T_{1/2}$	$T_{3/4}$	T_{above}	$T_{env.}$
8:00 - 9:00	30.0	30.0	30.0	30.0	31.0	30.0
9:00-10:00	32.0	31.0	31.0	35.0	37.0	30.0
10:00-11:00	34.0	33.0	34.0	36.0	39.0	31.0
11:00-12:00	36.0	34.0	36.0	38.0	42.0	31.0
12:00-13:00	38.0	36.0	40.0	40.0	45.0	31.0
13:00-14:00	40.0	38.0	43.0	45.0	47.0	31.0
14:00-15:00	42.0	42.0	45.0	47.0	48.0	31.0
End of the Day	**42.00**	**43.00**	**45.00**	**47.00**	**48.00**	**31.0**

The values of temperature show that all the contained liquid mass in the thermal drum present levels temperature above of those ones ideal for the bath. They also demonstrate that the system was capable to heat all the water of the drum, in this ideal temperature, in only one day of test. This is an important characteristic for a water heating solar system. After the test, the water of the drum was shaked to know the gotten average temperature, reaching a corresponding value 47.0°C.

To evaluate the system in the real condition of functioning, it was proceeded a simulation from the baths in the schedules of 7am, 12pm and 6pm, leaving 50 liters to each test, and the results of the levels of temperature for each water withdrawal of the drum, before and after, are shown in Table 3.

Table 3. Data of the test for the banns simulation

Day	Twater before	Twater after	Hour
5/mar	47.0	43.0	18:00
6/mar	38.0	35.0	07:00
6/mar	44.0	40.0	12:00
6/mar	44.0	40.0	18:00
7/mar	35.0	33.0	07:00
7/mar	42.0	39.0	12:00
7/mar	45.0	41.0	18:00
8/mar	37.0	35.0	07:00
8/mar	43.0	38.0	12:00
8/mar	43.0	38.0	18:00

The data presented in the table demonstrate that the system had autonomy for three days of use, generating levels of temperature in the water generally superior to the ideal levels for bath. The levels of radiation for such days had been inside of the average foreseen for the Northeast region, for this period, around 700W/m², on average.

To evaluate the thermal loss of the alternative solar collector of the heating system one measured the levels of temperature of inherent parameters to this process that are presented, in average values, in the Figure 2.

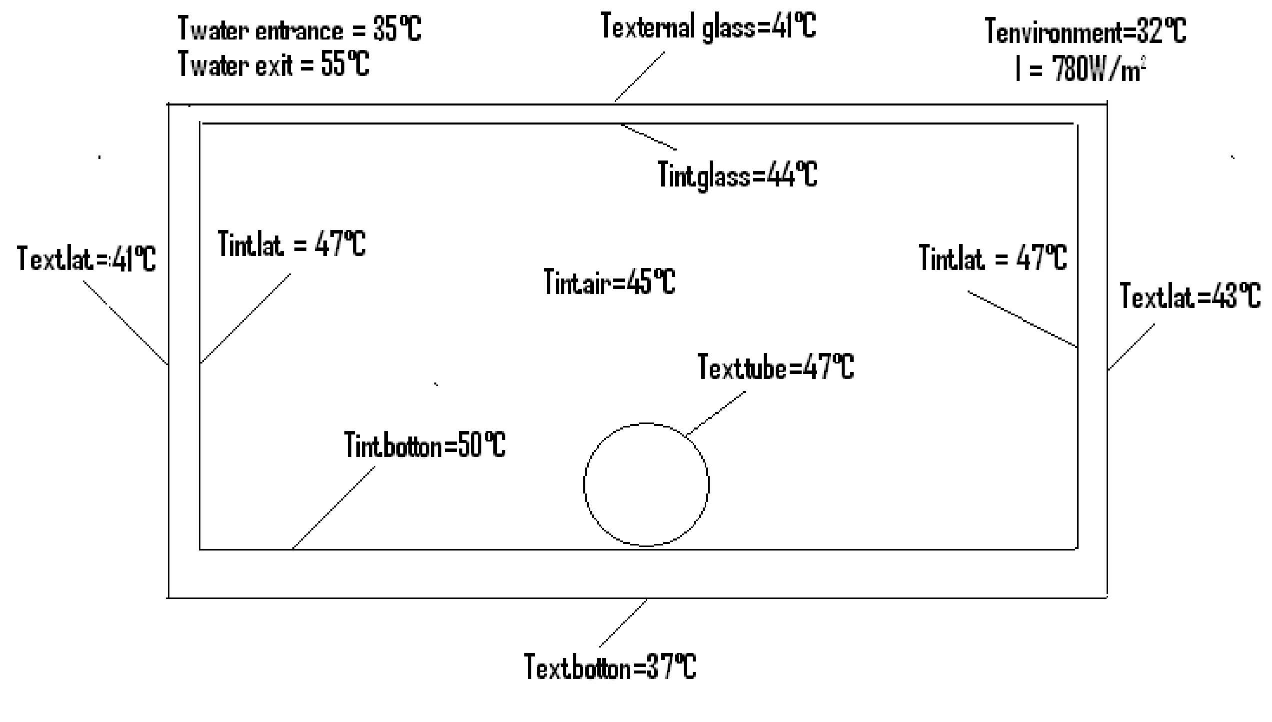

Figure 2. Thermal loss parameters of the collector in study.

In relation to its average value, the temperature of the external surface of the PVC absorber tubes was below of the temperature for thermal degradation beginning, around 60°C, what it demonstrates that the use of PVC tubes is viable as absorber elements in solar collectors.

The necessary materials to the construction of the collector in study had been: 2.0 gypsum bags, 2 bags of EPS in dusty. It was also used 24 connections in T of PVC of ¾" and 30.0 meters of PVC tube of ¾". Its final weight was around 80kg. Its cost of manufacture was around R$150.00. The used product for the waterproofing of the collector box was a cement mixture, white glue and sugar and the ink used for its painting was the black synthetic enamel.

The results of the test to evaluate the thermal efficiency of the alternative thermal reservoir is presented in the Table 3.

Table 3. Test with the alternative thermal reservoir.

HOUR	Twater	Tenvironment	Treservoir
16:00	**45.0**	**27.0**	**29.0**
18:00	43.5	26.0	27.0
20:00	42.5	25.5	26.0
22:00	41.0	25.0	26.0
00:00	40.0	24.5	25.5
02:00	39.0	25.0	25.5
04:00	38.5	25.0	26.0
06:00	38.0	27.0	31.0
07:00	**37.5**	**28.0**	**35.0**
09:00	37.0	29.0	37.5
11:00	37.0	30.0	38.5
13:00	37.0	30.0	38.5
15:00	37.0	28.0	35.0
16:00	**36.5**	**27.0**	**32.0**

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The data demonstrates the significant thermal efficiency of the considered alternative thermal drum. It had a temperature fall, during 15 hours, from the end of the afternoon and during the night, correspondent to 7.5°C and during 24 hours equal to 8.5°C. This fall of temperature is a little above of the pointed one for literature with respect to conventional thermal reservoirs, of copper or inox, that present values around to 5.0°C for the tested level of temperature. For the more critical level that happens during the night, the loss was of 7.5°C, 50.0% greater that the reached with the conventional reservoirs, however does not make impracticable the use of this type of considered thermal reservoir, once although this is a significant increase, the loss was low. It is standed out, still, the price of the considered, very smaller in the alternative drum than the conventional reservoirs.

This perceives that the temperature of the external surface of the drum was well next to the ambient temperature during all the night reflecting low thermal loss in the lateral of the reservoir. The temperature of the drum reached values above of the ambient temperature for the period when the drum started to be warm for the global solar radiation absorbed by the same, once it was painted with black ink. Therefore, the loss most significant occurred for bottom and in the cover of the reservoir. In respect to the mechanics of the considered alternative reservoir, it cannot be verified damages to its structure, demonstrating to support the corresponding weight to the volume of water contained in the drum. It did not have occurrence of leaking, what it certifies its efficient hindrance, also gotten through polymeric resin.

5. CONCLUSIONS AND SUGGESTIONS

With basis on the results of the tests with the heating system during the survey of thermal performance, can be presented the following conclusions, as well as possible suggestions for optimizations and future works effectuations with alternative collectors.

1. The considered alternative collector presents thermal, economic and materials viabilities, although they present inferior levels of thermal efficiency to the conventional collectors. Its cost of manufacture is well below in relation to the commercially available conventional collectors;
2. The proposed heating system demonstrated itself viable for the considered use, which is the residential water heating for bath;
3. The alternative collector revealed itself resistant in relation to atmospheric variations;
4. The main characteristic of the heating system considered is its big speed of heating of the mass of fluid. All the water mass contained in the thermal reservoir is warm above of the ideal temperature for bath for the first day of test;

5. It can be proven that the composite used for the confection of the box allowed the collector to be composed of only three elements, eliminating the absorber plate and the thermal insulator, providing a reduction of the cost of the collector;
6. The new model of attainment of absorber grid through the use of connections in T produced the desired effect, not presenting problems of leaking;
7. The temperature of the absorber tubes in the alternative collector was far from the critical level for beginning of the thermal degradation process around 60°C. In what such effect says respect to the thermal degradation is brightened up by the black ink that it recovers the absorber tubes that contain black pigments absorber of ultraviolet radiation.
8. The thermal loss of the heating system was above of the pointed one for literature; however it was in compatible level with heating systems that use alternative collectors;
9. The weight of the collector was high, needing to study alternative forms using the composite considered for the attainment of a lighter collector. However, this does not bring restriction to its use therefore when it is installed could be definitively static, without movement necessity;
10. The low cost of the collector represents a considerable advantage in relation to the available conventional systems, being able to increase the capacity of socialization of such heating system. The alternative thermal reservoir revealed efficient for the considered end and presents low cost, what it represents a considerable advantage in relation to the available conventional reservoir in the market.
11. It is necessary to make a deepened study, with more test days to have more real and comparative analysis, what is already in course.

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