LOW COST ALTERNATIVE SOLAR COLLECTOR WITH PVC TUBES ABSORPTION SURFACE

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Abstract. *An alternative new model of solar collector is presented, composed for multiple units of PVC tubes in parallel to absorb solar radiation, through a new model of linking between these ones and the water exit and admission pipes. The collector's box is made with a composite of matrix ceramic and coated with resin, propitiating the elimination of the thermal insulator, usually glass wool. The collector is composed of only three elements: the box, the absorb grid and glass. It will board constructive aspects, demonstrating the easiness to manufacture of this prototype that is characterized for presenting a cost of manufacture sufficiently reduced. It will be presented values of thermal parameters of the collectors, working in regimen of thermosiphon in a volume of water in the order of 250 liters (66.03 gallons). It will demonstrate the thermal, economic and the materials viability of this collector, enabling it to serve as another option to the conventional systems of market heating, mainly to the attainment of low temperatures.*

Keywords: solar collector, collector alternative, low cost

1. Introduction

With the emphasis given to the environmental question, when the developed world prioritizes the use of the clean energies and renewed, the water heating through the use of solar collectors has represented, together with the photovoltaic cells, converting of the solar energy in electrical energy, one of the most viable applications in residential and industrial levels Yacov and Zemel (2000); Trends in Renewable Energies (2000-2002).

The brazilian northeast presents a quite significant solar potential, corresponding to an average availability solar potential that corresponds to 600W/m^2, as Atlases of Solar Irradiation of Brazil Bezerra (2001).

According to Bezerra (1999), 42% of the consumption of electric energy in Brazil is directed to the sector of constructions, being 84.1 % correspondent the companies and residences and 15.9% to the public administration, with ciphers reaching 13,8 % of the gross internal product of the country.

The author mentions that the residential section answers for 25% of the national consumption of energy and in agreement with manual of energy company of Brazil the consumption of the electric shower is the second largest in a residence, corresponding to 25%, just losing for the refrigerator/freezer that corresponds to 30%. Its use reaches the peck schedule from 6:00pm to 7:00pm, corresponding to 8.5% of the national demand of energy on this schedule.

These data point the importance of the substitution of the electric thermal source by solar source for the obtaining of hot water mainly in time of rationing of energy, gaining big importance once the Brazilian hydraulic option for the electric power generation is practically with its exhausted resources.

With the main objective of reducing the manufacture cost of a solar prototype destined to the heating of water for bath, an alternative solar collector was developed and constructed, that presents lower costs than the conventional plans. This collector has as main characteristics the use of PVC tubes (polyvinyl chloride), in substitution to the copper conventionally used and its box is made through a mixture of gypsum, wood powder and sisal fibers, forming a composite, of cost much cheaper than the materials conventionally used, which are: profile of aluminum, glass fiber and steel plates. This type of considered alternative material presents the advantage of being a good thermal insulator, which eliminates two components of a collector: the absorber plate and the thermal isolation.

It will be shown resulted of the tests realized with the collectors, the alternative and the conventional ones, demonstrating its thermal, material and economic viabilities. In the analysis of materials it will be approached questions about thermal and UV radiation degradations inherent to the use of the PVC as absorber surface of the solar radiation.

2. State of the art

2.1. Alternative collectors

Alternative collectors are those that differ in geometry, materials and constituent elements in relation to those used in the making of the conventional collectors. Another factor of difference is the type of regime of operation of this one: forced flow, with the use or not of a pumping system, or termosiphon.

The main objective of the study of alternative collectors is the reduction of the production cost, to the socialization of its use in domestic and industrial water heating systems, once the cost of the same ones represents 50% of the total cost of investment for the acquisition of these systems. This high cost is due to the use of materials of significant price in its production.

These systems have a long useful life, but they request high initial investment, and this explains the drop rate of development of water heating solar systems in the world. It becomes necessary and fundamental, the development of systems of lower cost with good thermal performance Cristofari (2002). With this objective, several works have been developed, demonstrating that the low cost solar plastic collectors present wide viability of use as its been demonstrated in the followed cited studies.

Rivera, in 1994, presented work on tubular alternative collector with multiple units absorbers of PVC. Lourenço, in 1997, showed the results reached with an alternative collector with absorber grid formed by multiple tubes of aluminum. Both demonstrated the thermal and economical viabilities of such collectors, proving the competitiveness of the same ones in relation to the conventional collectors.

The use of a polymeric absorber was studied by Van Niekerk et al., in 1996, with the objective of evaluating the efficiency of collectors with parallel tubes in South Africa. Matrawy and Farkas, in 1997, compared a collector with two parallel plates (TPPC), with, respectively, a collector with parallel tubes (PTC) and a collector with tubes in serpentine (STC).

Shah, in 1999 presented study on the thermal modeling in domestic collectors for water heating at low flow.

The use of collectors with polypropylene tubes and polyethylene absorption plates of high density is quite focused by the literature. Those collectors are used for heating and acclimatization of swimming pools Gil (2001).

With the objective of getting a low cost water heating solar system, it is being studied since 18 years ago in the ambit of the Solar Energy Laboratory of the Federal University of Rio Grande do Norte alternative systems to viably the use of the solar energy and to make it accessible to the larger portion of the population.

Among the studied collectors we can mention: the one of parallel tubes forming a serpentine; in labyrinth, sandwich type parallel plates, the one formed by units of heating constituted by glass bulbs (fluorescent lamps carcasses having in its interior PVC tubes); and an alternative plane with PVC tubes. Excepting this last one, all the other generations were put to work in forced flow regime, with only a work fluid passage inside the same Souza (2002).

In 2002 Souza to studied two alternatives collectors, in labyrinth and fin, shown that the collectors, with absorber grid formed by PVC tubes presented thermal, materially and economic viability.

2.2. Thermal and UV radiation degradations inherent to PVC

In a solar collector that it uses as absorber elements PVC tubes, the first question is about the inherent degradations of its exposure to the ultraviolet radiation and heat. The literature shows that the susceptibility to the thermal waste of PVC increases when it's obtained of temperature levels above 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 wavelength affect the mechanical integrity of the tubes of this material Souza (2002).

3. Description of the collectors in analysis

The conventional collector has its box confectioned in profile of aluminum with bottom of aluminum of 0.5mm of thickness; has thermal isolation of glass wool in the bottom and lateral; absorber grid formed by 08 copper tubes of ½" connected in parallel; admission and discharge tubes of aluminum of 2" and absorber fins made in foil of aluminum of 0.5mm of thickness and covering of transparent plane glass of 3.0 mm of thickness incased in the profile of which the box is made. The built collector presents the following dimensions: width of 1.0m; length of 1.30m and 0.09m height, with equivalent area to 1.30m^2. That area value was defined in function of the available length of the copper tubes.

The proposed alternative collector has as main characteristic the use of low cost alternative materials for the construction of its box and a multi tubes absorber grid, allowing the obtaining of a larger circulating flow, which has for objective to speed up the thermal exchange between circulating fluid and the water contained in the thermal reservoir.

Before the construction of the prototype, it was built several models, with different compositions and materials, allowing a choice of the most appropriate material, that it presents the characteristics of good thermal efficiency, mechanical resistance to the impact and economical viability. It was used mixtures of the following materials, for the obtaining of composites: gypsum + wood powder; gypsum + wood powder + sisal; gypsum+ expanded polystyrene

(EPS); gypsum + coconut powder. After evaluations thermal, economical and material, it was chosen the composite to the base of gypsum, wood powder and sisal, being still placed a reinforcement of wire screen, in the box's bottom.

The collector was built with absorber surface formed by 20 PVC tubes of 20.0mm coupled the admission and discharge tubes of PVC 50.0mm. The area of the collector is of approximately $0.7m^2$ (1.31 x 0.51m). The principle operation and work regime are the same of the conventional collector. The area of the collector was defined in function of the number of tubes to be used in the absorber grating, interlinked in parallel through a new system that allows the decrease of the distance among two consecutive tubes.

It is important to stand out that with this box's use for the collector, the box's bottom functions as absorber surface, in contact with the absorber tubes, and as its material is a good thermal insulator, this makes unnecessary, therefore, the placement of a thermal insulating material between the absorber grating and the box's bottom. To avoid the absorption of water on the part of the box, it was applied two layers of polymeric resin.

4. Experimental procedure

The heating systems with the conventional plane collector and with the alternative they were rehearsed for identical conditions of radiation, in termosiphon regime, for a volume of 250 liters, being measured parameters of temperature of entrance and exit of the collector fluid, internal and external temperatures of the collector, the water temperatures in the thermal reservoir, temperature of the absorber tube and global solar radiation.

With relation to the internal and external temperatures of the collector, it was measured: temperature of the internal air; temperature of the internal and external surfaces of the glass; temperature of the external air; temperature of the internal and external surface of the base of the collector; temperature of the internal and external surface of the lateral faces; temperature of the absorber plate, in five points of the grid Souza (2000); Souza (2002); Duffie (1991).

The entrance and exit temperatures of the water in the collector were measured in 30minutes intervals, from 8:00am to 4:00pm. The collector temperatures were measured in the interval among 11:00am at 1:00pm, in 15 minutes, intervals, period of practically constant radiation.

For the temperature measurement were used thermocouples of copper-constantan, with diameters of 0.25 and 0.5mm, respectively, connected to a digital thermometer.

With an objective to prevent that the absorber tubes reaches the critical temperature to the beginning of the thermal degradation process, above 60^oC, the values of the external temperature of the same ones was measured in several points of the absorber grid to evaluate the behavior of this parameter.

Literature mentions the PVC waste when submitted to the heat and the ultraviolet radiation, component of the spectrum of the solar radiation; however it doesn't quantify the degradation level, when submitted at inherent temperature levels to the use of the tube of PVC as absorber element in a solar collector.

Souza (2002), it demonstrated that such degradations can be combated through larger volume of water inside the absorber grid, that makes impossible the reaching of the critical temperature and with a painting of the same ones with opaque black, inherent to the obtaining of thermal energy starting from the electromagnetic energy, that lessens the effect of the UV degradation. The mentioned author demonstrated that in spite of such degradations the use of tubes of PVC as absorber elements and conductors of heat in solar collectors, it is fully viable.

The box of the collector after being built passed through a drying process corresponding to 72 hours, in solar greenhouse, and presented a weight corresponding to 45.0 Kg, with its support reaching 5.0 Kg. The volume of water in the absorber grating of the collector corresponds to 7.0 Kg. The glass of the covering weighs around of 2.0 kg. Therefore, the total weight of the produced collector corresponds to 59.0 kg.

The heating systems constituted by the two types of collectors, are shown in Fig. (1).

(a)

(b)

Figure 1. Solar heating systems in test: (a) using alternative collector and (b) using conventional collector.

4. Theoretical development

The parameters that better characterize a solar collector are the thermal efficiency and the losses global coefficient. For the determination of the thermal efficiency it was used the Eq. (1) shown to follow. For the determination of the losses global coefficient it was used the equation (2). Also had been determined the absorbed heat (Q_{abs}) by the collectors, (Q_u) and the lost heat by collectors (Q_l), through the use of the equations.(3), (4) e (5), shown to follow Duffie and Beckman, 1991; Souza,2002.

$$\eta_t = \frac{Q_u}{A.I} \quad (1)$$

Where:

Q_u = the useful heat transferred to water (W);

I = global solar radiation (W/m^2);

A = collector area (m^2).

$$U_{loss} = \frac{(\tau_v.\alpha_p - \eta_t) I}{(T_{pm} - T_a)} \quad (2)$$

Where:

τ_v = glass transmissivity (%);

α_p = plate absortivity (%);

η_t = thermal efficiency (%);

T_{pm} = average temperature of plate of absorption (°C);

T_a = ambient temperature (°C).

$$Q_{abs} = \tau_v.\alpha_p.I.A \quad (3)$$

$$Q_u = \dot{m}.c_p.\Delta T \quad (4)$$

where:

$\dot{m} = \rho.\,Q$ = mass outflow (Kg/s);

c_p = specific heat the constant pressure (KJ/kg.°C);

ΔT= gradient of temperature of the fluid in the collector (°C)

$$Q_l = Q_{abs} - Q_u \quad (5)$$

5. Results analysis

5.1. Proposed alternative collector

The Tables (1), (2) and (3) presents the medium parameters that shows the thermal efficiency of the collector in study for three days of tests and the Fig. (2), (3) and (4) shows the comparative behavior assumed by the same ones and the values of water temperature in reservoir.

Table 1. Thermal results of the collector for the first test day.

Hour	$T_{entrance}$(°C)	T_{exit} (°C)	ΔT (°C)	I (KW/m^2)	η_t (%)
9-10	30	35	5	0,7	49,0
10-11	31	36,5	5,5	0,75	50,6
11-12	31,5	37,5	6	0,80	52,0
12-13	32	37	5	0,80	43,0
13-14	34	36	2	0,78	18,0
14-15	35	36	1	0,68	10,0

Table 2. Thermal results of the collector for the second test day.

Hour	$T_{entrance}$(ºC)	T_{exit} (ºC)	ΔT (ºC)	I (KW/m^2)	η_t (%)
9-10	30,5	36	5,5	0,7	54,2
10-11	32	37,5	5,5	0,75	50,6
11-12	32	37,5	5,5	0,80	47,4
12-13	33	36	4	0,80	34,5
13-14	34,5	37,0	2,5	0,78	22,1
14-15	36,0	37,5	1,5	0,68	15,2

Table 3. Thermal results of the collector for the third test day.

Hour	$T_{entrance}$(ºC)	T_{exit}(ºC)	ΔT (ºC)	I (KW/m^2)	η_t (%)
9-10	31	36	5	0,7	49,2
10-11	32	37	5	0,75	46,0
11-12	32,5	37,5	5	0,80	43,1
12-13	33	37,0	4,0	0,80	34,5
13-14	35	38	3,0	0,78	26,5
14-15	36	38	2,0	0,68	20,2

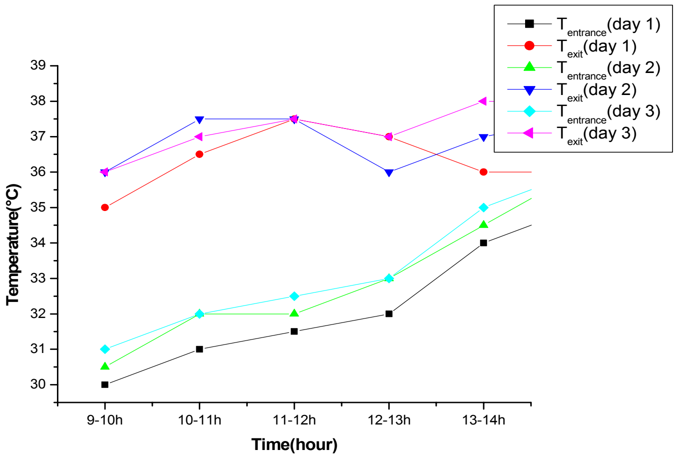

Figure 2. Fluid exit and entrance temperature.

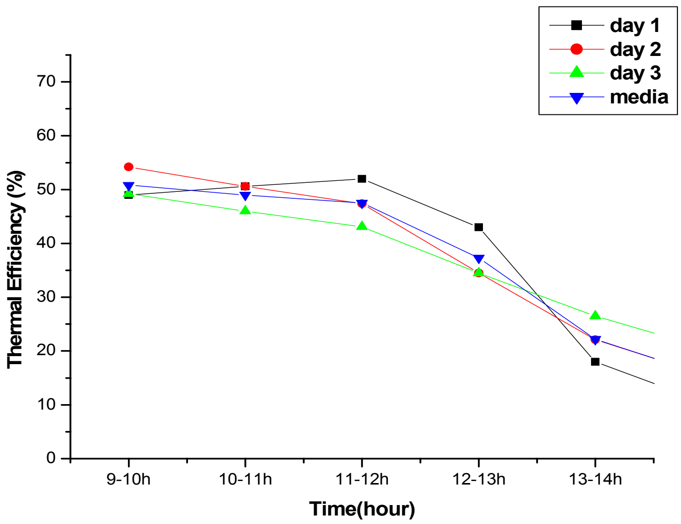

Figure 3. Thermal efficiency of the collector.

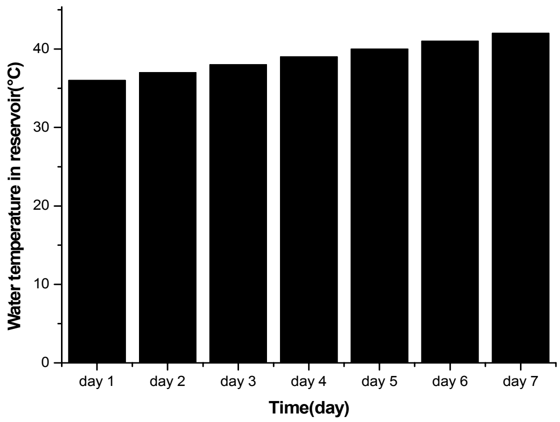

Figure 4. Evolution of the water temperature in reservoir.

The general thermal results obtained with the system shows the viability of the same one, although it have not been obtained ideal temperature levels in the reservoir for the bath, for a four people enough volume, because they don't guarantee the maintenance of the ideal temperature of bath after the entrance of cold water for the use of the warm water during the night.

In other words, it was obtained the bath ideal temperature; however a larger area of collector will be demanded for the warranty of the maintenance of that ideal level after the completion with cold water of the volume of hot water removed. The schedules thermal efficiency of the collector was close to 60.0%, with maximum temperature of exit of 43.5°C. The principal characteristic thermal of the system it was its heating speed, in the allowing the obtaining a faster of the water temperature inside the reservoir. It can be noticed that with only six working hours, the reservoir already reached a uniform temperature, for every volume.

In spite of the good thermal efficiency of the collector, the temperature of exit of the same was below of that one desired temperature for the attainment of appropriate levels of temperature for bath in the interior of the reservoir; it has reached in the seventh day of operation a value corresponding to 43.0ºC. The fluid exit temperature of the collector should reach larger values so that in the reservoir the water can reach a temperature around 45.0°C, capable to maintain the reservoir to an ideal temperature of bath, even after the use during the night, with consequent entrance of cold water inside of the same.

The wanted temperature level for the water volume contained in the reservoir should be around 45.0ºC. For the obtaining of that level it becomes necessary a superior area of collector. Preliminary tests made with two collector reception areas, 1.0 m^2 and 1.5 m^2, produced the intended effect, which is the obtaining of a very superior temperature in the reservoir. The system of 1.5m^2 is composed by two collectors in series, obtaining maximum temperature of 52.0°C in the exit of the collector and generating inside the reservoir the following thermal distribution of the water: superior level – 50.0°C, medium level – 45.0°C and inferior level – 42.0°C.

In relation to temperature of the external surface of the absorber tubes, its values were always below the critical temperature for begin of the thermal degradation that is above 60.0 º C. The reached maximum value was equal to 40.7 ºC being much smaller than the PVC deflection temperature, above 75.0° C.

In relation to the tests accomplished for determination of materials parameters it can be noticed that the used composite presents good resistance to the impact, which is the main solicitation in which the box of the collector can be submitted, in what it concerns to shocks when of your handling and transport. The introduction of a metallic frame in the composite causes an increase of about 100% in your resistance to the impact.

With relationship the traction, compression, flexion and torsion the produced composite samples, gaining didn't presented significant resistance to those efforts, what doesn't make unfeasible the proposed box, once such solicitations won't usually be imposed to the structure (Souza, 2003).

With relationship to the parameter absorption of water, significant when in the period of rains, with the exposed collector to the atmosphere, it can be noticed that the applied coating to the composite with polymeric resin has shown effective. The collector is already exposed since more than a year, having been submitted to intense pluviometer index.

5.2. Collectors comparison

The Tables (4) and (5) show the data of the 1st test day made with the collectors in study.

Table 4. Data obtained with the alternative collector.

Hour	Tent(°C)	Texit(°C)	ΔT(°C)	I(Kw/m^2)	η_t (%)
9-10h	30.0	35.0	5.0	0.70	49.0
10-11h	31.0	36.5	5.5	0.75	50.6
11-12h	31.5	37.5	6.0	0.80	52.0
12-13h	32.0	37.0	5.0	0.80	43.0
13-14h	34.0	36.0	2.0	0.78	18.0
14-15h	35.0	36.0	1.0	0.68	10.0

Table 5. Data obtained with the conventional collector.

Hour	Tent (°C)	Texit (°C)	ΔT(°C)	I(Kw/m^2)	ηt (%)
9-10h	30.0	37.0	7.0	0.70	32.0
10-11h	32.0	42.5	7.5	0.75	32.0
11-12h	33.0	43.5	10.5	0.80	42.0
12-13h	35.0	43.5	8.5	0.80	34.0
13-14h	36.0	42.0	6.0	0.78	25.0
14-15h	37.0	41.0	4.0	0.68	20.0

The Figure (5), (6) and (7) show the behavior assumed by the parameters fluid exit and entrance temperatures and, temperature gradient and hourly thermal efficiency.

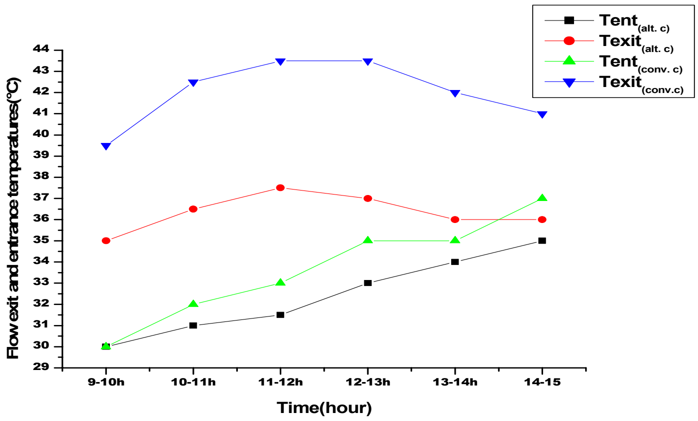

Figure 5. Behavior of the fluid exit and entrance temperatures.

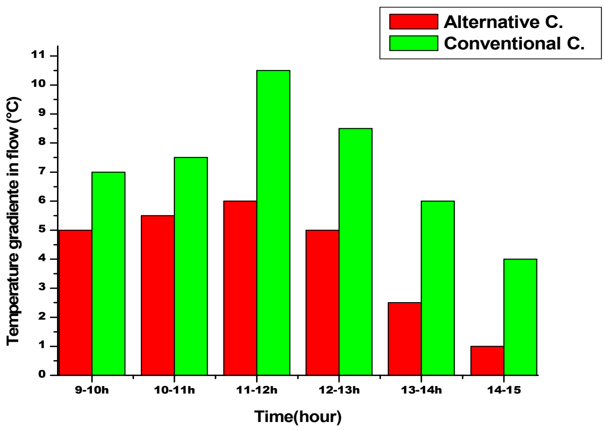

Figure 6. Behavior of the gradient temperature.

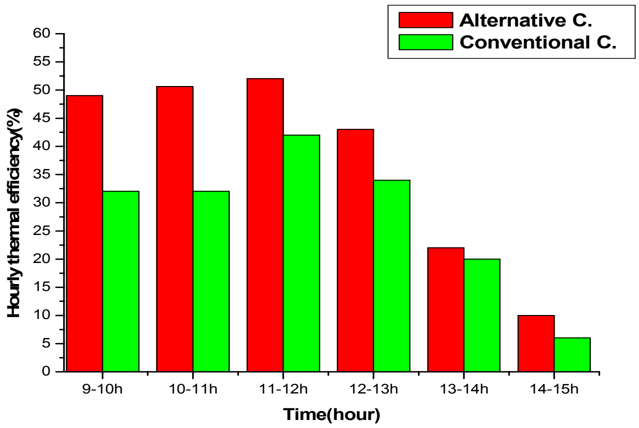

Figure 7. Behavior of the hourly thermal efficiency for the studied collectors.

The values of the thermal efficiency obtained for the alternative collector are greater than the presented ones by the conventional collector, in function of its smallest area and of its smallest time of heating of the flow mass, reaching maximum values of 52.0% in the alternative collector and 42.0% in the conventional collector.

With relationship the generated thermal gradient it is noticed that the values obtained with the conventional collector are larger than the ones generated by the alternative collector. The maximum temperature reached by the alternative collector in the 1st test day was of 37.5°C while in the conventional it was of 43.5ºC. However it is pointed out that the area of the alternative collector is almost half of the conventional collector area.

In what it concerns to the temperatures of the mass of water contained in the reservoir it is noticed that the alternative collector presented in the 1st test day a temperature corresponding to 36.0°C, increasing in about 1.0°C for every day of test, reaching in the seventh test day value corresponding to 42.0°C, while in the third test day with the conventional collector a level of 40.5°C was reached. It is emphasized that the 1st test day was used as comparative element once it was not possible the rehearsal of the conventional collector for a more extensive period, in function of the climatic conditions, and also being considered that the 1st operation day of a collector in termosiphon really show the behavior that will have in next test days.

Another factor that was observed is that in only six hours of test the alternative collector got the uniform of the water temperature in the thermal reservoir, while in the conventional collector such uniform it didn't happen for a day of heating. That is due to the fact of the use of 20 absorber tubes of big diameter in the alternative collector, what makes that the circulating real flow inside the collector be larger.

In relation the external temperature of the absorber tubes, the measured values, $T_{maximum}$ = 41.0°C and T_{media} = 40.0°C, are well below the critical level for beginning of the thermal degradation, around 60.0°C, demonstrating the viability of use of such tubes as absorber elements and heat conductors.

Another parameter that shows the thermal behavior of a solar collector is the losses global coefficient, whose value was calculated, in function of the present data in the Fig. (8). The Table (6) displays the values of $Q_{absorber}$, Q_{useful}, Q_{loss} and Losses Global Coefficient, U_{Loss} for the two collectors in study.

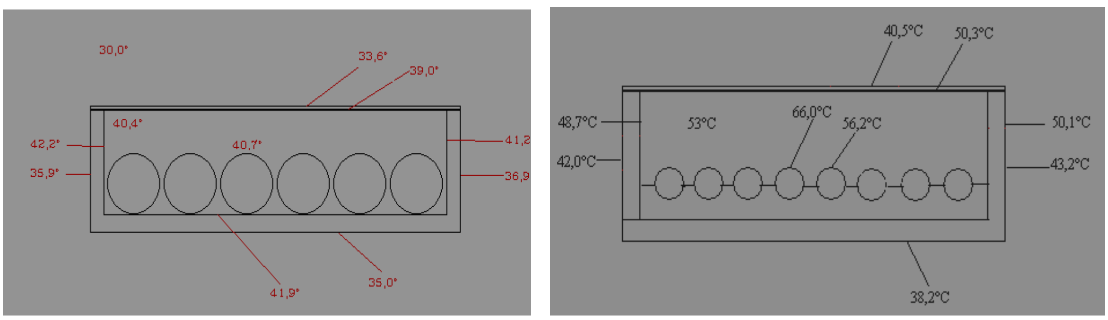

Figure 8. Temperature levels in the alternative and conventional collector.

Using the data shown in the illustrative outlines of the two collectors, it was determined the values of absorbed heat, useful heat and lost heat. The thermal efficiency considered for the calculation of the parameters contained in the table it was an average of the values for two hours. The Table (6) displays the calculated values for those parameters, in the two collectors.

Table 6. Values of thermal loss of the rehearsed collectors.

COLLECTOR TYPE	$Q_{ABSORBER}$ (W)	Q_{USEFUL} (W)	Q_{LOSS} (W)	U_{LOSS} ($W/m^2.°K$)
ALTERNATIVE C.	428.4	290.0	138.4	12.9
CONVENTIONAL C.	795.0	435.4	359.6	11.6

6. Conclusions and Suggestions

With base in the results of the comparative test made with the two collectors in study, during the thermal efficiency tests, it was possible to come to the conclusions to proceed, as well as possible suggestions for optimization and effectuation of futures works with alternative collectors.

6.1 Conclusions

1. The proposed alternative collector presents viabilities in the thermal, materials and economical fields. Its production cost is around U$30.00 that is commercially much lower than the relative ones to the conventional collectors available. The production cost of the conventional collector was around U$60.00;
2. The heating system that uses the alternative collector was competitive with the system that uses the conventional collector;
3. The weight of the alternative collector was around 50.0 Kg, that is much larger than the conventional collectors;
4. The box of the alternative collector was shown resistant in relation to the atmospheric variations;
5. The proposed alternative collector is competitive with the conventional collector, having a larger heating speed of the flow mass;
6. The composite used for the box's making allowed the collector to be composed by only three elements, providing a decrease of the cost of the collector;
7. The conventional collector generated a larger temperature gradient than the one obtained with the alternative collector, however with an area almost twice larger;
8. For the obtaining of more appropriate temperature of hot water for bath, a heating system in termosiphon, using alternative collectors, should be formed by two collectors in series, with absorber grids in parallel;
9. The temperature of the absorber tubes in the alternative collector was inferior the level critical for beginning of the process degradation thermal around 60°C. In relation the degradation such thermal effect is softened by the opaque black ink that recovers the absorber tubes, that it contains black pigments that absorbs ultraviolet radiation.

6.2 Suggestions

1. The excessive weight presented by the proposed collector, it can be reduced through the polystyrene expanded (EPS) use in flakes in substitution to the wood powder. Being used the proportion of same parts of gypsum and EPS in volume, the weight becomes around the half. Such modifications were already implemented and a new collector was already built and meets shown in Fig. (9);

Figure 9. Constructed optimized alternative collector.

2. For the obtaining of larger temperature levels with the alternative collector is suggested an increase in the collector area and the decrease of the number of absorber tubes, and in the new built and shown collector in the previous illustration the number of tubes is of 15, with diameter of 25.4mm and has the dimensions of 1.5m x 0.70m x 0.10m;
4. It is necessary to do a more deepened study, with more days of experimentation to have an analysis comparative more real comparison, what is already in course. Of this analysis it is possible to conclude that the conventional collector propitiated the obtaining of maximum temperature of the flow inside the collector is of 48.0°C, while for the alternative collector the reached maximum temperature was around 43.0°C.

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8. Responsibility notice

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