LOW COST ALTERNATIVE SOLAR COLLECTOR WITH ABSORPTION SURFACE FORMED BY PVC TUBES

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ABSTRACT

A no conventional 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 same and the pipes of admission and water exit. The collector's box is made with a composite of matrix ceramic and coated with resin, propitiating the elimination of the thermal isolation, 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 such archetype 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). One 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

NOMENCLATURE

$T_{ent.f}$	fluid entrance temperature in the collector, C
T_{ef}	fluid exit temperature in the collector, C
ΔT	thermal gradient in the fluid in the collector, C
I	global solar radiation, W/m^2
η_t	thernal efficiency, %
Tmax	maximum temperature of external surface in absorber PVC tubes, C
Tm	media temperature of external surface in absorber PVC tubes, C
Q_A	absorber heat by collectors, W
Q_U	useful heat transfered to water, W
Q_L	loss heat by collectors, W
U_{LOSS}	thermal loss global coeficient, W/m^2.K

INTRODUCTION

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

The brazilian northeast presents a quite significant solar potential, corresponding to a medium readiness that locates in the strip from 500 to 700W/m^2, according to Atlas of Solar Irradiation of Brazil (Bezerra ,2001).

According to Bezerra (1999), 42% of the electric power consumption in Brazil are addressed to the section of constructions, being 84.1% corresponding to companies and residences and 15.9% the public administration, with figures reaching 13.8% of the country's gross domestic product. The author mentions that the residential section answers for 25% of the national consumption of energy and in agreement with manual of an energy company of Brazil the consumption of the electric shower is the largest second in a residence, corresponding to 25%, just losing for the refrigerator/freezer that corresponds to 30%. Your use reaches the schedule of pick from 18:00 to 19:00h, 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 for the solar source for the obtaining of hot water mainly in time of rationing of energy, gaining big importance once the Brazilian hitric option for the electric power generation has almost exhausted resources.

Looking for a way to reduce the cost of production of a solar prototype destined to the heating of water for bath, was constructed an alternative solar collector, 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 your box is made through a mixture of gypsum, wood powder and sisal fibers, forming a composite, of much cheaper cost than the materials conventionally used, which are: profile of aluminum, glass fiber and steel plates.

This kind of proposed alternative material presents the advantage of being a good one insulating thermal, which eliminates two components of a collector: the absorber plate and the thermal isolation.

Results of the tests will be shown realized with the collectors, the conventional and the alternative, being demonstrated its thermal, materially and economically viabilities. In the analysis of materials the subject of the thermal degradations will be approached and for inherent UV to the use of PVC as an absorber surface of the solar radiation.

STATE OF THE ART

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 the same: 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, looking for the socialization of its use in systems of domestic and industrial heating of water, once the cost of the same ones represents 50% of the total cost of investment for the acquisition of a solar system for heating of water. This high cost is due to the use of materials of significant price in your production. The same tends long useful life, they request high initial investment, and this explains the drop rate of development of solar systems for heating of water in the world. It becomes necessary and fundamental, the development of systems of smaller cost with good thermal performance (Cristofari, 2002). With this aim, several works have been developed, demonstrating that the plastics solar collectors of low cost present wide use viability as they demonstrate the studies to proceed told.

Rivera (1994) presented work on tubular alternative collector with multiple units absorbers of PVC. Lourenço (1997) showed the results reached with an alternative collector with absorber grating 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. (1996) with the objective of evaluating the acting of collectors with parallel tubes in South Africa. Matrawy and Farkas (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 (1999) presented study on the thermal modeling in domestic collectors for heating of water to the low flow.

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

Looking for forms of obtaining of a heating system at a low cost, it is being studied there is more than 18 years in the ambit of the Solar Energy Laboratory of the Federal University of Rio Grande do Norte alternative systems to turn viable the use of the solar energy for the considered end and to turn it accessible to a larger portion of the population.

Among the studied collectors they are the collectors: parallel tubes forming a serpentine; in labyrinth, plate's parallel type sandwich, formed by units of heating constituted by glass bulbs (fluorescent lamps carcasses having in your interior PVC tubes); and an alternative plane with tubes of PVC. Except for this last one, all the other generations were begun to work in regime of forced flow, with only a passage of the work fluid 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.

Thermal and UV Radiation Degradations Inherent to PVC

In a solar collector that it uses as absorber elements PVC tubes, the first lifted up subject is about the inherent degradations to its exhibition 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 your 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).

DESCRIPTION OF THE COLLECTORS IN ANALYSIS

The conventional collector has your box made 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 tubes of copper 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 fit 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 characteristic principal the use of alternative materials of low cost for your box's construction and a multi tubes absorber grating, allowing the obtaining of a larger circulating flow, that has for objective to accelerate the thermo change 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, for the choice of the most appropriate material, that it presented 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+ polystyrene expanded (EPS); gypsum + coconut powder. After evaluations thermal, economical and of materials, it was chosen the composite to the base of gypsum, mountain 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 operation principle 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 point out that with this box's use for the collector, the box's bottom works as absorber surface, in contact with the absorber tubes, and as your material it is a good one insulating thermal, it is released, 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.

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 fluid entrance in the collector, temperature of exit of the fluid of the collector, internal and external temperatures of the collector, temperatures of the water in the thermal reservoir, temperature of the absorber tube and global solar radiation.

It was also measured: the internal and external temperatures of the collector, temperature of the water, in the entrance and exit of the collector; temperature of the internal air; temperature of the internal and external surfaces of the glass, respectively; 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 grating (Souza, 2000; Souza and Gomes, 2002; Duffie and Beckman, 1991).

The entrance and exit temperatures of the water in the collector were measured of 30 in 30 minutes, from 8:00 to 16:00. The collector temperatures were measured in the interval among 11:00 at 13:00 o'clock, of fifteen in fifteen minutes, radiation period practically constant.

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

As one wanted to avoid that the absorber tubes reached the critical temperature for the beginning of the degradation process, $T>60^oC$, was measured the values of the external temperature of the same ones in several points of the absorber grating to evaluate the behavior of that parameter.

The 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 temperature inherent levels to the use of the tube of PVC as absorber ement in a solar collector.

Souza (2002) it demonstrated that such degradations can be combated through larger volume of water inside the absorber grating, what does with that the critical temperature is not reached and of a painting of the same of black opaque, inherent the obtaining of thermal energy starting from the electromagnetic energy, that lessens the effect of the degrading of the ultraviolet radiation. The mentioned author demonstrated that in spite of such degradations the use of tubes of PVC as absorber elements and drivers of heat in solar collectors, it is fully viable.

The box of the collector after having built, and gone by a dry process corresponding to 72 hours, in solar greenhouse, it presented a weight corresponding to 45.0 Kg, with your support reaching 5.0 Kg. The volume of water in the absorber grating of the collector corresponds to 5.5 l. The glass of the covering weighs in lathe 2.0 kg. Therefore, the total weight of the 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. Heating Solar systems in test: (a) using alternative collector and (b) using conventional collector.

RESULTS ANALYSIS

Proposed alternative collector

The Tables 1,2 and 3 show the medium parameters that it mirror the thermal efficiency of the collector in study for three days of tests and the Figure 2, 3 and 4 mirror 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 day of test.

Hour	T_{ent} (ºC)	T_{exit} (ºC)	ΔT (ºC)	I (W/m²)	η_t (%)
9-10	30.0	35.0	5.0	700	49.0
10-11	31.0	36.5	5.5	750	50.6
11-12	31.5	37.5	6.0	800	52.0
12-13	32.0	37.0	5.0	800	43.0
13-14	34.0	36.0	2.0	780	18.0
14-15	35.0	36.0	1.0	680	10.0

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

Hour	$T_{ent.}$ (ºC)	T_{exit} (ºC)	ΔT (ºC)	I (W/m²)	η_t (%)
9-10	30.5	36.0	5.5	700	54.2
10-11	32.0	37.5	5.5	750	50.6
11-12	32.0	37.5	5.5	800	47.4
12-13	33.0	36.0	4.0	800	34.5
13-14	34.5	37.0	2.5	780	22.1
14-15	36.0	37.5	1.5	680	15.2

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

Hour	T_{ent} (ºC)	T_{exit} (ºC)	ΔT (ºC)	I (KW/m²)	η_t (%)
9-10	31.0	36.0	5.0	700	49.2
10-11	32.0	37.0	5.0	750	46.0
11-12	32.5	37.5	5.0	800	43.1
12-13	33.0	37.0	4.0	800	34.5
13-14	35.0	38.0	3.0	780	26.5
14-15	36.0	38.0	2.0	680	20.2

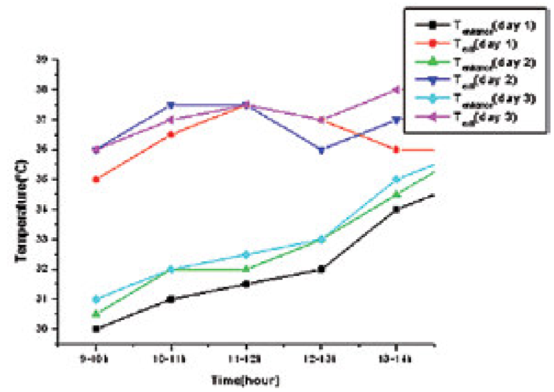

Figure 2. Fluid exit and entrance temperature.

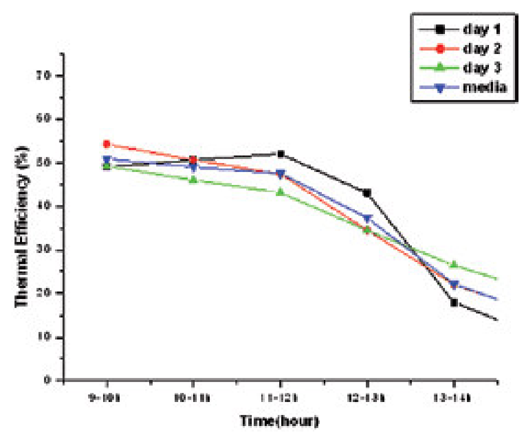

Figure 3. Thermal efficiency of the collector.

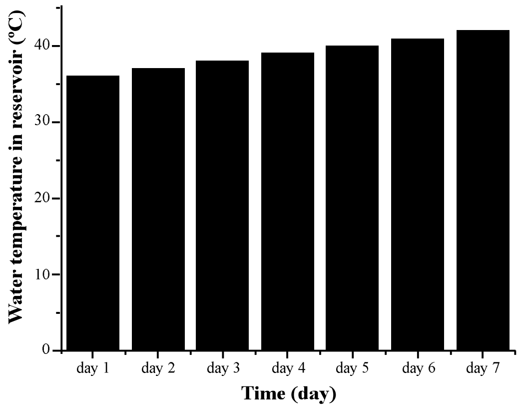

Figure 4. Evolution of the water temperature in reservoir.

The general thermal results obtained with the system they demonstrate the viability of the same, although they have not been obtained temperature levels inside the ideal reservoir for the bath, for an enough volume for four people, 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 ideal temperature, however an area of larger 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 efficiency thermal of the collector were close to 60.0%, with maximum temperature of exit of 43.5°C. The principal characteristic thermal of the system it was your heating speed, in the uniform of the 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 acting of the collector, the temperature of exit of the same was on this side of the temperature wanted for the obtaining of temperature levels inside the reservoir adapted for bath; it was reached in the seventh day of operation a value corresponding to 43.0ºC.

The temperature of exit of fluid of the collector should reach larger values so that one can obtain in the reservoir 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 the same. The temperature level wanted for the volume of water contained in the reservoir it should be around 45.0ºC. For the obtaining of that level it becomes necessary an area of superior collector.

They were already experienced preliminary two reception areas, 1.0 m^2 and 1.5 m^2, which 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 surface it expresses of the absorbers tubes, your values were always below the temperature it criticizes for begin of the thermal degradation that is above 60.0 º C. Be pointed out that the reached maximum values equal 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 to main solicitation 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 samples, starting from the obtained composite, they didn't present significant resistance those efforts, what doesn't make unfeasible the proposed box, once such solicitations won't usually be imposed to the structure.

With relationship to the parameter absorption of water, significant when of 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 was shown effective. The collector already meets exposed there is more than six months, having been submitted to intense index pluviometer.

COLLECTORS COMPARISON

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

Table 4. Data obtained with the alternative

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/m²)	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 entrance temperatures and fluid exit, temperature gradient and hourly thermal efficiency.

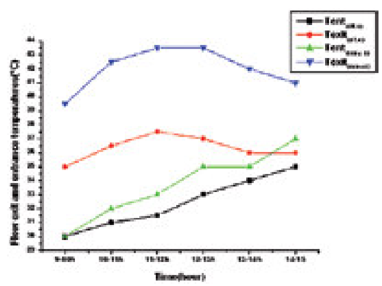

Figure 5. Behavior of the fluid exit and entrance temperatures

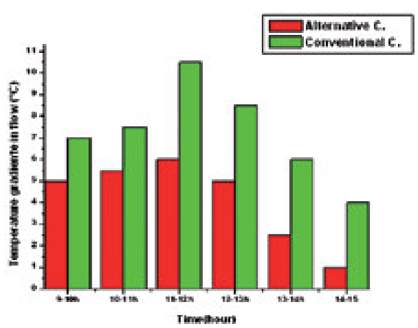

Figure 6. Behavior of the gradient temperature.

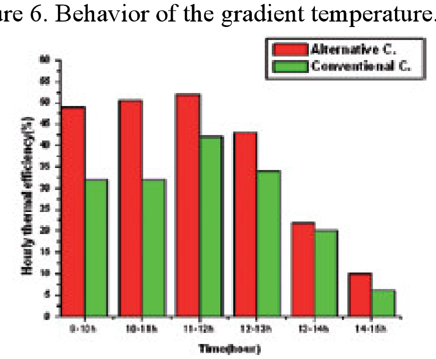

Figure 7. Behavior of the hourly thermal efficiency for the studied collectors.

From the analysis of the obtained data it is noticed that says respect to the thermal revenue the values in what obtained for the alternative collector they are larger than introduced them by the conventional collector, in function of your smallest area and of your smallest time of heating of the flow mass, reaching maximum values of 52.0% in the alternative and 42.0% in the conventional.

With relationship the generated thermal gradient it is noticed that the values obtained with the conventional collector they are larger than generated them by the alternative collector. The maximum temperature reached by the alternative collector in the 1° day of test it 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 the half of the area of the conventional collector.

In what it concerns to the temperatures of the mass of water contained in the drum it is noticed that the alternative collector presented in the 1° day of test a temperature corresponding to 36.0°C, increasing in about 1.0°C for every day of rehearsal, reaching in the seventh day of rehearsal value corresponding to 42.0°C, while in the third day of test with the conventional collector a level of 40.5°C was reached. It is emphasized that the 1st day of test 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 1° day of operation of a collector in termosiphon really mirrors the behavior that will have in next days of test.

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

In relation the external temperature of the absorber tubes, the measured values, $T_{maximum}$ = 41.0°C and T_{media} = 40.0°C, they 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 conductors of heat.

Another parameter that mirrors the thermal behavior of a solar collector is the global coefficient of losses, whose value was calculated, in function of the present data in the Figure 8. The Table 6 displays the values of Qabsorber, Quseful, Qloss and Losses Global Coefficient, ULoss for the two collectors in study.

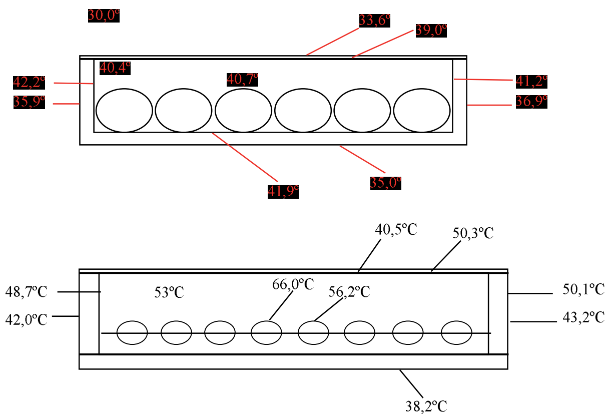

Figure 8. Temperature levels in the alternative and conventional collector.

Using the data shown in the illustrative outlines of the two collectors, it is determined the values of absorbed heat, useful heat and lost heat. The thermal revenue considered for the calculation of the parameters contained in the table it was an average of the values for two o'clock. The Table 6 displays the certain values for those parameters, in the two collectors.

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

TYPE	Q_A (W)	Q_U (W)	Q_L (W)	U_{LOSS} (W/ m^2.K)
ALTERN.	428.4	290.0	138.4	12.9
CONVENT.	795.0	435.4	359.6	11.6

CONCLUSIONS AND SUGGESTIONS

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

CONCLUSIONS

1 The proposed alternative collector presents viabilities in the thermal field, of materials and economical. Your production cost is around U$30.00 that is commercially much lower than the relative ones to the conventional collectors available. The cost of production of the conventional collector was around U$60.00;
2. The system of composed heating for 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 bad weather;
5. The proposed alternative collector is thoroughly competitive with the conventional collector, tends a speed of heating of the flow mass larger;
6. It can be proven that the composite used for the box's making it 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 that obtained with the alternative collector, however with an area almost twice larger;
8. A heating system, to termosiphon, using alternative collectors of the type that was object of this study should be formed by two collectors in parallel, for the obtaining of more appropriate temperature for the use of hot water for bath;
9. The temperature of the absorber tubes in the alternative collector was far away from the critical level for beginning of the process degradation thermal around 60°C. In relation the degradation such thermal effect it is softened by the opaque black ink that recovers the absorber tubes, that it contains absorbers black pigments of ultraviolet radiation.

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 mountain powder. Being used the proportion of same parts of gypsum and EPS in volume, the weight falls around the half. Such modifications were already implemented and a new collector was already built.
2. For the obtaining of larger temperature levels with the alternative collector is suggested the box's increase and the decrease of the number of absorber tubes, and in the new built collector and shown in the previous illustration the number of tubes it is of 15, with diameter of 25.4mm and the healthy box's dimensions: 1.5m x 0.70m x 0.10m;
3. For a better vedation of the box of the collector it is suggested the use of fixation fasteners between the same and the glass, seated on eraser, according to the illustration that shows the new built collector;
4. It is necessary to do a study more deepened, with more days of experimentation to have an analysis comparative more real comparison, what is already in course. Of that analysis it can be ahead that the conventional collector propitiated the obtaining of maximum temperature of the flowed inside the box in the strip of 48.0°C, while for the alternative collector the reached maximum temperature was around 43.0°C.

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Received: September 06, 2006
Revised: October 06, 2006
Accepted: November 06, 2006