SOLAR HEATING SYSTEM TO PROMOTE THE DISINFECTION OF WATER FOR POOR COMMUNITIES

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Abstract. *It presents a heating system using low cost alternative solar collectors to promote the disinfection of water in low income communities that take water contaminated by bacteria. The system consists of two solar collectors, with total area of 4 m² and was built using PET bottles and cans of beer and soft drinks. Each collector is made up of 8 PVC tubes, connected in series and work in continuous flow. It will determine the flux the most appropriate to generate the temperature to promote the disinfection. Will be presented results of the efficiency and thermal loss of system and results of analysis of water after undergoing the process of heating.*
Keywords: Disinfection of water, solar heating system, poor communities

1. INTRODUCTION

Nowadays are increasingly present discussions between civil organizations, academic institutions, scientific and government authorities about the impending shortage of water resources on our planet. Brazil, despite their condition comfortable for its huge water availability, especially in the Amazon region can not be unrelated to that issue since the water in Brazil are not distributed in a homogeneous, and now many feel that the Brazilian regions the problems of lack of water and live with frequent conflict for that reason (Silva, 2004).

Previous studies carried out revealed the existence of contamination by fecal bacteria in samples of water for human consumption in communities of the state of Rio Grande do Norte. Data released by UNICEF (United Nations Fund for Children), the report " World Situation of the Children 2005", indicate the rate of Brazil with access to drinking water (89%) lower than that of some countries like Mexico, Chile, and Uruguay (UNICEF, 2005). Thus, the population will be required to have a source of water for their survival often contaminated artesian wells.

The technique used constantly in various countries to disinfect drinking water is the addition of chlorine (Cl2) to water, this is due to its operation be more advantageous to existing alternatives. On the other hand, many low-income communities can not have access to treated water due to became a high cost for the family budget. Furthermore, according to EPA (1990) and research previously undertaken by Dons Bach (1981) confirm the direct effect of chlorine with the onset of cancer.

The use of solar energy as proposed for disinfection of water in the state of Rio Grande do Norte may be technically feasible as the solar intensity in the region is quite favorable. In addition to this study this factor has a significant social importance since a significant portion of their population has no access to treated water. This new alternative has the advantage of using disposable materials such as PET bottles (polyethylene ethylene) and aluminum cans (beer and soda).

This study aims to determine the most appropriate flow to generate temperature to promote the disinfection of water. Moreover, the thermal performance will be analyzed of the heating system through the results of thermal efficiency and heat loss of the system. And finally, will be presented the results of analysis of water, after undergoing the process of heating.

2. BIBLIOGRAPHIC REVIEW

In recent decades, the use of solar energy to the practice of water disinfection was made without a deeper study of the process. However, recent different groups of surveys began to explore the process of disinfection of water by solar energy.

Batista (2008) studied the process of solar water disinfection using an experimental reactor that works with the synergistic effect of UV light with temperature and the catalytic activity of $Ti0_2$ to the inactivation of Escherichia coli bacteria present in contaminated water from artesian well. The disinfection system studied was able to promote complete disinfection in 150 minutes using only the photothermal effect and in 120 minutes with the addition of a solar concentrator and $Ti0_2$ fixed.

Sichel et al. (2007) showed for temperatures above 45 ° C in a process of solar disinfection, happens a synergistic interaction between high temperature and solar radiation, increasing the efficiency of disinfection and by reducing the time of treatment.

Felix (2008) conducted a numerical and experimental study of the disinfection efficiency, to use solar energy for water treatment. The methodology used in the treatment of disinfection was package contaminated water in PET bottles and expose them to sunlight. The results showed an average of 80% efficiency of disinfection of contaminated water.

Souza et al (2008) presented a preliminary development of a plant for solar disinfection of water showing the kinetic processes and microbiological of the disinfection.

Gomes (2008) presented a pilot plant using plans collectors to study the solar photocatalysis for disinfection of water contaminated with Eschericgia coli, Enterococcus faecalis and humic acids. The results showed that Enterococcus are more resistants to the photocatalytic treatment than the bacteria Escherichia coli, requiring a greater amount of UV energy for their removal.

Yak (2006) proposed a solar thermal reactor based on the maximum absorption of solar radiation and minimum loss heat converted. The system consists of two concentric tubes of glass separated by vacuum. The internal tube is externally coated with a layer of aluminum, which was deposited on dark aluminum nitrate to absorb solar radiation. Starting from a temperature of 25 °C in a typical day of summer, after two hours of exposure can be achieve 65°C, sufficient to have a slow water pasteurization.

Metcalf (2006) demonstrated the ability to pasteurize contaminated water for human consumption using solar cookers. It was proved only one minute at a temperature of 65 ° C to inactivate 99.999% of bacteria that causing diseases.

Amaral et al (2006) found that solar radiation is effective in water disinfection with reductions after twelve hours of exposure of 98.2%, 99.9% and 100% in numbers of mesophilic microorganisms, total coliforms and E. coli, respectively, without recrudescence of microorganisms after 72 hours. Completed the feasibility of solar radiation to promote the water disinfection of rare wells, with the largest reductions occur in E. coli.

3. MATERIALS AND METHODS

The heating system proposed is composed of two alternative solar collectors use units absorbers formed by PETS bottles, beer or soda cans and two tanks to the supply of contaminated water and collection of water treated. The two collectors are formed by absorbing grade of PVC pipes connected at series to obtain a higher temperature of the water that it runs. The area of each collector is 2.0 meters, making the system at 4.0 meters on total. The union between absorbers and the tubes was made using connections to have the same diameter and material. The reservoirs of power and collection are of polyethylene. The scheme will be of continuous flow forced with just a passing of the working fluid inside the collector

Each collector of 2.0 m² is made of 96 bottles PETs involving the eight PVC tubes of 20 mm external diameter comprising the absorber of the collector grid, connected by tees of the same material and diameter. To promote the service in series were placed PVC rings in the tees connections to have divert of the flow to another tube. Inside the unit heaters in number of 48, formed of two PET bottles, with the tube inside, were placed two fins (l = 20 cm, b = 6 cm) surrounding the tube to increase the area of absorption of solar radiation overall incident. The fins were manufactured using cans of beer and soft drinks, cut to his upper and lower ends and longitudinally. In the space between two units of heat was placed a bottle pet, cut at both ends, forming a glove, to minimize the effect of heat sink. The grade of absorber was painted of matte black for better absorption of global solar radiation incident. The tubes of the absorber were glued with special glue for PVC.

The collector in study has not box neither glass surface as cover. The greenhouse effect is generated inside the heating unit. The diameter of the central cylinder is 100 mm. Below are described the processes of manufacture and assembly of this type of collector.

The process of manufacture of the double fins collector consists of the following steps:

1. Cutting of PET bottles for mounting the units of heat;
2. Cutting of the bottles that will be glove;
3. Wash of the bottles PETs;
4. Cutting of the PVC pipe with 1.62 m;
5. Cut for the manufacture of cans of fins;
6. Manufacture of PET gloves;
7. Manufacture of fins for a craft process of compression molding;
8. Painting of absorber pipes with matte black ink and synthetic enamel;
9. Painting of fins;
10. Manufacture of metal structures for mounting the collector.

The process of assembly of the fin collector consists of the following steps:

1. Placing of the tees in the pipes using PVC glue;

2. Placement of the rings of PVC to provide movement in the series;
2. Slide the tube of a PET bottle cut on half of a unit of heat;
3. Fixing of the fins in the absorber tube through the use of wire;
4. Plug the other cut PET bottle;
5. Plug the bottle-shaped pet glove;
6. Do the procedures 2, 3 and 4 for the other units of heat;
7. Placing of the tees at the other end of the PVC pipe absorbers.

The system was tested in forced flow, with only a passage of the working fluid inside and were measured the temperatures of in and out of the first collector, the output temperature of the second collector, and global solar radiation. The temperatures were measured during 30 minutes for a period from 10:00 to 13:00, for determining the most appropriate stream for the desired disinfection. In this phase of the research the water that was used on the system was the water from public network.

The temperatures were measured with the cromel-alumel thermocouples connected to a digital thermometer and solar radiation was measured by a pyranometer. The heating system composed of two solar collectors with grade absorber in series also connected in series is shown on Figure 1.

The microbiological analysis of water before and after the process of heating will then be performed to obtain the diagnostic efficiency of the plant designed in respect of kinetic and microbiological processes. The quantification of total coliforms and E. coli in the samples pre-and post-disinfection will be carried out with the technique MPN (most probable number), using the Colilert method in series of five tubes, according to Standard Methods for the Examination of Water and Wastewater (1998).

Figure 1. Solar heating system for disinfection of water.

The thermal efficiency of the heating system can be determined by the equation shown below.

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

Where:
P_u = total useful power transferred to the working fluid, in W.
I = solar radiation in W/m².
A = area of collector (area exposed to solar radiation) in m².

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

Where:
m = Mass flow in kg/s.
c_p = specific heat of water, KJ / kg ° C.
ΔT = temperature gradient between the fluid input and output, in °C.

The thermal efficiency of the system for each flow rate studied can be determined for equations (3), (4), (5) and (6), presented below. To determine the thermal efficiency of each collector, the numerical values presented in the equations below should be divided by two, since the area of each collector is half the total area of the system.

$$\eta_{t_{20l/h}} = 10^3 \frac{Kg}{m^3} . \frac{20.10^{-3} m^3}{3600s} .4{,}18 \frac{KJ}{Kg} . \frac{\Delta T}{I} = 0{,}0058 \frac{\Delta T}{I} \quad (3)$$

$$\eta_{t_{30l/h}} = 10^3 \frac{Kg}{m^3} . \frac{30.10^{-3} m^3}{3600s} .4{,}18 \frac{KJ}{Kg} . \frac{\Delta T}{I} = 0{,}0087 \frac{\Delta T}{I} \quad (4)$$

$$\eta_{t45l_{/h}} = 10^3 \frac{Kg}{m^3} . \frac{45.10^{-3} m^3}{3600s} .4{,}18 \frac{KJ}{Kg} . \frac{\Delta T}{I} = 0{,}013 \frac{\Delta T}{I} \quad (5)$$

$$\eta_{t_{60l/h}} = 10^3 \frac{Kg}{m^3} . \frac{60.10^{-3} m^3}{3600s} .4{,}18 \frac{KJ}{Kg} . \frac{\Delta T}{I} = 0{,}017 \frac{\Delta T}{I} \quad (6)$$

The overall coefficient of heat loss was determined by parameters of power absorbed by the collector (P_{abs}.), power transferred to the working fluid (P_u), mean temperature of plate (T_{pm}) and temperature (T_a) of the collector area (A), the mass flow (m) of the fluid specific heat (c_p) and the difference in temperature of the fluid from the system (ΔT) as the equations (7) to (10).

$$P_{abs} = \tau_v . \alpha_p .\mathrm{I.A} \quad (7)$$

$$P_u = \dot{m} . c_p . \Delta \mathrm{T} \quad (8)$$

$$P_p = P_{abs} - P_u \quad (9)$$

$$U_{loss} = \frac{P_p}{A.(T_{pm} - T_a)} \quad (10)$$

4. RESULTS AND DISCUSSIONS

Table (1) shows the average data measured in the tests conducted for three days of testing, with different flow rates, during the lifting performance of the heating system under study.

Table 1. Data average of days of tests with the solar system, where Tec_1 and Tec_2 are the temperatures of entrance of the collectors 1 and 2, $T_{exit\ c1}$ and $T_{exit\ c2}$ are the temperatures of exit of the collector 1 and 2, ΔT_{c1} e ΔT_{c2} is the temperature different in the collectors 1 and 2, ηt_{c1}, ηt_{c1} and ηt_{sist}
are the thermal efficiency of the collectors 1, 2 and system and I is the global solar radiation

OUTFLOW (liters/hour)	T_{ec1} (°C)	$T_{exit\ c1}$ (°C)	ΔT_{c1} (°C)	ηt_{c1} (%)	I (KW/m²)	$T_{exit\ c2}$ 2 (°C)	ΔT_{c2} (°C)	ΔT_{sist} (°C)	ηt_{c2} (%)	ηt_{sist} (%)
20	30,2	59,2	29,0	48	0,70	65,2	6,0	35,0	9,4	29,0
30	30,4	55,7	25,3	62,8	0,70	61,2	5,5	30,3	13,7	37,6
45	30,0	49,3	29,3	71,7	0,70	55,0	5,7	21,7	19,6	43,8
60	31,4	46,4	15,0	72,8	0,70	53,4	7,0	22,0	34,0	53,4

The efficiency of the second module is lower than the first. This according to the configuration of the absorber grid by the connection in series of the two collectors, which provide a higher temperature gradient in the first module.

Despite the near saturation of the module 2, the temperature still grew 20.7%, 19.8, 28.9 and 46.7 for 20, 30.45 and 60 l/h, respectively. This demonstrates that the second module also contributes significantly to achieving a higher level of temperature, vital to the process of disinfection of water.

Among the levels of flow tested at higher temperature was reached to 20 l/h, as was expected, but for this flow the volume treated per day is only 140 liters. For the flow of 30 l/h, an increase in flow of 50%, there was a decrease in temperature of 6.2%, treated with a volume of 210 liters, an increase of 50%. For 45 l/h and flow of 60 l/h despite the greater efficiency in the second module, mainly to 60 l/h, the levels of medium temperatures obtained are below 60 ° C, insufficient for effective treatment desired. Could be used a third collector, or just a module with 3.0 m² of area for an assessment of the level of temperature reached. It would be important to check the temperature at various points of the absorber grid to verify if there is saturation on the system.

One solution is the use of higher flow rate, 60 l/h, which showed significant performance, and after the removal of two modules to do the treated water pass through another unit of treatment that would be a cylinder parabolic concentrator to increase the temperature obtained. This solution could double the volume of treated water on 30 l/h, the flow rate more appropriate for the tests that were carried out, on the final exit temperature of the collector, and conducive to greater efficiency in the process of disinfection.

The preliminary tests performed with two modules of the alternative collector PET, 2m² each module, shown to obtain a temperature around 65°C for a flow of 20 l/h. The volume of treated water per day was, then, at 480 liters. To increase the production of treated hot water can be to increase the area of solar collectors once the cost per square meter of the system is extremely low.

With respect to thermal loss of the heating system, the procedure of calculation shown below, allows the determination of overall heat loss coefficient for the lower flow, 20 l/h, where the absorbers tubes have a higher temperature, and therefore, greater heat loss. Table (2) present values of loss thermal.

Table 2. Parameters of heat loss of the heating system.

OUTFLOW (l/h)	**$P_{absorber}$ (W)**	**P_{Useful} (W)**	**P_{loss} (W)**	**U_{loss} (W/m².°C)**
20	2167,5	945,1	1222,4	12,2

The values calculated by both methods point to an overall loss coefficient well above the characteristic of conventional collectors, located in the middle range between 6.0 and 12.0 W / m². ° C (Duffie & Beckman, 1991), but should give consideration that the collector in study does not provide thermal insulation and glass cover of the storage box. Even with that rate the system was feasible for the end proposed, can be explained its apparent low cost. The microbiological analysis showed that the exposure of bottles to sunlight and heat produced as a consequence, leads to a good efficiency in the treatment of contaminated water through the use of solar energy. The greater the level of solar radiation incident on the collector and the temperature level reached by water, therefore, will be more efficient in the process of disinfection.

5. CONCLUSIONS

1. The most appropriate flow to the process of disinfection was 20 liters / hour, with higher rates of temperature at the exit of the collector, can of 30 l/ h collector also be used to provide a greater volume of water treated;
2. The heat loss of the heating system is significant in light of the lack of thermal insulation;
3. The heating system studied was shown to be feasible for the proposed order and may be added another solar device in series to increase the temperature and provide a more effective disinfection;
4. The PET type collectors have as the main advantages the low cost and simple manufacturing processes and assembly, and represent an option that can be mass scientific community in both poor to use the benefits of hot water and treated, as far as income generation, the manufacture and marketing of and type of collector;
5. The technology of disinfection proposal advantages over other processes, because of being easily viable and use of clean energy, widely available and inexhaustible;
6. Another important characteristic in the plant for disinfection is the use of recyclable materials in its construction, which contribute to alleviating environmental problems, in line with the prime objective of the work, which is producing decontaminated water to poor communities;
7. Is needed to better the study for determine the best efficiency degree of disinfection through the use of solar energy, by exposure to radiation or by heating the water at higher temperature.

6. REFERENCES

Moreira da Silva, M..J. Desinfecção de Água utilizando Energia Solar. (SODIS): Inativação e Recrescimento Bacteriano. Campinas: UNICAMP, 2004. 81p. Tese de Mestrado.

Unicef (Fundo Das Nações Unidas Para a Infância), no relatório “Situação Mundial da Infância 2005”.

Dons Bach KW, Walker M. Drinking Water. Huntingdon Beach, CA: Int’l Institute of Natural Health Sciences, 1981

U.S Water News. EPA Seeking to Expand Number of Drinking Water Contaminants to 34. August 1990: 8
Sodis Efficiency: The Process, Technical Note #9, http://www.sodis.ch, outubro de 2004.
Dale Andreatta PE, Yegian DT, Connelly L, Metcalf RH. Recent Advances in devices for the Heat Pasteurization of drinking water in the Developing World. 29th Intersociety Energy Conversion Engineering Conference (IECEC-94), vol. 4, 1994. p. 1741-6.
Lawand TA, Alward R, Ayaoub J. Solar Disinfection of water. Clean and energy forever. Proceedings of th 1989 Congress of the International Solar Energy Society, vol 3, 1990. p 1952-6.
Brandão, C.C.S., Monteiro, P.C.G., Fonseca, B.M., Arantes, C., Avaliação da Desinfecção Solar na Região Centro-Oeste do Brasil Usando Diferentes Organismos Indicadores de contaminação, XXVII Congresso Interamericano de Engenharia Sanitária e Ambiental, ABES - Associação Brasileira de Engenharia Sanitária e Ambiental, 2000.
BRASIL.Portaria n. 518, de 25 de março de 2004. Estabelece os procedimentos e responsabilidades relativos ao controle e vigilância da qualidade da água para consumo humano e seu padrão de potabilidade, e dá outras providencias. Brasília: ANVISA, 2004.
Apha, awwa, wef; Standard Methods for the Examination of Water and Wastewater; 20th ed.; Washington D. C., 1998, 11p.
Davis, M. L. Cornwel, D. A. Introduction to environmental engineering. 3.ed. New York: McGraw-Hill, 1998. 919 p.

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