SOLAR WATER DISINFECTION IN NORTHEAST BRAZIL: KINETICS OF THE MICROBIOLOGICAL PROCESS AND THE STUDY FOR THE DEVELOPMENT OF A PILOT PLANT

Paulo Mário M. Araújo *
paulo_mario@unit.br

Lorna Falcão Félix*
lorna_ambiental@hotmail.com

Sara C. Orellana*
sara_cuadros@yahoo.com

Gerson Antas Porto*
porto_gap@hotmail..com

*Instituto de Tecnologia e Pesquisa, Universidade Tiradentes, Av. Murilo Dantas,CEP: 49032-490, Aracaju-SE (Brasil)

ABSTRACT

In this work an experimental and numerical study of the decontamination efficiency is carried through, aiming at the application of the solar energy in the water treatment. The methodology used in the disinfection treatment is the one proposed by Solar Water Disinfection (SODIS). The contaminated water samples were collected at the communities of Robalo and Saramén, where the population is usually very poor and the incidence for water borne diseases is high. For the microbiological analyses, the pre and post-disinfection, the Colilert method was used. The gotten results had shown the maximum efficiency of 87%, with the temperature of the water of 50ºC and time of solar exposure of 4hs. The results had been treated numerically, through the balance of mass and energy, thus allowing theoretical and experimental comparisons. This study presents initial considerations for the development of an experimental pilot plant.

Key-words: Solar energy, water treatement, communities, microorganismos.

1. INTRODUCTION

These days there are many quarrels between civil organizations, academic, scientific institutions and governmental authorities about the imminent scarcity of the water resources in our planet. When the water availability in Brazil is analysed it seems in a comfortable condition, especially in the Amazon region, but the water resources in the country are not geographically distributed equally and already many Brazilian areas feel the problem of lack of water and live with constant conflicts for this reason (1).

Previous studies by our research group detected the existence of contamination by faecal bacterium in water samples for human consumption in small communities in the state of Sergipe (Robalo and Saramén). In this work the community analysed was Robalo, area that presents a high index for water borne diseases and with high infantile mortality due to lack of treated water.

Data published for the UNICEF (United Nations Childrens Fund), in the report "World-wide Situation of Infancy 2005", points to Brazil with a rate of access to potable water (89%), smaller than some countries as Mexico, Colombia, Chile, Guatemala and Uruguay (2). Rivers, streams, dams and artesian wells are frequently contaminated. Thus, the population needs to have safe water sources for its survival. The figure 1 shows collection at a contaminated water source.

Figure 1: Place of collection in the community of Robalo.

The technique most often used in diverse countries for water disinfection is the addition of chlorine (Cl_2) into the water, as its functionality is still more advantageous than any of the existing alternatives. On the other hand, many poor communities can not have access to treated water because of its high cost for the family budget. Beyond this, according to EPA (U.S Environmental Protection Agency) and previous research, there is a direct link of chlorine with cancer appearance (3,4).

The solar energy utilization to disinfect water in the state of Sergipe, can be technically practicable once the solar intensity in the region is sufficiently favourable. For this reason and for its social significance, this research was done, as more then half million people (30% of the population) in this state doesn't have access to treated water. This new alternative has the advantage to use disposable materials as bottles PET (polyethylene terephthalate), in accordance with the proposed methodology by SODIS (Solar Water Disinfection Project). This method consists of water treatment through the synergetic effect of solar radiation and temperature, eliminating microorganisms responsable for serious diseases like dysentery, typhoid fever and cholera (5).

The aim of this work is to quantify the efficiency of water decontamination by solar energy and to study about the balance between mass and energy, and bacterium increase after the treatement. With the experimental and numerical results achieved, there are presented first considerations for the future development of an experimental pilot plant, adapted to each region's needs.

2. BIBLIOGRAPHICAL REVIEW

In the last decades, the use of solar energy for practical water disinfection was done without a deeper study of the process. However, different groups of research had recently started to study the process of water disinfection for solar energy.

Dale Andreatta et al. (6) described diverse methods for pasteurization of water using solar energy.

Lawand et al. (7) observed that some liters of contaminated water exposed to the solar radiation with minimum intensity of 500 W/m^2 in a period of 2 the 4 h can be pasteurized.

In Brazil, studies carried by Brandão et al (8), with water that presented turbidity of 110 Nephelometric Turbidity Units (NTU) and initial concentration of total fecal coliforms (UFC) of 106 per 100ml had been inactivated 100% in a time exposure of 2 hours and water temperature of 50°C.

In accordance with law N° 518/2004, the Brazilian Health department in water samples originating in wells, sources, springs and other forms of supply without canalized distribution, tolerates a presence of total coliformes for each 100ml of sample, in the absence of *Escherichia coli* and/or thermotolerant coliforms (9).

3. A NEW ALTERNATIVE FOR WATER DECONTAMINATION IN THE STATE OF SERGIPE: SOLAR ENERGY

3.1 Method and material

The experiments were carried out in the Laboratory of Energy and Materials and in the Laboratory of Engineering of Bioprocesses, Institute of Technology and Research, at the Tiradentes University. Located in the city of Aracaju-SE (South Latitude 10,9°), it receives an average intensity from total solar radiation of 1892 kWh/m^2 year .

Identical bottles PET with capacity of 2 liters were used each. In assay 1 the bottles were covered with paper aluminum to test only the effect of the temperature in the water. In the assay 2, bottles were transparent and smooth to optimize the absorption of the light, and in the assay 3, bottles were painted opaque black color.

Water proceeding from artesian wells located in the Robalo community, in the state of Sergipe was used to evaluate the efficiency of the method of water disinfection for solar energy. Water samples were collected and after that taken the laboratory to confirm the presence of the bacteria of the total coliforms groups and faecal coliforms (*Escherichia coli*), indicating microrganismos of fecal contamination.

3.2 Experiments

The bottles used in the experiment were cleaned with distilled water and use of a chamber UV, to discard a possible contamination before the treatment. The bottles were exposed to solar light for four hours, from 11:00 to 15:00 hourss, as it shows in figure 6. Each hour three bottles - a cloudy one, transparent and a black color - were removed and analyzed for quantities of *E. coli*. Three more bottles were analysed after 48hs, and thus successively during the four current hours of experiment.The figure 2 shown the in-progress experiment.

Figure 2: In progress experiment, bottles displayed to the sun.

Throughout the experiment the temperatures were recorded of the water, of the environment and on the surface of the bottles. The temperatures of the water in the three assays are shown in figure 4. At intervals of five minutes data of the total solar radiation was collected during four hours of experiment, through an acquisition system model AQ-USB RESOLUTION 4350, as it shows in Figure 3.

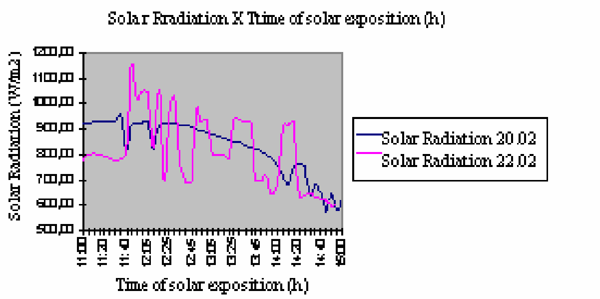


Figure 3: Average of the total solar radiation during solar exposure (11:00 to 15:00h).

The quantification of total coliforms and E. coli in the samples before and after disinfection was done with the NMP (Most likely Number of Microrganisms) technique, using the Colilert method in a series of five pipes, which conforms to the Standard Methods for the Examination of Water and Wastewater (10).

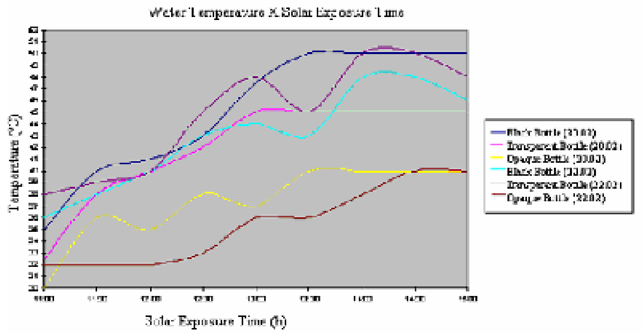


Figure 4: Temperature of the water during the experiments.

3.3 <u>Kinetic of disinfection</u>

3.3.1 Balance of the mass

The kinetics of disinfection is conducted by the law of Chick,that represents the decline of the number of viable microrganisms over time, in instant data (11).

With the objective to calculate the constant of death of the microrganismos the following procedure is used:

$$\frac{dN}{d(t)} = -k(t)N$$

So,

$$\frac{dN}{N} - K(t)d(t) \qquad \textbf{Equation 1}$$

According to Donaire & Jardim (12) the treatment efficiency was established for equation 2:

$$E = -\log\left(\frac{N}{N_0}\right) \qquad \textbf{Equation 2}$$

Where:
E: efficiency
N_0: number of microorganisms before the treatment
Nf: number of microorganisms after the treatment

Integrating equation 1 of N_0 as far as Nf, has:

$$\int_{N0}^{N} \frac{dN}{N} = -\int_{0}^{t} k(t)dt$$

It gives:

$$k(t) = \frac{1}{0{,}434295} * E'(t)$$ **Equation 3**

3.3.2 Balance of the energy

The balance of energy in the bottles is given by the equations:

Solid phase (PET)

$\mu_S ?_S Cp_S$ dTs/dt = ? A I(t) – h_i A ($T_S - T_L$) – he A (T_S – Ta) **Equation (4)**

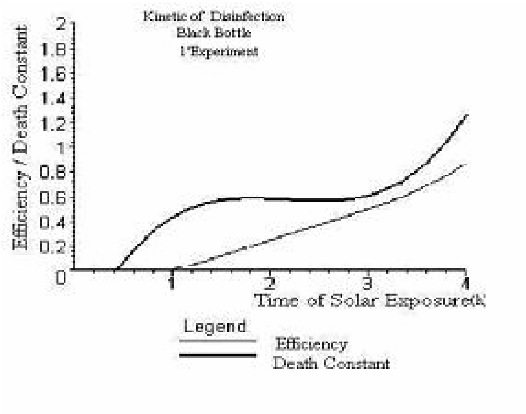
Liquid phase (water)

$\mu_L Cp_L dT_L/dt = ?_L$ T A I(t) + h_i A ($T_S - T_L$) **Equation (5)**

Where:

µ viscosity
Cp: specific heat
?: density
? emissivity
A: total area of the bottle
I: luminous intensity (W/m^2)
T : Transmission
h_i: natural convection internal coefficient (liquid-solid)
he: natural convection external coefficient (solid-air)
Ts: temperature in the surface of the bottle
Ta: ambient temperature
T_L: temperature in the liquid

The efficiencies for the black and transparent bottles had been gotten through equation 2 and the interpolation of the experimental data, using the polynomial interpolater of Gregori Newton. The decline percentage k(t) had been gotten through equation 3, like it´s shown on figure 5.



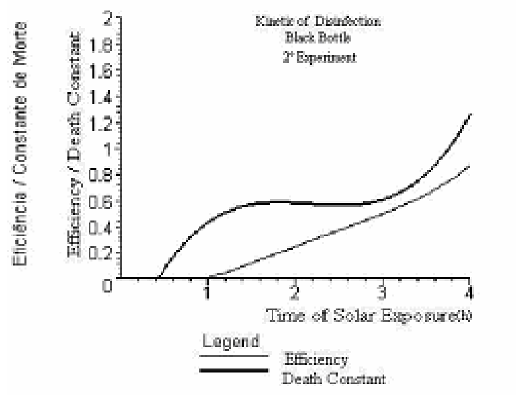


Figure 5: Variation of the efficiency and the constant of death, for *E coli*, in function of the period of solar exposure, 11:00 to 15:00 hours.

3.3.3 Results and discussion

Initial pH in the water samples was 6,8 and the final pH was 7,0. The turbity in the beginning of the experiments was 1,4 NTU.

In the first experiment (20.02) the temperature of the water, in assay 3 (black bottle), reached the maximum at 13:30h, with a temperature of 50°C, and remained constant during the rest of the experiment. In the second experiment (22.02), assay 2 (transparent bottles) also presented its maximum of 50ºC in the water, but remained constant for only half hour. Assay 1 (cloudy bottles) presented maximum temperature of 40°C, as it shows figure 3. The data of the total solar radiation are presented in figure 4.
Significant treatment for total coliforms was not measured, , as this experiment evaluated only the efficiency of disinfection for *E. coli.*

The kinetic study of disinfection takes into consideration the efficiency of the treatment, the numerical analysis for the constant calculation of death and the balance of energy. Jointly they disclose that solar exposure less than 1hour produces efficiency null. With exposure times longer than 1hour (Figure 5), the efficiency grows reaching 87% in 4 hours. Times of exposure above 4 hours, with an average solar radiation of

800w/m^2 and temperature of the water 50°C allowed total disinfection, according to the values found in literature. The theoretical and experimental comparisons, through the energy balance, had shown satisfactory agreement.
The bacterial increase has important function in the maintenance of the potability of the water, and this type of treatment does not possess residual character. The data of this phase of the experiments are in tables 1 and 2, showing that on all there occured bacterial increases after 48 hours of confinement. One gives credit that the increase must be high initial contamination. However, it can be affirmed that the method allowed to inactivate great part of the bacteria.

TABLE 1: INCREASE OF *ESCHERICHIA COLI* IN THE 48H BOTTLES BLACK AND TRANSPARENT AFTER CONFINEMENT.

20.02.2006 Solar Exposure Time (h)	*Escherichia coli*			
	N NMP/100ml		Increase NMP/100ml	
	Black Bottle	Bottle Tranparent	Black Bottle	Bottle Tranparent
11:00	›8,0	›8,0	›8,0	›8,0
12:00	›8,0	›8,0	›8,0	›8,0
13:00	4,6	8,0	8,0	8,0
14:00	2,6	4,6	4,6	4,6
15:00	1,1	4,6	2,6	4,6

TABLE 2: INCREASE OF *ESCHERICHIA COLI* IN THE 48H BOTTLES BLACK AND TRANSPARENT AFTER CONFINEMENT.

22.02.2006 Solar Exposure Time (h)	*Escherichia coli*			
	N NMP/100ml		Increase NMP/100ml	
	Black Bottle	Bottle Tranparent	Black Bottle	Bottle Tranparent
11:00-T0	8,0	8,0	8,0	8,0
12:00-T1	8,0	8,0	8,0	8,0
13:00-T2	4,6	4,6	4,6	4,6
14:00-T3	2,6	2,6	4,6	2,6
15:00-T4	1,1	1,1	1,1	2,6

3.3.4 Plant pilot

The plant has as its objective a safe water supply for human consumption, improving the conditions of life of the population in the following places: communities lacking infrastructure, houses of farms, and aboriginal areas with no electric energy, among others. Due to the difficult situation found in the community of the Robalo a pilot plant was projected for approximately 12 families, with the objective to improve the quality of life of the population.
The plant consists first of a plastic tank of 1000L with a polyester filter that receives the contaminated water. The contaminated water is pumped through a "bomb sheep". After its filtration the water passes to another plastic tank, also of 1000L, which contains triturated seeds of oleifera clay jars for removal of the turbidity of the water. The clay jar seeds are used as a natural clarifier, substituting for chemical coagulants such as sulphate of aluminum. Next the water passes to a plain plate of iron, painted with black color opaque, that contains two reflectors, to favor the absorption of the solar radiation. The water is stored inside of the black plate with a glass plate of 5mm thickness for approximately five hours, with solar radiation greater than 800 w/m^2 and temperature of the water of 50°C. The treated water goes to another 1000L tank. The entire system is controlled through a timer and a thermostat that open and close the valves of entrance and exit of the water in the disinfection system (figure 6).

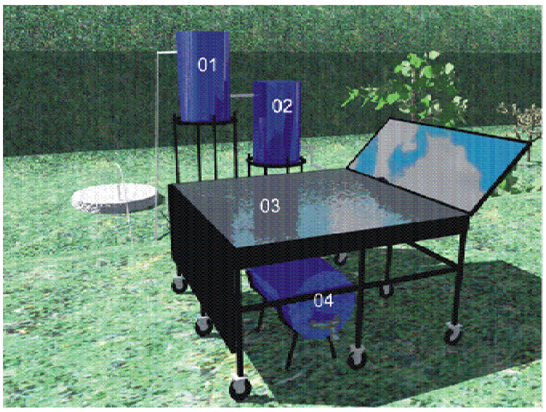


Figure 6: Initial project of the plant pilot.

(1) Plastic Tank of 1000L for filtration;
(2) second plastic tank, also of 1000L, with triturated seeds of *moringa oleifera*;
(3) System of disinfection;
(4) Tank with treated water

4. CONCLUSION

The research was attractive as the scientific study of a technology that has as main objective to make available low-cost, treated water for communities lacking safe drinking water. These technologies are used many times without confirming the trustworthiness of the process. Factors as the high initial concentration of total Coliforms and E. coli, the solar exposure time and the water temperature must be taken in consideration, for a satisfactory efficiency in the treatment.

The experiments disclosed that the alternative of water disinfection for solar energy is technically viable, once the microbiological inactivation and acceptable indices in the reduction of the bacterial increase occurs. The next step is to test the archetype of the experimental plant.

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