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

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Abstract

An experimental and numerical study of decontamination efficiency was carried through to evaluate the application of solar energy in water treatment in Northeast Brazil. The methodology used was the one proposed by Solar Water Disinfection (SODIS). Contaminated water samples were collected at the community of Robalo, Sergipe State, Brazil, which is characterized by poverty, social exclusion and a high incidence of waterborne diseases. The method used for pre- and post-disinfection microbiological analyses was the Colilert® QuantiTray (IDEXX) one. The results show that the efficiency of the disinfection process reached 80 to 100%, however a post-treatment increase in colony counts was observed in some samples. The experimental results were treated numerically, to give disinfection kinetics, thus allowing theoretical and experimental data to be compared. This study further presents considerations for the development of an experimental pilot plant for water disinfection using SODIS.

Keywords: Solar energy, Water treatment, Communities, Microorganisms

1. Introduction

The imminent scarcity of water resources in our planet has been the subject of many quarrels between civil organizations, academic and scientific institutions and

Nomenclatures

E	Treatment efficiency, %
k	Tax of decline (bacterial death) with the time, 1/s
N	Number of microorganisms, MPN/mL
N_f	Number of microorganisms after the treatment, MPN/mL
N_o	Number of microorganisms before the treatment, MPN/mL
t	Time, s

governmental authorities. When analyzing water availability in Brazil, especially in the Amazon region, a comfortable scenario is usually found. However, this is a false picture, because water resources are not equally distributed in the country geography, and population in many areas experiment constant water-related conflicts [1].

Previous studies by our research group detected the existence of contamination by fecal bacteria in water samples for human consumption in small communities, namely Robalo and Saramén, located in the State of Sergipe, Northeast Brazil.

In the report *World-Wide Situation of Infancy* 2005 [2], it was pointed out that Brazil has smaller rate of access to potable water than other Latin American countries as Mexico, Colombia, Chile, Guatemala and Uruguay. In Sergipe State, more then half million people (30% of the population) do not have access to treated water.

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

Because of its great practical potential, the use of solar energy for water disinfection has been studied further in-depth in the last few decades. Dale Andreatta et al. [5] described diverse methods for pasteurization of water using solar energy. Lawand et al. [6] observed that some liters of contaminated water exposed to solar radiation with minimum intensity of 500 W/m^2 in a period of 2 to 4 h can be pasteurized. In Brazil, studies carried by Brandão et al. [7] using water that presented turbidity of 110 Nephelometric Turbidity Units (NTU) and initial total fecal coliforms concentration of 106 UFC per 100 mL demonstrated that 100% decontamination can be achieved in a time exposure of 2 hours and water temperature of 50°C.

The Brazilian Health Ministry (Regulation No. 518/2004) establishes that total coliforms are tolerated in water samples originating in wells, sources, springs and other forms of supply without canalized distribution, provided *Escherichia coli* and/or thermotolerant coliforms are absent [8].

The utilization of solar energy in water disinfection in Northeast Brazil is technically practicable because solar intensity in the region is sufficiently favorable. For this reason and for its social significance, this research was conducted.

The objective of this work is to determine the efficiency of water decontamination using solar energy, through a study of the kinetics of disinfection and pre- and post-treatment bacterial count determination. The new alternative

presented has the advantage to use disposable materials such as PET (Polyethylene Terephthalate) bottles, in accordance with the proposed methodology by SODIS (Solar Water Disinfection Project). The method consists in water treatment through the synergetic effect of solar radiation and temperature, eliminating microorganisms that may cause serious diseases like dysentery, typhoid fever and cholera [9].

With the experimental and numerical results, initial considerations for the future development of a pilot plant adapted to the necessities of the region are presented. In this work we analyzed a community named Robalo, which presents a high incidence of waterborne diseases and high infant mortality due to lack of treated water.

2. Experimental Procedure

Water was collected from artesian wells in a villa named Robalo, near the coast at Mosqueiro, Aracaju, Sergipe State, Brazil.

The experiments were carried out in the Laboratory of Energy and Materials and in the Laboratory of Bioprocess Engineering, at the Institute of Technology and Research located in the city of Aracaju, Sergipe (South Latitude 10.9°). This spot receives a total solar radiation average intensity of 1892 kWh/m^2 per year.

Three experiments were performed to evaluate the parameters affecting disinfection efficiency:

- Experiment I (influence of solar radiation) – (A) cloudy bottles, (B) transparent bottles and (C) black bottles,
- Experiment II (influence of oxygen concentration) – (A) bottles without manual agitation and (B) bottles with manual agitation, and
- Experiment III (influence of temperature) – bottles were placed inside a box-type solar cooker.

The solar cooker used during the experiments was projected in the Laboratory of Energy and Materials, made with wood, with a selective teflon surface, processed for the method of thermal aspersion in a steel matrix, with the objective of increasing its energy efficiency, as shown on Fig. 1.

Fig. 1. Solar Cooker Used during the Experiments.

The dimensions of the solar cooker were as follows:

- Internal dimensions: 62 cm × 50 cm × 21 cm
- Thickness of the internal wood: 1 cm
- External dimensions: 72 cm × 60 cm × 26 cm
- Thickness of the external wood: 2 cm
- Reflector: 59 cm from the base.

Water proceeding from artesian wells located in the Robalo community, Sergipe State, was used to evaluate the efficiency of the method of solar energy water disinfection. Water samples were collected and taken to the laboratory to confirm the presence of total coliforms and microorganisms of fecal origin (*Escherichia coli*).

The bottles used in the experiments were washed with ethanol 70%, sterile distilled water and exposed to UV light to discard a possible contamination before the treatment.

During the experiments, the temperature of the water, the environment and the bottles surface were measured. Total solar radiation was measured in intervals of 5 minutes through an acquisition system (AQ-USB RESOLUTION 4350).

The quantification of total coliforms and *E. coli* in the samples was carried through with the MPN (most probable number) technique, using the Colilert Method in a series of five pipes, according to the Standard Methods for the Examination of Water and Wastewater [10].

On experiment Type I, the water samples were placed in three different types of bottles –opaque (covered with aluminum), transparent, and black (outer surface painted with black spray) - and exposed to solar light for four hours, from 11:00 to 15:00. Each hour a 100 mL-sample was withdrawn from one bottle of each type and analyzed for quantities of *E. coli*. After that, the bottles were kept in a styrofoam box at room temperature in the dark for 48 h to determine the extent of bacterial increase. Figure 2 shows the in-progress experiment.

Fig. 2. In-progress Experiment Type I, in which Opaque, Transparent and Black Bottles were Displayed to the Sun.

On experiment Type II, the water samples were placed in transparent bottles and displayed to the solar light on the surface of a black canvas from 10:00 to 15:00, as shown on Fig. 3. Half of the bottles remained static (group A) and the other half had their contents manually homogenized periodically (group B). Each hour a 100 mL-sample was withdrawn from one bottle of each group and analyzed for quantification of total coliforms and *E. coli*. After that, the bottles were kept in a styrofoam box at room temperature in the dark for 48 h to determine the extent of bacterial increase.

Fig. 3. In-progress Experiment Type II, in which Transparent Bottles were Displayed to the Sun.

On experiment Type III, the water samples were placed in two 2 L transparent PET bottles. One of the bottles was pierced, and a thermometer was placed inside to measure the water temperature, and the other one (test bottle) was used to determine the bacterial count. The two bottles were placed inside the solar cooker. Each hour a 200 mL-sample was removed from the test bottle, and half of this volume (100 mL) was used to determine total coliforms and *E. coli*, while the other half was kept in a styrofoam box for 48 h to determine the extent of bacterial increase.

3. Theory

The kinetics of disinfection was conducted by the law of Chick, which represents the decline of the number of viable microorganisms over time, in instant data [11].

With the objective to calculate the constant of bacterial death of the microorganisms the following procedure was used:

$$\frac{dN}{dt} = -k(t)N \tag{1}$$

So,

$$\frac{dN}{N} = -k(t)dt \tag{2}$$

According to Donaire and Jardim [12] the treatment efficiency was established for Eq. (3):

$$E = -\log\left(\frac{N_f}{N_o}\right) \tag{3}$$

Integrating Eq. (2) of N_0 as far as N_f, has:

$$\int_{N_0}^{N_f} \frac{dN}{N} = -\int_0^t k(t)dt \tag{4}$$

It gives:

$$k(t) = \frac{E'(t)}{0.434295} \tag{5}$$

The efficiencies for black and transparent bottles were obtained through Eq. (3) and the interpolation of the experimental data, using the polynomial interpolator of Gregori Newton. The decline percentage $k(t)$ was obtained through Eq. (5).

4. Results and Discussions

For experiments types I, II and III, the initial pH in water samples was 6.8 and pH after solar disinfection was 7.0. The turbidity in the beginning of the experiments was 1.4 NTU and in the end of the experiments it was 1.6 NTU. Significant alteration for these parameters did not occur.

4.1. Experiment type I

Experiment Type I was performed three independent times between February and March, 2006. On the 20th February (first run), water temperature reached its maximum (50ºC) in black bottles at 1:00 local time and remained constant until the end of the procedure. On February 22nd (second run), the water in transparent bottles also reached a maximum of 50ºC, but maintained this temperature for only half an hour, while opaque bottles reached the maximum temperature of 40°C, as shown on Fig. 4. On March 23rd (third run), the water temperature in transparent bottles reached 50°C as its maximum. Data on total solar radiation is presented in Fig. 5.

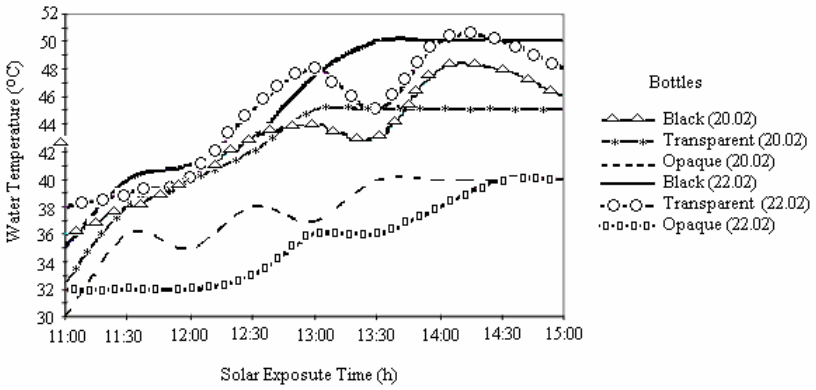

Fig. 4. Water Temperature during the First and the Second Experimental Runs.

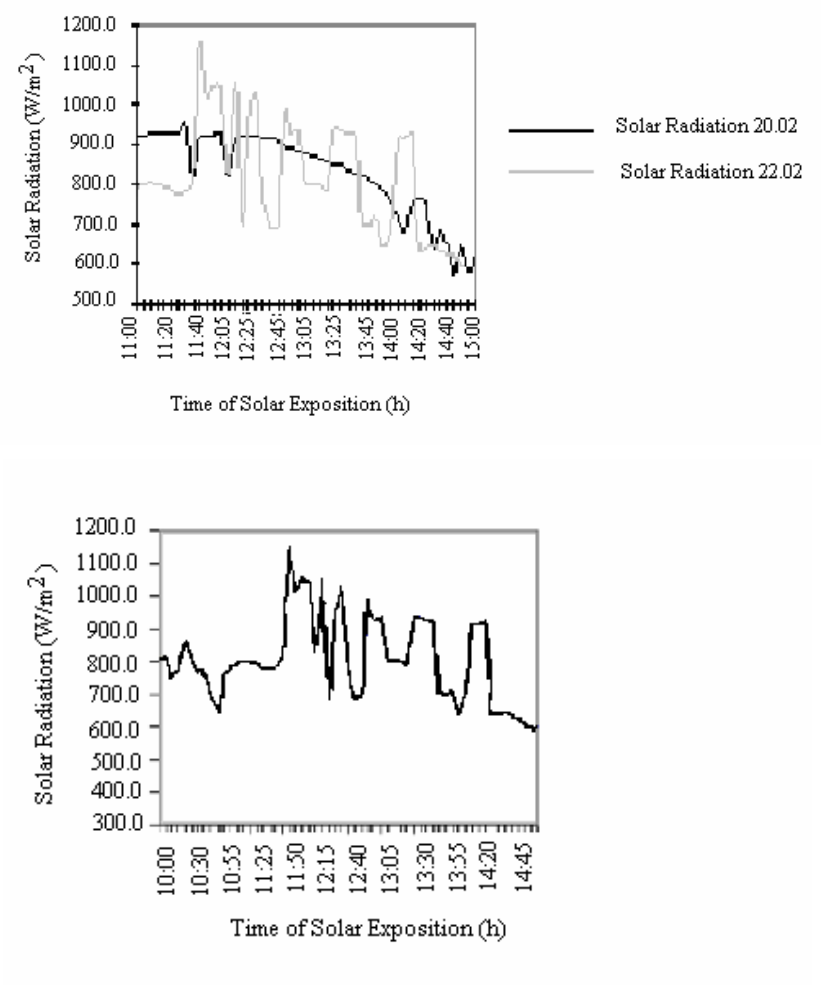

Fig. 5. Average Solar Radiation during Solar Exposition during Type I Experimental Runs.

Significant removal of total coliforms did not occur, thus we evaluated the efficiency of disinfection for *E. coli* only.

The study of the kinetics of disinfection took into consideration the efficiency of the treatment and the numerical analysis for the calculation of the constant of bacterial death. Jointly, they indicate that a solar exposition shorter than 1 h is not efficient. For longer exposition times the efficiency grows, reaching an average of 87% after 4 h, as shown on Figs. 6 and 7. As expected, when exposition times were longer than 4 h, as shown on Fig. 8 for the experiment type III, with an average solar radiation of 800 W/m^2 and temperature of the water 50°C, total disinfection was achieved.

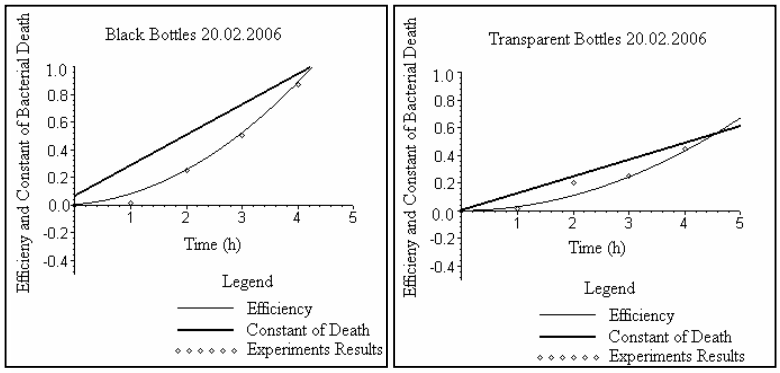

Fig. 6. Efficiency and Constant of Bacterial Death over the Time of Solar Exposition for Black Bottles (Left) and Transparent Bottles (Right), on the First Type I Experimental Run.

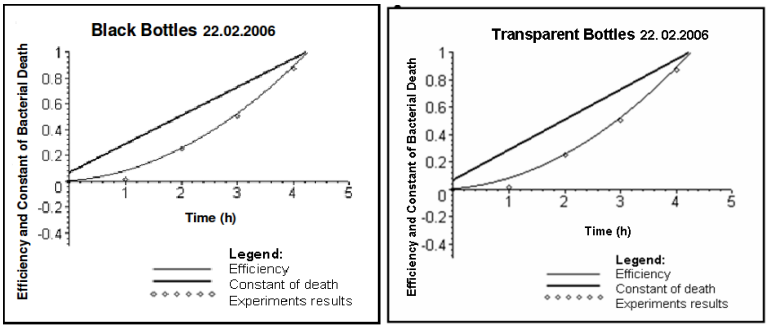

Fig. 7. Efficiency and Constant of Bacterial Death over the Time of Solar Exposition for Black Bottles (Left) and Transparent Bottles (Right), on the Second Type I Experimental Run.

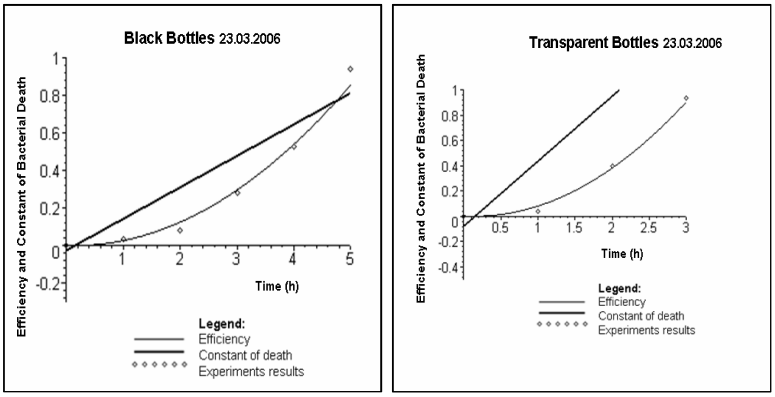

Fig. 8. Efficiency and Constant of Bacterial Death over the Time of Solar Exposition for Black Bottles (Left) and Transparent Bottles (Right), on the Third Type I Experimental Run.

The absence of bacterial increase is decisive for the maintenance of water potability, since solar disinfection does not have a residual character. The data collected during experiment I are presented in Tables 1, 2 and 3. Results show that in all the assays bacterial increase occurred after 48 h of confinement, and the increase was higher in more initially contaminated samples, as expected. However, it can be affirmed that the method allowed inactivation of most bacteria.

Table 1. Increase in *Escherichia coli* Viable Cells in Black and Transparent Bottles after the 48 Hour-Confinement. February 2006, First Run.

Solar Exposure Time (h)	*Escherichia coli*			
	Bacterial count immediately after solar exposure (MPN/100 mL)		Bacterial count after 48 h of confinement in the dark (MPN/100 mL)	
	Black Bottle	Transparent Bottle	Black Bottle	Transparent Bottle
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 in *Escherichia coli* Viable Cells in the Black and Transparent Bottles after the 48 Hour-Confinement. February 2006, Second Run.

Solar Exposure Time (h)	*Escherichia coli*			
	Bacterial count immediately after solar exposure (MPN/100 mL)		Bacterial count after 48 h of confinement in the dark (MPN/100 mL)	
	Black Bottle	Transparent Bottle	Black Bottle	Transparent Bottle
11:00	8.0	8.0	8.0	8.0
12:00	8.0	8.0	8.0	8.0
13:00	4.6	4.6	4.6	4.6
14:00	2.6	2.6	4.6	2.6
15:00	1.1	1.1	1.1	2.6

Table 3. Increase in *Escherichia coli* Viable Cells in the Black and Transparent Bottles after the 48 Hour-Confinement. March 2006, Third Run.

Solar Exposure Time (h)	*Escherichia coli*			
	Bacterial count immediately after solar exposure (MPN/100 mL)		Bacterial count after 48 h of confinement in the dark (MPN/100 mL)	
	Black Bottle	Transparent Bottle	Black Bottle	Transparent Bottle
10:00	› 8.0	› 8.0	› 8.0	› 8.0
11:00	8.0	› 8.0	› 8.0	› 8.0
12:00	8.0	8.0	›8.0	‹ 1.1
13:00	4.6	‹ 1.1	4.6	‹ 1.1
14:00	2.6	‹ 1.1	2.6	‹ 1.1
15:00	‹ 1.1	‹ 1.1	1.1	‹ 1.1

Assay 1 (opaque bottles) did not present significant efficiency. This is possibly because the maximum temperature reached in these experiments was similar to the temperature used to promote the proliferation of coliform bacteria (35°C).

4.2. Experiment type II

On Experiment Type II, we evaluated the influence of oxygen concentration in water, by homogenizing manually one bottle but not the other. The experiment was repeated three times, as three independent runs. On the 23rd of March, the water temperature reached its maximum at 11:30, with average temperature of 43°C, remaining practically constant until the end of the experiment. On the 5th of April, the best result was obtained with maximum temperature of 50º C, which rained constant for one hour. On the 10th of April, the temperature of the water reached 45°C at 1:00, as shown on Fig. 9. Data on total solar radiation are presented in Fig. 10.

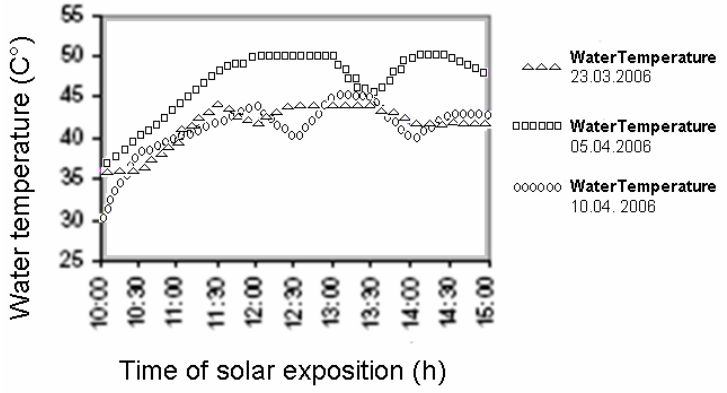

Fig. 9. Water Temperature during All Type II Experimental Runs.

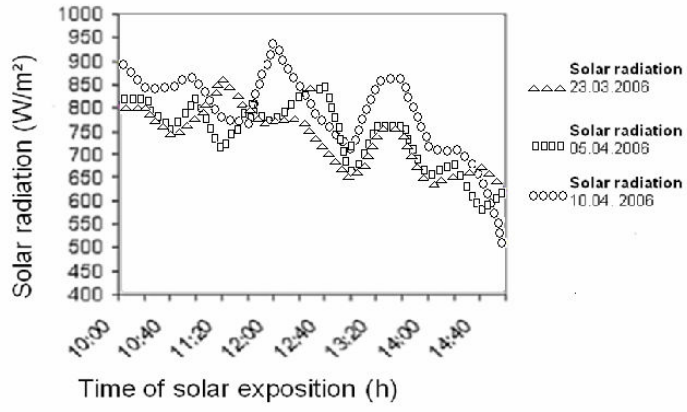

Fig. 10. Average Solar Radiation during Solar Exposition (from 10:00 to 15:00) on All Type II Experimental Runs.

The results on the kinetics of disinfection showed that oxygen concentration in water has a strong influence on the process efficiency. Bottles that underwent manual agitation were 100% efficient for *E. coli* removal after four hours of solar exposition, on three independent experiments. However, a solar exposition time shorter than 1 h was not efficient, as shown on Figs. 11 and 12.

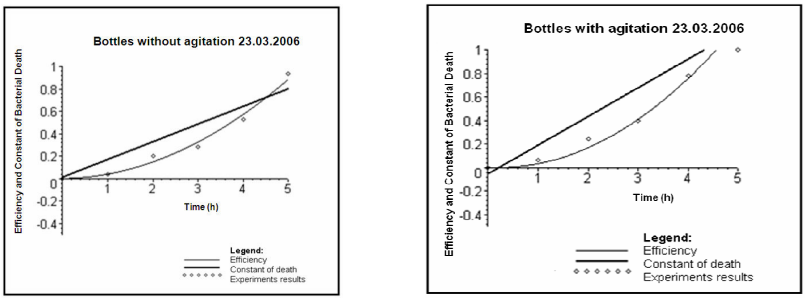

Fig. 11. Efficiency and Constant of Bacterial Death throughout Solar Exposition during Type II First Experimental Run.

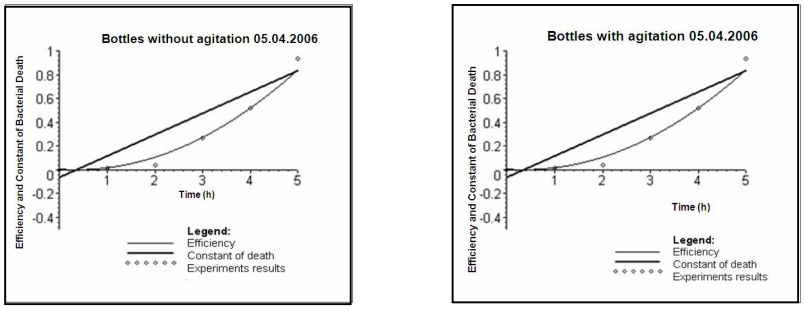

Fig. 12. Efficiency and Constant of Bacterial Death throughout Solar Exposition during Type II Second Experimental Run.

Similarly to experiment type I, significant removal of total coliforms did not occur, thus we evaluated the efficiency of disinfection for *E. coli* only.

The assay with bottles under manual agitation produced good results regarding the absence of bacterial increase after 48 h of confinement. The data of this phase of the experiments is presented in Tables 4, 5 and 6. The data show that bacterial increase occurred only in bottles that remained static. It can be affirmed that the method allowed the inactivation of most of contaminant bacteria.

4.3. Experiment type III

On experiment type III, we analyzed the effect of a solar cooker in the efficiency of the solar treatment.

Table 4. Increase in *Escherichia coli* Viable Cells in Bottles with and without Manual Agitation after the 48 h-Confinement. March, 2006, First Run.

Solar Exposure Time (h)	*Escherichia coli*			
	Bacterial count immediately after solar exposure (MPN/100 mL)		Bacterial count after 48 h of confinement in the dark (MPN/100 mL)	
	Bottles without manual agitation	Bottles with manual agitation	Bottles without manual agitation	Bottles with manual Agitation
10:00	> 8.0	> 8.0	> 8.0	> 8.0
11:00	8.0	> 8.0	> 8.0	> 8.0
12:00	8.0	8.0	> 8.0	< 1.1
13:00	4.6	< 1.1	4.6	< 1.1
14:00	2.6	< 1.1	2.6	< 1.1
15:00	< 1.1	< 1.1	1.1	< 1.1

Table 5. Increase in *Escherichia coli* Viable Cells in Bottles with and without Manual Agitation after the 48 h-Confinement. April, 2006, Second Run.

Solar Exposure Time (h)	*Escherichia coli*			
	Bacterial count immediately after solar exposure (MPN/100 mL)		Bacterial count after 48 h of confinement in the dark (MPN/100 mL)	
	Bottles without manual agitation	Bottles with manual agitation	Bottles without manual agitation	Bottles with manual Agitation
10:00	> 8.0	> 8.0	> 8.0	> 8.0
11:00	> 8.0	> 8.0	> 8.0	> 8.0
12:00	8.0	8.0	> 8.0	> 8.0
13:00	4.6	1.1	8.0	1.1
14:00	2.6	1.1	8.0	1.1
15:00	< 1.1	< 1.1	8.0	< 1.1

Table 6. Increase in *Escherichia coli* Viable Cells in Bottles with and without Manual Agitation after 48 h of Confinement. April, 2006, Third Run.

Solar Exposure Time (h)	*Escherichia coli*			
	Bacterial count immediately after solar exposure (MPN/100mL)		Bacterial count after 48 h of confinement in the dark (MPN/100mL)	
	Bottles without manual agitation	Bottles with manual agitation	Bottles without manual agitation	Bottles with manual agitation
10:00	> 8.0	> 8.0	> 8.0	> 8.0
11:00	> 8.0	> 8.0	> 8.0	> 8.0
12:00	> 8.0	8.0	8.0	> 8.0
13:00	8.0	1.1	4.6	1.1
14:00	1.1	< 1.1	2.6	1.1
15:00	< 1.1	< 1.1	< 1.1	< 1.1

The experiment was conducted twice, as two independent runs. On the 10th of April, an experiment was carried through from 10:00 to 15:00, and the water temperature reached its maximum at 1:00, with a temperature of 80°C, which remained constant for one hour. On the 22nd of May the experiment was carried through only from 10:00 to 12:00, and in spite of that a higher maximum temperature (85°C) was reached. As shown on Fig. 13, the solar cooker promoted a significant increase in the water temperature. The data on total solar radiation is presented in Fig. 14.

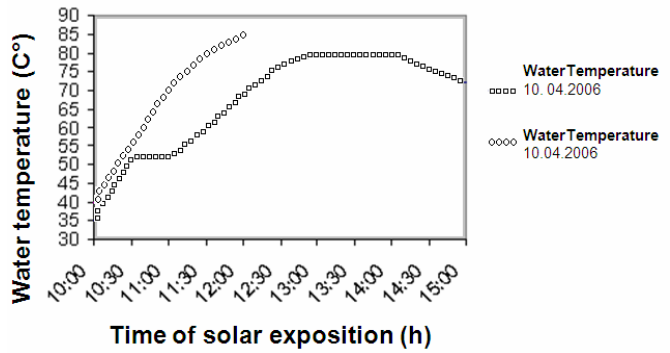

Fig. 13. Water Temperature during Type III Experimental Runs Performed on April and May, 2006.

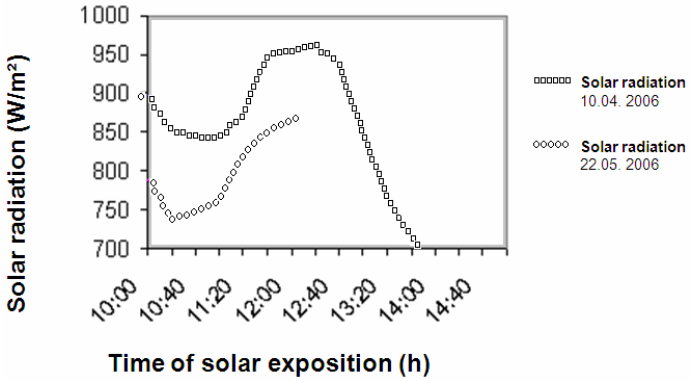

Fig. 14. Average Solar Radiation during Solar Exposition (from 10:00 to 15:00) on Type III Experimental Runs.

Type III experiment showed the best results for disinfection kinetics. The use of the solar cooker was of basic importance to raise the temperature of the water and to get maximum efficiency in a shorter possible time (Tables 7 and 8). It is possible that the solar cooker acts by minimizing the climatic interferences, thus increasing the efficiency of the whole process. As shown on Fig. 15, a maximum efficiency of 100% was reached after only one hour of solar exposition when the solar cooker was used.

Table 7. Increase in *Escherichia coli* and Total Coliforms in Transparent Bottles from Experiment III (Solar Cooker) after 48 h of Confinement. April, 2006.

10.04.2006	*Escherichia coli*		Total Coliforms	
Solar Exposure Time (h)	Bacterial count immediately after solar exposure (MPN/100 mL)	Bacterial count after 48 h of confinement in the dark (MPN/100mL)	Bacterial count immediately after solar exposure (MPN/100mL)	Bacterial count after 48 h of confinement in the dark (MPN/100mL)
11:00	> 8.0	-	> 8.0	-
12:00	< 1.1	> 8.0	< 1.1	< 1.1
13:00	< 1.1	< 1.1	< 1.1	< 1.1
14:00	< 1.1	< 1.1	< 1.1	< 1.1
15:00	< 1.1	< 1.1	< 1.1	< 1.1

Table 8. Increase in *Escherichia coli* and Total Coliforms in Transparent Bottles from Experiment III (Solar Cooker) after 48 h of Confinement. May, 2006.

22.05.2006	*Escherichia coli*		Total Coliforms	
Solar Exposure Time (h)	Bacterial count immediately after solar exposure (MPN/100mL)	Bacterial count after 48 h of confinement in the dark (MPN/100mL)	Bacterial count immediately after solar exposure (MPN/100mL)	Bacterial count after 48 h of confinement in the dark (MPN/100mL)
10:00	> 8.0	-	> 8.0	-
11:00	< 1.1	< 1.1	< 1.1	< 1.1
12:00	< 1.1	< 1.1	< 1.1	< 1.1

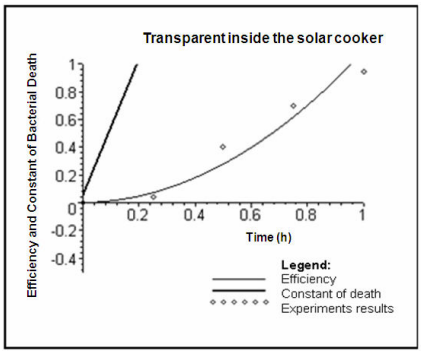

Fig. 15. Efficiency and Constant of Bacterial Death throughout Solar exposition.

Bacterial increase depended significantly on the temperature that the water reached during the disinfection. However, on experiment type III, an average temperature of 85°C was reached, which according to Sommer *et al.* [13] constitutes a process of solar pasteurization (SOUPS) and not solar disinfection

(SODIS). The term pasteurization is used to refer to a process that inhibits any possibility of bacterial increase.

4.4. Pilot Plant Project

Based on the results, a pilot plant was designed with the objective of providing a safe water supply for human consumption and improving the conditions of life of the population in communities lacking infrastructure, farmhouses and aboriginal areas with no electric energy, among others. Due to the critical situation found in the community of Robalo, a pilot plant was projected for approximately 12 families.

The plant consists first of a plastic tank of 1000 L with a polyester filter that receives the contaminated water. The contaminated water is pumped through by a ram pump. After being filtered, the water passes to another plastic tank, also of 1000 L, containing triturated seeds of *Moringa oleifera* Lam. (*Moringaceae*) clay jars for turbidity removal. The clay jar seeds are used as a natural clarifier, substituting chemical coagulants such as sulphate of aluminum. Next, the water passes to a plain plate of iron painted with solid black, that contains two reflectors to favor solar radiation absorption. The water is stored inside the black plate with a 5 mm-thick glass plate for approximately five hours, with solar radiation greater than 800 W/m^2 and water temperature of 50°C. The treated water then goes to another 1000 L tank. The entire system is controlled through a system composed by a timer and a thermostat, which opens and closes the entrance and exit valves for the water in the disinfection system (Fig. 16).

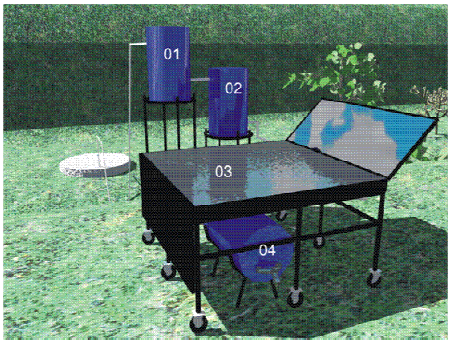

Fig. 16. Pilot Plant Project. (1) Plastic Tank of 1000 L for Filtration; (2) Second Plastic Tank, also of 1000 L, with Triturated Seeds of *Moringa oleifera*; (3) Disinfection System; (4) Tank with Treated Water.

5. Conclusions

This research represents the scientific study of a technology that has the potential of making available low-cost potable water for communities lacking safe drinking water. These technologies are often used without confirming the trustworthiness of the process. Factors such 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 showed that solar energy is a technically viable alternative for water disinfection, and an archetype of experimental plant has been proposed and will be tested next.

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References

1. Silva, M.J.M. (2004). *Desinfecção de Água utilizando Energia Solar. (SODIS): Inativação e Recrescimento Bacteriano. Campinas*: UNICAMP, Tese de Mestrado.
2. UNICEF - United Nations Children's Fund (2004) *The State of the World's Children 2005 - Official Summary*.
3. U.S Water News. EPA seeking to expand number of drinking water contaminants to 34. August 1990: 8.
4. Dons Bach, K.W.; and Walker, M. (1981). Drinking water. Huntington Beach, CA: Int'l Institute of Natural Health Sciences.
5. Andreatta, D.; Yegian, P.E., D.T.; Connelly, L.; and Metcalf, R.H. (1994) Recent advances in devices for the heat pasteurization of drinking water in the developing world. *The 29th Intersociety Energy Conversion Engineering Conference (IECEC-94)*, 4, 1741-1746.
6. Lawand, T.A.; Alward, R.; and Ayaoub, J. (1990). Solar disinfection of water. Clean and energy forever. *Proceedings of the 1989 Congress of the International Solar Energy Society*, 3, 1952-6.
7. Brandão, C.C.S.; Monteiro, P.C.G.; Fonseca, B.M.; and Arantes, C. (2000). Avaliação da desinfecção solar na região Centro-Oeste do Brasil. *XXVII Congresso Interamericano de Engenharia Sanitária e Ambiental*.
8. Brasil. Portaria no. 518, de 25 de março de 2004. *Estabelece os procedimentos e responsabilidades relativos ao controle e vigilância da qualidade da água para consumo humano*. Brasília: ANVISA, 2004.
9. SODIS. SODIS Efficiency: The Process, Technical Note #9. http://www.sodis.ch, Accessed on June, 2008.
10. APHA/AWWA/WEF (1998). *Standard methods for the examination of water and wastewater*. 20th Ed., Washington D. C.
11. Davis, M.L. Cornwell, D.A. (1998) *Introduction to environmental engineering*. 3rd Ed. New York: McGraw-Hill.
12. Donaire, P.P.R.; Jardim, W.F. (2003). Desinfección Solar de aguas de represa en Campina Grande, Paraíba, Brasil. In: Marta I. Litter; Héctor D. Mansilla. (Org.). *Desinfección Solar de aguas en comunidades rurales de América Latina*. Argentina: Marta Litter, 2003, v. ,37-62.
13. Sommer, B., et al. (1997). SODIS - An Emerging Water Treatment Process. *Journal of Water Supply*: *Research and Technology - AQUA*, 46 (3), 127–137.