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

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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 to the efficiency of the disinfection process, reaching a average of 80 the 100% of death of the microorganisms, however increase in some samples was observed. The results had been treated numericamente, with kinetic of disinfection, thus allowing the theoretical and experimental comparisons. This study it presents initial considerações for the development of a plant experimental pilot.

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 (Silva 2004).

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 (UNICEF, 2005). Rivers, streams, dams and artesian wells are frequently contaminated. Thus, the population needs to have safe water sources for its survival. The Fig. 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 (Dons Bach, 1981 and EPA, 1990).

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 (SODIS, 2004).

The objective of this work is to after quantify the efficiency of water decontamination for solar energy carrying through a study of kinetic of disinfection and the bacterial increase the treatment. With gotten the experimental and numerical results initial considerations for the future development of a plant pilot, adapted to the necessities of the region are presented.

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. (1994) described diverse methods for pasteurization of water using solar energy.

Lawand et al. (1990) 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 (2000), 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 (ANVISA, 2004).

3. 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 KW/m².year.

The experiments was divided in three: Type I – (1) cloudy bottles, (2) transparent bottles and (3) black bottles; Type II – (1) bottles without manual agitation and (2) bottles with manual agitation and Type III - Influence of the solar cooker type box in the disinfection efficiency.

The solar cooker, used during the experiments, was projected in the Laboratory of Energy and Materials, wooden fact, with a selective surface of teflon, processed for the method of thermal aspersion in a steel matrix, with the objective to increase its energy efficiency. As it shows Figure 2.

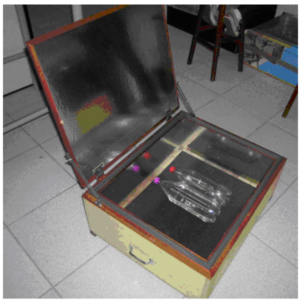

Figure 2. Solar cooker used during the experiments.

It follows below the dimensions of the related solar cooker:

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

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.

The bottles used in the experiment were cleaned with etanol 70%, distilled water and use of a chamber UV, to discard a possible contamination before the treatment.

To the long one of the experiments the temperatures of the water had been gotten, of the environment and in the surface of the bottles. During all the experiment, the total solar radiation was measured in intervals of 5 minutes through a system of acquisition AQ-USB RESOLUTION 4350.

The quantification of *Coliformes total* and *E. coli* in the samples daily pay and after-disinfection was carried through with technique NMP (Most likely Number of Microrganismos), using the Colilert Method, in series of five pipes, as the Standard Methods for the Examination of Water and Wastewater (1998).

In the Experiment Type I, the bottles were exposed to solar light for four hours, from 11am to 3pm. 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 3 shows the experiment in progress.

In the experiment Type II, the bottles had been also displayed to the solar light in the period of 10:00am to 3:00pm, also on a black canvas, as it shows Figure 4. To each hour two bottles were removed and analyzed for quantification, in its content, of *Coliformes total* and *E. coli*. After the withdrawal of aliquot of 100ml of each bottle, the same ones were kept in a box of isopor for the increase analysis 48h after the treatment and thus successively during the four current hours of experiment.

The water samples had been placed in two bottles PET of 2L each. The bottle was pierced, with a thermometer inside, to measure the temperature of the water, to another bottle was used to quantify the microbiological action. Soon after that the two bottles had been ece of fishes inside of a "solar cooker" type box. To each hour they were removed aliquot of 200ml of one of the two bottles that had been placed inside of the solar cooker. Of the aliquot withdrawals, 100ml was analyzed for quantification, in its content, of Coliformes total and E. coli and 100ml the treatment was kept in a box of isopor for the increase analysis 48h after, and thus successively during the four current hours of experiment.

Figure 3. In progress experiment, bottles displayed to the sun

Figure 4. Exposition of the bottles the solar intensity of the 10:00 to 15:00h.

3.1. KINETIC OF DISINFECTION

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 (Davis and Cornwel, 1998).

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

$$\frac{dN}{d(t)} = -k(t)N \qquad (1)$$

So,

$$\frac{dN}{N} = -k(t)d(t) \qquad (2)$$

Where:
N: Number of microorganisms
k(t): Tax of decline (death) with the time
t: time

According to Donaire & Jardim (2003) the treatment efficiency was established for Eq. **(**3):

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

Where:
E: efficiency
$N_{0:}$ number of microorganisms before the treatment
Nf: number of microorganisms after the treatment

Integrating Eq. (1) of N_0 as far as Nf, has:

$$\int_{N0}^{Nf} \frac{dN}{N} = -\int_{0}^{t} k(t)dt \qquad (4)$$

It gives:

$$k(t) = \frac{1}{0{,}434295} * E'(t) \qquad (5)$$

The efficiencies for the black and transparent bottles had been gotten through “Eq. (3)” and the interpolation of the experimental data, using the polynomial interpolater of Gregori Newton. The decline percentage k(t) had been gotten through “Eq. (5)”.

4. RESULTS AND DISCUSSION

For the experiments TYPE I, II, III: pH initial in the water samples was of 6,8 and pH final, after the solar disinfection, was of 7,0. The turbidez in the beginning of the experiments was of 1,4 NTU and in the end of the experiments it was of 1,6 NTU. Significant alteration for these parameters did not occur.

4.1. EXPERIMENT TYPE I: Assay (1) - Cloudy bottle, Assay (2) - Transparent Bottle and Assay (3) - Black Bottle.

It is perceived that in 1º day of experiment (20/02/2006) the temperature of the water, in assay 3 (black bottle), after reached its maximum value to 1:00pm, with the temperature of the water of 50°C, remaining itself constant to the long one of the experiment. In 2º day of experiment (22/02/2006), Assay 2 (transparent bottles) also presented its maximum of 50ºC in the temperature of the water, however remaining itself constant for only half hour. Assay 1 (cloudy bottles) presented maximum temperature of 40°C. In 3° experiment (23/03/2006) the temperature of the water in Assay 2 (transparent bottles) also reached maximum temperature in the water of 50°C, as it shows Figure 5. The data of the total solar radiation are presented in Figure 6.

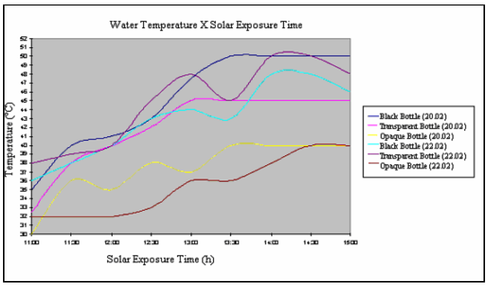

Figure 5. Temperature of the water to the long one of the experiments.

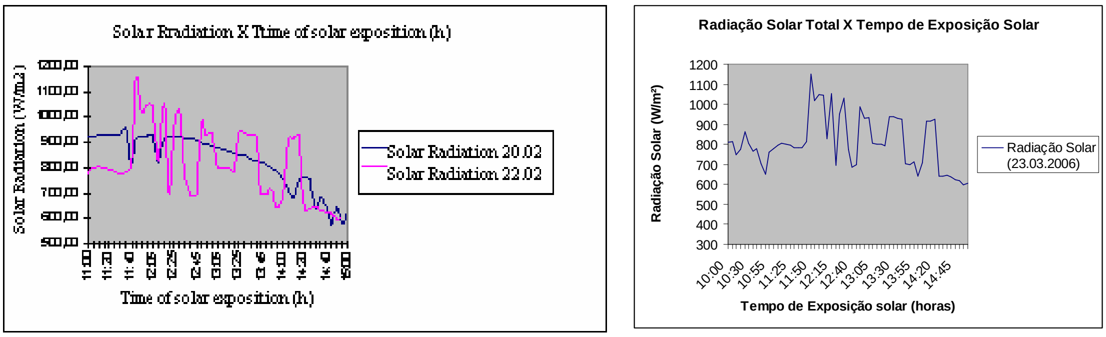

Figure 6. Average of the total solar radiation to the long one of the time of solar exposition.

Significant treatment for *Coliformes Total* did not occur, being evaluated only the efficiency of disinfection for *E. coli.*

The study of the kinetic one of disinfection it takes in consideration the efficiency of the treatment and the numerical analysis for the calculation of the constant of bacterial death. Jointly they disclose that the time of lesser solar exposition that 1h produces efficiency null. For bigger times that 1h is observed, as Figures 7 and 8 that the efficiency grows reaching in average 87% in 4h. As it was of if to wait, times of exposition above of 4h, third experiment Figure 9, with an average solar radiation of 800W/m^2 and temperature of the water 50°C allow getting total disinfection.

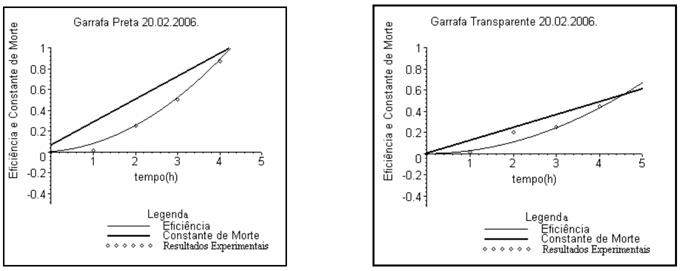

Figure 7. Efficiency and constant of death to the long one of the time of solar exposition

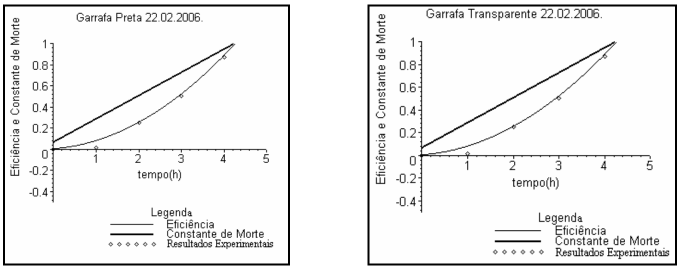

Figure 8. Efficiency and constant of death to the long one of the time of solar exposition.

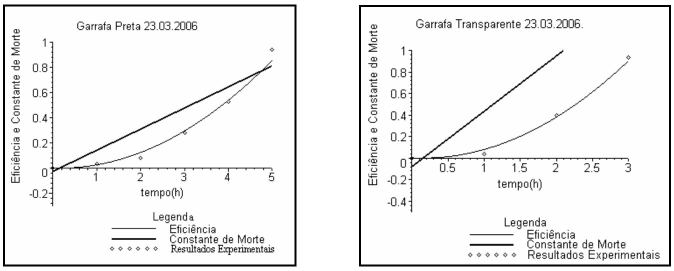

Figure 9. Efficiency and constant of death to the long one of the time of solar exposition.

The bacterial increase has important function in the maintenance of the potabilidade of the water, a time that this type of treatment does not possess residual character. The data of this phase of the experiments are in Tab. 1, 2 and 3 showing that in all the assays occurred bacterial increase after 48h of confinement, in the contaminated samples more. However, it can be affirmed that the method allowed inactivating great part of the bacteria.

Assay 1 (cloudy bottles) did not present significant efficiency. This behavior must it the fact that the temperature reached in these experiments is next to the used temperature to promote the proliferation of coliformes bacteria of the group (35°C).

Table 1: Increase of Escherichia coli in the bottles black and transparent after confinement 48hs.

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 bottles black and transparent after confinement 48hs.

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	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 of Escherichia coli in the 48 bottles black and transparent after confinement h.

23.03.2006 Solar Exposure Time (h)	*Escherichia coli*			
	N (NMP/100ml)		Increase (NMP/100ml)	
	Black Bottle	Bottle Tranparent	Black Bottle	Bottle Tranparent
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

4.2. EXPERIMENT TYPE II: Influence of the Concentration of Oxygen in the Water - Assay (1) - Bottles without manual agitation and Assay (2) - Bottle with manual agitation

In 1º day of experiment (23/03/2006) the temperature of the water, after reached its maximum to 11:30, with average temperature of 43°C, remaining itself practically constant to the long one of the experiment. 2º day of experiment (05/04/2006) presented the best one resulted with maximum temperature of 50ºC, remaining itself constant for one hour. In 3º day of experiment (10/04/2006) the temperature of the water arrived 45°C at 13:00. As it shows Figure 10. The dates of the total solar radiation are presented in Figure11.

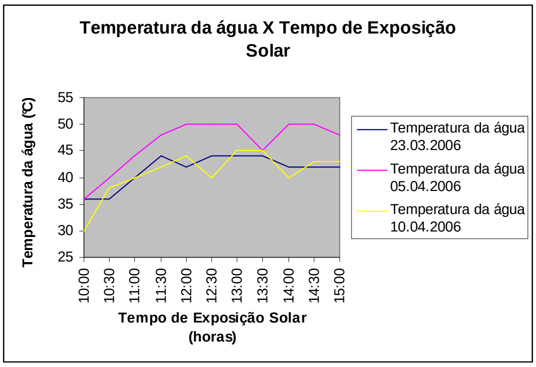

Figure 10. Temperature of the water to the long one of the two days of experiment.

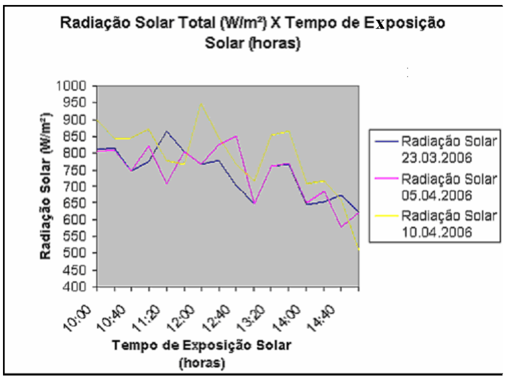

Figure 11. Average of the total solar radiation to the long one of the time of solar exposition (10:00 to 15:00h).

The results of the kinetic one of disinfection disclose that one strong influence of the concentration of oxygen in the water occurs. In the three days of experiment, the bottles with manual agitation had presented efficiency of 100% in four hours of solar exposition. Different of that it occurred in the previous assays. Time of lesser solar exposition that 1h produced efficiency null. As Figures 12 and 13.

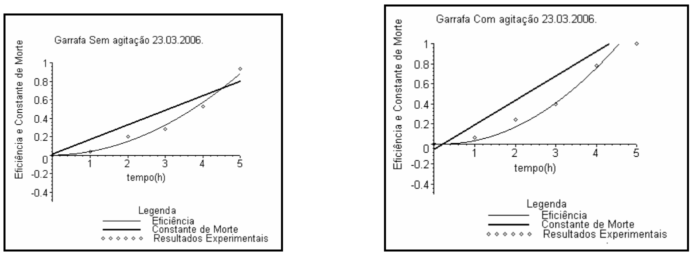

Figure 12.Efficiency and Constant of death to the long one of the time of solar exposition.

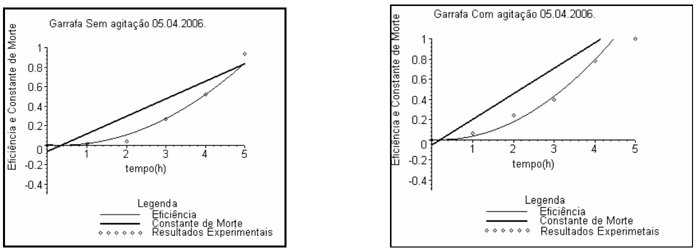

Figure 13. Efficiency and constant of death to the long one of the time of solar exposition.

Significant treatment for total coliformes did not occur, being evaluated only the efficiency of disinfection for *E. Coli*.

Assay 2 (bottles with manual agitation) presented good resulted how much to the bacterial increase after 48hs of confinement. The data of this phase of the experiments are in "Tables 4, 5 and 6". The data show that for bottles without agitation bacterial increase occurs, however for bottles with agitation does not occur. It can be affirmed that the method allowed to inactivate great part of the bacteria.

Table 4. Increase of Escherichia coli in the bottles with manual agitation and without agitation after 48 hs of confinement.

23.03.2006 Solar Exposure Time (h)	*Escherichia coli*			
	N (NMP/100ml)		Increase (NMP/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	‹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 of Escherichia coli in the bottles with manual agitation and without agitation after 48 hs of confinement.

05.04.2006 Solar Exposure Time (h)	*Escherichia coli*			
	N (NMP/100ml)		Increase (NMP/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	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 of Escherichia coli in the bottles with manual agitation and without agitation after 48 hs of confinement.

10.04.2006 Solar Exposure Time (h)	*Escherichia coli*			
	N (NMP/100ml)		Increase (NMP/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

4.3. EXPERIMENT TYPE III: Influence of the Use of the Solar Cooker in the Efficiency of the Treatment

The 1° experiment (10/04/2006) was carried through with time of solar exposition of the 10:00am to 3:00pm, the variables in 2º experiment (22/05/2006) had been monitored only during the period of the 10:00 to 12:00hs.

In 1º day of experiment (10/04/2006) the temperature of the water, after reached its maximum to 1:00pm, with temperature 80°C, remaining itself constant for one hour. 2º day of experiment (22/05/2006) presented the best one resulted with maximum temperature of 85°C. It is noticed, as it shows Figure 14, that the “Solar Cooker” acts significantly with satisfactory increase of the temperature of the water. The dates of the total solar radiation are presented in Figure 15.

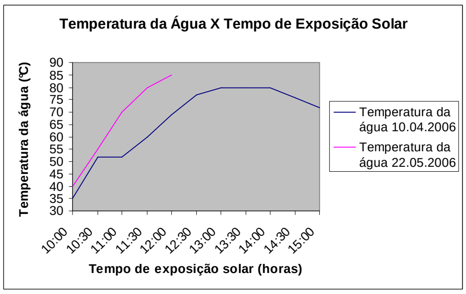

Figure 14. Temperature of the water to the long one of the two days of experiment.

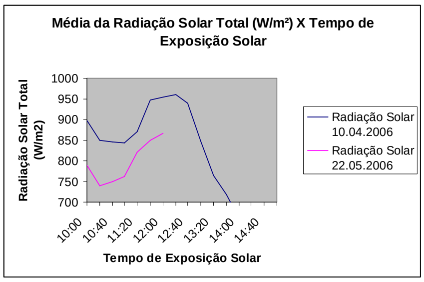

Figure 15. Average of the total solar radiation to the long one of the time of solar exposition (10:00 to 15:00h)

These experiments had presented the best ones resulted in the Kinetic one of Disinfection. The use of the "Solar Cooker" was of basic importance to raise the temperature of the water and to get maximum efficiency in a lesser possible time. The "Solar Cooker" minimizes the climatic interferences increasing the efficiency of the process. In accordance with Figure 16, with the use of the “Solar Cooker”, can be reached the maximum efficiency of 100% during only one hour of solar exposition.

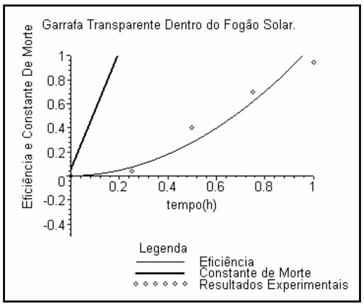

Figure 16. Efficiency and Constant of death to the long one of the time of solar exposition.

The bacterial increase depends significantly on the temperature that the water reached during the disinfection. But the experiment Type III, obtained to reach average temperature in the order of 85°C. In these conditions according to SOMMER et al (1997), has a process of solar pasteurização (SOUPS) and not solar disinfection, being used this term pasteurização as a process that inhibits any possibility of bacterial increase.

Table 7. Increase of total Escherichia coli and Coliformes in the transparent bottles after 48hs of confinement.

10.04.2006 Solar Exposure Time (h)	*Escherichia coli*		Coliformes totais	
	N (NMP/100ml)	Increase (NMP/100ml)	N (NMP/100ml)	Increase (NMP/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 of total Escherichia coli and Coliformes in the transparent bottles after 48hs of confinement.

22.05.2006 Solar Exposure Time (h)	*Escherichia coli*		Coliformes totais	
	N NMP/100ml	Increase NMP/100ml	N NMP/100ml	Increase NMP/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

5- PILOT PLANT

The pilot 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, which 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 16).

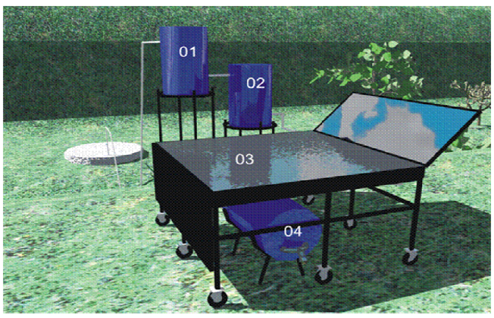

Figure 16. Initial project of the pilot plant.

(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

6. 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.

7. REFERENCES

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8. RESPONSIBILITY NOTICE