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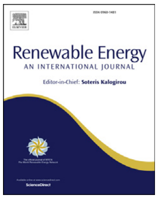

Solar pasteurizer for the microbiological decontamination of water

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ABSTRACT

Proposing solutions for potable water supply in semiarid regions such as Brazil's Northeast region is of great importance. In addition to the water shortage, the lack of chemical and biological quality in the water is another difficulty to be faced. Taking advantage of the high levels of solar irradiation in those regions, the use of solar systems for water treatment is possible. In this paper, an automated solar pasteurizer system was used for the microbiological decontamination of water. The main characteristics of the solar pasteurizer are energetic self-sufficiency and robustness, the ability to promote decontamination regardless of the turbidity or pH, absence of production of trihalomethanes, local biome preservation (Caatinga), control of treatment time and the absence of secondary contamination derived from the mixture of contaminated water with water in treatment. The system was able to treat the water in pre-programmed temperatures and time intervals of 3600 s at 55 °C; 2700 s at 60 °C; 1800 s at 65 °C; 900 s at 75 °C; and 15 s at 85 °C. The microbiological analysis performed (presence/absence of Total Coliforms and *Escherichia coli*) indicated the efficacy of the system, making it suitable for water treatment. It was found that productivity (batches' frequency) is directly proportional to accumulated irradiation. The pasteurizer is able to treat the water starting at the solar irradiation level of ≥ 12.2 MJ/m^2 for systems without a heat recovery exchanger. The use of a heat recovery exchanger in this system, to preheat the water at the collector's inlet, is of great importance because it induces an increase in productivity of approximately 50% (highest productivity reaching 30 L in a day) and lowers the minimum level of solar irradiation 8.3 MJ/m^2.

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1. Introduction

Water is one of the most important natural resources necessary to human beings. The lack of this resource is even wider in the semiarid regions of developing countries because in those areas, there is no adequate means of supply or distribution. The main sources of water supply for the local population are: dams, weirs, runoffs, shallow wells and springs. All of these are susceptible to contamination by disease-causing microorganisms, among which the main pathogenic agents are protozoa, virus and bacteria. Water is consumed by the population even though it is unfit for human consumption from either the microbiological or chemical point of view. Consequently, millions of deaths occur by infectious causes every year [1].

Microbiological decontamination of water becomes a very complex task in semiarid regions because it involves a great territorial extension, low demographic density, low levels of rural electrification and limited access to water. Given this problem, the development of technologies for microbiological water treatment becomes of vital importance to these remote communities. There are several applicable methods for water treatment such as chlorination, filtering, boiling, ultraviolet irradiation (UV) and pasteurization.

The decontamination by chlorination (oxidizing halogen) is one of the most common water treatments. Its cost is considered low; it is widely available and easy to apply, and it has the ability of residual decontamination when used with a small excess of dosage. However, in addition to altering the water's flavour when it comes in contact with organic matter, the chlorination may generate carcinogenic substances called trihalomethanes [2,3].

Filtering devices, especially those homemade and constructed

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by the natives of semiarid regions, have been used in many developing countries. However, when the filter has a low quality due to improper porosity and the lack of regular cleaning and replacement, it removes a low percentage of bacteria (approximately 90%) becoming unable to ensure water potability for human consumption. In the case of slow sand filtering (another filtering technique largely used), the filter's properties depend on a biological film formed internally, which is responsible for the removal of approximately 98% of the waterborne pathogens [4,5].

One of the physical methods that have been applied in remote areas for water decontamination is the treatment with UV radiation, which has a biocide effect in microorganisms. Due to the lack of electrification in these regions, the UV radiation used comes from the sun. This process deactivates the DNA sequences involved in viral and bacterial reproduction [6,7]. To obtain good results in the decontamination by UV radiation, the pathogen must receive a certain exposure dosage of irradiance during a period of time. A 3-log reduction of *Escherichia coli* requires a fluence close to 2000 kJ/m^2 – dose of solar radiation integrated in the UVA and UVB wavelength range. However, UV treatment efficiency is highly influenced by water turbidity and the quantity of aggregates of solid particles in suspension because of the photon absorption or reflection induced by these particles [2,7].

Another physical method that uses solar energy as an acting agent for water decontamination is pasteurization. This method consists of using heat to destroy pathogenic microorganisms. Researchers in Ref. [8] showed the susceptibility of *E. coli* to 60 °C during an exposure of 45 min. The school of medicine of The University of Utah showed results of pasteurization with the protozoa *Giardia lamblia* at a temperature of 60 °C for 3 min. Harp et al. [9] proved that it was possible to deactivate the protozoa *Cryptosporidium parvum* (responsible for many intestinal and respiratory diseases and great number of human deaths) by heating the water for 16 s at a temperature of 71.1 °C. Pasteurization is considered the most reliable and promising method for pathogenic elimination in semiarid regions [10]. It destroys completely the microorganisms responsible for water contamination with temperatures lower than the water's boiling point regardless of turbidity and pH, which influence other methods in a significant way [11].

According to Husnain [12], filtration plus chlorination seems to be a low-cost treatment suitable for surface water in rural regions, although the development of simples and trustful disinfection methods still is necessary. The author indicates that other technologies, such as SODIS or boiling, if properly stimulated by the government, could be suitable. So, as the available water in many regions of the Northeast of Brazil are not adequate for treatment with chlorination, as well as filtration has its problems inherent to the material used in the construction, the use of an applicable method to these regions is necessary [2,3]. An adequate and promising alternative for those remote regions, capable to guarantee the treatment with efficiency, in addition to not harming the environment, are the solar water heating systems that perform pasteurization. Some solar systems that use this method may present an attractive cost-benefit, as well as being a sustainable solution for water disinfection in rural areas [13].

In literature are also found discussions about systems that utilize the principle of solar disinfection together with thermal effect for water treatment [14–19]. Studies show a better treatment efficiency when the synergic effect of the optical and thermic inactivation is applied.

Nonetheless, to perform water heating using the Sun as an energy source, pasteurization systems with solar thermal collectors have been developed. These systems developed may be of two types: the ones that operate by batches and the ones that work with a continuous flow, and normally, they present productivity and solar energy collected expressed in L/m^2 h or L/m^2 day and MJ/m^2 or kWh/m^2, respectively. Some of these systems were developed with reflectors or concentrators with the objective of reaching considerable pasteurization temperatures.

Safapour and Metcalf in Ref. [20] testified that pasteurization is most effective when it uses reflectors directed to dark containers, when compared to transparent containers. They claimed that by using this method it is possible to reach temperatures around 70 °C, which is sufficient to pasteurize water when subjected to this temperature for 30 min.

The PAX World Service developed a continuous flow system made with 15–18 m of piping painted black and inserted inside a solar oven with a glass lid [21]. The system produces 16–24 L/day of treated water and is controlled by a thermostatic valve that opens when the temperature of 83.5 °C is reached. Amsberry et al. in Ref. [22] showed a box shaped collection device built with reflectors, which operates by natural convection. The system is powered by a cold water tank and makes use of pre-heating by heat exchanger. This is a continuous flow system that does not use valves, able to produce 55 L/day and reach 74 °C temperature.

Flat-plate solar thermal collectors have also been used by systems to pasteurize water. In Refs. [23], the constructed system reaches an amount of 50 L/m^2 of treated water in a day using the temperature of 75 °C. In this system, an adjustable thermostatic valve was used to control the flow. The valve's “setpoint” was studied (the temperature in which the valve is triggered for the microorganism deactivation). A solar pasteurizer was developed with evacuated tube collectors [24]. This system works by a continuous flow and has no use of control valves. The control is made by the density difference of the fluid when heated. In a typical clear sky day, the system was able to treat 86.2 L of water. Similarly, other authors have investigated solar pasteurization systems using different settings, such as the type of valve and the use of solar concentrator. Onyango et al. [25] investigated a system that uses a flat solar collector that releases batches of water when the temperature exceeds 84 °C by a thermostatic valve. It was reported that the system is capable of treating 49 L of water, up to 95 L if attached to a solar reflector. Also using a flat solar collector, researchers in Ref. [26] tested a system controlled by solenoid valve triggered by a thermostat, which allowed to configure a certain temperature for the treatment. Moreover, the hot water output was used to preheat the incoming water. This system was capable of producing 171 L/m^2 to 60 °C and 39 L/m^2 to 90 °C. More recently, Abraham et al. in Ref. [27] managed to treat water using a solar concentrator system, a valve triggered by temperature and a heat exchanger in a continuous flow operation. This study shows in detail the modelling to predict the temperature reached by the concentrator, and the relationship between the temperature and the population of microorganisms.

Although various configurations have been studied, none of the cited systems allows to find out more than one temperature “setpoint” or the time control for the water treatment. In addition, the researchers did not report a containment mechanism to ensure the isolation between the treated water and the water in treatment.

In the present work tests were conducted in a solar pasteurizer based in the use of flat-plate solar thermal collectors. The prototype developed is capable of separating water in treatment (confined) from contaminated water through automatic control of input and output valves in the solar collector. Furthermore the system enables the insertion of “setpoints” of treatment, being flexible in the configuration of the pasteurizing (temperature x time). Thus, it is possible to execute treatment at different temperatures. The tests relate to the productivity of the system with or without a heat exchanger and to its effectiveness in water decontamination.