



Solar water disinfection by a Parabolic Trough Concentrator (PTC): flow-cytometric analysis of bacterial inactivation



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ABSTRACT

An innovative solar water pasteurizer was developed to directly heat the water by solar radiation using a “Parabolic Trough Concentrator” (PTC). The efficiency of drinking water pasteurization by using the PTC was studied with a combination of analytical methods including flow-cytometric determination of total cell concentration and enumeration of cells with damaged membranes before and after treatment. Fluorescent staining of all microbial cells with two nucleic acid stains, SYBR[®]Green I and Propidium Iodide (live/dead staining), was used. The effectiveness of the pasteurizer to inactivate spiked *Escherichia coli* cells in contaminated water was also investigated. Flow-cytometric analysis revealed that cellular membranes of all microbial cells were strongly damaged after exposure in all the tested water samples. The pasteurizer reached a maximum daily water production of 66 L on a sunny day and was stable in its *E. coli* reduction rates. The results of this study suggest that the pasteurization temperature of 87 °C is able to inactivate bacterial cells in drinking water. Despite this, water pasteurized in this way is not sterile and has to be consumed quickly, since treated water samples incubated at 30 °C for 72 h exhibited a potential microbial regrowth.

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1. Introduction

Since 1990 more than 2 billion people worldwide have gained access to improved drinking water sources (UNICEF and WHO, 2012), however, most developing countries have a continued need for safe drinking-water to prevent waterborne diarrheal diseases that still cause more than 2 million child deaths per year (UNICEF, 2012). Household drinking water treatment methods are recommended among the actions to reduce diarrheal incidences (Esrey et al., 1991; Fewtrell et al., 2005; UNICEF and WHO, 2009). Boiling or heating water with fuel is one of the oldest, most widespread and effective household drinking water treatments (Clasen, 2009; Sobsey, 2002). Nevertheless, the boiling of water has a number of disadvantages and alternative methods (Argaw, 2001; Blanco et al., 2009; Bundschuh and Hoinkis, 2012) can be applied. Since water can be disinfected by pasteurization at much lower

temperatures than the boiling temperature (WHO, 2011) and sunlight is freely available in many parts of the world (IIASA, 2012), solar water pasteurization is considered as one of the most innovative water treatment techniques (Burch and Thomas, 1998). Indeed, by heating water with solar energy to a sufficiently high temperature (>60 °C) for a few minutes (<30 min), enteric bacteria can be completely inactivated (Ciochetti and Metcalf, 1984; Safapour and Metcalf, 1999). Various solar pasteurization procedures have been investigated (Duff and Hodgson, 2005; Jørgensen et al., 1998; Rolla, 1998) and conventional enumeration techniques (e.g. plate count or MPN methods) were used to assess the reduction in viability (i.e., cultivability) of microbial (bacterial) cells after thermal treatment (Spinks et al., 2006).

During the last three decades several studies have demonstrated that cultivation-based techniques largely underestimate the number of active microbial cells in water (Staley and Konopka, 1985; Bartram et al., 2003). Hence, these methods do not provide reliable information to characterize the bactericidal mechanisms of disinfection processes (Hammes et al., 2008; Ramseier et al., 2011). For example, many microbes were reported to enter a so-called “Viable-But-Not-Cultivable” (VBNC) state as a response to stress

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conditions (Oliver, 2005). Cells in the VBNC state fail to grow on the bacteriological media on which they would normally grow and develop into colonies (Kell et al., 1998; Bogosian and Bourneuf, 2001; Hammes et al., 2011), which adds to the risk of overestimating the effectiveness of disinfection processes (Berney et al., 2006, 2007).

Recent technological advancements in flow-cytometric methods have led to new opportunities to provide rapid and accurate bacteriological data from water samples (Hoefel et al., 2005). Fluorescent staining in combination with flow cytometry (FCM) is a cultivation-independent approach to assess bacteria in drinking water at the single-cell level (Berney et al., 2008; Hammes et al., 2008, 2011). This method allows direct enumeration of the total cell concentration in water and permits, at the single cell level, to collect information on the physiological state of the entire microbial community analyzed (Hammes and Egli, 2010; Joux and Lebaron, 2000).

The present study was carried out to investigate and quantify cellular activity and viability of natural microbial flora and standard hygiene indicator bacteria, before and after pasteurization treatment by using a solar Parabolic Trough Concentrator (PTC). The system, equipped with a thermostatic valve to regulate flow, was designed and built to use solar energy for drinking-water production especially for remote and isolated communities in developing countries. The effectiveness of the pasteurization process using the PTC prototype was investigated by applying both cultivation-dependent and -independent methods, i.e., by FCM combined with fluorescent dyes, and the conventional cultivation-based enumeration of *Escherichia coli* concentration (WHO, 2011).

2. Materials and methods

2.1. Basic configuration of the pilot plant

The solar pasteurizer investigated in this study was a parabolic trough concentrator (PTC) described by Bigoni et al. (2012). Sun rays are reflected by aluminium mirrors onto a black steel pipe (the absorber) located in the optical focal line of the collector (Fig. 1). The untreated water entering the pipe was gradually heated up to the pasteurization temperature by the solar radiation reflected by

the mirrors. The PTC had the following main components: a revolvable parabolic metal frame, three 100 by 200 cm highly reflective anodized aluminium sheets (Lastre Alluminio Lucide Lega 1050, Maestri Metalli, Brescia, Italy), and an absorber element, a black galvanized steel pipe. The absorber was 3 m long, the internal diameter was 3.8 cm, the wall thickness was 0.18 cm and it had an internal volume of 3.4 L. The parabolic frame dimensions were 3 m in length and 1.9 m in width; the parabolic curve had the focus line placed 40 cm above the parabola vertex where the absorber pipe was fixed. The rotational degree of freedom, using two pivots fixed on the frame support, allowed the parabolic collector to accurately follow the declination of the sun from Summer to Winter solstices. Thus, when the system was pointed towards the sun, the incident sun rays reflected by the aluminium mirrors were focused onto the absorber. At the end of the absorber pipe a thermostatic control valve (Thermostat 1.060.87; Behr Thermo-tronik, Kornwestheim, Germany) was placed to control and regulate the water heating process. The valve installed was pre-set to an opening temperature of 87 °C in order to assure an acceptable degree of microbial inactivation. The valve, a completely automatic device without the employment of batteries or electricity connections, was driven by the expansion and the contraction of a phase-change wax placed inside the valve body. During the water heating process the valve was closed and there was no flow or leakages from the absorber until the wax reached its melting point at 87 °C. When the water temperature was 87 ± 2 °C the wax turned to liquid within 2–3 s and, expanding, it pushed against a stationary stainless steel piston and created the force to open the valve that was compressed by a spring. Hence, the warmed water flowed out of the absorber into the storage water tank until fresh water, coming from the raw water tank, cooled down and solidified the wax again. When the water outflow reached 82–83 °C the valve shut after 2–3 s. The pasteurization device was supplied with test (raw) water from a high-density polyethylene (HDPE) tank (80 L) that was placed on a 1.5 m high platform to gravity feed the solar device. The bottom of the tank was placed 55 cm above the absorber in order to ensure a minimum hydrostatic pressure to allow the water to flow out when the water level in the tank was low. The raw water was fed into the absorber pipe through an HDPE plastic tube that was 2 cm in diameter and 1.5 m long. After the treatment, the water was stored

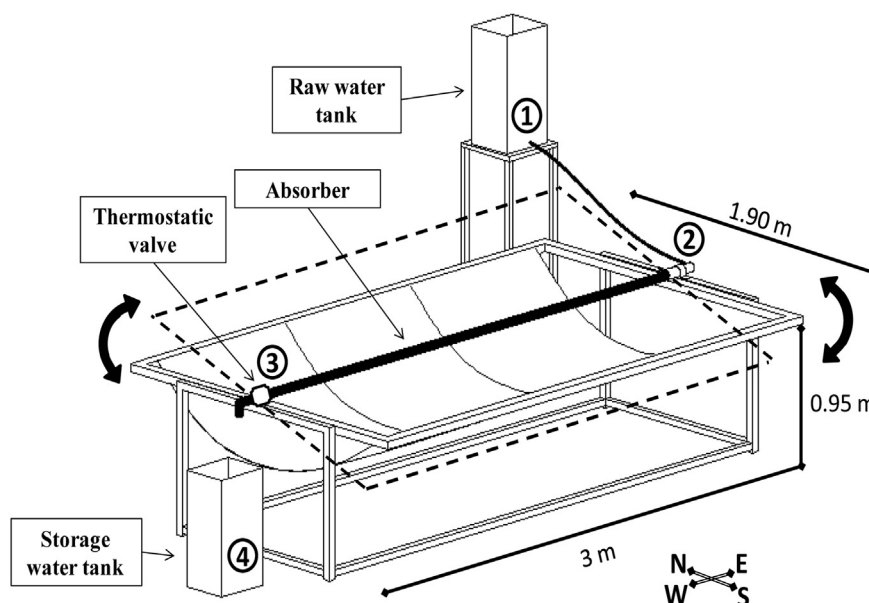


Fig. 1. Sketch of the PTC system used for solar water pasteurization (1, 2, 3, 4: four thermocouple probes).

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