Journal of Water Process Engineering 23 (2018) 277–284

Contents lists available at ScienceDirect

Journal of Water Process Engineering

journal homepage: www.elsevier.com/locate/jwpe

Modified biosand filter coupled with a solar water pasteurizer: Decontamination study

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ARTICLE INFO

Keywords:
E. coli
Modified biosand filter
Solar heater
Total coliforms
Turbidity

ABSTRACT

Modified biosand filters (MBSF) and solar pasteurizers have been used as individual drinking water treatment systems around the world. The aim of this study is to evaluate the performance of a MBSF coupled with a solar pasteurizer for effective treatment systems for source water. The MBSF was designed with an extra disinfection layer with zero valent iron (ZVI) and three layers of underdrain to remove *Escherichia coli* (*E. coli)*, total coliforms and turbidity. A flat solar panel with a solenoid valve was used as a solar pasteurizer and an extra disinfection system to remove residual *E. coli* and total coliforms from filtered water. The pasteurizer produced an average of 4.5 l of pasteurized water per day. 75 °C was selected as pasteurization temperature. A 96.25% reduction (log 1.65) in total coliforms, 98% reduction (log 2.27) in *E. coli* and 94.8% reduction in turbidity was observed in the filtered water samples. After the pasteurization, 100% of the *E. coli* and 99.99% of the total coliforms reductions were observed in the filtered and the unfiltered water. The turbidity level of the pasteurized unfiltered water did not meet the drinking water standards. However, the water quality met World Health Organization drinking water standards for the MBSF system coupled with the solar pasteurizer.

1. Introduction

Accessing to safe drinking water is a basic human need and is required to sustain the life. Unfortunately, more than one sixth of the world population still lack access to this precious resource. According to the World Health Organization (WHO), more than 1.5 million deaths occurred in children under five years of age due to consumption of the unclean drinking water [1]. The production of adequate and safe drinking water is extremely important to decrease the mortality and morbidity.

Biosand filters (BSF) have been developed for single dwellings in the developing countries and rural communities to treat the water [2–4]. In BSF, water passes through the sand following a layer of gravel, and enters the underdrain. The biological layer composed of microorganisms and particles built up on the sand, breaks down organic particles and strains out particles from water physically [5–7]. However, modified biosand filters (MBSF) usually consist of additional adsorbent media or different layers of underdrain in addition to BSF. The turbidity, heavy metals, bacteria, viruses and protozoa removal by MBSFs have been reported in many studies [8–11]. An iron oxide-coated sand MBSF removed 99.3% of the bacteria and 90% of the turbidity [12]. A melia azedarach biomass enriched BSF removed 97.9–99.9% of the iron, 31–61% of the lead and 100% of *Escherichia coli (E. coli)* [11]. A previous study showed that an MBSF with a brass disinfection layer and three layers of underdrain removed 90.11% of the total coliforms, 98.2% of *E. coli*, 88.5% of the turbidity; a MBSF with a ZVI disinfection layer and three layers of underdrain removed 97.3% of the total coliforms, 98.2% of *E. coli* and 91.5% of the turbidity. It was found that during the maturation of the biofilm on the filter (the biological layer maturation time built up on the sand), using a disinfection layer (brass or ZVI) increased the percentage of *E. coli* removal. In fact, according to this study, the MBSF with ZVI gave better total coliforms and turbidity removal (96.93% and 91.5% respectively) when it was compared with the BSF (91.29% and 88.71% respectively) and the MBSF with brass (90.11% and 88.5%) [13]. Another study showed that, the BSF media enriched with zero valent iron (ZVI) removed 99% of the fecal coliforms/total coliforms/fecal streptococci [14].

Although the initial removal efficiency of the pathogens can be achieved up to 99% by the BSFs, residual pathogen population in the filtered water can regenerate 15]. Therefore, the disinfection process is necessary to prevent the regeneration of the pathogens after the filtration. Boiling, chlorination, ultraviolet (UV) treatment, membrane filtration or reverse osmosis systems can be applied as the disinfection units to inactivate enteric bacteria, protozoa and viruses. However, those treatments are expensive and energy consuming, and cause health hazards due to the formation of byproducts or can be non-acceptable by the public due to the taste of the water.

Solar pasteurization is an energy and a cost efficient alternative

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https://doi.org/10.1016/j.jwpe.2018.04.008
Received 1 October 2017; Received in revised form 4 April 2018; Accepted 7 April 2018
2214-7144/

disinfection technology. In addition, it avoids formation of some harmful byproducts. Solar pasteurization utilizes solar radiation to heat the water to inactivate and destroy pathogenic microorganisms [16]. Plastic bottles, solar-concentrated flow-through systems, parabolic trough collectors and Fresnel type solar collectors have been investigated as solar pasteurizers in many studies [16–20,21–24]. When contaminated water was heated up to 65 °C and above in the plastic bottles, a complete disinfection occurred and this reduced the rate of childhood diarrhea by 10% [25]. In a different study, a solar pasteurization process reduced 90% of the total heterotrophic bacteria and coliform, and as a result the diarrhea risk was reduced by 42.5% [26]. A commercial solar heating system produced bacteriologically safe water in 4 h from a sample of water with 10^5–10^7 *E. coli*/mL [27]. A process of uninterrupted solar radiations reduced 10^6 colony-forming units per milliliter (CFU/mL) to 4 CFU/mL for *E. coli K-12* [28]. A borosilicate glass tube fitted with a compound parabolic collector reduced 10^5 and 10^7 CFU/100 mL to less than 1 CFU/100 mL for *E. coli* [29]. An automatized solar pasteurizer reduced 14,000 most probable number of coliforms per 100 milliliter (MPN/100 mL) to less than 3 MPN/100 mL for total coliforms at 55 °C, 60 °C, 65 °C, 70 °C and 85 °C, and 40 MPN/100 mL– < 3 MPN/100 mL for *E. coli* at 65 °C, 75 °C and 85 °C [30]. A solar reactor removed 99.99% of total coliforms in 30 min [31]. A flat solar collector achieved a complete removal of total coliforms and *E. coli*, and an average of 98.7% reduction of the heterotrophic bacteria at 85 °C in 15 s [32]. The flow through solar panels eliminated the coliform and thermotolerant coliform bacteria, *Streptococcus faecalis*, *E. coli* and *Salmonella typhimurium* via heating a water sample to 65 °C and above [21].

It is a fact that solar pasteurizers cannot remove metals, organic materials, taste and odor, salinity and turbidity [33–35]. In addition, the turbidity caused by suspended and colloidal matters can host pathogens, and provide environment for the growth of pathogens, which in turn hinder water treatment [15,36]. Therefore, pretreatment is a necessary step before the pasteurization. Solar pasteurizer studies were focused on either daily water productivity of the pasteurizers or microorganism removal in the literature. There are only a few studies focusing on the turbidity removal which suggested filtration before solar pasteurization (SOCO-DIS system) due to decreased efficiency caused by high turbidity (by 10–15%) [17]. There is no other study focusing on filters coupled with pasteurizers to produce safe drinking water effectively. Consequently, the aim of this study is to examine the turbidity and microorganism removal performance of a MBSF coupled with a solar pasteurizer system to deliver safe water for individuals. The Emirate of Abu Dhabi/UAE uses WHO and Gulf Cooperation Council (GCC) drinking water standards. According to WHO and GCC drinking water standards for microbial parameters, total coliforms, *E. coli* or thermo-tolerant fecal coliform bacteria counts should be zero in a 100 mL sample [37,1]. Therefore, *E. coli* and total coliforms were chosen as two microbial parameters monitored in this study. A filter was used as a pretreatment system to remove the turbidity, *E. coli* and total coliforms, and a solar pasteurizer was used to remove residual bacteria from the filtered water. The solar pasteurizer performance for the filtered and unfiltered water was tested as well.

2. Materials and Methods

2.1. Filter setup

The filters were set up with a ZVI extra disinfection layer and three layers of underdrain as the MBSF based on the results of the previous study (The MBSF ZVI gave better total coliforms and turbidity removal (96.93% and 91.5% respectively) when it was compared with the BSF (91.29% and 88.71% respectively) and the MBSF with brass (90.11% and 88.5%) [13]. Two acrylic flow cells with 5.08 cm inner diameter and 60 cm height, coupled with end plate assembles with mesh stainless steel screens were used as laboratory scale MBSF columns at Khalifa University, in the Environmental laboratory. Sand was purchased from Marinara Transport Company and sieved with a Humboldt sieve shaker. Sieved sand was washed and dried in an oven. Successive layers of 4 cm of pea gravel (size:12.5 mm), 4 cm of granular gravel (size:3.35 mm), 2 cm coarse sand (size:1.18 mm), 4 cm fine sand (size:0.42 mm) mixed with the iron particles (size:0.84 mm, 15% volume basis, approximately 4.4 gr was added to fine sand) and 36 cm fine sand were placed inside the scaled down filter columns based on the full size structure [13]. As an outlet tube, 0.5 cm inner diameter PVC outlet tubing was used and raised 5 cm above the height of the filter media. A diffuser with approximately 2 mm of diameter holes was placed 10 cm above the filter media. The standing water was maintained 3–4 cm above the filter media during the pause period. The volume of the filled column was 4.62 L (sand + gravel + water) with a void space of 0.35 L. The filters were filled with water before loading in order to avoid air spaces. The porosity/void fraction of the sand was 0.4. The filters were run intermittently twice a day (with 12 h pause period) with 0.4 L of water for 60 days (including maturation period). The initial flow rate for the column with the first charge was approximately 0.013 L/min (0.38 m/h), which was in the prescribed range (0.16–1.1 m/h) [8,38]. The flow rates were measured daily. The water temperature was in the range of 24–26 °C during the testing period.

2.2. Solar pasteurizer setup

The prototypes were built and tested in Khalifa University, Abu Dhabi Campus (24°26′52″N and 54°23′41″E). The mean solar insolation rates were measured using a Solar Light PMA2100 Dual-Input data logging radiometer.

A 40 cm x 60 cm wood frame with an aluminum sheet (0.24 m^2 aperture area, 170 mL capacity) was built as a solar pasteurizer prototype. The filtered water transferred to a cold-water tank (Coleman, 7.57 l, insulated jug cooler) coupled with a respirator which was placed approximately 30 cm above the collector panel. The filtered water was led to the upper tube connected to the cold-water tank and then to a serpentine shaped copper pipe which had an inner diameter of 7 mm and a length of 4.5 m. The exit pipe was connected to an automatic heat sensor valve (MOS FET transistor-resistor circuit with a solenoid valve which receives a control signal from an Arduino microcontroller along with the temperature sensors DS18B20) to dispense the water to the treated water tank. The treated water tank (Coleman, 7.57 l, insulated jug cooler) was placed 0.1 m below the collector panel as shown in Fig. 1. All circuits were powered by photovoltaic electricity. The initial filtered water temperature was 26 ± 1 °C during the testing period. The solenoid valve prevented water being withdrawn below the chosen

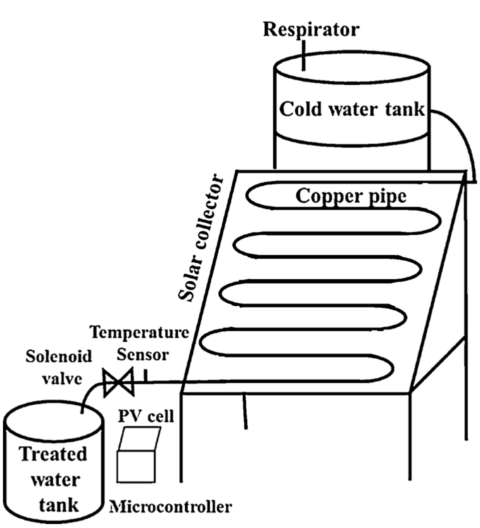

Fig. 1. Solar pasteurizer set up.