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Characterization of the relationship between ceramic pot filter water production and turbidity in source water

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ABSTRACT

Ceramic pot filters represent a common and effective household water treatment technology in developing countries, but factors impacting water production rate are not well-known. Turbidity of source water may be principal indicator in characterizing the filter's lifetime in terms of water production capacity. A flow rate study was conducted by creating four controlled scenarios with different turbidities, and influent and effluent water samples were tested for total suspended solids and particle size distribution. A relationship between average flow rate and turbidity was identified with a negative linear trend of 50 mLh^{-1}/NTU. Also, a positive linear relationship was found between the initial flow rate of the filters and average flow rate calculated over the 23 day life of the experiment. Therefore, it was possible to establish a method to estimate the average flow rate given the initial flow rate and the turbidity in the influent water source, and to back calculate the maximum average turbidity that would need to be maintained in order to achieve a specific average flow rate. However, long-term investigations should be conducted to assess how these relationships change over the expected CPF lifetime. CPFs rejected fine suspended particles (below 75 μm), especially particles with diameters between 0.375 μm and 10 μm. The results confirmed that ceramic pot filters are able to effectively reduce turbidity, but pretreatment of influent water should be performed to avoid premature failure.

1. Introduction

Ceramic pot filters (CPFs) have become a common household water treatment solution in areas where people rely on untreated surface water, or where the risk of recontamination during water distribution and storage is high. According to Hunter (2009), CPFs are the most effective over the long-term among various household water treatment technologies, and Oyanedel-Craver and Smith (2008) found that the silver coated CPFs, made using primarily local materials and labor, represent a sustainable point-of-use water treatment technology for poor communities. The most widely available locally-produced CPF is the ICAITI/PFP type described by Lantagne et al. (2010) which has been adopted in over twenty countries. However, a study of the current practices in CPF manufacturing in developing countries described by Rayner et al. (2013) shows that manufacturing processes vary widely both between and within factories posing concerns about the consistency and quality of locally produced filters due to the absence of standardized quality control procedures. In addition, variability in characteristic of the influent waters, and in use and cleaning practices makes it difficult to predict the quantity of water that a CPF will produce over its lifetime.

Several studies have been conducted both in the laboratory and in the field to better understand CPFs behavior and assess their effectiveness in terms of removal efficacy of microorganisms, suspended particles, and water production capacity. Simonis and Basson (2011) presented an overview of fifteen laboratory and field studies of bacterial testing showing an average log reduction value (LRV) of 2.0 for *E. coli* that corresponds to the threshold required by the World Health Organization (WHO) (2011) for a

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household water treatment to be considered protective against bacteria. However, the study documented a high variability in the efficacy, with LRVs ranging from 0.9 to 6.8. Bielefeldt et al. (2010) described the particle removal performance of six CPFs made in Nicaragua using water engineered with natural particles (with a turbidity of 40 NTU) and kaolin clay particles (with a turbidity of 3 NTU) from 2 μm to 100 μm, and with fluorescent microspheres (0.02–10 μm) to simulate microorganism removal efficacy. The 40 NTU scenario presented an average LRV of turbidity slightly below 2.5. Larger microspheres were preferentially removed with average LRVs from 1.5 (0.02 μm particles) to 3.2 (10 μm particles). The smallest particles (0.02–0.1 μm) were partially washed out from the CPF when clean water was filtered after the experiments, and similar results of contamination of clean water treated after spiked tests have been observed with *E. coli* by Bielefeldt et al. (2009). A long-term investigation described by Salvinelli and Elmore (2015) showed that flow rates decrease over time and that turbidity negatively affects both the average flow rate and the rate at which it decreases. According to Lantagne (2001) and van Halem et al. (2007), flow rate decrease is significant when surface water is treated, and scrubbing the filter, as recommended by manufacturers and The Ceramic Manufacturing Working Group (CMWG) (2011), partially and temporally restores the flow rate. van Halem et al. (2009) concluded that a potential cause of failure is the physical fouling by colloids, and that neither organic nor inorganic fouling are the principal causes of clogging. Therefore cleaning the filtering unit provides a temporary benefit but does not prevent long-term clogging, thus the flow rate is the limiting factor of CPFs' lifetime and sustainability.

Mihelcic et al. (2009) stated that turbidity has a negative impact on many water treatment processes in different ways, including clogging filters and therefore reducing their effectiveness. They also concluded that turbidity is easily measurable in the field with the use of a turbidity tube, and that the pretreatment turbidity limit for ceramic filters is between 15 NTU and 20 NTU. Schweitzer et al. (2013) presented two hydraulic models, for paraboloid- and frustum-shaped CPFs, that can be used to predict water level in the filter, instantaneous volumetric flow rate, and cumulative volume of water produced. The models do not include the effect of turbidity and filter clogging over time, and a quantitative description of how turbidity affects filter hydraulic performance is suggested as future work. According to Salvinelli and Elmore (2015), turbidity seems to be the principal indicator in characterizing CPF lifetime in terms of water production capacity, but its relationship with CPF flow rate is not well understood. It was also concluded that initial flow rate is a powerful indicator of CPF performance, but it is unclear how it can be representative of the average flow rate.

This paper describes a study of CPF water production capacity under controlled conditions using four different turbidity scenarios. The primary purpose of this study is to assess the relation between turbidity and flow rate with the intent of identifying a method to estimate CPF average flow rate. The secondary objective is the characterization of the suspended particles retained and released by the filter in order to better understand the clogging mechanisms and identify possible pretreatments that could enhance the filter lifetime.

2. Material and methods

An experiment was conducted in the ground water hydrology laboratory of the Missouri University of Science and Technology (Missouri S&T) to assess how turbidity impacts CPF flow rate. Twelve ICAITI/PFP type filtering units manufactured and quality tested by a CPF factory located near Antigua, Guatemala were selected from a stock shipped to Missouri S&T. The quality control test in the factory consists of three consecutive 1 h falling head flow rate tests conducted using clear water and the calibrated T-device described by CMWG (2011). Flow rate is typically used by manufacturers as the primary quality control parameter. Rayner et al. (2013) explains that this quality control practice is intended to ensure that each CPF can produce sufficient daily water, that there is sufficient contact time with the silver, and that there is production consistency between units. Only filtering units producing between 1 Lh^{-1} and 2 Lh^{-1} in at least two tests at the Antigua facility are distributed to consumers. All the filters used in the study passed the quality test at the factory, but their flow rates were not recorded and provided to the authors. First, the twelve filters were soaked in deionized (DI) water for one day and a 24 h constant head flow rate test was conducted in order to establish a baseline daily average flow rate for each individual filter, called initial flow rate (Qi). Then the filters were divided into four sets of three, and each set was used to establish four different systems with the same setup and conditions except for the turbidity of the untreated water. Three different engineered waters were created mixing tap water from the Rolla, Missouri, USA, municipal system and alluvial soil from a local river called Little Piney Creek. The fourth water source was Rolla municipal tap water which has the following typical characteristics: hardness 280 mg/L as $CaCO_3$, TDS 330 mg/L, conductivity 0.5 mS/cm, pH 6.8, ionic strength 0.008 mol/L, and free chlorine residual 0.28 mg/L. The soil was collected, dried at 105 °C for 24 h, crushed using a soil mortar and pestle, sieved through a 200-mesh (0.075 mm) test sieve (Soiltest Inc.) using a portable sieve shaker (CE Tyler RX-24), and added to the tap water in three different concentrations: 125 mg/L for the Low Turbidity (LT) system, 250 mg/L for the Medium Turbidity (MT) system, and 375 mg/L for the High turbidity (HT) system.

In order to maintain constant conditions and to maximize the flow rate of each filter over the time that the experiment was conducted, constant head apparatuses similar to the one described by Salvinelli and Elmore (2015) were used. With the goal of reducing the sedimentation of suspended particles and therefore maintaining the turbidity level relatively constant in the water sources, a compressed air distribution system was added to the original design for the three systems using engineered water, as shown in Fig. 1. Likewise, the pump timer frequency was increased and the water was recirculated every 15 min. The float valve was adjusted to maintain a constant water level 21.5 ± 0.6 cm above the bottom of the CPF.

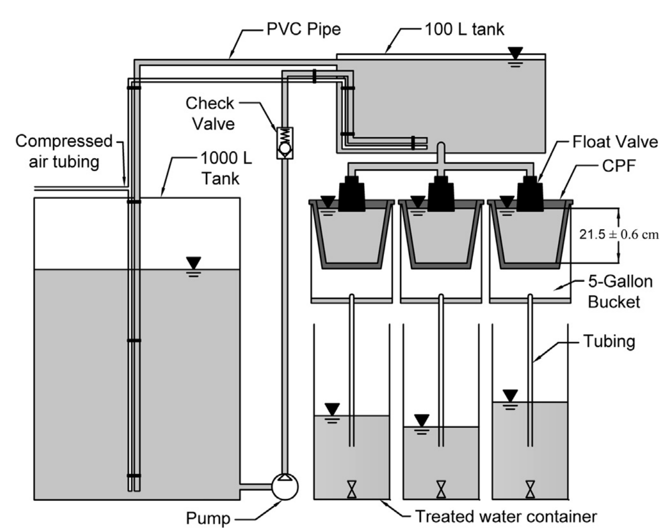

Fig. 1. Constant head apparatus with air mixing (after Salvinelli and Elmore, 2015).