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Reduction of organic matter in drinking water using a hybrid system combined with a rock biofilter and membrane in developing countries

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ABSTRACT

In many developing countries, inadequate access to safe drinking water is a major cause of morbidity and mortality. Furthermore, approximately 100 million people worldwide are exposed to arsenic (As) in drinking water. The World Health Organization is thus now encouraging the development and supply of a low-cost technology that can treat domestic water. The present study combined the use of a trickling filter (TF) with a biosand filter (BSF). Additionally, to remove As (V) from water, the use of the absorbents Fe–Mn–Si (FM-α) and zero-valent iron was experimentally investigated. Different compositions of influent were supplied in five stages. Efficiency was analyzed in terms of the total organic carbon, turbidity, UV_{254}, As (V) content, flux, power consumption, total solids, and volatile solids of samples taken from four treatment systems (M-1: membrane, M-2: BSF + membrane, M-3: TF + membrane, and M-4: TF + BSF + membrane). Results show that the removal of organic matter and decline in flux over 45 d reduced in the order M-4 > M-2 > M-3 > M-1. The combination of TF, BSF, and M-4 was shown to have the most stable operation even under shock loading. The biofilm of the BSF and sieving effect played an important role in reducing the content of organic matter. The recovered flux of M-1 decreased and the M-1 membrane was backwashed four times. In comparison, M-3 required backwashing four times, M-2 required backwashing once, and M-4 did not require backwashing during operation. The M-4 system removed 95% of organic matter without any cleaning of the top soil throughout the experiment and reduced turbidity by 99%. Between systems M-1 to M-4, the most effective system was M-4 because of its stable operation without backwashing of the membrane throughout the experimental period. The M-2 system with FM-α embedded in the layers of sand removed 77% of As (V), while the M-4 system, using zero-valent iron adsorbents, removed 97% of As (V).

Introduction

Approximately 800 million people around the world do not have access to clean drinking water, most of whom are living in developing countries (WHO/UNICEF, 2010). Generally, these people are exposed to the risk of waterborne diseases such as diarrhea because of the absence of a clean water supply (John and Mark, 2003). Furthermore, more than 100 million people worldwide are known to be exposed to arsenic (As), with large quantities of arsenic having been detected in drinking water in developing countries such as Laos, Myanmar, Cambodia, Inner Mongolia, Vietnam, India, and Nepal (Southeast Asian Water Environment, 2008). Arsenic in drinking water is a carcinogen that causes cancer in the skin, kidney, lung, and bladder in addition to diseases of the skin, kidney, heart, and vessels (EPA, 2000a). Thus, the World Health Organization has been encouraging the development of a low-cost technology that can treat domestic water (Sobsey, 2002; WHO, 2007) and limit the As concentration in drinking water to 10 μg/L. Low-cost membrane technologies can prevent the spread of waterborne diseases. For example, Life Straw® (costing US$20–30/unit) is a Sawyer filter that separates and removes bacteria and viruses from water. The use of a membrane has many advantages over existing sterilization methods (AWWA, 1996; Bodzek and Konieczny, 1998; Lazarova et al., 1999; Arnal et al., 2001). However, rivers, lakes, and ponds in the cities of developing countries are polluted with highly concentrated organic matter (John and Mark, 2003; Haarhoff et al., 2009) as a result of industrialization, and this organic matter fouls surface membranes.

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A biosand filter (BSF) is an alternative low-cost technology (costing US$20–30/unit) that uses affordable materials (Andrew et al., 2013; Duke et al., 2006) and costs less than other technologies of chemical disinfection and ceramic filtration in terms of management and maintenance. Microorganisms that exist in the biofilms that grow within a BSF can biodegrade dissolved organic pollutants included in synthetic water (Fox et al., 1984; Bellamy et al., 1985). BSFs have also been reported to reduce turbidity by 39–91% (Wiesent-Brandsma et al., 2004; Stauber et al., 2006; Duke et al., 2006; Earwaker, 2006; Jenkins et al., 2009). The use of a BSF can reduce the occurrence of diarrhea. Almost 100% of viruses can be removed with a BSF (Kaiser et al., 2002; Andrew et al., 2013; Wiesent-Brandsma et al., 2004; Duke et al., 2006; Earwaker, 2006; Stauber et al., 2006). However, problems remain to be solved in maintaining the quality of water in the BSF process; i.e., the filtration is slower than the treatment rates of other water purification systems and the concentration of dissolved organic matter in the influent has to be kept very low (Gary, 1991), and physical and biological processes such as those relating to membranes and BSFs cannot properly remove heavy metals such as As from synthetic water. There is thus a need for an additional process to remove heavy metals.There are physical processes that can be employed to remove As, such as coagulation and precipitation (Sancha, 2000; Ahmed et al., 2001), oxidation using solar light (Hug et al., 2001), biochemical oxidation using bacteria (Katsoy iannis et al., 2002), and filtration using reverse-osmosis and nanofiltration membranes (Brandhuber and Amy, 1998). To remove As from underground water, studies have investigated ion exchange (EPA, 2000b) and the use of metal oxidants such as aluminum (Ike et al., 2008), zero-valent iron (ZVI) (Nikolaidis and Dobbs, 2003), and manganese-coated sand (Subramanian et al., 1997).

In the present study, we have developed a hybrid system of a BSF combined with a trickling filter (TF) that prevents a flux decline of the membrane and reduces the content of organic matter. Additionally, the metal oxidants Fe–Mn–Si (FM-α) and ZVI are embedded in the BSF to remove As.

Materials and methods

System design

Four identical microfiltration membranes (Philos Co. Ltd.) were connected to TF and BSF reactors as shown in Fig. 1 and the removal of organics and the decline in flux were compared for each membrane. The membranes were designed to be unpowered. Tables 1 and 2 give the module configurations and properties of the membrane, respectively.

The BSF reactor was made of acrylic rectangular prisms having a width of 20 cm, length of 20 cm, and height of 65 cm. Each layer was filled with a different medium (gravel and sand) as shown in

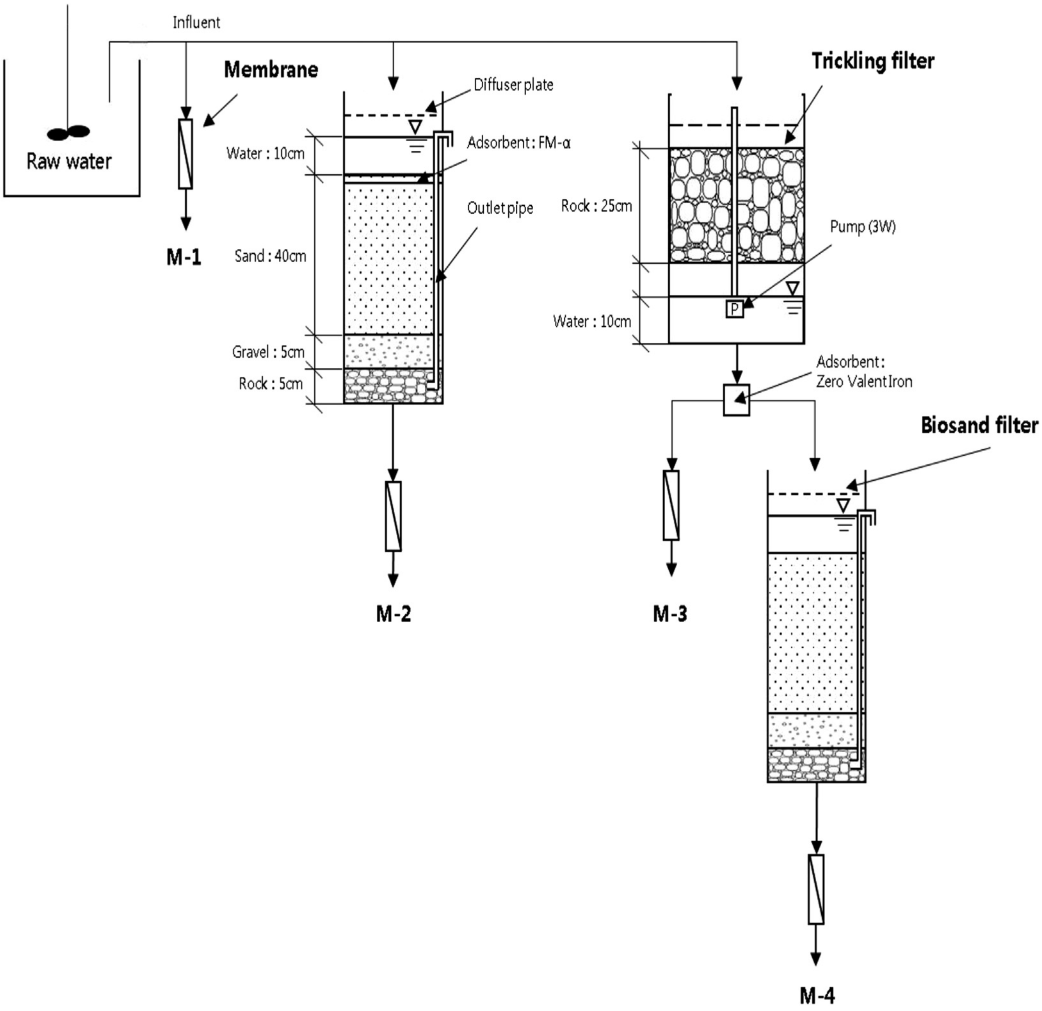

Fig. 1. Schematic of systems.