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Research article

Evaluation of the resilience of a full-scale down-flow hanging sponge reactor to long-term outages at a sewage treatment plant in India

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ABSTRACT

Resilience to process outages is an essential requirement for sustainable wastewater treatment systems in developing countries. In this study, we evaluated the ability of a full-scale down-flow hanging sponge (DHS) reactor to recover after a 10-day outage. The DHS tested in this study uses polyurethane sponge as packing material. This full-scale DHS reactor has been tested over a period of about 4 years in India with a flow rate of 500 m^3/day. Water was not supplied to the DHS reactor that was subjected to the 10-day outage; however, the biomass did not dry out because the sponge was able to retain enough water. Soon after the reactor was restarted, a small quantity of biomass, amounting to only 0.1% of the total retained biomass, was eluted. The DHS effluent achieved satisfactory removal of suspended solids, chemical oxygen demand, and ammonium nitrogen within 90, 45, and 90 min, respectively. Conversely, fecal coliforms in the DHS effluent did not reach satisfactory levels within 540 min; instead, the normal levels of fecal coliforms were achieved within 3 days. Overall, the tests demonstrated that the DHS reactor was sufficiently robust to withstand long-term outages and achieved steady state soon after restart. This reinforces the suitability of this technology for developing countries.

1. Introduction

Sustainable operation of sewage treatment facilities is a challenge in developing countries, where budget shortages, a scarcity of land on which to construct facilities, untrained technical staff, unreliable facilities, and/or unstable electrical power supplies are commonplace. In recent years, upflow anaerobic sludge blankets (UASB) have been widely used for sewage treatment in developing countries because of their simple operation and maintenance, low running costs, and high efficiency (Gomec, 2010; Monroy et al., 2000; Sato et al., 2006). However, because it does not attain the discharge standards set by most developing countries, the effluent from the UASB process needs additional treatment to improve its quality (Foresti, 2002; Haandel and Lettinga, 1994). Several conventional biological processes, such as polishing ponds (stabilization ponds), activated sludge, and trickling filters, have been applied as post-treatments for UASB effluent (Chernicharo et al., 2015; Chong et al., 2012; Kassab et al., 2010). Although much effort has been devoted to developing these post-treatment processes, the performance and applicability of the majority have not been verified at the full-scale (Chan et al., 2009; Kassab et al., 2010; Khan et al., 2011).

In an attempt to advance this situation, a post-treatment process called the down-flow hanging sponge (DHS) has been implemented in a full-scale experiment in India (Okubo et al., 2015; Onodera et al., 2016). The DHS is recognized as a promising post-treatment process (Kassab et al., 2010). It is somewhat similar to the trickling filter system, but it uses a sponge as an alternative support material (Agrawal et al., 1997; Machdar et al., 1997; Onodera et al., 2013; Tawfik et al., 2006b). The quality of the

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effluent from the DHS process is comparable to that of the effluent produced by the activated sludge process (Tandukar et al., 2007). In addition, because backwashing is unnecessary, the operation and maintenance of the DHS are simpler than for the trickling filter process (Onodera et al., 2016; Tandukar et al., 2005). While macrofauna overgrazing on the biomass is a long-standing problem in trickling filter systems (Daigger and Boltz, 2011), the DHS is able to prevent snail overgrazing on the sludge retained inside the sponge media (Onodera et al., 2015b). During the pilot-scale experiment, a DHS reactor with a flow rate of 50 m^3/day showed better treatment performance, and used approximately 75% less energy and produced 85% less excess sludge, than the conventional activated sludge process (Tanaka et al., 2012). A full-scale experiment of the DHS reactor with a flow rate of 500 m^3/day has been successfully run for more 1800 days at a sewage treatment site in India. This experiment confirms that, because of its simple operation and maintenance, low energy requirements, and low production of excess sludge, the DHS is a practical and suitable technology for developing countries (Okubo et al., 2015; Onodera et al., 2016).

To guarantee successful operation over the long-term in developing countries, the system must be sufficiently robust to cope with process outages. Process outages are often caused by facility inspections, handling accidents, and power cuts, and may last for anything from between a few hours to a number of days. In our experience, the treatment facility is sometimes interrupted at the site. In such situations, the sewage treatment system is exposed to starvation conditions, and there is concern that these conditions can cause the process to collapse. For instance, studies have reported a serious decrease in the performance of the activated sludge process because of anaerobic conditions (Kim et al., 2007; Urbain et al., 1993). Even under aerobic conditions, the amount of biomass, sludge activity, and the number of active cells in activated sludge decreased during a starvation period (Oviedo et al., 2003). The main concern for the trickling filter process is biofilm dry-out or detachment. Therefore, the treatment facilities need to be sufficiently robust to survive after outages, and facilities need to be able to both avoid process collapse and reach steady state rapidly once restarted. To our knowledge, to date, no studies have evaluated the robustness of these secondary treatment procedures in municipal treatment systems in developing countries.

The aim of this study is to evaluate the robustness of a full-scale DHS reactor to a process outage. The DHS reactor was stopped for 10 days, during which it had no water supply or rainfall. Outages may have various detrimental impacts on the process performance; for example, the retained sludge may dry out and sludge may be lost from the DHS reactor after restart. Further, the biomass may be subjected to starvation and anaerobic conditions, and the amount and activity of the biomass may decrease, leading to inadequate performance when the system is restarted after the outage. Therefore, during this study, we attempted to calculate the water retention in the sponge media during the outage, the amount of sludge lost after the restart, and the time taken for recovery of the performance on removing suspended solids (SS), chemical oxygen demand (COD), ammonium nitrogen, and fecal coliform.

2. Materials and methods

2.1. Operating conditions of the full-scale DHS reactor

The full-scale DHS reactor is in operation at the sewage treatment plant in Karnal, India. The plant consists of a UASB followed by a polishing pond. The hydraulic retention time (HRT) of the UASB reactor is approximately 13 h. Part of the UASB effluent is used as the influent for the DHS reactor. Detailed information about the sewage treatment facilities and operating conditions have been reported elsewhere (Okubo et al., 2015). A picture and a schematic diagram of the DHS reactor are provided in Fig. 1(A and B). The reactor consists of a concrete column that is 5.5 m high and has a diameter of 5.3 m; the volume of the reactor column is 126 m^3. A hydraulically-driven rotary distributor was set up at the top of the DHS reactor, and a clarifier was also installed under the reactor. The hanging sponge curtain was made by tiling polyurethane sponge bars (right triangle: 25 mm) onto the both sides of a plastic sheet, the upper part of which was equipped with reinforced plastic bars and hooks. The sponge volumes in the upper and lower sponge modules were 12.6 m^3 and 18.5 m^3, respectively, meaning that the sponge had a total volume of 31.1 m^3. The sponge occupied 24.7% of the total volume of the reactor. Void spaces comprised 98% of the polyurethane sponge. The sponge bars were horizontally tiled on the sheets in the upper and lower sponge modules at intervals of 10 and 15 mm, respectively. Each sponge curtain was hung at appropriate intervals to allow fresh air to flow through the open spaces between the curtains.

The DHS reactor was fed with some of the effluent from the UASB at a flow rate of 500 m^3/day and a recirculation ratio of 100%. The DHS had an HRT of 1.5 h based on the sponge volume. The temperature of the water in the DHS influent was between 15 and 33 °C. The wastewater was sprinkled from the distributor, and

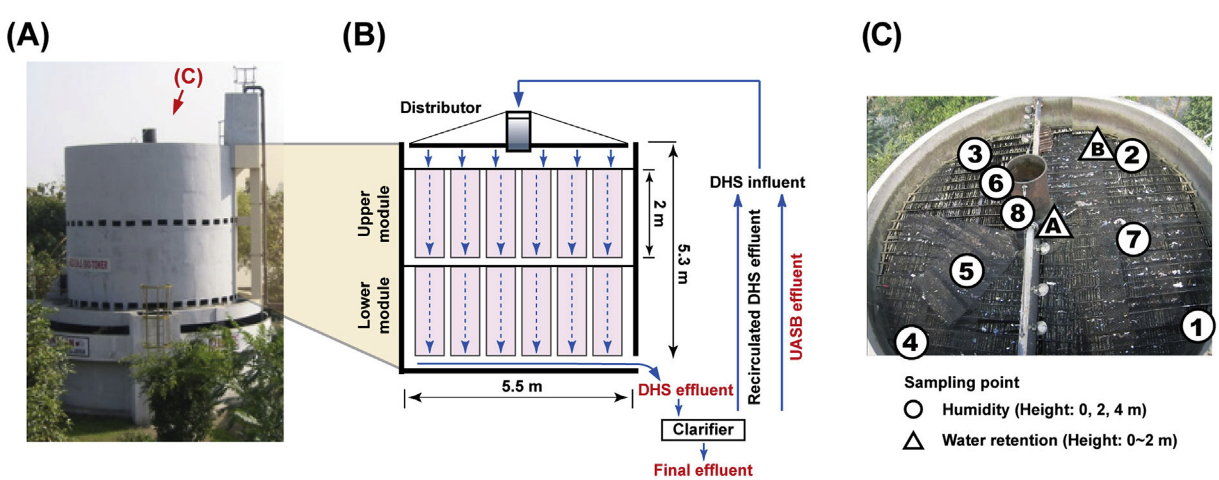

Fig. 1. (A) Image of the full-scale down-flow hanging sponge (DHS) reactor, (B) diagram of the hanging sponge module in the DHS reactor, and (C) humidity and water retention sampling points in the DHS reactor. Video data of the DHS reactor have been reported elsewhere (Onodera et al., 2016).

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