Development of simple and cost-effective treatment system for municipal wastewater

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Abstract

This study developed an alternative municipal sewage treatment system based on the pilot- and full-scale experiments. This proposed system consisting of upflow anaerobic sludge blanket (UASB) and trickling filter using a polyurethane sponge as packing material. This aerobic process was originally developed and named as a down-flow hanging sponge (DHS). DHS reactors accomplished high process performance during pilot- and full-scale experiments in Japan and other countries. The effluent quality of the DHS reactors was comparable to that of activated sludge systems. Moreover, advantages of DHS reactors include simple operation and maintenance (O&M), no required oxygen supply, small land requirement, and less excess sludge production. Indeed, the estimated energy requirement and excess sludge production of UASB and DHS systems were found to be approximately 75 and 85 % lower than those of conventional activated sludge systems, respectively. The high process performance can be attributed to the fact that the DHS reactor maintains much of the sludge in the reactor at concentrations 5–10 times higher than activated sludge. This indicates that DHS reactors have the potential for use as reliable, affordable, and efficient treatment systems, and can be used widely including developing countries.

Key words: municipal wastewater, down-flow hanging sponge (DHS)

Introduction

Providing appropriate wastewater treatments is a challenge, especially in developing countries that have limited budgets, lack of technical skills, and less available land. During construction of wastewater treatment plants (WWTPs), appropriate treatment systems need to be selected to reduce the risk of future problems and failures. For selection of systems, many parameters should be considered, including economic, institutional and political, climatic, environmental, land availability/properties, sociocultural, and other local issues (Tsagarakis et al., 2001).

Because of its simplicity, the upflow anaerobic sludge blanket (UASB) process as anaerobic treatment is becoming increasingly popular, especially in developing countries under hot climate conditions. The UASB reactor offers advantages over other conventional process such as the activate sludge process, including lower energy consumption, lower excess sludge production, and simple operation and maintenance. However, the UASB reactor alone is not sufficient for wastewater treatment, because the final effluent does not consistently meet local discharge and reuse standards. Therefore, appropriate post-treatment processes are required for further treating the UASB effluent. Post-treatment process performance was evaluated in a number of studies, but most of the processes have still only been tested on a small scale (Kassab et al., 2010).

Because post-treatment has not yet been established using conventional biological processes, we have developed a novel treatment process named down-flow hanging sponge (DHS) as simple and cost-effective treatment concept. The different configuration of DHS reactor has been proposed to focus on the applicability emphasizing features such as the compactness and easy construction of the process. In addition, the fundamental study focusing on microbial composition in the DHS process has been conducted. As a result of the considerable progress on the DHS technology, pilot- and full-scale reactors was constructed to demonstrate the process performance in Japan and other countries. This paper introduces the basic concept and treatment mechanism of DHS, review its history of development, summarize the recent successful performance, and outlook for this technology.

Concept and treatment mechanism of DHS

The basic configuration of the DHS reactor is similar to the configuration of a trickling filter, except that the packing material in the DHS reactor is polyurethane sponge. Polyurethane sponge is insoluble, not biodegradable, low cost, and highly mechanically stable. Furthermore, sponge material has a void ratio of more than 95%. Therefore, unlike the stone and plastic media used in a trickling filter system, the sponge media provide a three-dimensional space on which biomass can grow and be retained within the reactor. As a result, much higher biomass was obtained in a DHS reactor than in a trickling filter system. The enormous amount of biomass and very long SRT expedite the treatment process. The long SRT facilitates growth and retention of slow growing nitrifying bacteria (Araki et al., 1999), which would lead to higher nitrification efficiency. Moreover, the DHS method provides adequate time for self-degradation of any attached biomass, reducing the production of excess sludge from the process (Onodera et al., 2013). The long SRT also may contribute for growth of bigger organisms such as bacterial predators like protozoa and metazoa in the DHS reactor (Onodera et al., 2013). Wastewater, distributed from the top of the DHS reactor, trickles down through the sponge media and collects at the bottom of the reactor (Okubo et al., 2015). Because of high potential of sponge media for water retention, the wastewater was treated under longer retention conditions in the DHS process (Onodera et al., 2015a). As a result of plug-flow regime, the organic removal followed by nitrification was conducted in the DHS reactor and it is shown ammonium oxidizing bacteria were dominant in the lower parts of the DHS reactor (Kubota et al., 2014).

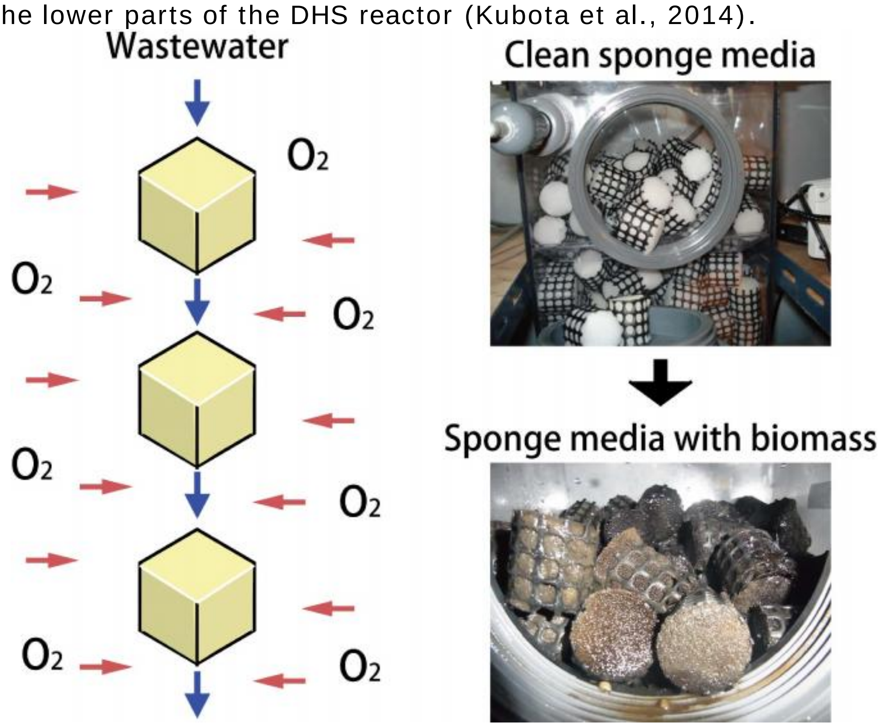

Figure 1. Concept and treatment mechanism of DHS

Reactor experiment of DHS technology

Base on the DHS concept, the different configuration of DHS reactor has been proposed to focus on the applicability emphasizing features such as the compactness and easy construction of the process (Figure 2). In brief, the configuration of the DHS-G1 reactor was sponge cubes (1.5 cm each) connected to each other diagonally in series with a nylon string (Machdar et al., 1997; 2000). The DHS-G2 reactor had long triangular polyurethane sponge trips (75 cm in length and triangular sides of 3 cm) tiled on both sides of a plastic sheet (2 m height) with 0.9 cm (Machdar et al., 2000). The DHS-G3 reactor was like conventional TF type using sponge media consisting of small sponge pieces with an outer support material (Tawfik et al., 2006). The DHS-G4 reactor had box modules with long sponge strips (2.5 cm×2.5 cm×50 cm), which were placed inside a net-like cylindrical plastic cover to provide rigidity (Tandukar et al., 2005; 2006). The DHS-G5 reactor also had modules constructed by lining up several DHS-G2 type sponge sheets (Tandukar et al., 2007). The DHS-G6 reactor used rigid sponge media instead of soft polyurethane sponge media to simplify the reactor construction (Onodera et al., 2014a).

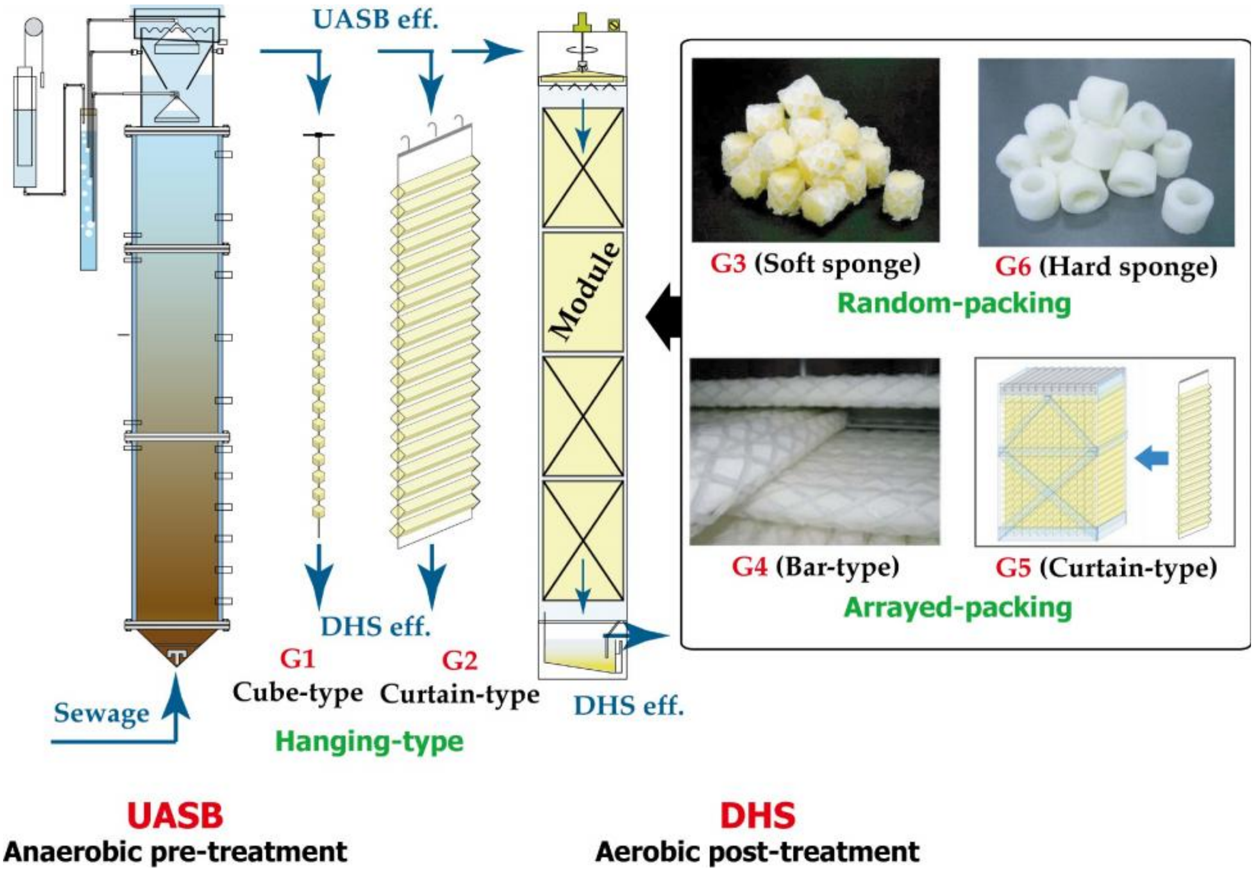

Figure 2. Configuration of DHS (generation 1 to 6)

Pilot- and full-scale experiment

The DHS has shown an excellent ability to polish the quality of UASB effluent in terms of SS, organic matters, ammonium, and pathogenic indicators in lab-scale and pilot-scale experiments (Machdar et al., 1997; 2000; Tandukar et al., 2007; Onodera et al., 2014a). A pilot-scale experiment on the UASB and DHS system at a flow rate of 50 m^3/day showed estimated energy requirement and excess sludge production of the system was approximately 75 and 85% lower than those of conventional activated sludge system, respectively (Tanaka et al., 2012). In addition, a pilot-scale experiment on DHS for direct treatment of low-strength municipal wastewater was performed for 1 year in Bangkok, Thailand. The DHS reactor retained dense sludge at 15.3–26.4 g VSS/L based on the sponge media volume, regardless of low influent organic concentration, resulting in superior effluent quality (Onodera et al., 2015a). Moreover, a full-scale DHS reactor at a flow rate of 500 m^3/day was constructed to demonstrate DHS process at an actual sewage treatment plant in India. The UASB+DHS system presented removal efficiency of 91% chemical oxygen demand $(COD)_{Cr}$, 95% biochemical oxygen demand (BOD), and 90% suspended solids (SS), producing the effluent with 37 mgCOD/L, 6 mgBOD/L and 19 mgSS/L (Okubo et al., 2015). The DHS reactor showed less excess sludge production of 0.04 kg SS/kg COD removed (0.12 kg SS/kg BOD removed) and low energy consumption of 0.12 kWh/m^3 (Okubo et al., 2015).

Outlook for DHS technology as sustainable wastewater treatment systems

The pilot- and full-scale experiment clearly indicated that DHS process can perform high performance and DHS was scaling up successfully. The long-term successful operation can be attributed to simple operation and maintenance. For long-term operational success, operational and maintenance simplicity of the treatment system is required to contribute reliability and affordability (Singhirunnusorn and Stenstrom, 2009). Moreover, the DHS reactor needed low energy consumption of 0.12 kWh/m^3 and produced low excess sludge of 0.12 kg SS/kg BOD removed (Okubo et al., 2015). This indicates that the DHS offer efficiency, reliability, and affordability, these elements are important for selecting appropriate technology in developing countries (Singhirunnusorn and Stenstrom, 2009). As a result of this successful full-scale experiment at a flow rate of 500 m^3/day (Okubo et al., 2015), another full-scale DHS reactor has been constructed at a flow rate of 5,000 m^3/day and operated since 2014 at Agra, Uttar Pradesh, India. We expect that the DHS technology might be distributed for many countries in future.

Conclusions

The successful reactor operation of the pilot- and full-scale experiments indicates that the DHS reactor have sufficient applicability (i.e., efficiency, reliability, and affordability) for treatment of municipal wastewater.

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