Bioresource Technology 152 (2014) 93–100

Contents lists available at ScienceDirect

Bioresource Technology

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

Development of a sixth-generation down-flow hanging sponge (DHS) reactor using rigid sponge media for post-treatment of UASB treating municipal sewage

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HIGHLIGHTS

- A down-flow hanging sponge (DHS) reactor with rigid sponge media was developed.
- The hydraulic retention time (HRT) was 2 h and the reactor was operated for 2 y.
- The DHS reactor performed satisfactorily, especially for nitrification.
- The rigid sponge media gave a long HRT and a high biomass concentration.
- Ventilation was required to obtain satisfactory DHS reactor performance.

ARTICLE INFO

Article history:
Received 26 August 2013
Received in revised form 25 October 2013
Accepted 29 October 2013
Available online 7 November 2013

Keywords:
Down-flow hanging sponge
Packing material
Ventilation
Sewage treatment
Upflow anaerobic sludge blanket

ABSTRACT

A sixth-generation down-flow hanging sponge reactor (DHS-G6), using rigid sponge media, was developed as a novel aerobic post-treatment unit for upflow anaerobic sludge blanket (UASB) treating municipal sewage. The rigid sponge media were manufactured by copolymerizing polyurethane with epoxy resin. The UASB and DHS system had a hydraulic retention time (HRT) of 10.6 h (8.6 h for UASB and 2 h for DHS) when operated at 10–28 °C. The system gave reasonable organic and nitrogen removal efficiencies. The final effluent had a total biochemical oxygen demand of only 12 mg/L and a total Kjeldahl nitrogen content of 6 mg/L. The DHS reactor gave particularly good nitrification performance, which was attributed to the new rigid sponge media. The sponge media helped to provide a sufficient HRT, and retained a high biomass concentration, extending the solids retention time. The DHS reactor maintained a high dissolved oxygen concentration under natural ventilation.

1. Introduction

Selecting appropriate sewage treatments is difficult in most developing countries, because of limited resources and technical knowhow. Because of its simplicity, the upflow anaerobic sludge blanket (UASB) process is becoming increasingly popular, especially in developing countries that have hot climates. The UASB reactor offers advantages over other conventional processes, such as the activated sludge process, including lower energy consumption, lower excess sludge production, and simple operation and maintenance (Sato et al., 2006; Seghezzo et al., 1998; Uemura and Harada, 2000). However, the UASB reactor alone is not sufficient for wastewater treatment, because the final effluent does not consistently meet local discharge and reuse standards (Seghezzo et al., 1998; Uemura and Harada, 2000; Sato et al., 2006; Kassab et al., 2010). Consequently, appropriate post-treatment processes are required for further treating the UASB effluent. Post-treatment process performances have been evaluated in a number of studies, but most of the available post-treatment processes have still only been tested on a small scale (Kassab et al., 2010).

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0960-8524/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biortech.2013.10.106

The down-flow hanging sponge (DHS) reactor has recently emerged as a viable post-treatment process. Several pilot-scale studies of the DHS reactor have demonstrated that the process is an efficient post-treatment for UASB effluent, is simple to operate and maintain, and produces low amounts of excess sludge (Agrawal et al., 1997; Machdar et al., 2000; Tandukar et al., 2005). The DHS reactor performed reasonably well in a long-term, 1360-day study (Tandukar et al., 2006a) and has also been used to treat industrial wastewater (Uemura et al., 2010; El-Kamah et al., 2011). A large-scale DHS reactor, with a capacity of 500 m^3/day, has been successfully established and operated at the Karnal sewage treatment plant in India (Uemura and Harada, 2010).

The basic configuration of the DHS reactor is similar to the configuration of a trickling filter (TF), except that the packing material in the DHS reactor is polyurethane sponge. Unlike the stone, gravel, or plastic media used in a TF system, the sponge media provide a three-dimensional space on which biomass can grow and be retained within the reactor, resulting in much higher biomass concentrations in a DHS reactor than in a TF system. Wastewater, distributed from the top of the DHS reactor, trickles down through the sponge media and collects at the bottom of the reactor (Uemura and Harada, 2010). Several studies have already been performed to test the practical applicability of the DHS reactor using different configurations, and these configurations have been named the first- to the fifth-generation DHS (DHS-G1 to -G5) reactors.

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 (Agrawal et al., 1997; Machdar et al., 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, 2006b). The DHS-G5 reactor also had modules constructed by lining up several DHS-G2 type sponge sheets (Tandukar et al., 2007). All of the previous DHS reactors have used soft polyurethane sponge media, of different shapes and sizes, except for the oil palm fiber-based DHS reactor studied by Machdar and Faisal (2011).

In this study, instead of using a soft polyurethane sponge medium, we developed a rigid sponge medium, to simplify the reactor construction. The rigid sponge was manufactured by copolymerizing polyurethane with epoxy resin. The new DHS reactor, using rigid sponge media, is called the sixth-generation DHS (DHS-G6) reactor. The basic design of the reactor is similar to the design of the DHS-G3 reactor (Tawfik et al., 2006), in which the sponge media were randomly packed. However, the rigid sponge media do not require any support materials, such as rigid plastic enclosures, to prevent the sponge from collapsing. The absence of enclosures means that all of the sponge surface area is exposed to wastewater, enhancing the interactions between the wastewater, air, and biomass in the sponge. A better process efficiency can, therefore, be expected from the new DHS reactor.

The main objective of this study was to determine the performance of the DHS-G6 reactor for sewage treatment using rigid sponge media at ambient temperatures. We systematically and comprehensively evaluated all the essential characteristics of the packing material that affected the process performance with regard to (1) biomass concentration, (2) wastewater retention time, and (3) oxygen uptake. In addition, the effects of ventilation conditions on the oxygen concentration inside the DHS reactor, wastewater, and the overall process performance, were investigated.

2. Methods

2.1. Reactor configurations

A schematic diagram of the combined UASB and DHS-G6 system is shown in Fig. 1. The UASB and DHS system was installed at a municipal sewage treatment plant in Nagaoka City, Japan, and fed with raw sewage after a brief settling period. The 4-m-tall cylindrical UASB reactor had a volume of 155 L (column volume 120 L, gas solid separator volume 35 L). The DHS reactor consisted of four segments, each with a height of 76.5 cm and a diameter of 24 cm, separated by 15 cm connecting segments. The connecting segments had removable windows to allow the reactor to be ventilated and wastewater samples to be collected. The rigid sponge media were randomly packed inside the reactor segments, and the total media volume was 46 L, giving a material occupancy ratio of 33.8% (based on the reactor volume). A rotary distributor was set on top of the DHS reactor and a clarifier with a volume of 9.13 L was installed at the bottom of the reactor.

2.2. Rigid sponge media packing material

The rigid sponge media was like a small hollow tube, with external and internal diameters of 42 and 22 mm, respectively, and a height of 30 mm. Each sponge piece had a total exposed surface area of 8042 mm^2 and a total volume of 30,158 mm^3. The specific surface area, without considering the microstructure (pore structure), was 267 m^2/m^3. The average pore size was 1.6 mm,

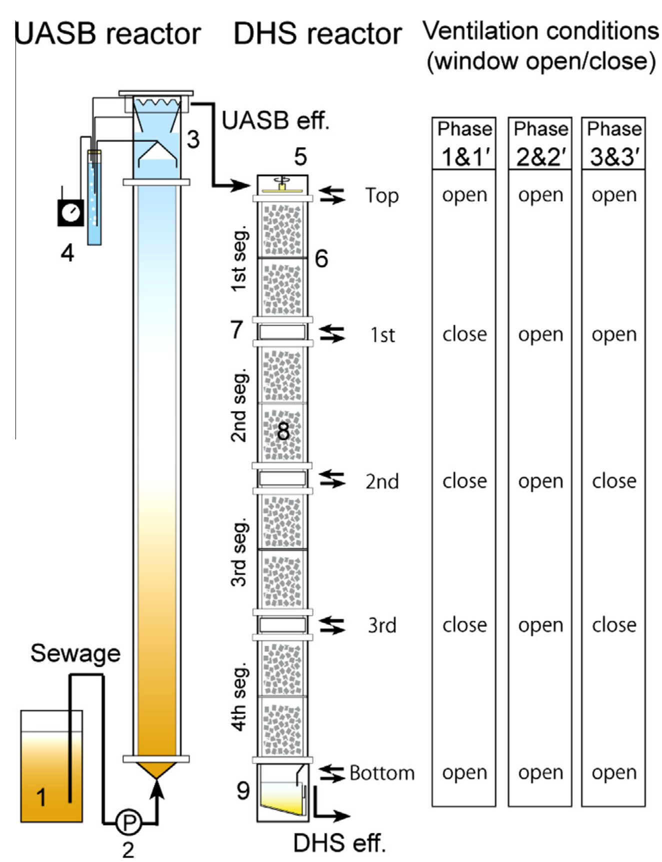

Fig. 1. Schematic diagram of the upflow anaerobic sludge blanket (UASB) and sixth-generation down-flow hanging sponge (DHS-G6) combined system. (1) Influent sewage tank; (2) pump; (3) gas solid separator (GSS); (4) gas meter; (5) distributor; (6) segment; (7) connecting segment (with window); (8) rigid sponge media; (9) clarifier. The ventilation conditions, altered using the connecting segment windows, used in Phases 1–3 and Phases 1–3′ are shown.