Bioresource Technology 204 (2016) 177–184

Contents lists available at ScienceDirect

Bioresource Technology

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

Long-term performance evaluation of down-flow hanging sponge reactor regarding nitrification in a full-scale experiment in India

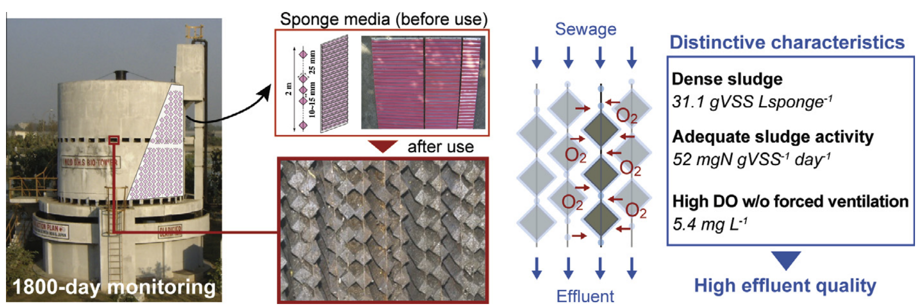
Takashi Onodera [a], Tsutomu Okubo [b], Shigeki Uemura [b], Takashi Yamaguchi [c], Akiyoshi Ohashi [d], Hideki Harada [e,*]

[a] Department of Regional Environmental Research Center, National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan
[b] Department of Civil and Environmental Engineering, National Institute of Technology, Kisarazu College, 2-11-1 Kiyomidaihigashi, Kisarazu, Chiba 292-0041, Japan
[c] Department of Civil and Environmental Engineering, Nagaoka University of Technology, 1603-1 Kamitomioka, Nagaoka, Niigata 940-2188, Japan
[d] Department of Social and Environmental Engineering, Hiroshima University, 1-4-1 Kagamiyama Higashi, Hiroshima 739-8527, Japan
[e] New Industry Creation Hatchery Center, Tohoku University, 6-6-04 Aoba, Aramakiaza, Aoba-ku, Sendai, Miyagi 980-8579, Japan

HIGHLIGHTS

- First full-scale DHS reactor was operated at 1.5-h HRT for over 1800 days in India.
- Removal efficiency of the DHS reactor was 79% for NH_4-N and 65% for TN.
- The DHS exhibited high DO, sludge concentration, and nitrification activity.
- A full-scale DHS is practically applicable to developing countries.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 11 November 2015
Received in revised form 4 January 2016
Accepted 5 January 2016
Available online 8 January 2016

Keywords:
Developing countries
Down-flow hanging sponge
Full-scale experiment
Municipal sewage
Nitrification

ABSTRACT

The first full-scale down-flow hanging sponge (DHS) reactor applied to post-treatment of effluent from an upflow anaerobic sludge blanket (UASB) reactor for the treatment of municipal sewage was evaluated, with emphasis on nitrification. The full-scale DHS reactor was successfully operated at a hydraulic retention time of 1.5 h for over 1800 days in India. The DHS reactor produced effluent with 6 mg L^{-1} ammonium nitrogen, corresponding to 79% removal efficiency. The total nitrogen removal by the DHS reactor was 65%. The high process performance of the DHS reactor was supported by its distinctive characteristics of (1) high dissolved oxygen of 5.4 mg L^{-1} in the DHS effluent without forced ventilation, (2) dense retained sludge in the range of 23–46 gVSS $Lsponge^{-1}$, and (3) adequate sludge activity of 52 mgN $gVSS^{-1}$ day^{-1} for nitrification. The full-scale experiment has proven that the DHS reactor has practical applicability to developing countries.

1. Introduction

To date, the combination of upflow anaerobic sludge blanket (UASB) and subsequent post-treatment processes has been recognized as an attractive alternative for treatment of municipal sewage, especially in developing countries (Kassab et al., 2010; Khan et al., 2011). The post-treatment process has been extensively developed using numerous conventional technologies, such as activated sludge (AS), trickling filters (TFs), rotating biological contactors (RBCs), and waste stabilization ponds, and the number of review papers on these technologies has increased in recent years (Chan et al., 2009; Chong et al., 2012; Kassab et al., 2010; Khan et al., 2011). However, these review papers point out that most

* Corresponding author.
E-mail address: hideki.harada.e3@tohoku.ac.jp (H. Harada).

http://dx.doi.org/10.1016/j.biortech.2016.01.005
0960-8524/

of the systems lack full-scale implementation, and further work is required to evaluate the full-scale performance.

To address the next challenge, a full-scale experiment using an aerobic post-treatment process called down-flow hanging sponge (DHS) has been conducted in India (Okubo et al., 2015). The DHS, a novel type of TF process using polyurethane sponge media as packing material, is recognized as a promising post-treatment alternative (Kassab et al., 2010). Unlike the gravel and plastic media, the sponge media provide a three-dimensional space for retention of sludge, resulting in much higher sludge concentration than in a conventional TF process (Onodera et al., 2015). The DHS reactor has advantages over other highly efficient processes, such as AS, including simple operation, easy maintenance, low operation and maintenance (O&M) costs and low excess sludge production (Tandukar et al., 2007). Although major disadvantages of the TF process are short resistance times, pumping costs, and biomass grazing by higher trophic organisms (Boller et al., 1994; Wik, 2003), the sponge media contribute to a longer residence time (Tandukar et al., 2006), compact reactor size provided by high sludge concentration (Onodera et al., 2013; Tandukar et al., 2007), and protection of the biomass against macrofauna over-grazing (Onodera et al., 2015). The bench-scale and pilot-scale DHS reactors have shown an excellent ability to polish the quality of UASB effluent in terms of suspended solids (SS), organic matter, ammonium, and pathogenic indicators (Machdar et al., 1997, 2000; Onodera et al., 2014; Tandukar et al., 2007; Tawfik et al., 2006). Moreover, the pilot-scale experiment using the combined UASB and DHS system with a flow rate of 50 m^3 day^{-1} showed that the estimated energy requirement and excess sludge production of the system were approximately 75% and 85% lower than those of the conventional AS process, respectively (Tanaka et al., 2012). Moreover, a full-scale DHS reactor with a flow rate of 500 m^3 day^{-1} was constructed at a municipal sewage treatment plant in India, and has shown high removal efficiency in terms of organic substances and SS, less excess sludge production, and low energy consumption (Okubo et al., 2015).

Despite the anaerobic process having little effect on nitrogen compounds (Chong et al., 2012), this previous report lacks any description of the process performance. Since there is increasing concern about the water environment and human health in developing countries, particular attention should be placed on the removal efficiency with regards to nitrogen. Indeed, the nitrification performance is sensitive to the conditions of the DHS reactor, which can be attributed to its functional characteristics of high dissolved oxygen (DO) uptake without forced ventilation (Onodera et al., 2014), dense sludge and nitrifying bacteria retention in the sponge media (Kubota et al., 2014), and vigorous microbial activity of the retained sludge (Machdar et al., 2000). Therefore, the evaluation of nitrification is useful to determine if the DHS reactor can be scaled up successfully. Moreover, it is important to prove the applicability of the full-scale DHS reactor to developing countries that have limited budgets, lack of technically skilled workers, and less available land. To this end, the affordability and simplicity as well as efficiency of the post-treatment process need to be evaluated.

The aim of this study is to evaluate the process performance with regard to nitrification of the full-scale DHS reactor. This paper focuses on the distinctive characteristics of the DHS process, including high DO uptake, dense sludge retention, and high sludge activity. The applicability of the DHS reactor was also assessed based on an on-site experiment during a long-term monitoring period of 1800 days at a municipal sewage treatment plant in India.

2. Methods

2.1. Reactor description and operating conditions

The full-scale DHS reactor was operated at a sewage treatment plant in Karnal, Haryana State, India. The sewage treatment plant comprised a UASB reactor and stabilization pond, referred to as a final polishing unit (FPU) in India. The design capacity of the sewage treatment plant was 40,000 m^3 day^{-1}. Images and a schematic diagram of the sewage treatment plant are shown in Fig. S1, and the operating conditions have been reported in detail elsewhere (Okubo et al., 2015).

Images and a schematic diagram of the full-scale DHS reactor are shown in Fig. S2, and the operating conditions are presented in Video Data 1. A concrete column with a height of 5.3 m and diameter of 5.5 m was constructed. The upper and lower sponge modules comprised 38 (upper module) and 43 (lower module) right triangular sponge bars (25 mm × 25 mm) that were tiled on serially connected plastic sheets measuring 2 m long and either 215 mm, 420 mm or 635 mm wide. The sponge volume was 12.6 m^3 and 18.5 m^3 in the upper and lower sponge modules, respectively; the total sponge volume was 31.1 m^3. The sponge occupancy was 24.7% based on the sponge and the reactor column volume. The sponge bars were horizontally tiled on the sheets at intervals of 10 mm and 15 mm for the upper and lower sponge modules, respectively. The sponge modules were hung at the appropriate intervals to allow fresh air to flow through the open spaces between the modules.

The full-scale DHS reactor was operated under ambient temperature and fed with a part of the UASB effluent at a rate of 500 m^3 day^{-1}. Half of the DHS settler effluent was mixed with UASB effluent in the receiving sump and then circulated to the top of the reactor (recirculation ratio: 100%). The wastewater was sprinkled from the hydraulically driven rotary distributor and then flowed down through the sponge modules. The reactor was equipped with a settler at the bottom of the concrete column with a hydraulic retention time (HRT) of approximately 2.5 h. The DHS reactor was operated at an HRT of 1.5 h based on the sponge volume. The recirculation rate and flow rate were temporarily changed during the monitoring on days 223–271, 312–397, and 566–595. The average data were obtained under normal operating conditions at a flow rate of 500 m^3 day^{-1} and recirculation ratio of 100%. Sludge control such as backwashing was not carried out during the operational period.

2.2. Analytical techniques

Samples of raw sewage, UASB effluent, DHS effluent, DHS settler effluent, and FPU effluent were collected by grab sampling between 8 and 10 a.m. Temperature, pH, and oxidation–reduction potential (ORP) were determined immediately after the sampling (pH meter: B212, Horiba, Kyoto, Japan, ORP meter: RM-30P, DKK-TOA, Tokyo, Japan). Routine analysis was carried out to monitor the following parameters: ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), total nitrogen (TN), and fecal coliforms. The water samples were passed through a glass filter (0.4 μm, GB-140, Advantec, Tokyo, Japan) to collect the SS and filtered samples. NH_4-N, nitrite nitrogen (NO_2-N), NO_3-N, and TN were analyzed using a HACH wastewater quality analyzer (DR-890, Hach, Loveland, Colorado, USA). Fecal coliforms, as indicator phathogens, were quantified by the most probable number (MPN) method using medium A1 (APHA, 1998). All other analytical procedures were done according to *standard methods* (APHA, 1998). TN was analyzed from day 926.