Ecological Engineering 97 (2016) 1–12

Contents lists available at ScienceDirect

Ecological Engineering

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

Performance evaluation of panelled anaerobic baffle-cum-filter reactor in treating municipal wastewater

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ARTICLE INFO

Article history:
Received 31 March 2015
Received in revised form 6 July 2016
Accepted 23 July 2016

Keywords:
Panelled anaerobic baffle-cum-filter reactor
Municipal wastewater
Decentralized wastewater treatment

ABSTRACT

A panelled anaerobic baffle-cum-filter reactor (PABFR) was developed to treat municipal wastewater in tropical climatic condition. The performance of the reactor was evaluated with respect to start-up mechanism, pollutant removal behaviour by varying hydraulic retention time (HRT) at different organic loading rates (OLR), resistance to shock loading, restart behaviour after a shutdown period and its potential to remove pathogen indicator. Acclimatization curve was plotted. It indicated a successful start-up period of 61 days with a COD removal efficiency of more than 90%. The alkalinity to volatile acid ratio was less than 0.5, which confirms reactor stability. Performance evaluation of the reactor was carried out for more than 682 days at 7 different HRTs ranging from 2 h to 40 h. The HRT of 8 h was found to be appropriate for PABFR configuration with removal efficiencies of 95%, 91% and 90% for suspended solids (SS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD), respectively. The recovery of the reactor after hydraulic shock (both transient and step) was two times better compared to conventional ABR because of the filter media present in the rear part of the PABFR. Reactivation after a short shutdown period was quick and yielded efficient treatment. The removal efficiency of the pathogen indicator was above 97.2% at a HRT of 8 h, but it is necessary to adopt appropriate post-treatment measures to guarantee reuse. Thus, with the above-mentioned properties, the PABFR is a suitable technology for decentralized municipal sewage treatment in suburban and rural areas of India.

1. Introduction

Water supply and sanitation are two of the most important and basic needs of human life. Almost 80% of water supplied for domestic use comes out as wastewater. In most of the cases,wastewater is let out untreated into the ground as potential pollutant of groundwater or discharged into nearby water bodies causing water pollution. In India, about 78% of the urban population have access to safe drinking water, but only 38% of the urban population have access to sanitation services (CPCB, 2009) like centralized treatment system. The status of municipal wastewater generation and treatment capacity in metropolitan cities (more than 10 lakhs population), class I cities (more than hundred thousand population) and Class II towns (fifty to hundred thousand population), according to the Central Pollution Control Board (2013) report,is shown in Table 1.

Thus, it is clear that those living in less developed and rural areas of India have no access to wastewater collection and treatment systems; they often dispose their wastewater improperly. Reusing or discharging untreated or insufficiently treated wastewater poses serious public and environmental health risks. Such impacts must be mitigated by finding affordable ways to treat wastewater (Moussavi et al., 2010). One solution to the present situation is decentralized treatment systems which are simple, cost effective and which operate at or near the point of waste generation from individual homes, clusters of homes, isolated and less developed communities or portions of larger existing communities that lack sewer systems (Gikas and Tchobanoglous, 2009).

From the foregoing discussion, it is seen that anaerobic digestion has higher potential in developing countries for decentralized municipal wastewater treatment, as it is suitable for tropical climate where artificial heating can be avoided, to cut down on costs (Aiyuk et al., 2006). The main drawback of anaerobic treatment is the long hydraulic retention time (HRT), which was overcome by the development of a number of high-rate processes that achieve separation between the hydraulic retention time (HRT) and the solid retention time (SRT). Though there are many high-

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http://dx.doi.org/10.1016/j.ecoleng.2016.07.020
0925-8574/

Table 1
Wastewater generation and treatment capacity(CPCB, 2013).

Type	Wastewater generation(MLD)	Total capacity of existing treatment plants(MLD)	Treated wastewater (%)
Metropolitan	15,644	8040	51
Class I City	35,558	11,553	32
Class II Town	26,967	2337	8

(CPCB, 2013).

Table 2
Filter media characteristics.

Description	Value
Specific surface area of the media (m^2/m^3)	400
Media height (mm)	16
Media diameter (mm)	22
Structure	Cylindrical with external fins
Specific gravity	0.95
Voidage(%)	>95

rate anaerobic reactors, one of the innovative designs developed by McCarty (1981) was an Anaerobic Baffled Reactor (ABR), which was described as a number of up-flow anaerobic sludge blanket (UASB) reactors connected in series (Barber and Stuckey., 1999). The baffles force wastewater to flow under and over them as the water passes from inlet to outlet and the bacteria within the reactor tend to rise and settle with gas production (Gopala Krishna et al., 2008). The up-flow chamber of the ABR is divided into three compartments from the bottom to the top as (a) sludge bed, (b) fluidized zone and (c) settling zone. The potential of ABR has been explored for the treatment of municipal wastewater by Barber and Stuckey (1999), Nasr et al. (2008), Feng et al. (2009), Bodke (2009), Sarathai et al. (2010), Liu et al. (2010), Feng et al. (2014), (Hahn and Figueroa 2016). The detailed review of ABR treating communal wastwater was well documented by Reynaud and Buckley (2016). ABR treating industrial wastewater like palm oil mill effluent (Faisal and Unno, 2001), acidic wastewater containing sulphate and zinc (Bayrakdar et al., 2009), pulp and paper (Zwain et al., 2016), biomethanation of vegetable market waste (Gulhane et al., 2016), wastewater from soybean protein processing (Zhu et al., 2008), food waste (Ahamed et al., 2015), nitrobenzene wastewater (Lin et al., 2012), and industrial azo dye effluent (Cui et al., 2014) were also studies.

The design and number of ABR compartments are found to underwent many modifications since its innovation; the stimulus behind the modification was to enhance solid retention, by changing hydraulic efficiency (mixing), number of compartments, recirculation, etc. in the reactor to improve the efficiency of the treatment processes. The modifications in the ABR was studied by many researchers, which are as follows, carrier ABR was studied by Huajun et al. (2008), in which the compartments of ABR was filled with carrier materials to improve the retention time of bacterial cells with very little loss of bacteria from the bioreactor and in addition, the bacteria could adhere on to the carrier material and grow. Bodkhe (2009) used a nine-chambered ABR. Han et al. (2004) modified the ABR, by created the fresh baffle with different crests to improve the hydraulic condition. Xu et al. (2016) studied the flow pattern and optimization of compartments and concluded that for best operating performance of the reactor and taking its economic factors into full consideration, the ABR compartments shall be kept between 4–5. Li et al. (2016) studied the hydraulic characteristics of MABR (4 compartments with the volume ratio of 3:1:5:5 and the baffles were transformed into a series of 120° angles, the peaks faced each other and the wave height was 20 mm) and elucidates that, larger the number of compartments in the reactor is, the smaller the amount of back-mixing occurrence. In the present study, the PABFR (Renuka et al., 2016) exhibits flow pattern intermediate between plow flow (PF) and continuous stirred tank reactor (CSTR) in the ABR part and becomes completely PF in the AF compartments. Therefore it is mentioned that superior design requires in-depth understanding of the hydrodynamics (flow pattern) within the system, by considering the geometry (number of chambers, baffle positioning, number of baffles, filter media characteristics) of the reactor for better performance. thus many researchers all over the world continued studying the ABR technology by modifying the basic configuration to obtain superior treatment efficiencies.

In this study, anaerobic baffled reactor and anaerobic filter were integrated into one single unit as Panelled Anaerobic Baffle-cum-Filter Reactor (PABFR). The idea behind this postulate is that it carries the reward of up-flow anaerobic sludge blanket reactor (UASB), anaerobic baffled reactor (ABR) and anaerobic filter (AF). The objective of the study was to find the performance efficiency of the PABFR in treating municipal wastewater during the start-up process, steady-state operation at varying HRTs, the ability of reactor to resist hydraulic shock loads, restart of reactor after starvation and efficiency of reactor in pathogen indicator removal.

2. Methodology

2.1. Experimental set-up of panelled anaerobic baffle-cum-filter reactor (PABFR)

The schematic diagram of the experimental set-up of the PABFR is presented in Fig. 1. The reactor was made of transparent plexiglass of 6 mm thickness. The length, breadth and height of the reactor were 60, 48 and 40 cm, respectively. The reactor consisted of 5 chambers, namely, 3 up-flow anaerobic baffled chambers (ABR1, ABR2 and ABR3) followed by 2 anaerobic filter chambers (AF1 and AF2) of equal size, shape and volume, connected in series as shown in Fig. 1. To collect the biogas produced, five separate gas manifolds were provided and the biogas was finally let into the biogas measurement unit (Ritter milligas flow meter., Germany). The liquid and sludge samples were collected from the ports placed at the top and bottom of all the five chambers in the reactor. The individual chamber was again divided into two by a hanging baffle, namely down-comer and up-comer. The ratio between the up-comer and the down-comer was maintained at 1:3, and the bottom portion of the baffle was inclined at 45° and in addition three more baffles were also placed on both sides of the inner wall. The anaerobic filter chambers were filled with plastic pall ring media. The description of the filter media is given in Table 2. The total volume of the PABFR was 115 L with a net working volume of 100 L. The volume of the individual sets of chambers (ABR1, ABR2, ABR3, AF1 and AF2) was 20 L. The net volumes of the down-comer and the up-comer were 5 and 15 L, respectively.

2.2. Wastewater feed and flow pattern

Municipal wastewater generated mainly from Anna University campus and residential quarters located at Kotturpuram, Chennai, was used as the feed of the reactor throughout the investigation. Raw wastewater was pumped into the experimental set-up with the help of a peristaltic pump and a flow regulator at varying flow rates. The PABFR was operated at various hydraulic retention times(HRT) thereby varying the organic loading rate (OLR). The average composition of municipal wastewater is shown in Table 3. Wastewater flows from the down-comer to the up-comer, within an individual chamber through the sludge bed formed at the bottom of the individual chambers. After treatment in a particular chamber, wastewater enters the next chamber from the top. Due to the