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An innovative approach to minimize excess sludge production in sewage treatment using integrated bioreactors

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ABSTRACT

The present investigation deals with an application of integrated sequential oxic and anoxic bioreactor (SOABR) and fluidized immobilized cell carbon oxidation (FICCO) reactor for the treatment of domestic wastewater with minimum sludge generation. The performance of integrated SOABR-FICCO system was evaluated on treating the domestic wastewater at hydraulic retention time (HRT) of 3 hr and 6 hr for 120 days at organic loading rate (OLR) of 191 ± 31 mg/(L·hr). The influent wastewater was characterized by chemical oxygen demand (COD) 573 ± 93 mg/L; biochemical oxygen demand (BOD_5) 197 ± 35 mg/L and total suspended solids (TSS) 450 ± 136 mg/L. The integrated SOABR-FICCO reactors have established a significant removal of COD by 94% ± 1%, BOD_5 by 95% ± 0.6% and TSS by 95% ± 4% with treated domestic wastewater characteristics COD 33 ± 5 mg/L; BOD_5 9 ± 0.8 mg/L and TSS 17 ± 9 mg/L under continuous mode of operation for 120 days. The mass of dry sludge generated from SOABR-FICCO system was 22.9 g/m^3. The sludge volume index of sludge formed in the SOABR reactor was 32 mL/g and in FICCO reactor it was 46 mL/g. The sludge formed in SOABR and FICCO reactor was characterized by TGA, DSC and SEM analysis. Overall, the results demonstrated that the integrated SOABR-FICCO reactors substantially removed the pollution parameters from domestic wastewater with minimum sludge production.

Introduction

The environmental management on liquid and solid wastes generated due to human activities has become increasingly critical due to increase in worldwide population growth. The aerobic biological process in conventional wastewater treatment system is the major unit operation followed for the treatment of domestic wastewater. However, the aerobic biological treatment process generates huge quantity of sludge owing to high concentration of suspended solids and biodegradable organic compounds present in the wastewater. Hence, anaerobic system has been considered to reduce sludge production and thereby to eliminate sludge disposal problems (Vorosmarty et al., 2010; Mungray and Patel, 2011; Pontes and De Lemos Chernicharo, 2011). Many integrated anaerobic and aerobic biological treatment technologies have been developed for the treatment of domestic wastewater (Watanabe et al., 2016). The upflow anaerobic sludge blanket (UASB) system was developed for the effective treatment of domestic wastewater. Although UASB treatment process is widely practiced, it has certain disadvantages such as high operation cost and extensive foot print requirement and

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applicability only to selective industrial wastewater (Buntner et al., 2013; Abbasi and Abbasi, 2012; Luciano et al., 2012; Wang et al., 2014). The global standards, made stringent on disposal of wastewater and solid waste (Verlicchi et al., 2011), demand the development of more efficient treatment technologies that have features such as minimum foot print requirement, less electric energy consumption and minimum sludge generation. Researchers have developed hybrid UASB reactor, membrane bioreactor (Lin et al., 2012; Buntner et al., 2013; Qiu et al., 2013; Wang et al., 2014), aerated bio filter (Chung et al., 2016), sequential batch reactor (Moawad et al., 2009), down-flow hanging system (Tandukar et al., 2007), Chemo autotrophic activated carbon oxidation system (Sekaran et al., 2007) *etc.* for the treatment of wastewater. Despite these technologies address efficient removal of organic pollutants and they generate huge quantity of sludge. There are reports on biofilm reactors to reduce the sludge production and low operational cost for treatment of sewage (Tawfik et al., 2010, 2012; Khan et al., 2015; Chatterjee et al., 2016; Deng et al., 2016). Biofilm reactor technology has been regarded as the simplest in design, flexible in operation and compact in space requirement for the treatment of wastewater. It served as an added advantage on freely moving carriers in the reactor to support biofilm development (Ødegaard et al., 2000; Leyva-Díaz et al., 2013). The design and operation of sequential oxic and anoxic zones in biological reactor improved the nutrients removal and anoxic zone facilitated the supporting area for sludge digestion (Wei et al., 2013). Design aspect of the sequential oxic and anoxic biofilm reactor with plastic material as carrier matrix for biofilm growth forms the novel part of the present investigation.

The biofilm moving bed reactors are known to produce less quantity of sludge than in activated sludge processes because of the longer food chains in biofilms under continuous operating conditions (Zhang et al., 2017; Leyva-Díaz et al., 2013; Qi et al., 2014). The sequential oxic and anoxic biofilm reactor (SOABR) is non cloggable under continuous mode of operation, it does not need backwashing and it has low head loss with high specific biofilm surface area. The biofilm attached carrier matrices move under constant motion throughout the entire volume of the reactor and the sloughed biomass from the carrier matrices is considered to be the sludge (Qiqi et al., 2012; Leyva-Díaz et al., 2013). The nutrient removal in SOABR was rate limitation process. So, the fluidized immobilized cell carbon oxidation (FICCO) reactor with hydraulic retention time (HRT) of 6 hr was operated sequentially after SOABR for the efficient removal of organics by immobilized microbial mass in the carbon matrix and microalgae biofilm in plastic carrier media. The effective removal of nutrients in sewage was possible through microalgae biofilm (Ruiz-Marin et al., 2010; Gao et al., 2015). The operation of SOABR fallowed by FICCO reactors have high sludge retention time with minimum sludge generation.

The disposal of the sludge generated from conventional treatment process becomes a confronting environmental issue to the industries. Hence, a technology for the efficient removal of organics with minimum sludge production is the hour of need. Hence, the present investigation was focused on the treatment of domestic wastewater using integrated SOABR with FICCO reactor to minimize sludge generation.

1. Experimental methods

1.1. Reactor design

A rectangular shaped bench top laboratory-scale SOABR was designed and fabricated using transparent acrylic sheets. The SOABR consists of three compartments of equal size (24 cm (L) × 24 cm (b) × 36 cm (H) with a capacity of 16 L which were connected internally in series as shown in Fig. 1. The bottom of the reactor was sloped at 8° with the base to increase the efficiency of flow dynamics of suspended particles present in the wastewater. The carrier matrices (cylindrical shaped packing material, diameter 21 mm) were filled by about 20% volume of the reactor (working volume fraction) for the growth of biofilm.

The modified FICCO reactor (volume, 32 L) was designed and fabricated with some modifications as reported by Karthikeyan et al. (2015). The FICCO reactor contains a triangular septum and the zone below this is kept under fluidization to hydrolyse the organic chemicals, and the zone placed above the triangular septum contains a hopper vessel with an aperture to facilitate wastewater to enter. The hopper zone contains packing carrier matrices to promote microalgae biofilm growth using the nutrients from the treated wastewater in the reactor.

The schematic process flow diagram of integrated SOABR with FICCO (SOABR–FICCO) reactor is shown in Fig. 1. The domestic wastewater collected from the sewage collection tank located in a residential colony, Central Leather Research Institute, Chennai (India) was applied twice in a day. The study was performed for 120 days with HRT of 3 hr in SOABR and 6 hr in FICCO reactor.

1.2. Physico-chemical analysis of the wastewater

The samples were collected at regular time intervals for the analyses of turbidity @ λ_{600} nm, chemical oxygen demand (COD), bio-chemical oxygen demand (BOD_5), total solids (TS), total dissolved solids (TDS) and total suspended solids (TSS) in accordance with the methods summarized in the standard methods for the analysis of wastewater (APHA-standard methods, 1998). Total solids of the wastewater sample was determined by weighing the mixed liquor samples collected from the reactor before and after drying at 105°C. The biomass concentration in terms of the mixed liquor volatile suspended solid (MLVSS) was analysed by loss on ignition at 600°C for 2 hr. The sludge volume index (SVI) is considered as the volume of (mL) unit weight of activated sludge that settled in 30 min (APHA-standard methods, 1998).

$$\mathrm{SVI}\left(\frac{\mathrm{mL}}{\mathrm{g}}\right)=\frac{1000H_{30}}{H_0A_0} \quad (1)$$

where H_{30} is the height of sludge in mL after 30 min of settling, H_0 is the initial height of the slurry in L and A_0 (mg/L) is the initial mixed liquor suspended solid concentration in the slurry.

1.3. TGA and DSC analyses for SOABR and FICCO sludge

Required quantity (8–10 mg) of dry sludge from SOABR or FICCO reactor after continuous mode of operation was loaded in a platinum TGA pan and thermo gravimetric analysis (TGA)