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Start-up and performance of a hybrid anoxic reactor for biological denitrification

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HIGHLIGHTS

- ▸ A hybrid reactor was studied for its application to denitrification of wastewaters.
- ▸ Microbial granules developed in the reactor within 15 day of reactor start-up.
- ▸ Complete nitrate removal was possible at 740 g NO_3–N/m^3 day loading at an HRT of 6 h.
- ▸ Complete denitrification resulted at a COD/NO_3–N ratio as low as 2.2.
- ▸ Denitrification efficiency was more than 95% on industrial wastewater.

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ABSTRACT

This study was aimed at denitrification of wastewater using a hybrid anoxic reactor (HAR), which uses self immobilized microbial granules under fluidized condition. Granulation of the denitrifying biomass was studied in the HAR with methanol and acetate as carbon sources. It was observed that by the end of 15 day almost spherical granules with a settling velocity of 1.5 cm/s and a mean diameter of 0.5 mm were produced. By stepwise increment of the influent nitrate concentration, the removal rate reached 740 g NO_3–N/m^3 day with a removal efficiency of almost 100% at a hydraulic retention time of 6 h or higher. For complete denitrification, the ratio of the organic substrate required to amount of nitrate nitrogen removed was as low as 2.2 g COD/g NO_3–N. The study was then extended to denitrifying a nitrified toxic industrial effluent. Denitrification was on par with the synthetic wastewater and efficiency of more than 95% was achieved.

1. Introduction

The removal of nitrogen, present in the form of organic/ammoniacal or nitrate nitrogen, from wastewater is of great interest because excessive nitrate in groundwater and surface waters is linked to various health and environmental issues (Sun and Nemati, 2012). Biological nitrogen removal is considered to be the most promising approach for removal of nitrogen compounds from wastewaters (Zhu et al., 2007). It takes place in two steps, nitrification followed by denitrification, both of which are carried out by a different group of microorganisms. Nitrification and denitrification are different metabolic processes which puts forth the need for a separate reactor for the denitrification reaction.

Biological denitrification is the dissimilative reduction of nitrate (NO_3^-) to nitrogen gas (N_2), through the production of nitrite (NO_2^-) and gaseous nitric oxide (NO) and nitrous oxide (N_2O) intermediates. Free nitrogen is the major component of air and its release does not cause any environmental concern. Biological denitrification takes place when the dissolved oxygen concentration is less than 0.5 mg/L, ideally less than 0.2 mg/L, and uses nitrate as a terminal electron acceptor in the presence of an electron donor as a carbon and energy source (Skerman and MacRae, 1957; Van Haandel and Van der Lubbe, 2007). It is carried out by a group of facultative heterotrophic microbes which include *Pseudomonas*, *Paracoccus*, *Flavobacterium*, *Alcaligene*, and *Bacillus* spp. (Koren et al., 2000).

Adaptation of new technologies and modification of existing technologies for wastewater treatment are important for a sustainable future. The novel Hybrid Anoxic Reactor (HAR) is one such system designed and developed at the Waste Treatment Laboratory, Department of Biochemical Engineering and Biotechnology, IIT Delhi, for biological wastewater treatment. In this reactor, self immobilized microbial granules, which are formed without any support, are used under fluidized conditions. The HAR combines the advantages of an Upflow Anaerobic Sludge Blanket (UASB) reactor and the Anaerobic Fluidized Bed Reactor (AFBR), both of which have been successfully used for anaerobic treatment of wastewater (Lettinga et al., 1980; Lettinga and Hulshoff Pol,

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1986; Barros et al., 2010). It has the advantages of both attached growth systems and suspended growth systems. This reduces the size of the reactor without hampering the mass transfer rate. Also, it is resistant to shock loads and unfavourable conditions for growth. Because of the granular structure, a more favourable micro-environment can be maintained within the aggregates so that the metabolism can be sustained. However, it should be noted that the particle size should remain small in order to prevent serious diffusion limitation in the granules. In the HAR, a higher superficial liquid velocity than that normally used in a UASB reactor is applied (>4 m/h as compared to 1 m/h in a UASB reactor) to fluidize the bed of granulated sludge (Saravanan and Sreekrishnan, 2005). Because of the higher up flow velocities, mainly granular sludge will be retained in the system and a significant part of granular sludge bed will be in a fluidized state characterizing a fluidized bed reactor. As a result, there is better contact between the wastewater and sludge. Moreover, the transport of substrate into the sludge aggregates is much better as compared to situations where the mixing intensity is lower such as in a UASB. Owing to the various advantages explained above, it was possible for Kumar et al. (2008) to successfully test and use the HAR for the anaerobic treatment of low strength industrial wastewaters.

The key to the success of UASB reactor was the discovery that anaerobic sludge inherently had the capability to form self immobilized granules, provided the physical and chemical conditions for sludge flocculation were favourable. It was subsequently found that denitrifying bacteria were also able to create well-sedimented granules (Green et al., 1994; Jin et al., 2012). However the major disadvantage of such systems is the requirement of long start-up period, typically of the order of 1–8 months, along with the requirement of a sufficient amount of granular seed sludge for faster start-up (Lettinga et al., 1980; Green et al., 1994). Studies on the rapid granulation of biomass would widen the field level use of microbial granulation technology for wastewater treatment. Granulation of biomass and the properties of the granules depend on the source of inoculum (activated sludge, anaerobic or anoxic granulated sludge), the type of organic source, water hardness (higher hardness encourages granulation) and ratio of organic substrate to nitrate nitrogen (COD to NO_3–N ratio) (Pagáčová et al., 2009).

The present work was taken up to study the rapid granulation of denitrifying biomass in the HAR and to study its nitrate removal (denitrification) efficiency using synthetic wastewater. The performance of the reactor at different nitrate loadings was also studied. Most of the studies on biological nitrogen removal have been done using synthetic wastewater, but few studies focused on real industrial wastewater have been published. The way the biomass reacts to industrial wastewaters is different to that of synthetic wastewater because the industrial effluents may contain a variety of unknown substances that could inhibit the biological process. Hence this study was extended to observe the effect of actual wastewaters on the granular microbes and the denitrification efficiency of HAR. The possibility of field application of the HAR for denitrification of industrial wastewaters was also analyzed. For the actual field deployment of the HAR, effluent NO_3–N concentration below 10 mg/L is required to meet the local discharge standard for discharge in inland surface waters.

2. Methods

2.1. Reactor

Glass-made HAR with a working volume of 550 mL was used for the lab-scale experiments. Since the reaction and separation occur in the same vessel, no separate settling tanks were used. Influent was continuously provided to HAR from the bottom of the reactor using a peristaltic pump. Recirculation of the effluent was done using another peristaltic pump. The peristaltic pump was calibrated to give a superficial liquid velocity less than 2 m/h during reactor start-up (first 3 days) and 4 m/h and above thereafter, for fluidization. The schematic diagram of the lab-scale hybrid reactor setup is shown in Fig. 1a. Silicone tubes with inner diameter of 6.4 mm were used for all connections and in the peristaltic pump for recirculation. For feeding, silicone tube with an inner diameter of 2 mm was used. All open end outlets were water sealed to maintain anoxic condition.

For denitrification of the industrial effluent, stainless steel reactor, with a working volume of 34 L, was constructed with the dimensions as shown in Fig. 1b. Feeding and effluent recirculation with a liquid superficial velocity in excess of 4 m/s was achieved using centrifugal pumps. The industrial wastewater was fed from the bottom and exit was from the top of the reactor. Vinyl tubing of inner diameter 12.7 mm was used for all connections. All open end outlets were water sealed to maintain anoxic condition.

2.2. Wastewater and feed

During the initial granulation studies synthetic wastewater was prepared using tap water containing basic nutrients required for growth and granulation. Synthetic wastewater of the following composition was used: Carbon source (methanol/acetate) – 0.75 gCOD/L, yeast extract – 1 g/L, di-potassium hydrogen phosphate – 1.74 g/L, potassium di-hydrogen phosphate – 1.36 g/L, sodium nitrate – 0.3 g/L, sodium chloride – 5 g/L, calcium chloride – 0.3 g/L. Nitrate, provided as sodium nitrate, was the sole pollutant to monitor denitrification. Calcium chloride and sodium

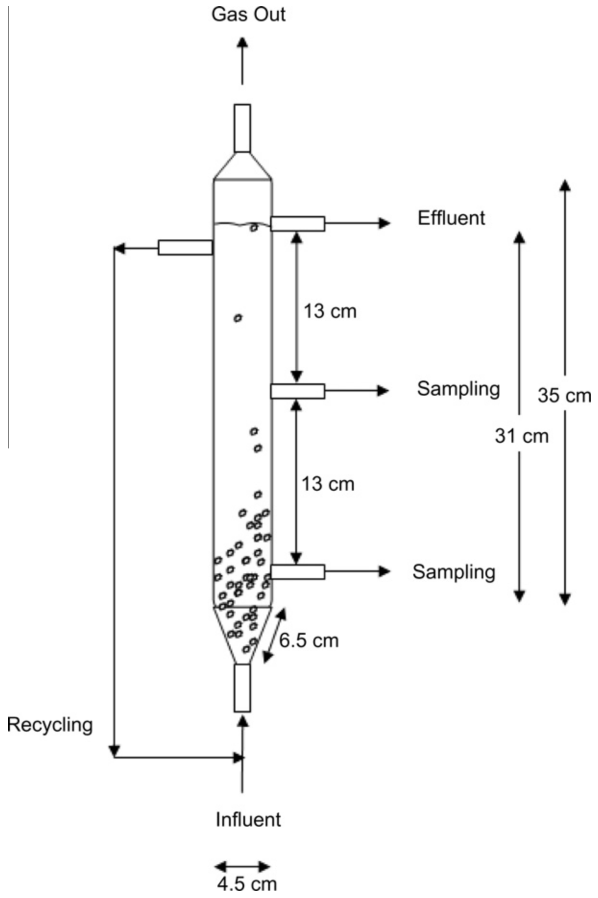

Fig. 1a. Schematic of the lab-scale hybrid reactor (not to scale).