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Research article

Investigation of a new double-stage aerobic-anoxic continuous-flow cyclic baffled bioreactor efficiency for wastewater nutrient removal

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ABSTRACT

Nitrogen and phosphorus are among the potential pollutants of receptive water sources entering into these water sources via sewage, which are not sufficiently treated. The purpose of this study is to investigate the efficiency of a new two-stage aerobic-anoxic continuous-flow baffled cycling reactor (CFBCR) to reduce nitrogen and phosphorus load from wastewater. Therefore, a double-stage baffled reactor was used in which the second part was integrated with the settling part causing the sludge to be spontaneously returned to the second reservoir. Additionally, the effect of different concentrations of chemical oxygen demand (COD) of 400–800 mg/L, ammonia of 40–60 mg/L, phosphate of 12–20 mg/L, internal rate of return of 100–200% and the retention time of 18–30 h was investigated. Furthermore, to investigate the performance of this reactor, four phases with different aeration and mixing conditions were designed. The percentage of ammonia removal with influent concentration of 40 mg/L in phase 2 with intermittent mixing and one-hour aeration time was 98.7%; effluent nitrate average concentration was 8.4 mg/L NO_3-N, and phosphate removal percent was 83%. The best nutrient removal efficiency was with the retention time of 24 h and internal return rate of 150%. In conclusion, CFBCR reactor with continuous influent and effluent and reduction of the need for sludge return, has the potential to be applied to remove nutrients from wastewater.

1. Introduction

Concerning urban development and economic growth, increase in population and climate change, changing of water consumption patterns and the resulting rise of demand, shortage of clean water sources have become a concern all over the world (Azhdarpoor et al. 2014a, 2014b; Yavari et al., 2017). High levels of nutrients (mainly nitrogen and phosphorus) in surface water can lead to negative impacts on water quality such as growing of harmful alga, lack of oxygen in the oceans and contamination of drinking water sources. Methods of removing nutrients from wastewater include physical, chemical, physicochemical and biological methods (Meffe et al., 2016). Biological methods of wastewater treatment, due to their compatibility with the environment, lower cost, less sludge production, and higher flexibility compared to other methods, are one of the important priorities of environmental engineering (Ramalho, 2012). Among various biological processes, nitrification and denitrification processes have been considered due to their simplicity and economic benefits. Nitrification is carried out in two stages. First, ammonia is converted into nitrite, and in the second step, nitrite is converted to nitrate. Biological denitrification is also a sequential reaction involving the reduction of nitrate to nitrite and ultimately the conversion of nitrite to nitrogen gas by nitrate reductase and nitrite reductase enzymes (Hua et al., 2016). Design of biological wastewater treatment systems is useful for simultaneous removal of chemical oxygen demand (COD), total nitrogen (TN) and total phosphorus (TP) in a single system for wastewater treatment and environment protection (Sibag and Kim, 2012). In addition, removing nitrogen and phosphorus simultaneously can reduce the need for a carbon source, reduce aeration costs, result in lower cellular efficiency and, consequently, cause less sludge to be produced. Furthermore, by using a single reactor, the complexities of operation, and the subsequent costs are lowered (Wang et al., 2014). Biological nutrient removal processes include Phordox (A/O), A2/O, Five Step Bardenpho process, Cape Town University process (UCT), Modified UCT, VIP (Virginia Initiative Plant), Phostrip Processes and Sequencing Batch Reactor (SBR) processes (Liu and

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Wang, 2017). The A/O process is an anaerobic-aerobic process designed for reducing phosphorus. The main points of this process are its short hydraulic retention times (HRT), high input organic load, production of depositing sludge, and efficient removal of phosphorus; however, it lacks the ability of simultaneous removal of nitrogen and phosphorus, and its flexibility in controlling the process is low (Dubber and Gray, 2011). Recently, SBR systems have been modified by adjusting the steps in the react cycle to provide anaerobic and aerobic phases in certain numbers and sequences for biological nutrient (C, N, and P) removal (Yi Jing Chan et al., 2009). However, the flow in this process is discontinuous and it requires more sophisticated designing, and the operations in its other processes are also complicated (Dubber and Gray, 2011). In the present study, a double-stage baffled reactor was used in which the second part was integrated with the settling part resulting the sludge to be spontaneously returned to the second reservoir. Moreover, in both parts, the aeration and mixing units were alternately used so that the aeration(aerobic) of the first part operated simultaneously with mixing(anoxic) the second part and aerating the second part work by mixing in the first part to allow alternating anoxic and aerobic conditions without interrupting influent and effluent wastewater. The main idea behind the invention of this new reactor, something which was not done in previous studies, was devising a process whereby the A/O and SBR methods are combined to add and boost the advantages of both systems and reduce their drawbacks. In addition, with designing this reactor, spontaneous return of sludge from the settling part was carried out, facilitating the operation; this simplification of the process led to cost savings. Therefore, the purpose of this study was to apply a continuous-flow baffled cycling reactor (CFBCR) for simultaneous removal of phosphorus and nitrogen from wastewater and to examine the effect of different operational parameters on the reactor performance. The result of this study could lead to developments in wastewater treatment system using the devised continuous flow aerobic-anoxic cyclic baffled reactor to remove nitrogen and phosphorus.

2. Materials and methods

2.1. Reactor configuration

The reactor used in this study was a plexiglas reservoir with a total volume of 40 L and an efficient volume of 18 L with the length, width and height of $20 \times 45 \times 20$ cm, divided into two separate parts by the baffle, and at its end, it has an integrated diagonal settling part. The sludge deposited in this section is spontaneously returned to the second part of the reactor (Fig. 1). The internal return was carried out by a RS ELECTRICAL aquarium pump from reservoir 2 to 1 connected to a digital timer. Two analogue timers were used for timing in different phases such that a timer was applied for reservoir 1 aeration and reservoir 2 mixing and the other timer was assigned to reservoir 2 aeration and reservoir 1's mixing. The influent wastewater was supplied with a peristaltic pump from a 20-L reservoir.

2.2. Operating the reactor

The reactor was operated for 180 days. To set up the reactor, the return sludge from the secondary settling unit of the Municipal Wastewater Treatment Plant of Shiraz was used for the system microbial seeding (mixed liquor suspended solids = 10,000 mg/L, hydration = 99%, pH = 6.5). Daily feeding with synthetic wastewater was carried out by peristaltic pump (longer pump BT100-1L). The reactor's operating area temperature was kept at approximately 20 °C. The dissolved oxygen (DO) amount in the aerobic phase was between 2 and 3 mg/L, and in the anoxic phase, it was less than 0.2 mg/L, measured by HACH DO meter. To aerate, two air diffusers connected to the HAILIA air pump at the bottom of reservoirs, 1 and 2 were used, and to create anoxic conditions, mixing (agitator) unit was used. Sample pH was between 7 and 7.5, and to measure the pH, Mertrohm pH meter was used. Reactor MLSS was maintained in the range of 1500–2500 mg/L (SRT = 25 days). Moreover, the stream in input and output wastewater (18 l/d) was continuous.

2.3. Operation phases

According to Table 1, in the CFBCR suspended growth reactor, four different operating phases were used to determine the best nutrient removal conditions. For example, in Phase 1, the first reservoir run with continuous aeration, and the second reservoir run with one-hour mixing. In Phase 2, the first reservoir was aerated for one hour, while simultaneously, the mixing was carried out in the second reservoir, and after an hour, the cycle was exchanged, and the mixing was carried out in the first reservoir, and aeration was carried out in the second reservoir for one hour. In addition, in this phase, removal of nutrients and organic matters at various concentrations of 400, 600 and 800 mg/L and various HRTs of 18, 24, and 30 h, and internal return percentages of 100, 150, and 200% were investigated.

2.4. Wastewater composition

In this study city water was used to provide artificial wastewater. To prepare phosphate and ammonia, KH_2PO_4 and NH_4Cl were respectively used, and carbon source included glucose and cellulose. COD concentration was 400, 600 and 800 mg/L respectively, and ammonia concentration was 40 and 60 mg/L (Table 2).

2.5. Sampling

After collecting reactor effluent samples, filtration was performed by using Whatman filter and, after dilution, various parameters such as COD, ammonia, nitrate, nitrite, phosphate, and MLSS were measured. The experiments were conducted as one factor in time, and with the change of a parameter, the rest of the parameters were kept constant. In each phase of operation, the experiment continued for 3–10 days until reaching stable conditions. The minimum number of samples in each phase was 3–5 samples.

2.6. Analytical methods

The COD and MLSS measurements were conducted according to the method in the Standard Methods for Examination (APHA, 2005). Spectrophotometric methods (DR-HACH5000 model) were used to measure the concentrations of ammonia (NH_4^+), nitrate (NO_3) and nitrite (NO_2) in the effluent from the reactor. Nessler method (No. 8038) was used to measure ammonia, the ascorbic acid method (No. 8048) was used to measure phosphate, cadmium reduction method (No. 8039) was employed to measure nitrate, and diazotization method (No. 8507) was used to measure nitrite.

3. Results and discussion

3.1. Nutrient removal efficiency in different phases

3.1.1. Removal of nitrogen compounds

The presence of aerobic-anoxic cycles at different times in the CFBCR reactor has led to an increase in nitrification and denitrification efficiency, having a significant effect on increasing nutrient