e-ISSN: 2458-8156

Journal Homepage: http://dergipark.gov.tr/ejens

EJENS

European Journal of Engineering and Natural Sciences

DergiPark AKADEMİK

CODEN: EJENS

Performance of Nitrogen and Phosphorus Removal of Moving Bed Biofilm Reactor Operated as Sequencing Batch

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Publication Info

Paper received:
29 May 2016

Revised received:
15 October 2016

Accepted:
01 March 2017

Abstract

In this study, nitrogen and phosphorus removal from municipal wastewater in moving bed biofilm reactor operated as sequencing batch was investigated. Kaldnes (K1) material as biofilm carrier media was used in the study. Operation consisted of anaerobic/aerobic/anoxic/aerobic phases with hydraulic residence times of 120 min/330 min/210 min/50 min. In the moving bed biofilm reactor with the filling ratio of 50% operated as sequencing batch, average effluent chemical oxygen demand (COD), ammonium-nitrogen (NH4-N), nitrite-nitrogen (NO2-N), nitrate-nitrogen (NO3-N) and phosphate-phosphorus (PO4-P) values after the cycle duration of 12 h were determined to be 27 mg/L, 0.7 mg/L, 0.04 mg/L, 0.6 mg/L and 0.7 mg/L, respectively. The average COD, NH4-N and PO4-P removal efficiencies were obtained as 92%, 97.5% and 91.3%, respectively.

Key words

Moving bed biofilm reactor, Nitrogen removal, Phosphorus removal, Sequencing batch biofilm reactor

1. INTRODUCTION

Nitrogen and phosphorus are commonly present in wastewater streams such as municipal, industrial and agricultural wastewaters [1]. When untreated or insufficiently treated wastewater discharges to water bodies such as lake and river, it causes several problems such as eutrophication and the depletion of dissolved oxygen [2]. Therefore, removal of these contaminants from wastewaters for reducing their damage to the environment is of great importance [3, 4].

In order to improve the quality of treated wastewater and meet the demands of environmental regulations, advanced treatment technologies have been developed [2]. The moving bed biofilm reactor (MBBR) having advantages of both attached and suspended growth systems is one of the advanced wastewater treatment process [5]. It is filled with carrier materials, on which biomass is attached, and freely move and circulate in the reactor by aeration in aerobic process or mechanical stirring in anoxic/anaerobic process. The carrier materials are kept inside the reactor by means of a sieve placed outlet of the reactor [6]. The MBBR relies on the attachment of biomass on plastic carriers, which allows retaining a significant amount of active biomass in the reactor regardless of the hydraulic conditions. This feature is very attractive for preventing washout of slow growing microorganisms like nitrifiers from the process [7]. It is a continuously operating, non-cloggable biofilm reactor with no need for backwashing, low head-loss and a high specific biofilm surface area [5]. It has some advantages such as a shorter hydraulic retention time (HRT), higher organic loading rates, a higher nitrification rate and larger surface area for mass transfer [8]. It has been widely applied to treat both municipal and industrial wastewaters due to the advantages of the attached growth process such as compact, stable removal efficiency and simplicity of operation without its limitations such as medium channeling and clogging [3, 9]. Also, it has been used for upgrading and retrofitting existing wastewater treatment plants due to having advantages of both suspended and attached growth systems [6, 10].

Nitrogen is removed by the combination of nitrification by autotrophs under aerobic conditions and denitrification by heterotrophs under anaerobic conditions. Phosphorus removal is achieved by its uptake into biomass which can be discharged from the system as a surplus sludge. It is possible that nitrification, denitrification and phosphorus removal are achieved in one reactor when a sequencing batch reactor system (SBR) is used [11]. SBR systems have been modified to achieve nitrification and denitrification as well as COD and phosphate removal because of regulations on nutrient discharge limitations. When biological nutrient removal is desired, its cycle format can be flexibly adjusted to provide anaerobic, anoxic and aerobic phases in certain number and sequence [12]. Among various biological treatment systems, they have many advantages such as lower capital and operational costs and less bulking [1, 11, 13]. Over the years, many efforts have been made to modify the SBR system to improve the performance. Among others, the moving bed sequencing batch reactor (MBSBR) which incorporates both suspended-growth and attached-growth processes has attracted much interest among researchers in the field of wastewater treatment [1]. Nitrification and denitrification can also be successfully achieved in biofilm-based processes because nitrifiers, which are slow growing microorganisms, are retained by the biofilm [5].

In this study, removal of nitrogen and phosphorus from municipal wastewater was investigated in the moving bed biofilm reactor operated in the sequencing batch mode.

2. MATERIALS AND METHODS

2.1. Experimental Set-up and Operation

A schematic diagram of the experimental set up is depicted in Fig. 1. The reactor used in the study was made of plexiglass material and had a working volume of 1 L. The carrier elements, called K1, were used as support materials to provide a surface for biofilm growth in the moving bed biofilm reactor (MBBR). The reactor was filled with 50% carrier elements.

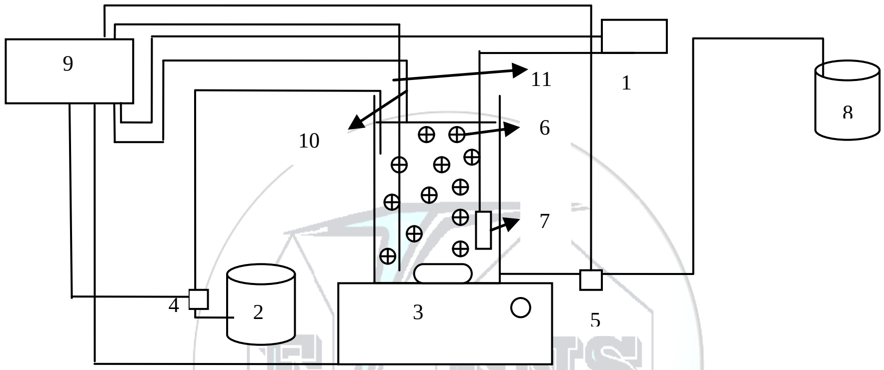

Figure 1. Schematic diagram of experimental set up. 1. air pump; 2. feed tank; 3. magnetic stirrer; 4. dosage pump, 5. drawing pump; 6. biofilm carrier materials; 7. air stone, 8. effluent tank; 9. programmable logic device; 10. filling level electrode; 11. drawing level electrode,

The reactor was inoculated with activated sludge taken from the secondary settling tank of the municipal wastewater treatment plant in Malatya, Turkey. The reactor was operated in a sequencing batch mode for COD, nitrogen and phosphorus removal. An operation cycle comprised a filling, reaction and drawing period. Reaction period consisted of anaerobic/aerobic/anoxic/aerobic phases with hydraulic residence times of 120 min/330 min/210 min/50 min. The filling plus drawing period was 10 minute. The MBBR was operated under hydraulic retention times of 12 h. The reactor was completely drained during drawing period at the end of each cycle. Aeration was supplied by air stone placed in the reactor by using an aquarium air pump. Airflow rate was controlled by rotometer. The alternation between aerobic, anoxic and anaerobic conditions was provided by the on and off control of the air pump. To make it work this way, the programmable logic device was used. The feed tank was filled periodically with the effluents collected from primary settler tank of the municipal wastewater plant in Elazığ, Turkey. Sufficient amount of ethanol solution was added in the reactor as an external carbon source at the beginning of the anoxic phase to reduce oxidized nitrogen (NO_2-N+NO_3-N) to nitrogen gas.

2.2. Biofilm Carrier

The carrier, called K1, was used in this study. The carrier was made from polyethylene with a density of 0.96 g/cm^3 slightly lower than the density of water and had an effective surface of 500 m^2/m^3. It was cylindrical with internal walls and external fins that protect the biofilm from abrasion. With a filling ratio of 50%, the available surface area (referred to the reactor volume) was 250 m^2/m^3.

2.3. Wastewater Characteristics

The study was carried out using wastewater collected from the primary settler tank of municipal wastewater plant in Elazığ, Turkey. The wastewater had chemical oxygen demand (COD) in the range of 328-336 mg/L, ammonium-nitrogen (NH_4-N) in the range of 17.3-21.7 mg/L, phosphate-phosphorus in the range of 8.7-10.8. The samples were stored in a refrigerator at 4 ^{o}C until use.

2.4. Analytical Methods

Samples were taken from the reactor at the beginning and at the end of anaerobic, aerobic and anoxic phases. To remove microorganisms from the mixed liquid medium, these samples were centrifuged at 5000 rpm for 10 min. Supernatants were analyzed for COD, ammonium-nitrogen, nitrite-nitrogen, nitrate-nitrogen and phosphate-phosphorus contents. The concentration of COD and total suspended solids (TSS) in the liquid phase was determined in accordance with Standard Methods for Examination of Water and Wastewater [14]. In order to determine the amount of the biofilm in the reactor, 10 carrier materials taken from reactor was dried at 70 ^oC for 48 h and weighed. The higher temperature was not used because of deformation risk of the carrier materials [15]. It was subsequently cleaned to remove the attached biofilm, followed by drying and weighing again. Then, biofilm amount was calculated taking into account the number of elements per liter. The nitrogen species (ammonium-nitrogen (NH_4-N), nitrite-nitrogen (NO_2-N) and nitrate-nitrogen (NO_3-N)) and phosphate-phosphorus (PO_4-P) were measured by standard test kits (Merck Spectroquant) using Nova 60 Spectroquant. The dissolved oxygen concentration and pH in the reactor were measured using an O_2 electrode and a pH electrode by a multimeter (Hach HQ40D).

3. RESULTS AND DISCUSSION

3.1. COD Removal

Effluent COD concentration and COD removal efficiency obtained in the moving bed biofilm reactor operated as the sequencing batch are depicted in Fig. 1. Effluent COD concentration obtained after 12-h cycle changed in the range of 16 to 32 mg/L. Average effluent COD concentration was 27 mg/L. COD removal efficiency changed in the range of 90.5-95.2%, with average removal efficiency of 92%. Effluent TSS concentration varied in the range of 220 to 280 mg/L. The average amount of biomass attached to the carrier materials was 3.1 kg/m^3.

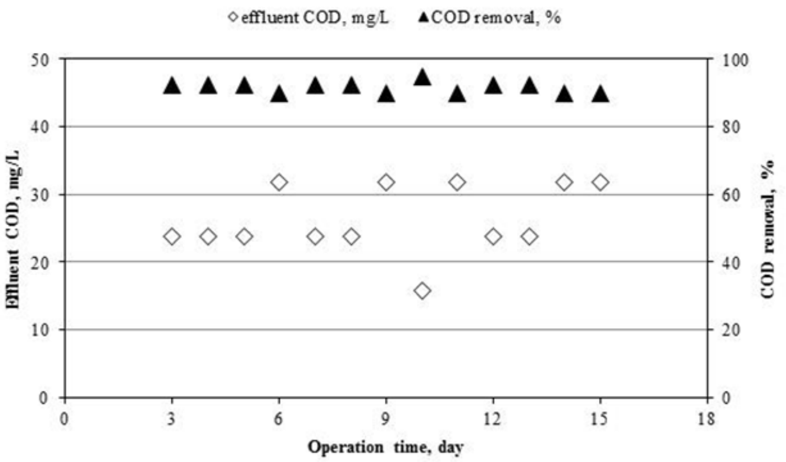

Figure 2. Effluent COD concentrations and COD removal obtained by MBBR operated as sequencing batch

3.2. Nitrogen Removal

Variation of effluent NH_4-N, NO_2-N and NO_3-N concentration and NH_4-N removal efficiency obtained is depicted in Fig 3. Effluent NH_4-N concentration varied between 0.1 and 0.8 mg/L, with average effluent level of 0.7 mg/L. Effluent NO_2-N and NO_3-N concentration changed in range of 0.01-0.1 mg/L and 0.1-1.8 mg/L, respectively. Average effluent level of NO_2-N and NO_3-N was observed to be 0.04 mg/L and 0.6 mg/L. NH_4-N removal efficiency varied between 96% and 99.5%, with average removal efficiency of 97.5%. As can be seen from the results obtained, nitrogen removal from the municipal wastewater can be removed by moving bed biofilm reactor operated in the sequencing batch mode with the cycle of 12 h.

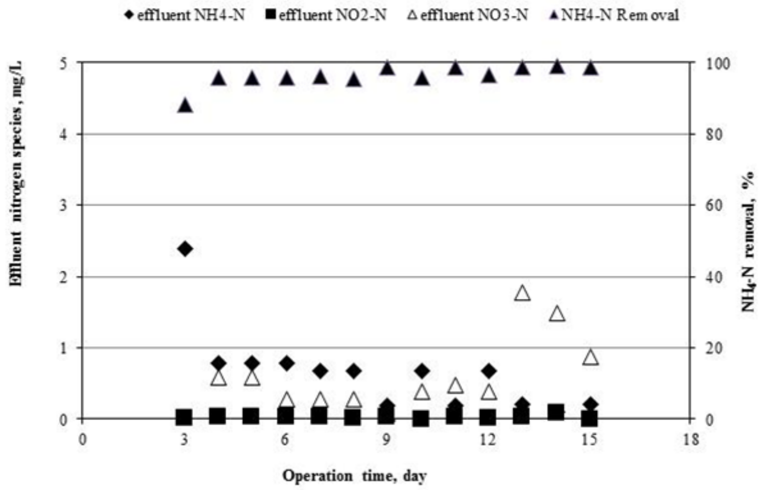

Figure 3. Concentrations of effluent nitrogen species and NH_4-N removal obtained by MBBR operated as sequencing batch

Biological nitrogen removal from wastewater is achieved by nitrification under aerobic conditions and heterotrophic denitrification under anaerobic conditions [1, 16]. Nitrification is a process consists of two steps which ammonia is converted to nitrite by ammonia-oxidizing bacteria and then nitrite is converted to nitrate by nitrite-oxidizing bacteria. Nitrite and/or nitrate are reduced to nitrogen gas by heterotrophic bacteria during denitrification process [16, 17]. In the anaerobic, first aerobic (I), anoxic and last aerobic (II) phases of the cycle, variation of NH_4-N, NO_2-N and NO_3-N concentration is shown in Fig. 4. NH_4-N, NO_2-N and NO_3-N concentration at the beginning of the cycle was 21.7 mg/L, 0.05 mg/L and 0.4 mg/L, respectively. As can be shown from Fig. 4, NH_4-N, NO_2-N and NO_3-N were nearly constant during the anaerobic phase. NH_4-N was removed by assimilation and nitrification during the first aerobic phase. NH_4-N transformed to NO_3-N as result of nitrification in the end of the first aerobic phase and NO_3-N increased to 19.2 mg/L. NO_2-N did not accumulate in the reactor since the complete nitrification happened in the aerobic phases. In the anoxic and the last aerobic (II) phase, NH_4-N concentration was almost the same as NH_4-N concentration of aerobic (I). Adequate amount of ethanol solution was added into the reactor as a carbon source at the beginning of the anoxic phase to reduce the oxidized nitrogen (NO_2-N and NO_3-N) to nitrogen. As result of assimilation and denitrification, NO_3-N decreased to 0 mg/L in the anoxic phase in the present of the external carbon source added. Complete removal of the nitrogen species was achieved due to the addition of ethanol solution at thebeginning of the anoxic phase. Nitrogen gas generated in the anoxic phase as result of denitrification was removed in the last aerobic phase.

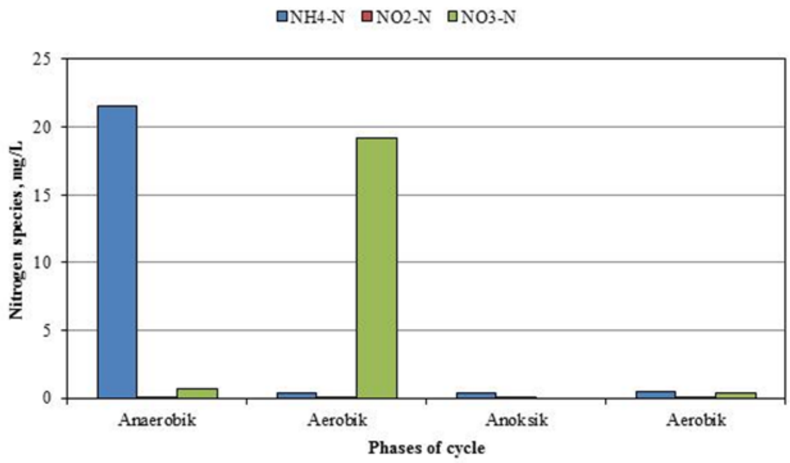

Figure 4. Concentrations of nitrogen species in phases of cycle in MBBR operated as sequencing batch

3.3. Phosphorus Removal

Variation of effluent PO_4-P concentration and PO_4-P removal efficiency obtained in the moving bed biofilm reactor operated as sequencing batch with the cycle of 12 h is depicted in Fig 5. Effluent PO_4-P concentration varied between 0.3

and 0.9 mg/L, with average effluent level of 0.7 mg/L. PO_4-N removal efficiency varied between 88.6% and 95.6%, with average removal efficiency of 91.3%. As can be seen from the results obtained, phosphorus from the municipal wastewater can be removed by moving bed biofilm reactor operated in the sequencing batch mode with the cycle of 12 h.

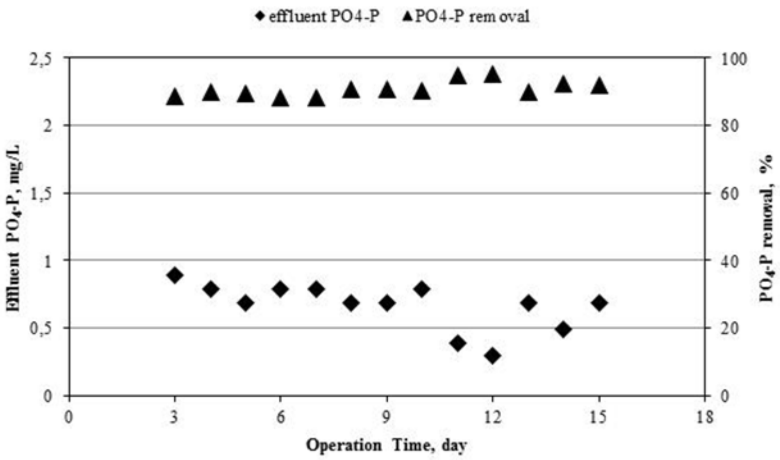

Figure 5. Effluent PO_4-P concentrations and PO_4-P removal in MBBR operated as sequencing batch

In the anaerobic, first aerobic (I), anoxic and last aerobic (II) phases of the cycle, variation of PO_4-P concentration is shown in Fig. 6. Initial PO_4-P concentration of 7.1 mg/L increased to 22.5 mg/L at the end of the anaerobic phase because of phosphate release by phosphorus accumulating organisms (PAOs). PO_4-P concentration decreased from 22.5 mg/L to 0.5 mg/L during the first aerobic phase due to phosphate uptake of PAOs. Phosphorus was significantly released by PAO during anaerobic phase while rapidly absorbed for PAOs growth and intracellular poly-P formation in aerobic phase [18, 19].

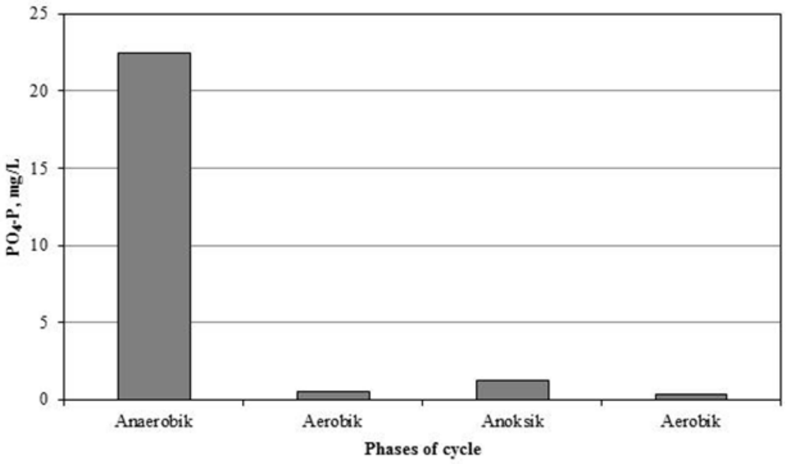

Figure 6. PO_4-P concentrations in phases of cycle in MBBR operated as sequencing batch

4. CONCLUSIONS

The moving bed biofilm reactor operated as sequencing batch with a cycle consist of anaerobic/aerobic/anoxic/aerobic showed good performance for removal of COD, nitrogen and phosphorus from the municipal wastewater. Effluent COD, NH_4-N, NO_2-N, NO_3-N and PO_4-P concentrations were on average 27 mg/L, 0.7 mg/L, 0.04 mg/L, 0.6 mg/L and 0.7 mg/L, respectively. When a cycle consists of anaerobic/aerobic/anoxic/aerobic with hydraulic residence times of 120 min/330 min/210 min/50 min, on average removal percentage of COD, NH_4-N and PO_4-P were obtained as 92%, 97.5% and 91.3%, respectively.

ACKNOWLEDGMENT

The authors wish to tank AnoxKaldnes AS for supplying the Kaldnes (K1) carrier materials.

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