Chemical Engineering Journal 301 (2016) 200–209

Contents lists available at ScienceDirect

Chemical Engineering Journal

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

High rate simultaneous nutrients removal in a single air lift bioreactor with continuous feed and intermittent discharge regime: Process optimization and effect of feed characteristics

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HIGHLIGHTS

- CNP removal process was investigated in an air lift bioreactor with CFID regime.
- The system performance at different wastewater characteristics was assessed.
- The effect of two independent variables on the performance was assessed using RSM.
- The variation trends of 7 responses were monitored over optimum condition.

ARTICLE INFO

Article history:
Received 23 February 2016
Received in revised form 28 April 2016
Accepted 29 April 2016
Available online 29 April 2016

Keywords:
Biological nutrient removal
Single bioreactor
Airlift bioreactor
Milk processing wastewater (MPW)
Soft drink wastewater (SDW)

ABSTRACT

In this research, continuous feed and intermittent discharge air lift bioreactor (CFIDAB) was evaluated under two independent variables to treat milk processing wastewater (MPW). The effect of HRT (6–14 h) and air flow rate (1–3 l/min) on the performance of CFIDAB was studied in a laboratory scale of the bioreactor. The optimum values of HRT and air flow rate were 10 h and 3 l/min, reaching SCOD, TN, and TP removal efficiency around 98%, 85%, and 78%, respectively. The results showed that TP and TN removal were enhanced simultaneously with an increase in HRT and air flow rate. Oxidation–reduction potential (ORP) measurement at the optimal condition showed the successful occurrence of anaerobic, anoxic, and aerobic zones in the CFIDAB. Moreover, the effect of feed characteristics on the process performance for milk processing and soft drink wastewaters was investigated. Based on the obtained data, CFDIAB operated with soft drink wastewater (SDW) showed a better performance in removal of carbon and phosphorus compounds, while nitrogen content was removed more efficient for MPW. As a result, the performance of CFIDAB is sensitive to BOD_5/COD ratio of wastewater. Overall, this single compartment air-lift bioreactor could act as an efficient biological nutrient removal system, providing the conditions for good carbon and nutrient removal. It showed an excellent reactor geometry as well as operating strategy to be used as a membrane bioreactor.

1. Introduction

Discharging industrial wastewaters containing excessive nitrogen (N) and phosphorus (P) concentrations into lakes and rivers causes eutrophication, which has become one of the current major environmental issues with regard to the environmental health and save water supply. Biological nutrient removal (BNR) processes have been developed for wastewater treatment plants (WWTPs). These processes generally rely on providing anaerobic, anoxic, and aerobic conditions in three separate compartments [1]. A major problem with conventional BNR systems is their low capacity in terms of reactor volume which has made these methods costly in investment, operation and maintenance [2].

The research to date has tended to focus on designing new systems to increase efficiency and removal rate of the BNR process. Different combinations of anaerobic, anoxic, and aerobic systems have been proposed for nutrient removal from synthetic and real wastewaters. In recent years, there has been an increasing interest in single bioreactors. Single bioreactors are considered to be the most economical, efficient and technological sustainable process for wastewater treatment [3]. Three strategies have been applied

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http://dx.doi.org/10.1016/j.cej.2016.04.144
1385-8947/

Nomenclature

A^2/O	anaerobic/anoxic/aerobic
BAF	biological aerated filter
BNR	biological nutrient removal
BOD	biological oxygen demand
CFID	continuous feed and intermittent discharge
CFIDAB	continuous feed and intermittent discharge airlift bioreactor
CNP	carbon, nitrogen and phosphorus
COD	chemical oxygen demand
sCOD	soluble COD
DO	dissolved oxygen
F/M	food to microorganism ratio
FBR–MBR	fluidized bed reactor–membrane bioreactor
HRT	hydraulic retention time
k	BOD rate constant
MPW	milk processing wastewater
OLR	organic loading rate
OPR	oxidation–reduction potential
PAOs	phosphorus accumulating organisms
RAAIB	radial anaerobic–aerobic immobilized biomass bioreactor
SBR	sequencing batch reactor
SDW	soft drink wastewater
SND	simultaneous nitrification–denitrification
SMPs	soluble microbial products
SVI	sludge volume index
TN	total nitrogen
TKN	total kjeldahl nitrogen
TP	total phosphorus
UAASB	up-flow aerobic anoxic sludge bed
WWTPs	wastewater treatment plants

to create different zones of dissolved oxygen (DO) concentration in a single bioreactor including: (1) time-based process cycle [4], (2) mass transfer limitation (granular sludge) [5], and (3) physical separation [6]. At the first strategy, aeration pump is on and off periodically and anaerobic, anoxic, and aerobic zones are taken place sequentially. This method is often used in sequencing batch reactor (SBR) and continuous feeding and intermittent discharge SBR (CFID SBR). In a study, an industrial estate wastewater was treated in an upflow aerobic/anoxic sludge bed bioreactor based on CFID SBR regime and intermittent aeration strategy, so that, aeration time with a range of 40–60 min/h was examined at different hydraulic retention times (HRTs). HRT of 12 h and aeration time of 40 min/h were reported as an optimum condition to achieve 91%, 60% and 32% as chemical oxygen demand (COD), total nitrogen (TN) and total phosphorus (TP) removal, respectively [7].

Mansouri et al. reported that intermittent aeration strategy with 50-min aeration time in a 6.5 h cycle provided more than 80%, 65%, and 60% of COD, TN, and TP removal efficiencies, respectively, in an intermittently aerated SBR [8]. One of the major problems associated with this method for its scale up is complicated operating procedure.

Another approach to accomplish nutrient removal in a single bioreactor is aerobic granular sludge (mass transfer limitation). The nitrification process occurs at the surface aerobic layer of the granule, while, denitrification process takes place in the inner part of granules where the penetration of DO is limited (anoxic zone) [9]. Aerobic granular sludge is not capable for efficient phosphorus removal. Therefore, in the majority of the researches, aerobic granular sludge has been coupled with intermittent aeration strategy to integrate carbon and nutrients removal processes [10].

Physical separation tactic offers the probability to simultaneous CNP removal in single bioreactors. From the literature, baffled bioreactors [11], radial anaerobic–aerobic immobilized biomass (RAAIB) bioreactor [12], and air-lift bioreactors [13] are utilized as single bioreactor with physical separation. Single bioreactors with physical separation strategy are easy to operate and handle compared to time-based processes and diffusion limited operation. Consequently, this group of single bioreactors could consider as a valuable replacement for conventional BNR systems in WWTPs.

Air-lift bioreactors have attracted substantial attention for simultaneous carbon and nutrients removal through the combination of three different zones (anaerobic, anoxic, and aerobic) in a single bioreactor. Haiyan et al. proposed a CNP removal processes based on an airlift intermittent circulation membrane bioreactor. It was reported that 78.6 g/m^3 day and 13.20 g/m^3 day of TN and TP were removed [14]. In another study, Airlift loop reactor under a limited filamentous bulking state was operated to treat synthetic wastewater, which the average removal efficiencies for COD, NH_4-N, TN and TP were 91%, 92%, 86% and 94%, respectively at HRT of 11 h [15].

It should be mentioned that the regime of the reported air-lift bioreactor configurations has been continuous. In an earlier study published [16], an air lift bioreactor with continuous feed and intermittent discharge (CFID) was operated successfully for treating soft drink wastewater (SDW). In the current study, one of the main aims was to study the effect of feed characteristic including organic compounds and nitrogen content on the system performance in terms of N and P removal. Total COD and nitrogen content in the wastewaters selected (soft drink and milk processing wastewaters) in this study were the same but with different nitrogen fractionation. Milk processing wastewater (MPW) with organic nitrogen concentration of 110–120 mg/l and moderate ammoniacal nitrogen (45–50 mg/l) and soft drink wastewater (SDW) with org-N of 5–10 mg/l and high ammoniacal nitrogen (140–150 mg/l). Moreover, carbon source in MPW is mainly in the form of lipid, while it is carbohydrate in SDW. Another novel objective was defined based on the significant finding on CNP removal obtained from the CFIDAB at HRT of 12 h as reported in the previous study (116 mg/l of TN and 30 mg/l of TP), indicating a remarkable difference in performance removing CNP relative to other single bioreactors. This result encouraged the authors to monitor the concentration profiles of COD, TP, NO_2^-, NO_3^-, and TKN in the riser and downcomer under optimum condition to find the mechanisms of nutrients removal in different zones of the bioreactor.

Besides, in this study, air flow rate as an influential factor in the airlift bioreactor was studied in a wide range (1, 2, and 3 l/min) to assess the capability of the CFIDAB providing anaerobic and anoxic zones (as a function of air flow rate). The effects of two independent variables, HRT and air flow rate, on the process were investigated and the experimental conditions were designed by design expert software. sCOD removal, TN removal, effluent NO_3^- concentration, effluent NO_2^- concentration, TP removal, sludge volume index (SVI), and effluent turbidity were monitored as process responses to analyze and model the process performance. Moreover, a comparative assessment was performed to illustrate the effect of feed characteristics with different BOD_5/COD ratio on the performance of CFIDAB removing CNP are discussed.