Optimization of Operation Conditions for Partial Nitrification of Anaerobic Sludge Digester Supernatant in Sequencing Batch Reactor

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Abstract— the supernatant obtained from the anaerobic digestion of excess sludge contains high amount of ammonia (1020 mg/L as NH4-N), which increases the nitrogen load during wastewater treatment. Anaerobic ammonium oxidation (ANAMMOX) process is the most economically viable option for removing nitrogen from wastewater containing high ammonia, however the anammox process required the substrates NO2-N and NH4-N in a ratio of 1:1.This paper deals with the optimization of process parameters for partial nitrification (PN). Initially anaerobic digestion (AD) was carried out for waste sludge taken from a 5L capacity lab scale SBR by using sewage sludge as inoculum which resulted in the specific biogas yield of 20.304 mL/g of VS of the sludge. Then the ammonia rich supernatant was separated and treated using PN to meet the required NO2-N/NH4-N ratio of 1:1. The partial nitrification was carried out in 1L bubble column reactor inoculated with nitrifying seed sludge from the lab scale SBR .Seven operational factors (pH, DO, Temperature, Cycle time, MLSS, C/N and aeration strategy) which significantly affect the NO2-N.NH4-N ratio were taken for the study. Plackett-Burman DOE was used to find out which of these factors have the most significant effect in achieving the required NO2-N: NH4-N ratio. A total of 12 runs based on the design were operated for a minimum of three days per run. Data was collected and the result feed to Minitab software to analyze the effect of the factors affecting the NO2-N/NH4-N ratio. The results showed that it is possible to reach a stable partial nitrification with high pH (7.60), low C/N (0.5), high cycle time (10hrs), low DO concentration (1mg/L), low MLSS/MLVSS (3500) mg/L), high temperature (32ºC) and intermittent aeration. The main effect interaction plots also shows the NO2-N/NH4-N increases with increasing pH, DO, Temperature and cycle time and decreases with the corresponding MLSS and C/N ratio operated. Pareto chart of the factors considered shows that the pH influence the NO2/NH4-N ratio the most and DO influence the least within the range of values taken.

Key words: Anaerobic Digestion (AD), Partial Nitrification (PN), Anaerobic Ammonium Oxidation (ANAMMOX), Sequencing Batch Reactor (SBR)

I. INTRODUCTION

The supernatant from the anaerobic digestion of sludge has a high concentration of ammonium (800–1000 mg N–NH_4/L) with unfavorable C/N ratio for nitrogen removal by denitrification. This supernatant is usually recirculated to the biological section of an activated sludge plant without pretreatment contributing to 15–20% of the influent nitrogen load [1]. The preceding anaerobic digestion step helps in the reduction of the organic load and the coexistence of heterotrophic activity within PN/ANAMMOX reactors, which may negatively affect these autotrophic processes [2]. The nitrogen removal can be carried out by partial nitrification/denitrification or ANAMMOX system. Partial Nitrification of ammonium to nitrite is presented as a possible way to achieve an ANAMMOX influent of the required composition, where ANAMMOX (Anaerobic ammonium oxidation is autotrophic process of nitrogen removal in which ammonium is converted, under anaerobic conditions, directly into nitrogen gas with nitrite as an electron acceptor and in the absence of organic carbon sources [3]. The PN conversion is done by ammonia-oxidizing bacteria (AOB) as represented in (Eq. [1]). According to the ANAMMOX reaction ratio, 1.32 g NO_2^-–N are consumed per g NH_4^+–N removed. Thus, optimal performance of PN for its coupling with the ANAMMOX process requires 57% oxidation of NH_4^+–N toNO_2^-–N (1.1) [4, 5].

$$NH_4^+ + 1.5\,O_2 \rightarrow NO_2^- + H_2O + 2H^+ \text{ (nitrification, AOB)} \quad (1.1)$$

$$NH_4^+ + 0.86\,O_2 \rightarrow 0.57\,NO_2^- + 0.43\,NH_4^+ + 0.58\,H_2O + 1.14\,H^+ \text{ (partial nitrification for ANAMMOX)} \quad (1.2)$$

The functioning principle of sequencing batch reactors (SBRs) is based on a cyclic sequence of fill, bio reaction, settle, and withdraw. One of the main advantages of SBR technology is its operational flexibility; this technology has been found to be effective to conduct [6, 7, 8, 9, 10]. However, limited information is available on the best approach for PN in view of its coupling with ANAMMOX using swine wastewater (SW). In a SBR the nitrification via nitrite could be achieved working with high ammonium concentration and an appropriate pH range. Nitrification to nitrite can be achieved working at temperatures over 20^{0}C with sludge retention time (SRT) below 2 days [11, 12], maintaining the pH around 8 or working with high ammonium concentrations [12, 13]. The key to obtain partial nitrification resides in the bicarbonate/ammonium ratio. The molar stoichiometric relationship for complete ammonium oxidation must be 2 mol HCO_3^- /mol NH_4^+. Therefore, to provide a 50% ammonium oxidation, ammonium and bicarbonate should be present in a molar ratio of 1:1 [14].

The aim of this study was to obtain nitrite through PN of digester effluent and to produce an effluent that is optimized for use in the ANAMMOX process as in (1.2). The partial nitrification was carried out in 1L bubble column reactor inoculated with nitrifying seed sludge from the lab scale SBR. Seven operational factors (pH, DO, Temperature, Cycle time, MLSS, C/N and aeration strategy) which significantly affect the NO_2-N.NH_4-N ratio were taken for the study. Plackett-Burman DOE was used to find out which of these factors have the most significant effect in achieving the required NO_2-N: NH_4-N ratio. A total of 12 runs based on the design were operated for a minimum of three days per run.

Data was collected and the result feed to Minitab software to analyze the effect of the factors affecting the NO_2-N/NH_4-N ratio.

II. MATERIALS AND METHODS

A. *Anaerobic Digester Effluent*

Initially the aerobic sludge from the lab scale SBR running for more than 1 year treating synthetic tannery wastewater for removal of organic carbon and nitrogen is taken and is inoculated with the sludge from Koyembedu biogas plant and the digester is set up based on VDI-4601. The digestion is carried for 35 days and the digester supernatant was collected. The characteristics of the digester effluent were: pH 7.9, 1840 ± 102 mg COD/L, 1092 ± 50.1 mg N-NH_4/L, 1135 ± 98.23 mg TOC/L, 1100.23 ± 56.1 mg TKN/L. The COD/N ratio of anaerobic digester supernatant was 1.67. The supernatant is stored at 4^0C in the laboratory until its treatment.

B. *Experimental Setup*

The treatment of the anaerobic digester supernatant was carried out at lab-scale where the partial nitrification was developed in SBR of 1litre. The temperature was maintained by means of a thermostatic bath and pH was monitored using a field measurement system connected to a pH/T probe. Temperature and pH profiles were monitored and these data were then exported and represented in each cycle. A closed intermittent-flow respirometer was used to characterize the system. Dissolved oxygen was measured using a portable oxygen meter. Air was supplied through aquarium air pumps, a flow meter, and porous stones, which provided fine bubbles. Biomass suspension and mixing were achieved through uninterrupted aeration during the reaction phases.

C. *Process Operation*

The partial nitrification was carried out in 1L sequencing batch reactor inoculated with 500 mL of nitrifying seed sludge from the 5L lab scale SBR running for more than 1 year treating synthetic tannery wastewater for removal from organic carbon and nitrogen. The reactor was operated at 50% volume exchange ratio where at the end of each cycle time 500 mL of the supernatant was removed and replaced with fresh digester effluent. Seven operational factors (pH, DO, Temperature, Cycle time, MLSS, C/N and aeration strategy) which significantly affect the NO_2-N.NH_4-N ratio were taken for the study. Plackett-Burman DOE was used to find out which of these factors have the most significant effect in achieving the required NO_2-N: NH_4-N ratio. A total of 12 runs based on the design were operated for a minimum of three days per run. Data was collected and the result feed to Minitab software to analyze the effect of the factors affecting the NO_2-N/NH_4-N ratio.

D. *Analytical Method*

The analyses of alkalinity, chemical oxygen demand (COD), TKN, ammonia nitrogen, nitrites and nitrates were performed following the methods reported in the standard methods for the examination of water and wastewater [15].

III. RESULTS AND DISCUSSION

The most important and significant factors which affect the NO_2-N.NH_4-N ratio were studied by Plankett-Burman method. In this factorial design, to achieve Plankett-Burman concept, each factors were examined at two levels: low level and high level was run to estimate the linear effects of the factors. A medium comprising of pH, DO, Temperature, Cycle time, MLSS, C/N and aeration strategy was designed. In order find out the significant factors for the for the NO_2-N.NH_4-N ratio, Plankett-Burman method was performed. A total of 12 runs based on the design were operated for a minimum of three days per run. Data was collected and the result feed to Minitab software to analyze the effect of the factors affecting the NO_2-N/NH_4-N ratio. The experiment was carried out by using software Minitab. Table 3.1 represents the factors used in this study and the corresponding response to the NO_2-N.NH_4-N ratio.

RUN	pH	DO	Temp	CT	MLSS	C/N	Aeration	NO_2-N/NH_4-N
1	7.65	4	35	10	10000	3.0	continuous	0.1260
2	6.50	1	20	10	10000	0.5	continuous	0.0530
3	6.50	4	35	5	10000	0.5	intermittent	0.0780
4	7.65	1	20	5	10000	3.0	intermittent	0.0075
5	7.65	1	35	10	3500	0.5	intermittent	0.2740
6	6.50	4	20	10	3500	3.0	intermittent	0.0776
7	6.50	1	35	5	3500	3.0	continuous	0.0350
8	7.65	4	20	5	3500	0.5	continuous	0.2340
9	7.65	4	35	10	10000	3.0	intermittent	0.0840
10	6.50	1	20	5	10000	3.0	continuous	0.1140
11	7.65	4	35	5	3500	0.5	intermittent	0.0330
12	6.50	1	20	10	3500	0.5	continuous	0.0160

Table 1: Factors and Corresponding response to the No_2-N.Nh_4-N Ratio

The results from the Table 1 shows that it is possible to reach a stable partial nitrification in run 5 with high pH (7.60), low C/N (0.5), high cycle time (10hrs), low DO concentration (1mg/L), low MLSS/MLVSS (3500) mg/L), high temperature (32ºC) and intermittent aeration. The graphical representation of that specific run is showed in the Fig.1.

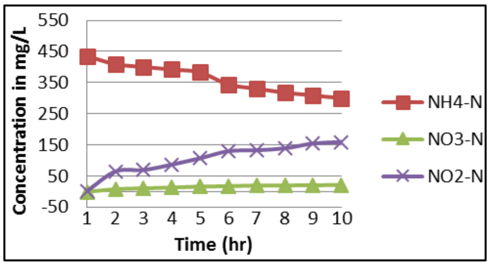

Fig. 1: Profile for NH_4-N, NO_2-N and NO_3-N for run 5

In the Fig.1, the removal efficiency of NH_4-N, NO_3-N AND NO_2-N was 32 %, 64.31% and 98.04% and the corresponding NO_2-N.NH_4-N ratio is 0.274.

The main effect and interaction plots in Fig.2 and 3 respectively shows that the NO_2-N/NH_4-N ratio increases with increasing pH, DO, temperature and cycle time and decreases with the corresponding MLSS and C/N ratio operated.

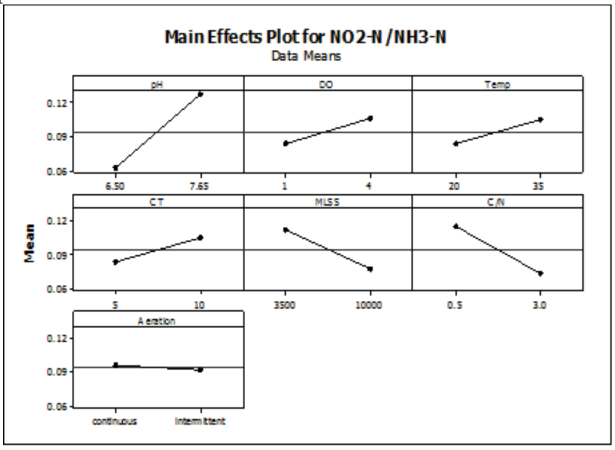

Fig. 2: Main effects plot for NO2-N/NH4-N ratio

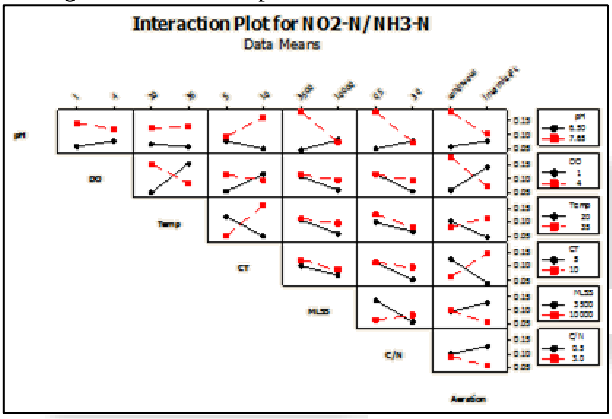

Fig. 3: Interaction Plot for NO_2-N/NH_4-N

Pareto chart of the factors considered shows that the pH influence the NO_2/NH_4-N ratio the most and DO influence the least within the range of values taken. Pareto chart is showed in the Fig.4.

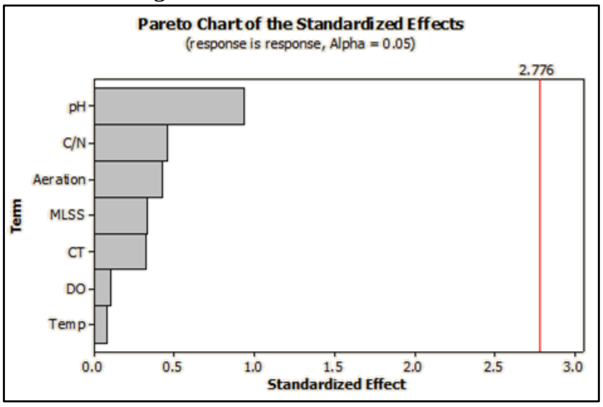

Fig. 4: Pareto Chart of the standardized effects

IV. Conclusion

The treatment of anaerobic digester supernatant with SBR appears to be a feasible method. SBR could be effectively used to produce a 50/50 ammonium-nitrite mixture suitable for the ANAMMOX process. The low nitrite concentration formed contribute to improve the SBR performance due to lack of toxicity and the inhibition of nitrate is achieved by combining the pH range and low dissolved oxygen concentration in the reactor. The Minitab software results showed that it is possible to reach a stable partial nitrification with high pH (7.60), low C/N (0.5), high cycle time (10hrs), low DO concentration (1mg/L), low MLSS/MLVSS (3500) mg/L), high temperature (32ºC) and intermittent aeration. The main effect interaction plots also shows the NO_2-N/NH_4-N increases with increasing pH, DO, Temperature and cycle time and decreases with the corresponding MLSS and C/N ratio operated. Pareto chart of the factors considered shows that the pH influence the NO_2/NH_4-N ratio the most and DO influence the least within the range of values taken.

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