Post-treatment of a submerged anaerobic membrane bioreactor (SAnMBR) effluent by an activated sludge system

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Abstract

An activated sludge pilot plant has been operated to investigate the removal of nitrogen, phosphorus, sulphide and dissolved methane from the effluent of a submerged anaerobic membrane bioreactor (SAnMBR). Ammonia, phosphate, dissolved methane and sulphide concentrations in the SAnMBR effluent were 55 mg NH_4-N·L^{-1}, 7 mg PO_4-P·L^{-1}, 43 mg DQO·L^{-1}, and sulfide 105 mg S^{2-}·L^{-1} respectively. The treatment of the effluent from SAnMBR is conducted in activated sludge pilot plant (800 L), which combines anaerobic, anoxic and aerobic zones. The solids retention time (SRT) was between 25 and 15 days and the hydraulic retention time (HRT) was 13 and 26 h. The results show a nitrification inhibition caused by the presence of sulphide which can be controlled optimizing the HRT. When the nitrification is well established, removal rates of N and P of 56% and 45%, respectively, are reached. The sulphide present in the influent is completely oxidized to sulphate in the effluent. This oxidation contributes to the denitrification process. Moreover, it was observed the presence of methanotrophic bacteria on the system using the FISH technique.

Keywords

Activated sludge; methanotrophic bacteria; submerged anaerobic membrane bioreactor; sulphide

INTRODUCTION

Anaerobic treatments of domestic wastewater involve various advantages compared to conventional treatments. These advantages include the production of biogas, which allows the energy recovery from the wastewater, and reduced sludge generation. However, the effluent of submerged anaerobic membrane bioreactors (SAnMBR) and upflow anaerobic sludge blanket (UASB) reactors contains nitrogen and phosphorus concentrations similar to that found in the influent wastewater; moderate concentrations of biodegradable organic matter; and significant concentrations of sulphide and dissolved methane (Giménez *et al.*, 2011; Khan AA *et al.*, 2011; Foresti *et al* 2006). Therefore, it is necessary a further treatment aiming at nutrient removal and dissolved gases. The characteristics of these effluents make it suitable to be treated by an activated sludge system with biological nutrient removal.

Nitrogen can be removed by nitrification and denitrification processes. In this latter process, the required electron donor can be a carbon source (volatile fatty acids, methane) or the sulphide present in the effluents of the anaerobic treatments. However, the sulphide concentration in the effluent of the anaerobic processes depends on the wastewater sulphate concentration which can notably vary considering the geographical location. Moreover, some studies (Sears *et al.*, 2004) mention the possible inhibition of nitrifying bacteria in the presence of sulphide. The dissolved methane is a very inexpensive carbon source and an effective greenhouse gas, being necessary their removal. Similar dissolved methane concentrations can be found in the effluent of UASB and SAnMBR reactors, ranging from 20 to 40% of methane in the biogas. According to the literature, it is possible to use methane as carbon source for denitrification in anoxic conditions (Islas-Lima *et al.*, 2004) by methanotrophic bacteria. The phosphorus from the effluent can be removed by a biological process (EBPR) or by chemical precipitation. The EBPR is widely accepted as one of the most economical and sustainable processes. However, the moderate concentrations of

biodegradable organic matter in the effluent could prevent great P removal efficiencies.
This paper presents a study for the treatment of a SAnMBR effluent in order to eliminate nitrogen, phosphorus, sulphide and dissolved methane. Moreover, the paper presents the results obtained in off-line tests carried out to assess the nitrification inhibition in the presence of sulphur compounds.

MATERIALS AND METHODS

Pilot plant description

An activated sludge pilot plant located at the Carraixet WWTP (Valencia, Spain) has been operated for 5 months. The activated sludge pilot plant consist of 800 L reactor (anaerobic 84 L, anoxic 332 L, aerobic 384 L) and a 80 L secondary clarifier (Figure 1b). The pilot plant has been operated under UCT configuration, treating the SAnMBR (Figure 1a) effluent. The anaerobic and the anoxic reactors are covered to minimize the superficial aeration and the loss of dissolved gases. Numerous on-line sensors and items of automatic equipment were installed in order to automate and control the pilot plant operations and gather on-line data about the state of the process. The on-line sensors consisted of: pH-Temperature, ORP, dissolved oxygen, suspended solids, ammonium and nitrate. The data acquisition and the pilot plant control were performed by a SCADA.

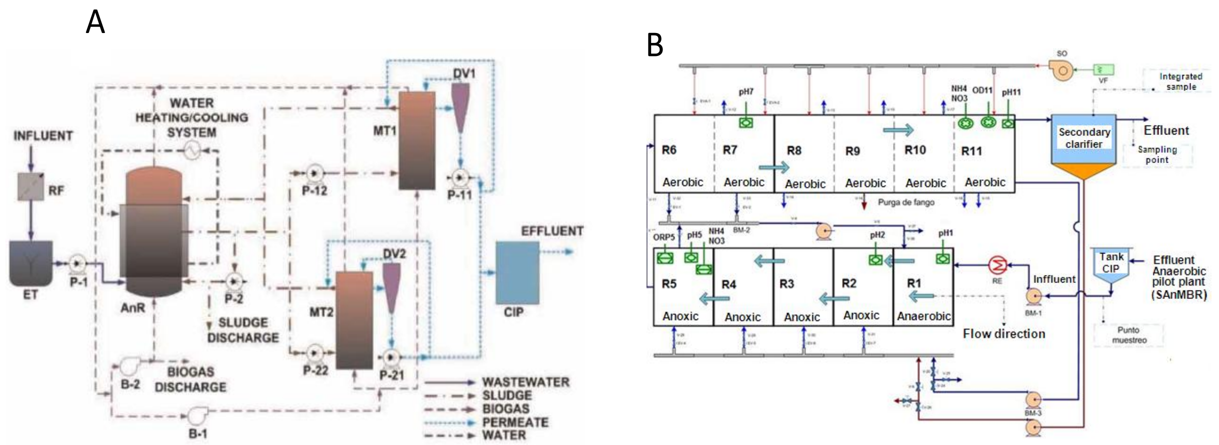

Figure 1. SAnMBR pilot plant (a), Activated sludge pilot plant (b).

Analytical methods

Influent, effluent, anaerobic, anoxic and aerobic reactor samples were analysed 3 times a week in order to evaluate the performance of the biological process. The parameters analysed were: total suspended solids, volatile suspended solids, volatile fatty acids, alkalinity, ammonium, phosphate, sulphide, thiosulphate and sulphate. Moreover, total and soluble COD, total nitrogen and dissolved methane were also determined once a week. Solids, COD, ammonium, phosphate and sulphide were colorimetric determined according to Standard Methods (APHA 2005). Sulphate and thiosulphate were measured by ion chromatography (761-Compact IC, Metrohm). Alkalinity and VFA concentrations were determined by titration according to the method proposed by WRC (1992). The dissolved methane in the influent stream was determined with the Henry law equation, measuring the methane concentration in the biogas produced in the SAnMBR using a gas analyser (X-Stream X2, Emerson). In addition, a sludge sample from the reactor was analysed once a week using the FISH technique (Amann *et al*., 1990).

Results and Discussions

The influent stream entering the post-treatment pilot plant showed a low biodegradable COD (30 ± 8 mg $COD \cdot L^{-1}$), high mean concentration of nutrients (55 ± 9 mg NH_4-$N \cdot L^{-1}$, 7 ± 2 mg PO_4-

P·L^{-1}, 105 ± 10 mg S^{-2}·L^{-1}) and a mean dissolved methane concentration around 43 ± 10 % mg COD·L^{-1}. After the start-up, the pilot plant was operated at a solids retention time (SRT) about 25 d and a hydraulic retention time (HRT) of 13 h (Period A). The dissolve oxygen concentration was maintained at 1 mg O_2·L and the temperature varied between 18 and 21ºC. Figure 2 shows that during this period the nitrification process was poor (<37%), obtaining N and P removal efficiencies about 25% and 64%, respectively. During this period, off-line respirometric batch experiments were carried out in order to evaluate the low nitrification observed.

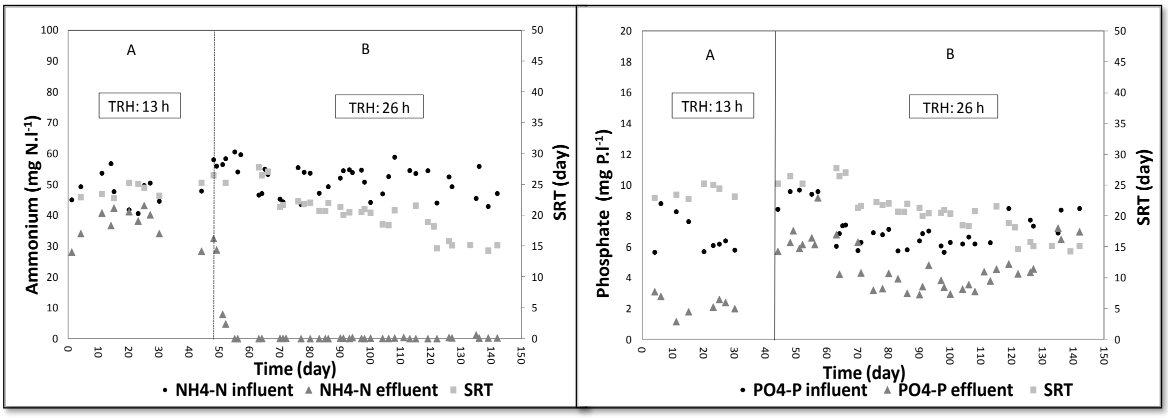

Figure 2. Evolution of ammonium, phosphate and SRT in the activated sludge system (periods A, B).

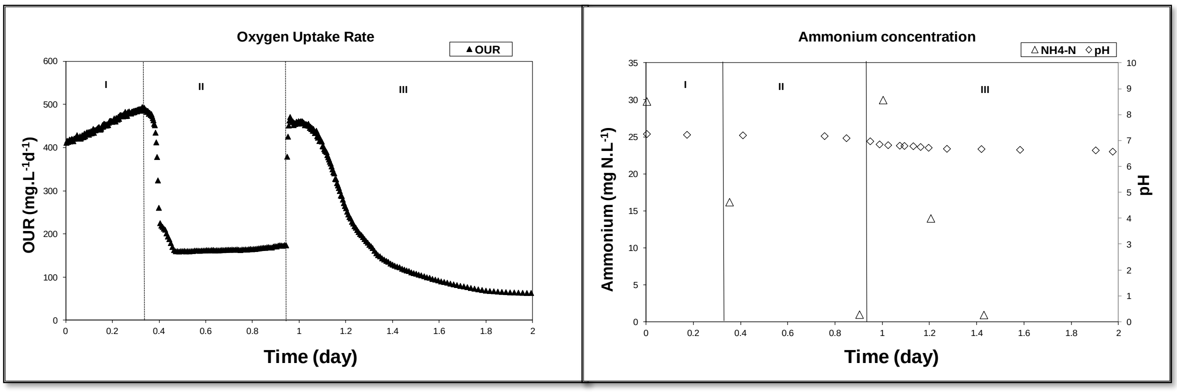

Figure 3. Evolution of OUR and ammonium in the off-line experiments.

Figure 3 shows the evolution of the oxygen uptake rate (OUR) of the activated sludge grabbed from the aerobic reactor of the pilot plant, containing ca. 30 mg NH_4-N·L^{-1}. As can be seen, in stage I, the OUR increases reaching a maximum value after 0.32 d. From this point, the OUR decreases steeply until the ammonium is almost depleted (stage II). At the beginning of stage III, 30 mg NH_4-N·L^{-1} were added to determine anew the response of the nitrifying biomass. The system quickly reached a maximum OUR value (0.024 d) decreasing later meanwhile the ammonium is being consumed. The rate of ammonium consumption in stage I and III was 1.61 and 3.29 mg N·L^{-1} h^{-1} respectively. These results point out that during stage I the nitrification is still being inhibited. Under the prolonged aerobic conditions maintained in the batch reactor, the inhibition completely disappears obtaining a completely nitrification (stage II). Thus, off-line experiments revealed that the inhibition observed in the pilot plant is not detected when the biomass is extracted from the pilot plant. This inhibition can be attributed to the presence of sulphide or thiosulphate in the system which inhibits nitrifying activity (Sears *et al*., 2004). During period A, sulphide and thiosulphate concentrations around 7.6 mg S·L^{-1} and 5.8 mg S·L^{-1}, respectively, were observed in the anaerobic reactor. In the anoxic reactor, the thiosulphate concentrations were about 2.5 mg S·L^{-1}. The HRT in the aerobic zone seemed to be not enough to overcome this inhibition. Once these sulphur compounds were completely oxidized to sulphate in the batch reactor, nitrification process was totally recovered.In order to enhance the nitrification process in the pilot plant, the retention time in the aerobic zone was increased during period B (HRT = 26 h). The rest of the operational parameters were: SRT from 25 to 15 d, OD = 1 mg $O_2{\cdot}L^{-1}$ and temperature ranging from 18 to 21ºC. As can be observed in Figure 2, the recovery of nitrification was observed reaching a complete nitrification and a nitrogen removal and phosphorus removal of 56% and 45%, respectively. Sulphide and thiosulphate were not observed in the anaerobic and anoxic reactors. During this second period, the influent biodegradable organic matter system only covered about 30% of the COD required for the denitrification observed. Therefore, other pathways such as sulphide oxidation and methanotrophic denitrification should be considered when evaluating the denitrification process.

The microbiological study carried out during period A showed the presence of ammonia-oxidizing *Betaproteobacterial* (AOB) (8 ± 1 %), nitrite-oxidizing bacteria *Nitrospirae* (NOB) (6 ± 2 %), denitrificans bacteria *Azoarcus-Thauera-Castellaniella* (3 ± 1 %), polyphosphate accumulating organisms *Accumulibacter phosphatis* (PAOs) (5 ± 2 %) and *type I* and *type II* methanotrophic organisms about (4 ± 2 % and 11 ± 3 %, respectively). During period B, an increase in AOB, NOB and, to a lesser extent, in methanotrophic bacteria were observed: *AOB* (16 ± 2 %), NOB (12 ± 1%) and methanotrophic (4 ± 1 %, *type I* and 13 ± 2 % *type II*). Moreover, was observed denitrificans bacteria (4 ± 1 %) and PAOs (3 ± 1 %).

CONCLUSIONS

The results obtained in this work indicate that an activated sludge system treating a SAnMBR effluent allows obtaining N and P removal efficiencies of 56 % and 45%, respectively, at high HRT. The HRT has a high influence on the nitrification. The low nitrification observed at low HRT was attributed to the inhibition of the nitrifying biomass in the presence of sulphur compounds such as sulphide or thiosulphate. This inhibition was evaluated with off-line respirometric batch experiments, where it was observed that the nitrification was recovered when nitrifying biomass was not under a continuous presence of sulphide or thiosulphate. Methanotrophic bacteria, contributing to denitrification process, were detected in both experimental periods by FISH.

ACKNOWLEDGEMENTS

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