DEVELOPMENT OF SIMULTANEOUS NITRIFICATION DENITRIFICATION PROCESS VIA NITRITE IN A FULL-SCALE MUNICIPAL WWTP

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Abstract

This work presents the high capability to remove ammonium and COD from domestic wastewater of simultaneous nitrification and denitrification (SND) process in the channel of oxidation ditch (OD) without the need for a special anoxic tank. It was carried out on full-scale small wastewater treatment plants in a region of Spain. Ammonium conversion efficiency of 90 %, TN removal performance of 70% and COD removal efficiency of 91% were obtained with the nitrogen and COD loading rate of 0.16 kg TN m^{-3} d^{-1} and 1.45 kg COD m^{-3} d^{-1}, respectively. Finally, a digital microscopic image processing is used to validate the results obtained based on floc size and opacity.

Introduction

Considering that the introduction of effluent quality standards is getting more strict in Spain, especially for nutrients (15 mg of Total Nitrogen (TN) per litre for wastewater treatment capacity between 10.000 to 100.000 population equivalent (PE)), many existing wastewater treatment plants (WWTPs) need to be upgraded in the near future. In addition, oxidation ditch (OD) is as competitive as other active sludge processes in biological nutrient removal efficiency (Liu, Y. et al., 2010).

Biological nitrification-denitrification is the most commonly used process for nitrogen removal from wastewater, i. e. (i) aerobic nitrification of NH_4^+ by chemolithoautotrophic bacteria to NO_2^- or NO_3^- with O_2 as the electron acceptor, and (ii) anoxic denitrification of NO_2^- or NO_3^- to gaseous N_2 by heterotrophic microorganisms using organic matter as carbon and energy source. The short-cut nitrification denitrification (SND) is a recent invention for nitrogen removal (Yoo, H., et al., 1999), (Weissenbacher, N., et al., 2008). The main physical explanation is that SND occurs within microbial flocs as a result of DO concentration gradient arising from diffusion limitations. In bio-floc processes, the basic concept to SND is to create an oxygen concentration gradient across the microorganism based agglomerates, so that both aerobic and anoxic conditions can be established inside the reactor. The size and density of sludge floc also affects DO diffusion. A large floc causes long diffusion distance within it, therefore needing much more DO and being more likely to form anoxic zones inside it. The denser the flocs, the more quantity of microbes contained per unit volume, and hence the more consumed oxygen and more difficult oxygen diffusion is obtained.

SND has advantages over the separated nitrification and denitrification processes, in the sense of that nitrification and denitrification occur concurrently in the same reaction vessel under identical operating conditions. In continuously operated plants under oxidation ditch system, SND offers the ability of (1) 40 % COD demand reduction during denitrification; (2) 63 % higher denitrification rate; (3) 300 % lower biomass yield during anaerobic growth; and (4) no apparent nitrite toxicity affects for the microorganisms in the reactor (Wang, J., et al., 2008).

The main goal of this research is to apply SND to the alternating cycles process based on decrease of maximum threshold of dissolved oxygen to 0.5 mg/l in a full-scale WWTP. Furthermore, the size and density of floc will be studied using computer vision (CV) techniques.

Methods

The proposed procedure for validating SND process is twofold: (1) oxidation-reduction potential (ORP), DO, NH_4^+-N influent and effluent and accumulated NO_3^--N profile validation; and (2) statistical treatment of floc images for characterization. The main statistics for this analysis are the maximum length of each piece of floc and its mean density. In Digital Image Processing terms, it can be stated that this process should need the following stages (Gonzalez R. C., 2001):

1. Background detection. This part is accomplished by means of histogram analysis, and provides a binary output image, i. e. a binary mask *M* where each pixel in the image is classified as background (black or 0) or object (white or 1). Under clear field illumination, this should ensure a reasonably good floc extraction.

2. Object labelling. Once the floc is segmented from the background, it can be further processed by taking some measurements of each connected object within the mask produced in the previous step, *M*. This usually includes a morphological step, where one can eliminate noisy pixels (i. e. isolated objects of 1x1 pixel size) and fill 1x1 gaps or holes. Once the noise has been rejected, the mask is labelled, providing a way to identify separated objects as connected groups of object pixels within the mask, and also a number of candidate objects. This is the so-called output label matrix *L*.

3. Floc features. There are a number of possible geometric features that can be computed for each piece of floc and its associated label in *L*, including area, perimeter and maximum length. In addition, a desirable feature for floc analysis is its mean density, which can be computed directly from the luminance information present in the floc object of *J* and located in *L*.

Results and discussion

In order to confirm that SND via nitrite is feasible in OD under low DO concentrations (DO = 0.5 mg l^{-1}), the change of nitrogen composition and online monitoring of ORP and DO was carried out (Fig. 1). From 13:00 to 20:00 the DO was kept under 0.5 mg/l and NH_4^+-N was removed without increase of NO_x^--N. This fact shows that denitrification was faster than nitrification rate. During this period, the efficiency of nitrification was 95 % and at the same time, the NO_x^--N profile showed a decreasing trend until it approached a stable value which was lower than the value of accumulated NO_x^--N in the reactor corresponding to the morning period. For this reason, it is possible to assure that: (1) 0.5 mg/l was the optimal concentration of DO; (2) this period of time presented the maximum SND efficiency, being TN removal efficiency more than 70 %.

To investigate the effect of DO on floc size (Fig. 2), the active sludge of floc size was measured using CV. The average of floc size under 0.5 mg/l of DO was 198.34 µm, being significantly bigger than mean floc size reported by (Liu, Y. et al., 2010) but similar to that reported in (Guo, J. et al., 2009). Large floc diameter should be attributed to the influent characteristics. Compared with the synthetic wastewater, the real municipal sewage had more complex constitute and content, particularly with some visible particles, which could promote to form large sludge flocs. On the other hand, low DO is usually believed to be one of the most frequent causes responsible for deteriorating its settlement rate by proliferation of filamentous bacteria, although the volume percent of floc with diameter lower than 50 µm was 15 %, assuring that the number of floc in the effluent was lower.

Floc opacity (FO) is used to study its biomass concentration. As opposite of transparency, it is defined by the degree to which microscopic light is absorbed by the floc. Fig 2 shows a rise trend of the opacity profile with floc size, assuring a correct accumulation of organic matter within floc to improve the denitrification process.

Conclusions

Nitrogen removal performance, sludge settling properties and floc morphology were investigated. It is concluded that DO limitation benefits SND via nitrite and total nitrogen removal. Moreover, low DO did not produce sludge with poorer settling properties.

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Figure 1. Daily profile of SND via nitrite in OD

Figure 2. From top to bottom: processed floc image; and opacity floc measurement ordered by maximum floc length.