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Pilot and full scale applications of sulfur-based autotrophic denitrification process for nitrate removal from activated sludge process effluent

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ABSTRACT

Sulfur-based autotrophic denitrification of nitrified activated sludge process effluent was studied in pilot and full scale column bioreactors. Three identical pilot scale column bioreactors packed with varying sulfur/lime-stone ratios (1/1–3/1) were setup in a local wastewater treatment plant and the performances were compared under varying loading conditions for long-term operation. Complete denitrification was obtained in all pilot bioreactors even at nitrate loading of 10 mg NO_3^-–N/(L.h). When the temperature decreased to 10 °C during the winter time at loading of 18 mg NO_3^-–N/(L.h), denitrification efficiency decreased to 60–70% and the bioreactor with S/L ratio of 1/1 gave slightly better performance. A full scale sulfur-based autotrophic denitrification process with a S/L ratio of 1/1 was set up for the denitrification of an activated sludge process effluent with a flow rate of 40 m^3/d. Almost complete denitrification was attained with a nitrate loading rate of 6.25 mg NO_3^-–N/(L.h).

1. Introduction

Nitrogen removal from domestic wastewater treatment plants is becoming obligatory due to stringent discharge standards. Conventional heterotrophic pre-denitrification processes (such as modified Ludzak-Ettinger (MLE) process) are quite effective provided that wastewater contains adequate amount of organic matter (C/N > 5–6) (Metcalf et al., 2003). In many countries, extended aeration activated sludge processes have been in use and these treatment plants may need to be modified to remove nitrate produced in the process. In this context, effective and economical alternatives should be considered.

Sulfur-based autotrophic denitrification process (reaction 1) has several advantages over heterotrophic one (Sahinkaya et al., 2011; Sahinkaya and Dursun, 2012). Elemental sulfur is a cheap and effective electron source (Sahinkaya and Kilic, 2014). Also, sludge production under autotrophic conditions is much lower compared to the heterotrophic processes (Oh et al., 2001). Another advantage is that sulfur packed column reactor may behave as a high-rate filter and remove particles and biomass escaping from secondary settling tank effluent of wastewater treatment plant. Reaction 1 (Sahinkaya et al., 2011; Sahinkaya and Kilic, 2014) illustrates that sulfur and nitrate are used as electron donor and acceptor, respectively, in the process.

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$$55S^0 + 50NO_3^- + 38H_2O + 20CO_2 + 4NH_4^+ \rightarrow 4C_5H_7O_2N + 55SO_4^{2-} + 25N_2 + 64H^+ \quad (1)$$

The major disadvantages of the process are sulfate and acid generation (Moon et al., 2006; Sun and Nemati, 2012). According to the reaction 1, around 4.57 mg $CaCO_3$ alkalinity is consumed and 7.54 mg sulfate is generated per mg NO_3^-–N reduction. Generally limestone is used for alkalinity supplementation due to its low cost and availability (Kim and Bae, 2004; Moon et al., 2006). The process efficiency has been generally evaluated in lab scale bioreactors especially for water denitrification (Oh et al., 2001; Moon et al., 2006, 2008; Liu et al., 2009; Sahinkaya et al., 2011, 2012). The studies have shown that sulfur-based autotrophic denitrification can be effectively used for drinking water denitrification. Simultaneous heterotrophic and sulfur-based autotrophic denitrification of drinking water has also been shown to be effective process (Oh et al., 2001; Sahinkaya et al., 2013).

Sulfur based-autotrophic denitrification was also tested in lab-scale reactors for the industrial wastewater treatment. Lee et al. (2001) investigated the performance of simultaneous sulfur-based autotrophic and heterotrophic denitrification process performance for the treatment of nitrified leachate containing 700–900 mg/L NO_3^-–N. The alkalinity needed in autotrophic denitrification process was supplemented by the alkalinity produced by heterotrophic denitrification process. By this way, the combined process did not need external alkalinity supplementation. In the study, complete denitrification was attained even when the bioreactor has been operated at hydraulic retention time (HRT) of 6.76 h and NO_3^-–N loading of 2.84 kg NO_3^-–N/(m^3.d).

Autotrophic sulfur-based denitrification process has been shown to be effective for simultaneous reduction of nitrate and some other oxidized contaminants, such as Cr(VI) (Sahinkaya et al., 2013; Sahinkaya and Kilic, 2014), bromate (Demirel and Bayhan, 2013), hexavalent uranium (Luna-Velasco et al., 2010), and perchlorate (Boles et al., 2012).

Although lab-scale bioreactor studies have shown sulfur based autotrophic denitrification process to be a good alternative, there is a gap in the literature on the use of the process for post denitrification of domestic wastewater in pilot or full scale bioreactors under real environmental conditions with the specific emphasis on the problems related to the full scale application of the process. This study aims at evaluating the performances of three sulfur-limestone packed pilot scale bioreactors at varying HRTs and nitrate loadings under ambient temperatures (6–28 °C). After pilot scale studies, the process efficiency was evaluated in a full scale column bioreactor receiving extended activated sludge process effluent serving around 200 people with a flow rate of around 40 m^3/day.

According to the best of our knowledge, this is the first study on the full scale application of sulfur-based autotrophic denitrification process for nitrate removal from activated sludge process effluent specifically addressing the problems related to its application, such as temperature, nitrate loading rate and hydraulic retention time.

2. Materials and methods

2.1. *Pilot scale bioreactors and experiments*

Three column bioreactors with total and working volumes of 25 L and 20 L, respectively, were operated in parallel. Diameter and the total height of each reactor were 0.15 m and 1.5 m, respectively. The reactors were filled with sulfur and limestone mixture up to 1.15 m of the column height. The reactors were fed in up-flow mode. Four sampling ports allowed sampling along the height of the columns (Fig. 1). The pilot scale reactors were located in a local domestic wastewater treatment plant in Istanbul. In order to test autotrophic wastewater denitrification performance, the reactors were fed with the effluent of a full scale activated sludge process. Full scale plant effluent was taken to a separate tank (Fig. 1) in which nitrate was externally supplemented to study the impact of high nitrate loadings. The reactors were filled with varying sulfur and limestone (2–3 mm particles) ratios (v/v): 1/1 (R1), 2/1 (R2), and 3/1 (R3) and operated at varying operational conditions for 150 days (Table 1). HRTs were calculated considering the empty bed volume. The porosity of the column bed was around 40%. The pilot scale reactors were inoculated with denitrifying activated sludge obtained from pre-anoxic tank of a full scale wastewater treatment plant. The R3 was operated until period 5 (Table 1) and its operation was terminated due to some technical reasons.

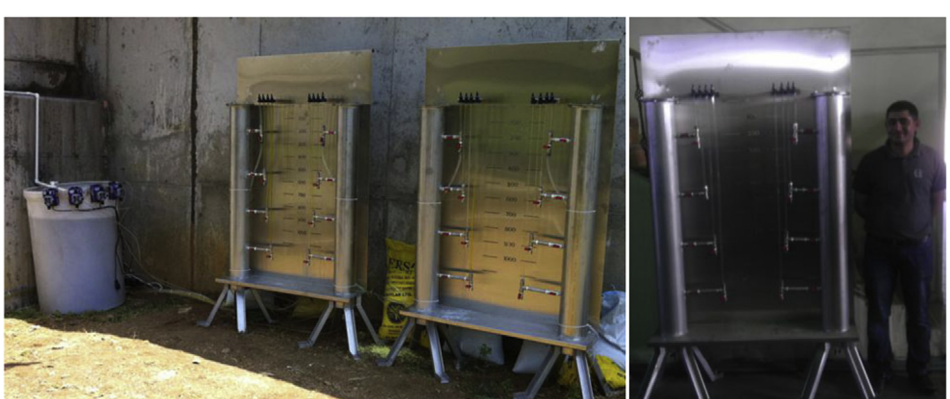

Fig. 1 – Sulfur and limestone packed pilot scale bioreactors.