
DISCUSSION

Of: **Cocurrent Biological Nitrification and Denitrification in Wastewater Treatment**, M. Spector, **70**, 1242 (1998).

G. Heiner

The author is to be commended on an interesting investigation to this aspect of biological nutrient removal (BNR). As designers seek to minimize costs of BNR systems, research into aerobic denitrification and avenues for its possible incorporation to full-scale designs should be continued. Other authors (Kornaros et al., 1996, and van Benthum et al., 1998) have also noted the possibility for reduced aeration and energy costs. In particular, for systems with supplemental carbon addition, the potential for reduced chemical costs makes this an area worthy of further investigation. However, as the author has acknowledged, some regulatory bodies may not encourage optimization of nitrous oxide (N_2O) production. Indeed, research conducted in Japan on N_2O production has been with the aim to control and minimize N_2O production (Hanaki et al., 1992, and Matsuo et al., 1997).

Setting aside the issue of greenhouse gases and focusing on the research presented, there are several issues related to N_2O production and the cocurrent biological nitrification and denitrification (CBND) process to which the author may be able to provide insight. First, N_2O emission during aeration has been reported by Matsuo et al. (1997) in a laboratory evaluation of nitrification–denitrification systems for night-soil treatment. In simulations of both a sequencing batch reactor system and an anoxic–oxic process with mixed liquor recirculation, N_2O emission was found to be greater at low dissolved oxygen (DO) levels (<1 mg/L) and much reduced at DO levels greater than 1 mg/L. In the present research on CBND, the author evaluated N_2O emissions at DO levels of 1.0 and 8.0 mg/L, respectively. What is the author's speculation on any potential relationship between N_2O emission reported in low-DO aeration systems and N_2O emitted during aeration following anaerobic conditioning?

Did the author monitor other reactor parameters such as alkalinity, pH, or oxidation–reduction potential (ORP) in the aerobic zone during CBND? How, for instance, does alkalinity consumption during CBND compare with alkalinity consumption of conventional nitrification or BNR systems?

Several researchers have reported production of N_2O during denitrification. Hanaki et al. (1992) reported that conditions of low chemical oxygen demand to nitrate ratio, short solids retention time, and lower pH favored establishment of organisms that produce N_2O during denitrification. In the research presented on CBND, the inclusion of an anoxic zone during SBR series 4 seemed to increase both total nitrogen removal and CBND. Does the author know whether N_2O or N_2 gas was produced in the anoxic zone? Is there a possible relationship between N_2O production during denitrification and N_2O production through CBND? Also, the author reports an approximate 80% reduction in oxygen respiration rates following the addition of nitrite. This observation may have broader implications with regard to overall

biochemical oxygen demand (BOD) oxidation capability of the system. Does the author wish to speculate on the effect of anaerobic storage on a combined BOD-oxidation and nitrogen-removal system or does present information indicate that possible application should be directed more toward systems with supplemental carbon addition?

Further, was an optimal chemical oxygen demand/total nitrogen ratio established during these experiments? Has the author experimented with other anaerobic-conditioning periods? Does the CBND effect decrease gradually at fewer than 8 hours or is it absent at lower periods? Has any attempt been made to correlate effectiveness of anaerobic storage period (measured by the initiation of CBND) with a process parameter within the anaerobic storage vessel such as pH, ORP, or volatile acid concentration?

It is stated that anaerobic conditioning induces denitrification pathways that might continue to function during aeration. However, it seems that, during the anaerobic storage period, there is no nitrogen present as nitrate or nitrite. Does anaerobic storage serve as a selector for CBND organisms or create conditions that inhibit the activity of nitrite oxidizers?

The hypothesis that nitrite-oxidizing organisms can be gradually washed out of a system producing N_2O has also been offered to explain observations of nitrogen removal in an intermittently aerated biofilm airlift reactor. In a recent study, van Benthum et al. (1998) observed N_2O emission during aeration without the accumulation of nitrite or nitrate. Similar to the present CBND study, one explanation offered for their results was that a competition for nitrite developed between nitrite oxidizers and reducers. It is interesting that, despite significant differences between the biofilm airlift reactor and a suspended-growth reactor, similar observations were reported.

The author's work has provided a valuable contribution to the understanding of aerobic denitrification and N_2O emissions and I look forward to further work by this researcher.

Acknowledgments

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Of: Cocurrent Biological Nitrification and Denitrification in Wastewater Treatment, M. Spector, **70**, 1242 (1998).

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This paper is an excellent one, providing both an empirical demonstration of a process for removal of ammonia-nitrogen ($\text{NH}_3\text{-N}$) from wastewater that has several advantages over current methods and an elucidation of the biological and chemical mechanism by which removal occurs. This clarification of the mechanism is important because the result is somewhat counterintuitive for those familiar with the conventional nitrification-denitrification process. It seems reasonable that using dissolved free oxygen would be metabolically easier for bacteria than extracting oxygen from ions in which it is combined with nitrogen. This expectation is in accordance with experience that oxygen inhibits denitrification, and such experience is the basis for the established technology, which has separate aerated zones or tanks for nitrification and anoxic environments for denitrification.

However, the author has found that if measures are taken to suppress the *Nitrobacter* population in return activated sludge (RAS), then nitrite is not converted to nitrate during aeration. Because nitrite inhibits cytochrome respiratory enzymes of many bacteria, in the presence of nitrite the aerated environment is, in effect, anoxic for them, and so by an alternative metabolic pathway they reduce the nitrite to nitrous oxide (N_2O) and N_2 . Hence, a balance is established between oxidation of $\text{NH}_3\text{-N}$ to nitrite and reduction of nitrite to N_2O and N_2 in a single aeration basin, and most of the removal of $\text{NH}_3\text{-N}$ occurs there. A subsequent anoxic denitrification step removes residual nitrite, ammonia, and nitrate, but this is minor compared to the removal in the aeration step. As the author notes, this process has the potential to reduce several costs associated with the current process, although there are also potential disadvantages.

A few substantive points must be discussed. First, in sequencing batch reactor (SBR) series 2, was the reactor operated differently in any way during the first 50 minutes of the 20:50-hour settling-conditioning period? Stating that the first 50 minutes were used to reduce dissolved oxygen, nitrate, and nitrite in the sludge blanket seems to imply that something was different during this time from the following 20 hours of conditioning, but if air supply and stirring were turned off when the first 50 minutes of settling began, what else might have been done later?

Second, why was the influent composition in Table 1 in the paper chosen? Is this mineral composition typical of a sample of primary effluent? Is the resulting mix of RAS and synthetic influent like real mixed liquor? Also, because adding the anoxic denitrification period greatly improves the nitrogen volatilization rate, is it reasonable to conclude that anoxic denitrification removes residual nitrite and nitrate to starve any surviving *Nitrobacter*?

Is it correct that the project described in this paper lasted

approximately 2 years? The test and graphs indicate that SBR series 1 lasted 40 weeks, series 2 and 3 lasted another 22 weeks, and series 4 lasted 39 weeks after the end of series 3. This totals 101 weeks, not counting any additional time that elapsed in preparations before the start of series 1 or between series 3 and 4. Hence, as this paper was submitted in May 1997, approximately 4 years or more have elapsed since the beginning of this project. Has any additional work been done, such as additional tests with real wastewater instead of an influent solution of laboratory chemicals or preparation for a pilot-scale test? Further, is it possible that the sporadic unexplained loss of nitrogen from the Largo treatment plant, mentioned at the end of the Source of Sludge subsection of the Methods and Materials section, could be the result of episodes of reduction of nitrite to N_2O and N_2 by the cocurrent biological oxidation and denitrification (CBND) effect?

Also, certain questions may need to be answered to make CBND a practical process for wastewater plants. First, can the settling-conditioning period be shortened to fewer than 8.5 hours to reduce storage volume needed for this stage of the process? Also, can volatilization rate be increased to more than 31 mg N/L for the process combining aeration and aerobic feeding, anoxic denitrification, and anaerobic settling-conditioning? Further, would it improve results to extend the anoxic denitrification period longer than 1 hour?

A more global environmental question is posed because we would like to see this concept developed further and hope that the currently potential obstacles in the last two paragraphs of the Conclusions section can be overcome. The end of the Conclusions seriously undercuts the apparently promising results of this study by emphasizing that the harmfulness of N_2O emissions from conventional denitrification is unavailable. Hence, it is uncertain whether implementing the CBND process in a full-scale plant and discharging the resulting gas would be significantly more harmful to the atmosphere than present denitrification operations, although it is widely believed that present systems primarily release N_2 .

On the other hand, discharging N_2O to the air is not the only option. Nitrous oxide decomposes into its component elements at temperatures higher than 520 °C (Parrington, 1961); so if CBND were carried out under conditions that allowed N_2O to be collected at a plant that burns methane from digesters for energy reclamation, adding N_2O to methane could produce a gas with enhanced heat value because of additional oxygen supplied by N_2O . Moreover, at atmospheric pressure, N_2O has both liquefaction and freezing points near -90 °C (Lide, 1997), which may open opportunities for removal by cold traps, especially at plants that have cryogenic oxygen systems.

Several questions and comments could also be made about minor points, as follows. Yeast is not typically considered an inorganic component as listed in Table 1 of the paper. The description of the analyses on page 1243 refers to "[^{15}N]potassium nitrate," but the formula given is K^{15}NO_2 for the nitrite and

additional description on page 1246 makes it clear that this is what was used. Is the notation at the top of Table 2 in the paper inconsistent? It seems that it would be more consistent to write either $\text{NH}_3\text{-N}$, and so on, to go with the $\text{PO}_4\text{-P}$ notation, or PO_4 to match notations for the forms of nitrogen.

We encourage the author to continue investigating this process and congratulate him on this work, which may be highly important in the future.

Acknowledgments

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Closure

M. Spector

The author thanks Heiner and Iranpour et al. for their comments. Although the issues raised are too numerous to address

here, the following clarifies several points. Research leading to the paper was conducted over a period of 7 years; run time was much longer than the 101 weeks cited in Iranpour et al.'s discussion.

An earlier publication (Spector, 1998b) reported that nitrous oxide (N_2O) was the initial reaction product of nitrate with methanol during denitrification of sludge in a closed reactor. Nitrous oxide initially accumulated to a maximum level, which accounted for 50 to 80% of nitrate removed, and was subsequently reduced to elemental nitrogen as rapidly as it was generated. This work indicates that high yields of N_2O are not unique to CBND and N_2O can be reduced to elemental nitrogen within a biological reactor *providing* that the reaction is conducted in a covered reactor system in which both gas and liquid flows are staged (Spector, 1998a).

The influent composition in Table 1 of the paper was selected because it was essentially the same as that used in laboratory studies leading to the commercialization of the A^2O and A/O wastewater treatment processes (Spector, 1987).

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