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Original Article

Effect of Nitrite and Nitrate-N Accumulation and Removal on the Suspended Solids in the Aeration Tank of Opal's Secondary Water Treatment Plant

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Abstract - *High concentrations of Total Suspended Solids (TSS) in the aeration tank of the Secondary Water Treatment Plant (SWTP) were found to be related to the increased levels of nitrate and nitrite-N because of the nitrification and denitrification processes under the reduced oxygen conditions at mesophilic temperature. This issue was triggered in the aeration tank due to the transfer of residual ammoniacal-N from the Extended Granular Sludge Bed (EGSB) reactor through the effluent water. Under the low oxygen nitrification conditions, more oxygen supply facilitated nitrification, thus converting nitrite into nitrate by Nitrobacter. Almost 90 % reduction in TSS was found in the disposal water @ 36-37 ^{o}C in the field conditions. However, in the case of high NO_3-N, low levels of Dissolved Oxygen (DO) are recommended to enhance denitrification in the presence of Nitrosomonas in such a manner that NO_2-N can squeeze O_2 from NO_3-N. Similarly, in the case of high NO_2-N, increased oxygen supply helped to reduce TSS. These strategies reduced TSS-laden N_2 liberation towards the surface of clarifiers. Total Suspended Solids (TSS) in the aeration tank were reduced to almost 90% compared to the initial solids in the aeration tank of the SWTP due to the nitrogen removal. Increased levels of DO (82 %) help to resolve the NO_2-N accumulation issue in the aeration tank. Sludge volume in the aeration tank was reduced by 62% compared to the initial volume. Similarly, a 50% reduction in SVI30 was observed after 40 days of samples under field conditions, thus showing the removal of nitrogen from the system, which reduced the floatation of TSS.*

Keywords - *Nitrification, Aerobic sludge, Nitrite, Nitrate, Aeration, Total dissolved solids.*

1. Introduction

Various nitrogen removal technologies, such as denitrification and nitrification, are used to remove nitrogen from the wastewater (Rahimi et al., 2020). Denitrifying bacteria are autotrophs and play a pivotal role during the nitrification and denitrification processes. One of the emerging technologies in the field of SWTP operations is to minimise the activities of nitrite oxidising bacteria without hampering the activities of ammonium oxidising bacteria in the aeration tank of the wastewater treatment plant (Sojka et al., 1992).

The partial elimination of nitrite oxidising bacteria was reported during the nitrogen removal study. However, at temperatures above 25 °C, the growth rate of ammonium oxidising bacteria is more active than the nitrite oxidising bacteria (Hellinga et al., 1998). Furthermore, nitrite oxidising bacteria can be washed out by reducing the sludge retention time (SRT), as reported in the literature (Munz et al., 2011). Nitrogen removal (98 %) was successfully managed by adjusting the DO levels in a two-stage oxic/anoxic bioreactor (Ma et al., 2023). An experiment on the effect of TSS on nitrogen removal at low and high concentrations of TSS found that at both the solid concentrations, nitrogen removal was 1.8-2.0 ppm hr^{-1} (Foladori et al., 2020). Furthermore, they found that nitrogen removal and TSS concentrations were linked with the light intensity as well as DO levels in the photobioreactor. Dissolved Oxygen (DO) through aeration control proved to be an efficient way to reduce the nitrite-oxidizing bacteria population, which helped N-removal over nitrite (Lochmatter et al., 2014). Experiments were conducted to see the effect of low DO, aeration phase length control (Blackburne et al., 2008; Lemaire et al., 2008), and intermittent aeration (Li et al., 2008; Fux et at., 2006) using sequencing batch reactors (SBR) to determine the nitrite removal from the system. Different techniques were used to control the nitrite-N by enhancing the ammonium oxidation. Furthermore, oxygen was supplied to ammonium-N and stopped at the completion of the oxidation process, thus reducing the time required for the natural nitrite oxidation by nitrite oxidising bacteria such as Nitrobacter (Lemaire et al., 2016). Research experiments were conducted to see the inhibition of nitrite-N by increasing or decreasing the aeration at different temperatures ranging from 12-27 °C (Ge et al., 2014). In our study, temperature was kept at 36-37 °C in the aeration tank in situ.

Selective inhibition of nitrite oxidising bacteria has also been achieved and reported (Anthonisen et al., 1976; Vadivelu et al., 2007) using several chemicals such as chlorate (Xu et al., 2011) or formic acid (Philips et al., 2002). In addition to chemical inhibitors, the competition for oxygen was used as a parameter to achieve N-removal over nitrite, which showed that nitrite oxidising bacteria were more sensitive to low oxygen concentrations (Ciudad et al., 2006; Guisasola et al., 2005). Many other studies were also conducted to establish the nitrite pathway with low dissolved oxygen (DO) concentrations (Tokutomi, 2004; Bernet et al., 2001; Ruiz et al., 2003.

The presence of nitrogen in the aeration tank helps suspended solids to float, which ultimately enters the clarifiers. Despite the fact that coagulant is added to settle solids down at the bottom of the clarifier, the high rate of nitrification triggers the solids to float to the surface of the clarifier. This Total Suspended Solids (TSS) ultimately increases the concentration above the recommended limits set out for the disposal of water (600 ppm) from the Secondary Water Treatment Plant (SWTP) in Australia.

In this research study, efforts are made to minimise the floatation of TSS through the nitrification and denitrification control using air blowers @ 36-37 °C temperature of the aeration tank in the field conditions. It was also found to be a cost-effective method by reducing the use of electricity to run the air blowers at a lower speed. A reduction in air blower speed may also be helpful to reduce noise pollution.

To date, little is known about the TSS behaviour in the aeration tank of the SWTP using the data on nitrification and denitrification processes in the natural environment. Not enough research findings are available in the literature on the aspect addressed in this research paper. However, there are few findings on the effect of nitrification and denitrification on the removal of nitrogen from the aeration tank of the SWTP. The unique idea of how nitrification processes affect the concentration of TSS in the aeration tank as well as in the clarifiers of the SWTP. Therefore, this research work was conducted in field conditions to evaluate and inhibit the nitrification and denitrification processes under mesophilic temperature through DO control and to see the effect on TSS concentration in the aeration tank of the SWTP. Not sufficient literature was found exactly on the specific topic.

2. Materials and Methods

Samples from the aeration tank were collected in a 1.0 L plastic container provided with a lid. The experiment was run for a period of 40 days. Samples were not taken every day because it was not possible due to the changing or running conditions of the SWTP. Mixed Liquor Suspended Solids (MLSS) were measured (Lipps et al.,2000; Smith and Greenberg, 1963). SVI30 was measured using the Imhoff Cone method (Sojka et al., 1992). HACH (Hach, 2022) vials TNT 835 (Nitrate-N), TNT 839 (Nitrite-N), and TNT 832 for NH_3-N were used to analyze nitrogen sources using the Spectrophotometer DR 3900. DO and pH were measured immediately after the sample collection using a combined pH and DO electrode (Mettlertoledo, 2022). Air (oxygen) was blown into the aeration tank (Aerzen, 2021) at a constant rate of 1.50 ppm under normal conditions.

3. Results and Discussion

Issues related to increased TSS in the aeration tank emerged due to the transfer of residual ammoniacal nitrogen (NH_3-N) in the aeration tank through the effluent water from the EGSB reactor. The presence of ammoniacal-N (20.90 ppm) in the aeration tank triggered the oxidation process in the presence of Nitrosomonas to form NO_2-N at low levels of supplied DO (0.69 ppm), as shown in Figure 1. High levels of nitrite-N were found after 16 days (25.44 ppm), which triggered TSS to float on the surface of clarifiers. Therefore, to mitigate this issue, it is recommended to facilitate nitrification by pumping more air into the aeration tank for the purpose of nitrogen removal under an oxic environment.

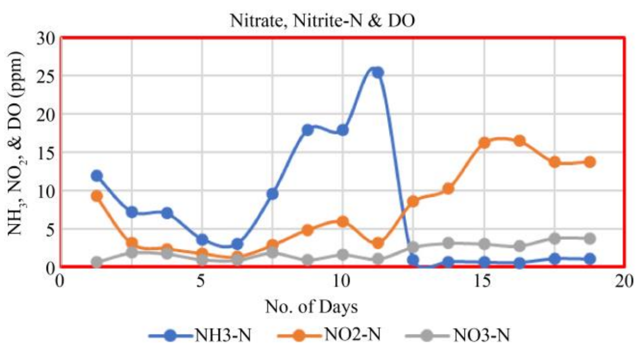

Fig. 1 Residual transfer of ammoniacal-N in the aeration tank

At this stage, NO3-N concentration in the aeration tank was also found to be high and in the range of 9.28 ppm, which was increased to 25.44 ppm (Figure 3) after 9 days of the experiment. A high concentration of nitrate-N released N_2 because of denitrification at low DO and forced the suspended solids to float at the surfaces of clarifiers. Visual observations of the impact of increased nitrite-N on the TSS behaviour were pictured and shown in Figure 2. The nitrification process did not allow the TSS to settle down even after the application of polymer used to settle the suspended solids in the clarifiers. Therefore, the amount of TSS in the supernatant solution at the surface of clarifiers got high (428 ppm), increasing the TSS concentration in the disposal water as data clearly shown in Figure 5.

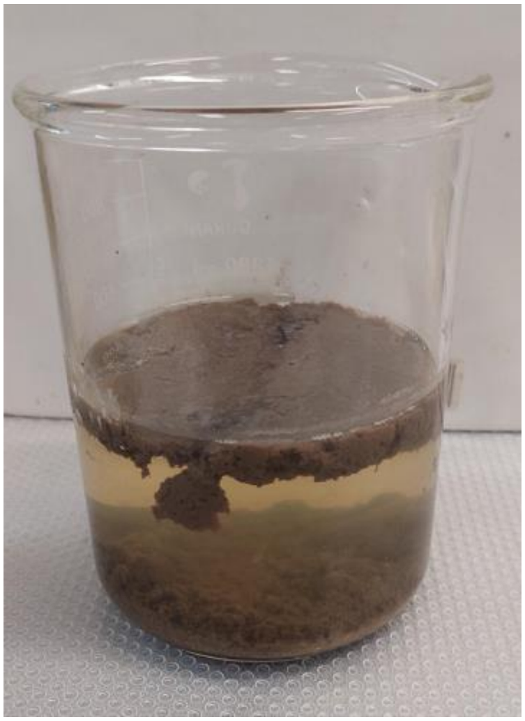

Fig. 2 Floating suspended solids because of the nitrification process in the aeration tank of the SWTP

Thus, in the case of high NO_3-N, low levels of DO in the aeration tank are recommended to enhance denitrification in such a manner that NO_2-N can squeeze O_2 from NO_3-N. This process will reduce TSS-laden N_2 liberation from the surface of clarifiers, as shown in Figure 3.

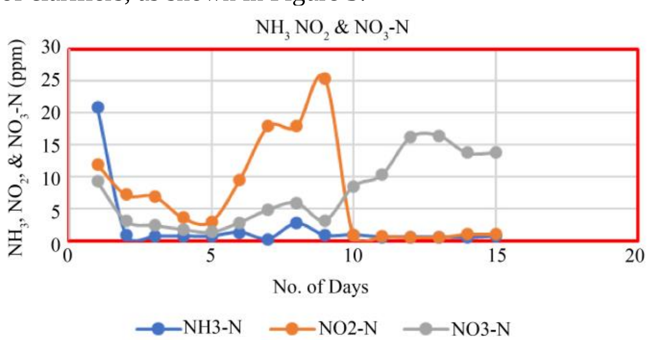

Fig. 3 Accumulation of ammonium, nitrate, and nitrite-N in the SWTP aeration tank

However, high levels of nitrite (25.44 ppm) in the aeration tank were caused by the low levels of DO (1.12 ppm). Under such conditions, more oxygen supply is recommended through the air blowers to facilitate nitrification, thus converting nitrite into nitrate by Nitrobacter under an oxic environment (Figure 3).

Increased oxidation process helped to reduce suspended solids in the disposal water (44 ppm). Almost 90 % reduction in TSS was found in the disposal water @ 36-37 ^{o}C in the field conditions, as shown in Figure 4.

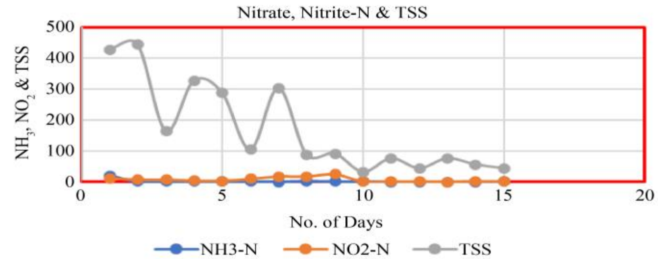

Fig. 4 Effect of nitrification and denitrification on the TSS in the SWTP aeration tank

The sludge volume in the aeration tank sample was found to be high due to the nitrite-N accumulation. However, after 28 days, it came down to 170 mL, and the reduction was found to be 62% compared to the initial volume of 450 mL. It is important to note that the data was not collected daily due to data collection limitations such as weekends and the disruption in the smooth running of the SWTP. Total Suspended Solids (TSS) in the aeration tank showed the same decreasing trend with time (Figure 5). It reduced to almost 90% compared to the initial solids in the aeration tank of the SWTP.

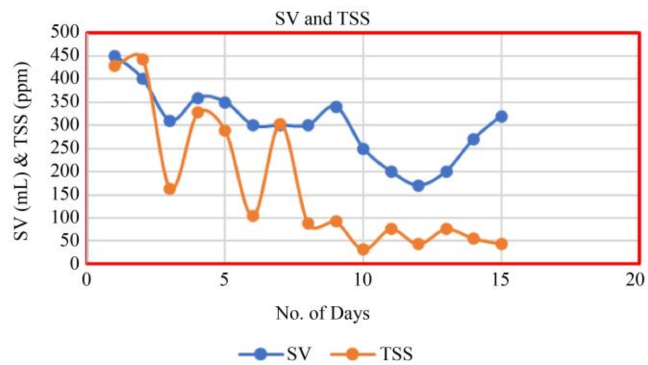

Fig. 5 Relationship between Sludge Volume and Total Suspended Solids during the Nitrification process

DO concentration, carbon to nitrogen ratio (C/N) as well as temperature and pH are known to influence aerobic denitrification rates (Ji et al., 2015). Therefore, increased levels of DO enhance the solution to the nitrogen-N accumulation and TSS issues in the aeration tank. DO increased 82% during the 40 days of trial in the field conditions, as shown in Figure 6. Some experiments reported that a very high electrical energy is required to supply a large amount of external oxygen for nitrification (Luo et al., 2019).

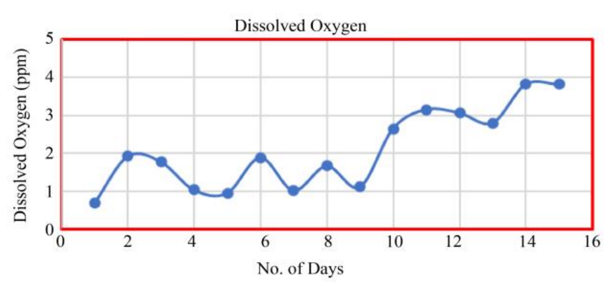

Fig. 6 DO in the aeration tank to control the nitrogen-N accumulation.

Ammoniacal-N played a significant role in the various parameters, such as Sludge Volume (SV), Sludge Volume Index30 (SVI30), and TSS during the nitrification and denitrification in the aeration tank (Figure 7). At the time of nitrification of NH_3-N to NO_2-N (Figure 3), an SV of 450 ppm (62 %) was recorded due to N_2 production. Nitrogen so produced pushed the TSS up towards the surface of clarifiers. Therefore, high TSS was recorded during that time. Similarly, SVI30 was reduced by 50% after 40 days of the experiment, thus showing the removal of nitrogen from the system. Some experiments showed that nitrogen removal was different at varying concentrations of TSS ranging from 0.2 to 3.98 g TTS/L (Garcia et al., 2017). The removal of nitrogen from the aeration tank was managed by increasing the oxygen level to 82 % during the trial period of 40 days (Figure 7).

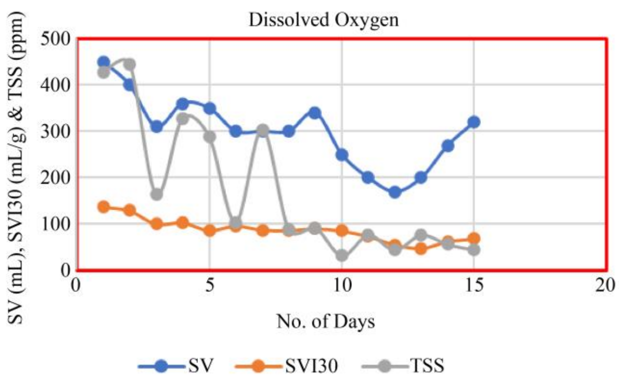

Fig. 7 Effect of residual ammoniacal-N on the different parameters

Testing of three forms of nitrogen was carried out to ascertain the level of different forms of nitrogen at the start of the experiment. Increased levels of these three forms of nitrogen had a significant impact on the TSS concentration and malfunction during the process. The concentration of NH_3-N, NO_2-N, and NO_3-N forms of nitrogen, which triggered the suspension of TSS at the surface of clarifiers, were confirmed through the nitrogen analysis and were found to be 20.90 ppm, 11.98 ppm, and 9.28 ppm, respectively as shown in Figure 8.

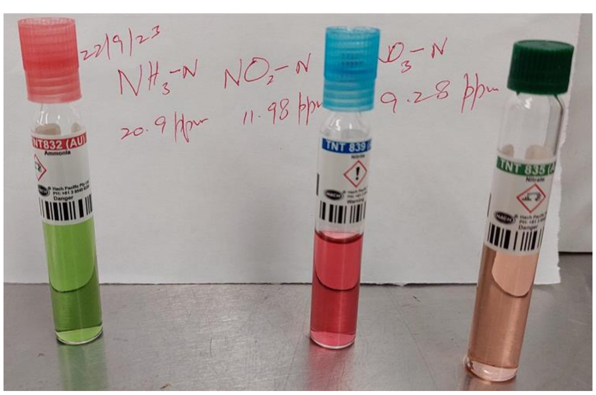

Fig. 8 Concentration of three forms of nitrogen in the aeration tank at the start of the experiment

Three forms of nitrogen were also measured at the end of the experiment to establish the normal nitrogen limits in the aeration tank of the SWTP for further reference (Figure 9). Limited data was available about the normal limits of ammoniacal-N, nitrite-N, and Nitrate-N and were found 0.361 ppm, 0.700 ppm, and 1.38 ppm, respectively.

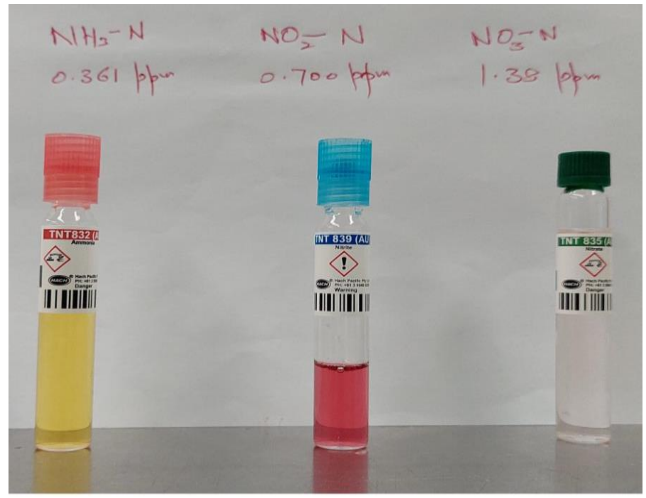

Fig. 9 Concentration of three forms of nitrogen in the aeration tank at the end of the experiment

Overall, residual ammoniacal-N, which came from the anaerobic reactor through the EGSB effluent, entered the aeration tank and caused nitrification. At this stage, oxygen in the aeration tank was low (0.69 ppm). Then, to convert the NH_3-N to NO_2-N oxygen through the blowers, it was gradually increased. This strategy helped to reduce the TSS load in the disposal of water coming from the top of clarifiers. In this research, efforts were made to find out the effect of nitrification on the TSS concentrations, which were almost not reported in the literature before. However, more research may be required on this aspect.

4. Conclusion

- Almost 90 % reduction in TSS can be achieved by increasing 82 % DO during the high nitrite-N time.
- N-removal efficiency can be achieved by increasing or decreasing the DO in the aeration tank @ 36-37 ^{o}C in the field conditions.
- Removal of nitrogen through the DO control can save energy and is a cost-effective approach.
- Noise pollution can be reduced by turning off the blowers or reducing the speed when less oxygen is required.
- It is recommended to facilitate nitrification by pumping more oxygen into the aeration tank for the purpose of nitrogen removal under the reduced oxygen environment.
- Do not supply O_2 when NH_3-N concentration is high in the clarifiers to enhance denitrification.

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