Assess the Denitrification Performance of Fermented and Dark-fermented Biosolids as External Carbon Sources Using Sequence Batch Reactors (SBRs)

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Abstract: The study has assessed the denitrification performance of fermented and dark-fermented biosolids as external carbon sources using lab-scaled Sequencing Batch Reactors (SBRs). This was done by adding fermented and dark-fermented biosolids into anoxic zones of two SBRs, and then assessing the change of effluent characteristics comparing to before adding and to a third controlled reactor. The results showed that by adding 150-170 mg rbCOD/L of either of the selected fermented biosolids, almost complete denitrification could be reached for tested SBRs (reduced from initial ~20 mg NO₃/L to < 1 mg NO₃/L). Finally, the experiment also found that the impact of NH₄ components of fermented and dark-fermented biosolids onto the final effluent were much lesser than expected, where only less than 2.5 mg NH₄/L were detected in the effluent, much lower than the added 5.0-5.7 mg/L.

Key words: Fermented sludge, dark fermentation, external carbon source, SBRs.

1. Introduction

Denitrification is the process of nitrate reduction where nitrate is served as electron acceptor (in place of oxygen) for the Degradation Of Organics (COD) by facultative heterotrophic organics. This is an essential biological process for Municipal Wastewater Treatment Plants (WWTPs), as the nitrification process in standard municipal wastewater does not actually remove nitrogen but only converts most of ammonia to nitrate.

For complete denitrification to happen, abundant organic carbon has to be available in anoxic zones of WWTP. However, this often does not occur, as most readily biodegradable organic carbon has already been consumed by the previous aerobic zone. Denitrification-specialized WWTPs set-up, like Modified Ludzack-Ettinger (MLE), or Bardenpho, was designed to address this issue. However, if the

readily biodegradable COD (rbCOD) inside municipal wastewater influent was not inadequate, low Specific Denitrification Rate (SDNR) and overall ineffective denitrification could still happen. Not to mention reconstructing and modifying an existing WWTP to improve the system efficiency is not always ideal or even possible, due to the need for high capital investment, high operating cost and sometime simply due to the lack of space/land available to implement extra treatment zones.

Hence, the lack of organic carbon for denitrification to happen has always been one of the biggest issues within the industry [1].

One of the simple solution is adding an external carbon source into post- or pre-anoxic zone to improve the denitrification process. It has an advantage of much easier and cheaper to implement (due to requiring little modifications to an existing WWTPs); provide immediate denitrification improvement; does not require high capital investment; ideal for short-term solution, but also viable for long

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term if a cheap and abundant external carbon sources could be secured. Hence, finding an alternative cost-effective external carbon substance was listed amongst the priorities of the wastewater treatment industry (especially during WEF 2005 [2]) and has been going on for the past two decades [3]. The focus was on local 'industrial waste products/by-products' that is rich in carbon and 'highly recommended especially if one WWTP can has the access' [3]. Many materials rich in carbon that has been studied in the past include industrial wastewater, corn starch, reject water [4], syrup from distillery, waste products from food industries [3].

Previous to this study, various conditions of fermented and dark-fermented Wasted Activated Sludge (WAS) and anaerobic digested biosolids (biosolids) were carried out to find the optimum conditions and assess their potential as external carbon sources. Two of the fermented and dark-fermented sludges (amongst seven) were picked out for further study here in this paper.

2. Material and Methods

2.1 Chemicals and Inoculums

The three SBRs used in this study were all seeded with the raw sludge, rich with denitrifying biomass from Sunburry WWTP. The sludge was collected from the pre-anoxic zone, preserved and transported in ice box to the lab where it was sieved to remove any large particles, before being fed into the SBRs. For this experiment, the three SBRs have been running on constant conditions for 10 months previous to the start of this experiment.

The SBRs used synthetic wastewater consist of commercial beef extract as main organic carbon and organic nitrogen sources. The additional nutrient and trace metal solutions for this synthetic wastewater were based on Hu et al. [5] consisting of 10 mg/L of CaCl_2 , 18 mg/L K_2HPO_4 , 11 mg/L KH_2PO_4 , 10 mg/L MgSO_4 , 0.15 mg/L CoCl_2 , 0.03 mg/L CuSO_4 , 10 mg/L FeSO_4 , 0.15 mg H_3BO_3 , 0.18 mg/L KI, 0.12

mg/L MnCl_2 , 0.06 mg/L NaMoO_4 and 0.12 mg/L of ZnSO_4 . All of the chemicals were supplied by Science Supply Australia.

The used fermented and dark fermented biosolids were generated from earlier experiments with original characteristics as shown in Table 1. Note that: their original pHs were 7.36 ± 0.01 and 6.89 ± 0.04 respectively. But because of the need to preserve this sample for the whole duration of the experiment (over 4 weeks), the pH were adjusted using sulfuric acid to $\text{pH} < 2$.

2.2 Analytical Method

COD, TN, Ammonia, Nitrate and Volatile Fatty Acid were analysed using HACH standard methods for the DR 5000 (Methods 8000, 10072, 10031, 10020 and 8196 respectively). pH and DO were tested by using the Mettler Toledo S20 Seveneasy pH meter and YSI 5100 dissolved oxygen meter.

Due to the soluble synthetic wastewater, the Mixed Liquor Volatile Suspended Solid (MLVSS) of all SBR reactors were found (using SPSS program) to be insignificantly different to the Mixed Liquor Suspended Solid (MLSS). Hence, these two values are interchanged in this experiment. The MLSS was measured the same way with Total Solids, where 100 mL of sample were dried overnight in 105 degrees oven.

2.3 Experimental Set-up

The chosen lab-scaled SBRs set-up (as seen in Fig. 1) is continuous running experiments 24 hours a days, 7 hours a week. The 8-hours cycle being dictated with typical commercial timer, consist of 0.5 hours of unmixed feeding, 4 hours of aeration, 2 hours of anoxic mixing, 1 hour of settling and 25 minutes of decanting. The 5 minutes gap at the end of the cycle is to prevent issues relating to timing devices error, where feeding and decanting happen in the same time leading to loss of sludge or influent.

The SBRs have effective volume of 4L each, with a decant percentage of 50% according to Kargi et al. [6],

Table 1 The original characteristics of fermented and dark-fermented sludge used in this experiment.

No	Types	rbCOD	NH ₄	C/N	VFA	VFA%
1	Fermented biosolids	11,730 ± 102	1,135 ± 25	10.34 ± 0.17	1,702 ± 68	14.5 ± 0.6
2	Dark fermented biosolids	11,257 ± 275	1,110 ± 11	10.14 ± 0.12	1,158 ± 5	10.3 ± 0.3

Fig. 1 The setup of the four SBRs.

including the sludge wasting. The Sludge Retention Time (SRTs) is calibrated and controlled to be within the range of 11.5-12.5 [6, 7]. The cycle duration is 8 hours, giving a HRT (Hydraulic Retention Time) of 16 hours. Other than the addition of calcium carbonate inside the feed, pH is usually not adjusted. But due to short HRT, the pH of all reactors always falls within the range of pH 7-8 of synthetic wastewater.

The SBRs had been running for roughly 10 months before the start of the experiments. The data collected and used for this specific experiment is roughly in 2 months. For the first 4 weeks (more than 2 SRTs), no external carbon source was used. During the next 4 weeks, the two types of fermented biosolids (after pH were adjusted back to neutral 7.0), were fed into the post-anoxic cycle to increase the rbCOD during anoxic zone by 150-170 mg COD/L. Reactor 1 was fed with fermented biosolids, and Reactor 2 was fed with dark-fermented biosolids

The SBRs performance was then monitored twice a week for NO₃, NH₄, TN, COD, pH, MLSS, DO and the effect of fermented biosolids on the system denitrification was assessed.

3. Results and Discussion

3.1 Results from the SBR Reactors

The resulted nitrate and ammonia concentration of the SBRs can be summarised in Fig. 2. Note: normally only NO₃ is affected by the denitrification process. But because the added fermented and dark-fermented also contain significant NH₄, that's why both NO₃ and NH₄ were monitored in this case..

As showed in the three graphs, during the one month built up to the start of the experiment (before Day 37), there were very limited denitrification happening during the anoxic period in all reactors. This was likely due to the low remained rbCOD of all four reactors previous to external carbon sources were added in (as seen in Fig. 3).

However, a clear drop of nitrate concentration could be seen in reactor 1 and 2 in the second half of the experiment (after fermented sludge was added). They were reduced from as high as 20 mg/L in one month built up to the start of the experiment to as low as insignificant (< 0.4 mg/L). The ammonia concentration in the effluent increased however as expected.

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Fig. 2 The nitrogen profiles of the three SBRs reactors.

Note: The $\text{NO}_3(\text{ini})$ and $\text{NH}_4(\text{ini})$ are the concentration of nitrate and ammonia before the start of the anoxic (also before fermented sludge is added). The $\text{NO}_3(\text{f})$ and $\text{NH}_4(\text{f})$ are the concentration of nitrate and ammonia after the anoxic/ in the effluent.

The exact values of all monitored parameters are showed in Fig. 3 as:

As it can be seen, almost complete denitrification (93-94% nitrate removal) was recorded when either of fermented and dark-fermented biosolids was added into the reactors. This rate is similar to what was

found in literature when fermented biosolids was used to enhance denitrification [8, 9]. In fact, most of the recorded effluent data found nitrate to be lower than < 1.0 mg/L with only few exceptions. What was not expected is the amount of NH_4 increase, as it's calculated that the added fermented biosolids will

Fig. 3 All measured parameters of all three reactors.

Note: Fermented biosolids were added into Reactor 1 and dark-fermented biosolids were added into Reactor 2.

increase the NH_4 concentration in the effluent by 5.0-5.7 mg/L (C/N ratio of 30:1 and 150-170 mg COD was added in). But actual results showed only an increase of 2.3 ± 0.8 mg/L and 1.8 ± 0.8 mg/L for fermented and dark-fermented biosolids reactors, indicating that more than half of the added ammonia was possibly absorbed into the solid sludge, rather than staying in the liquid effluent.

MLSS and pH were also measured but does not show any significant change.

The remained soluble COD, however, increased

from 40.6 ± 14.9 mg/L to 117.7 ± 35.3 mg/L, and 44.1 ± 8.4 mg/L to 120.4 ± 38.5 mg/L for fermented biosolids and dark-fermented biosolids respectively. These values indicate that a large portion of added COD from fermented biosolids was not used up. While it's possible to reduce the amount of added fermented biosolids, however, the less saturated rbCOD is inside the reactor, the lower denitrification rate it could achieve. Note: ~120 mg of rbCOD could be easily removed with as short as 15-30 minutes of aeration.

3.2 Specific Denitrification Rate (SDNR) Based on the SBRs Results

Because the amount of nitrate removed from a system can be estimated using:

$$NO_3\text{removed} = \frac{SDNR(20)}{1.026^{(20-T)}} \times MLVSS \times HRT$$

Where SDNR(20) is the specific denitrification rate at 20 °C, T is the temperature of the system, and the HRT is the hydraulic retention time of the anoxic zone, which is approximately 2 hours (specifically 110 minutes). But because the SBRs were operated in a controlled temperature of 20 °C, the SDNR of the two fermented biosolids could be calculated using:

$$SDNR(20) = \frac{NO_3\text{removed}}{MLVSS \times HRT}$$

The denitrification rate of fermented and dark-fermented biosolids in this case hence can be calculated to be 5.45 ± 0.61 and 5.50 ± 0.77 respectively.

The actual SDNR is likely to be higher than these two values. Because as showed in Fig. 2, during most tested samples, complete denitrification was reached for both reactors 1 and 2, means that the actual amount of NO_3 that can be removed should be higher.

4. Conclusion

What were found from this study could be summarized as below:

Adding fermented biosolids and dark-fermented biosolids onto the anoxic zones of the SBRs have resulted in almost complete denitrification for the tested reactors during the 4 weeks tested period (> 2 SRT). Where the nitrate concentration in the effluent have reduced from 19.8 ± 1.4 and 20.4 ± 1.3 mg NO_3/L to 1.5 ± 0.7 and 1.2 ± 0.8 mg NO_3/L respectively.

The amount of increased NH_4 concentration were just 2.3 ± 0.8 mg/L and 1.8 ± 0.8 mg/L, much lower than the calculated 5.0-5.7 mg/L, indicating that more than half of the input ammonia was possibly absorbed into the solid phase of the sludge, rather than staying

in the liquid phase of the effluent. This means the impact of nitrogen components in fermented biosolids were much lesser than expected.

The remained COD in the effluent increased to $117.7 \text{ mg/L} \pm 35.3 \text{ mg/L}$ and $120.4 \pm 38.5 \text{ mg/L}$. However, rather than reducing the amount of added carbon (which could affect denitrification efficiency), it would be easier to just remove them with a short aerobic zone right before settling phase

The denitrification rates calculated from the SBRs were found to be 5.45 ± 0.61 and 5.50 ± 0.77 . The SDNRs of fermented and dark-fermented biosolids are however should be higher than these two values.

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