

Performance Evaluation and Dissolved Oxygen Effect in Deep-bed Denitrification Filter: a Full-scale Plant Case Study

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Abstract. The aims of this study were twofold. Firstly, the denitrification performance in deep-bed denitrification filter (DBDF), serving as the advanced total nitrogen (TN) and total phosphorus (TP) removal technology, was evaluated. Secondly, the effect of dissolved oxygen (DO) into the DBDF on both the denitrification performance and the external carbon source addition was investigated. The operational results over eight months demonstrated good TN removal efficiency (87.8%) in the studied full-scale plant, in which 70.7% and 17.1% of TN were removed in the pre-denitrification in oxidation ditch and post-denitrification in DBDF, respectively. The DO concentration was inversely related to both the external carbon source dosage and the nitrate removed in DBDF. A dose of 3.60Kg methane (97%) was required to remove 1Kg nitrate, with approximately 26.2% of methane dosed was depleted by the DO in DBDF influent. It is suggested to take some measures to eliminate or mitigate the waterfall reoxygenation at process configurations before the DBDF, which is expected to save the cost of external carbon source.

Keywords: Deep-bed denitrification filter; Nitrogen removal; Dissolved oxygen; External carbon source.

1. Introduction

Biological nutrient removal (BNR) processes have been accepted as the most economical and sustainable technology for simultaneous nitrogen and phosphorus removal to meet the increasingly stricter discharge requirements in wastewater treatment. Many wastewater treatment plants (WWTP) in China have already adapted their operation to meet stringent nutrient discharge limits by adding advanced total nitrogen (TN) and total phosphorus (TP) removal technologies, such as deep-bed denitrification filter (DBDF), which can make the effluent TN levels less than 5 mg/L with the addition of external carbon source [1-3]. Joseph et al. [4] reported a full-scale operating experience of deep-bed denitrification filter to simultaneously achieve both low effluent TN and TP concentrations, i.e. effluent TN < 3 mg/L and TP < 0.18 mg/L.

In the current study, we focus on the denitrification performance of deep-bed denitrification filter with the addition of external carbon source, as well as the effect of dissolved oxygen (DO) on the denitrification and the external carbon source dosage.



2. Methods and Materials

2.1. Full Scale Plant Configuration

Figure 1 depicts the schematic diagram of the full-scale plant (100 000 m³/d), located at Hefei City, Anhui Province, China, which enforced the effluent to meet the Discharge limits of major water pollutants for municipal wastewater treatment plants & industries in the Chaohu basin (DB34/2710-2016). Besides, the mass concentrations of TP, TN, NH₄⁺-N, COD in effluent were required to below 0.3, 5, 1.5 and 30 mg/L, respectively. The oxidation ditch coupled with coagulation settler and DBDF combined processes were applied to treat municipal wastewater in the studied full-scale plant. Raw municipal wastewater was pretreated via screens and aerated grit chamber to prevent large solids from entering the oxidation ditch, which provided the alternating anaerobic/anoxic/aerobic conditions for the biological nitrogen and phosphorus removal. Returned activated sludge (RAS) was from the sedimentation tank to the anaerobic zone. PAC was added at the effluent from oxidation ditch to help phosphorus precipitation in sedimentation tank and coagulation settler. Because that effluent from coagulation settler may not meet the requirements of TN, TP and SS, DBDF was set to additionally remove TN via denitrification, as well as to remove both TP and SS. Methane (97%) was used as the external carbon source in DBDF in this study.

2.2. Influent Wastewater Characteristics

The major characteristics of the raw wastewater during the operational run are listed in Table 1. The BOD₅/COD ratio of raw influent was averaged at 0.48, indicating a reasonable good biodegradability of the influent and the available carbon source for nitrogen and phosphorus removal in the oxidation ditch. However, to ensure the stable and low TN and TP levels in effluent, external carbon source and PAC were essential for denitrification and phosphorus precipitation, respectively.

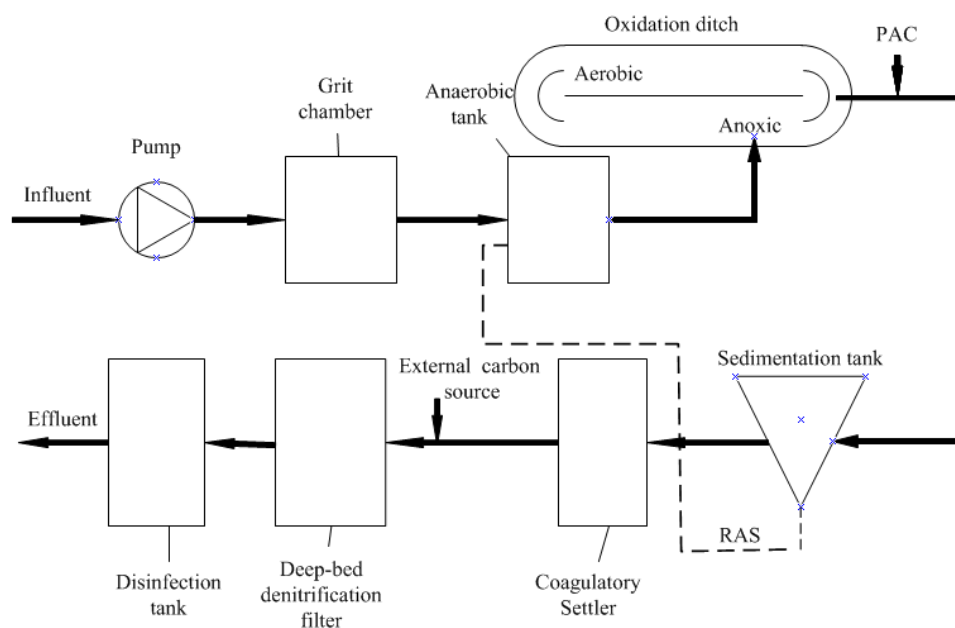


Figure 1. Scheme diagram of the full-scale plant

Table 1. The major characteristics of the influent

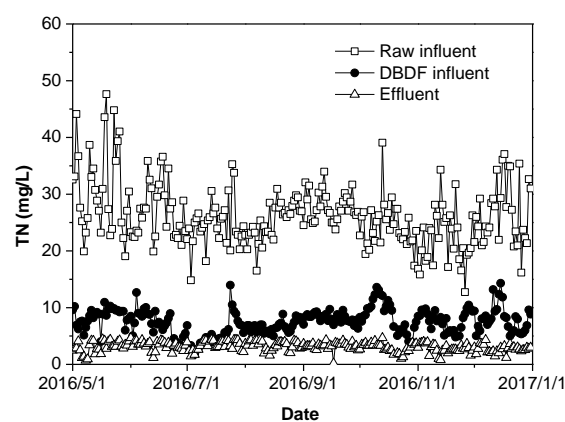
Items	Units	varitions	Averaged values
pH	-	7.03-7.67	7.31
COD	mg/L	63-488	186
BOD ₅	mg/L	25.8-152.6	81.3
SS	mg/L	80-248	166
NH ₄ ⁺ -N	mg/L	9.54-55.00	17.51
TN	mg/L	12.74-61.00	26.30
PO ₄ ³⁻ -P	mg/L	1.02-6.00	2.99
TP	mg/L	1.36-7.64	3.49
BOD ₅ / COD	-	0.14-0.86	0.48
BOD ₅ / TN	-	1.07-8.44	3.20
BOD ₅ / TP	-	7.75-65.55	26.65

3. Results and Discussion

3.1. TN Removal

Fig. 2 shows the TN removal in this system. The influent TN concentrations were fluctuated from 12.74-61.00 mg/L, with the averaged TN concentrations at 26.30 mg/L. After the biological nutrient removal in the oxidation ditch, the TN concentrations in DBDF influent were varied from 1.73-14.85 mg/L, with the averaged TN concentrations at 7.51 mg/L. The TN levels in final effluent were from 0.18-4.66 mg/L, with the averaged effluent TN levels at 3.10 mg/L, which constantly meet the requirement for TN below 5mg/L.

Overall, the biological nitrogen removal in the system can be divided into two parts: one is the pre-denitrification in the oxidation ditch, the other is the post-denitrification in DBDF. Fig. 3 shows the pre-denitrification, post-denitrification and total denitrification for TN removal in the system. The total TN removal efficiency of 87.8% was achieved, in which the TN removal for pre-denitrification and post-denitrification were 70.7% and 17.1%, respectively. In the case of occurrence of pre-denitrification decrease due to the fluctuation of influent characteristics or low temperature, the deep-bed denitrification filter can be used as the safeguard for effluent TN with the addition of external carbon source. It is suggested to make the best use of available carbon source in raw municipal wastewater for pre-denitrification in the actual operation, in order to decrease the load of deep-bed denitrification filter as well as the dose of external carbon source addition.

**Figure 2.** The variation of TN in the system

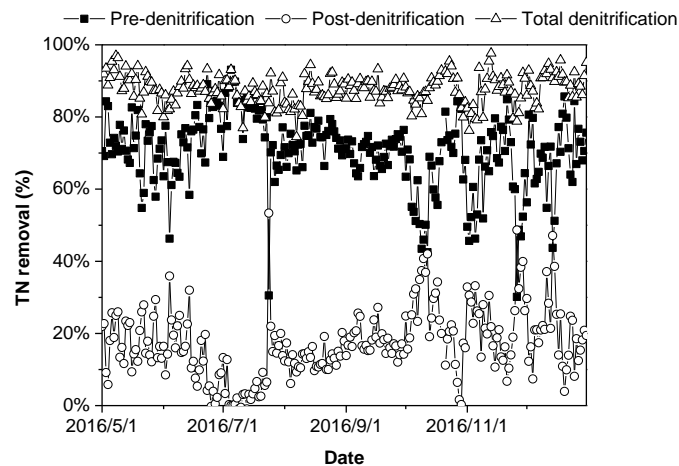


Figure 3. The pre-denitrification, post-denitrification and total denitrification for TN removal in the system

4. COD Removal

In the studied WWTP, Methane (97%) was used as the electron donor for heterotrophic denitrifying bacteria in DBDF, due to the lack of biodegradable organics in influent into deep-bed denitrification filter. The dose of methane directly affects the advanced denitrification efficiency. Lower dose could not ensure the satisfying TN removal, while excess dose would increase both the effluent COD levels and the treatment cost. Fig. 4 shows the COD concentrations in influent and effluent of DBDF during the whole operation. Stable and low COD levels below 30 mg/L in final effluent were obtained. The addition of external carbon source in DBDF did not present any significant effect on the effluent COD concentration. It is noted that sometimes the TN concentrations in DBDF influent were below 5mg/L (e.g. during 2nd July to 2nd August) (Fig. 2). In these cases, seasonal operational strategy that external carbon addition system switched off was utilized, when the DBDF was converted to the deep-bed filter (DBF) for SS and TP removal, but not for denitrification.

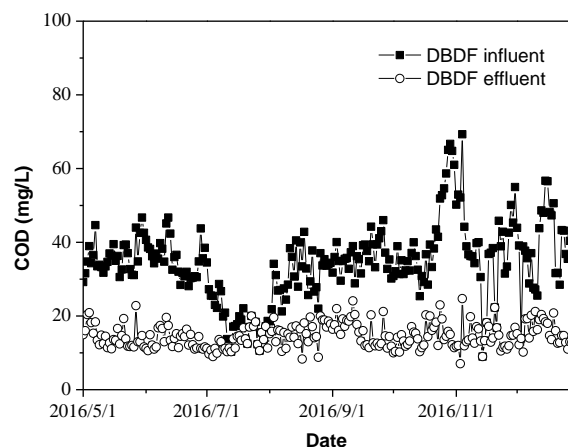


Figure 4. The variation of COD in DBDF

5. DO Effect

Heterotrophic denitrifying bacteria are facultative bacteria, which can grow under aerobic conditions or anaerobic conditions by aerobic respiration and anaerobic respiration, respectively. When the DO and nitrate coexist, aerobic respiration will take priority due to the more energy produced by aerobic

respiration. Therefore, denitrifying bacteria will select the DO as the electron acceptor when the simultaneous presence of DO and nitrate, thus the denitrification performance was affected. In order to ensure TN removal efficiency, the DO concentration in influent into DBDF should be reduced to relatively low level. However, in the studied DBDF for two-month operation, the DO concentrations in influent into DBDF were up to 5-7mg/L (see Fig. 5), attributing to the waterfall reoxygenation at the pumping station, sedimentation tank, etc. The heterotrophic bacteria will occupy the filter height and probably influence the denitrification efficiency and the waste of external carbon source, if the DO in influent is too high. Stable and low TN in Effluent in this study proved that the studied DBDF has high resistance to DO effect, probably attribute to the relatively low designed TN load, i.e. $0.62 \text{ kg}[\text{NO}_3^--\text{N}]/(\text{m}^3 \text{ d})$.

Fig. 5 also shows the relationships between the DO concentration in DBDF influent, nitrate removed and the ratio of carbon source depleted by DO during the studied operational run. The DO concentration was inversely related to both the dosage of external carbon addition and nitrate removed in DBDF. The higher the influent DO is, the higher ratio of carbon source depleted by DO as well as the lower of nitrate removed; and vice versa. A dose of 3.60Kg methane (97%) was required to remove 1Kg nitrate, in which 20%-40% (averaged at 26.2%) of methane dosed was depleted by the influent DO. It is suggested to take some measures to eliminate or mitigate the waterfall reoxygenation at process configurations before the DBDF, which is expected to save the cost of external carbon source. The theoretical average methanol dosage was 18.0mg/L based on the nitrate removed during the operational run, whereas the actual methanol dosage was averaged at 26.5 mg/L. The practical engineering coefficient was 1.47. Therefore, ignoring the influent nitrite effect and taking the comprehensive effect of influent DO on the denitrification into consideration, the actual methane dosage for advanced denitrification in the DBDF is roughly calculated through the nitrate concentration and DO concentration in influent, from the following formula:

$$C_{\text{methane}} = 1.47 * (2.47 * C_{\text{NO}_3-\text{N}} + 0.87 * \text{DO}) \quad (1)$$

Where C_{methane} ——the actual dosage of methane, mg/L;

$C_{\text{NO}_3-\text{N}}$ ——nitrate removed, mg/L;

DO——dissolved oxygen concentration in influent into DBDF, mg/L.

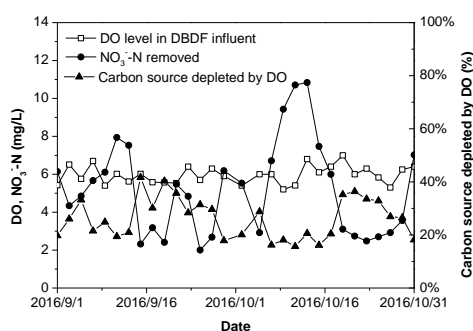


Figure 5. The DO levels, ratio of carbon source depleted by DO and nitrate removed in DBDF

6. Conclusions

The denitrification performance as well as the DO effect for the DBDF in a full-scale plant was studied. The following conclusions were obtained:

(1) The DBDF can be used as the safeguard for effluent TN levels below 5 mg/L with the addition of external carbon source. Good TN removal efficiency (87.8%) achieved in the studied WWTP, with 70.7% and 17.1% of TN were removed in the pre-denitrification in oxidation ditch and post-denitrification in DBDF, respectively.

(2) The DO concentration was inversely related to both the dosage of external carbon source and nitrate removed in DBDF. A dose of 3.60Kg methane (97%) was required to remove 1Kg nitrate, with

approximately 26.2% of methane was depleted by the influent DO. Some measures were suggested to take to eliminate or mitigate the DO effect in DBDF, which is expected to save the cost of external carbon source.

(3) The actual methane dosage for advanced denitrification in DBDF can be roughly calculated from the following formula: $C_{\text{methane}} = 1.47 * (2.47 * C_{\text{NO}_3\text{-N}} + 0.87 * \text{DO})$.

7. Acknowledgement

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8. References

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