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Upflow Anaerobic Sludge Bed Biofilm Coupling Two Biological Contact Oxidation Systems for Thetreatment of Piggery Wastewater

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Abstract: Piggery wastewater with low C and N was treated using an upflow anaerobic sludge bed biofilm reactor (UASBB) that coupled two biological contact oxidation ponds. Through this process, part of the total nitrogen (TN) and Chemical Oxygen Demand (COD) were removed, the concentration of ammonia and nitrite nitrogen ratio reached approximately 1:1 and the pH was adjusted to 7 to 8, which were favorable for anaerobic ammonium oxidation. Compared with the conventional activated sludge process, the coupled system can save 0.52 kg/(m^3 d) of oxygen and 0.838 kg/(m^3 d) of COD as well as recover 40.51 L/(m^3 d) of CH_4. The system was used to handle actual swine wastewater. When COD load reached 3 kg/(m^3d), the average removal efficiency of COD for raw pig farm wastewater, first-stage biogas slurry and second-stage biogas slurry were 97, 94 and 94.4%, respectively. When TN load reached 0.51 kg/(m^3 d), the above removal rates were 84.2, 82.5%and 83.8%, respectively. When ammonia load reached 0.3 kg/(m^3 d), the above removal rates were 88.2, 91.9 and 91%, respectively.

Key words: Piggery wastewater, UASBB, biological contact oxidation, biological nitrogen, anammox

INTRODUCTION

Piggery wastewater, particularly large-scale pig manure wastewater, has a complex composition, high nitrogen content and a high concentration of organic matter (Cantrell *et al*., 2009; Yang *et al*., 2002; Whang *et al*., 2009). The traditional anaerobic digestion process is incapable of biological denitrification but can easily cause chemical oxygen demand (COD)/NH_3-N imbalance resulting from anaerobic digestion effluent. The insufficiency of carbon sources affects the subsequent removal of ammonia nitrogen (Deng *et al*., 2009; Zhang *et al*., 2006). Many studies on the biological treatment of livestock wastewater have been conducted (Lovanh *et al*., 2009; Sakar *et al*., 2009; Yamamoto *et al*., 2008) but few successfully removed organic matter and nitrogen simultaneously.

Professor Lettinga *et al*. (1980) from the Netherlands developed the Upflow Anaerobic Sludge Bed (UASB) reactor, a high-rate anaerobic bioreactor, in the 1970s. UASBB could enrich different types of biomass granulation by adding a filler. Biomass granulation increased the number of bacteria involved in anaerobic ammonium oxidation (anammox), methanation and denitrification. Moreover, biological contact oxidation has become increasingly considered as useful for managing water quality issues (Li *et al*., 2010; Wang and Li, 2011). Thus, a full-scale pilot of anaerobic UASBB and aerobic two-biological-contact- oxidation pond process were integrated to achieve energy savings and improve effluent quality in full-scale livestock wastewater treatment.

MATERIALS AND METHOD

Test devices: Figure 1 shows the test devices used in this study, which included a UASBB reactor and two contact biological oxidation tanks. The UASBB reactor had a working volume of 11 L.

The first oxidation pond had an effective volume of 3.5 L, whereas the second oxidation pond had an effective volume of 7 L. The two contact biological oxidation ponds were overhung with a flexible filler with a diameter of 150 mm. The sand core aeration head was placed at the

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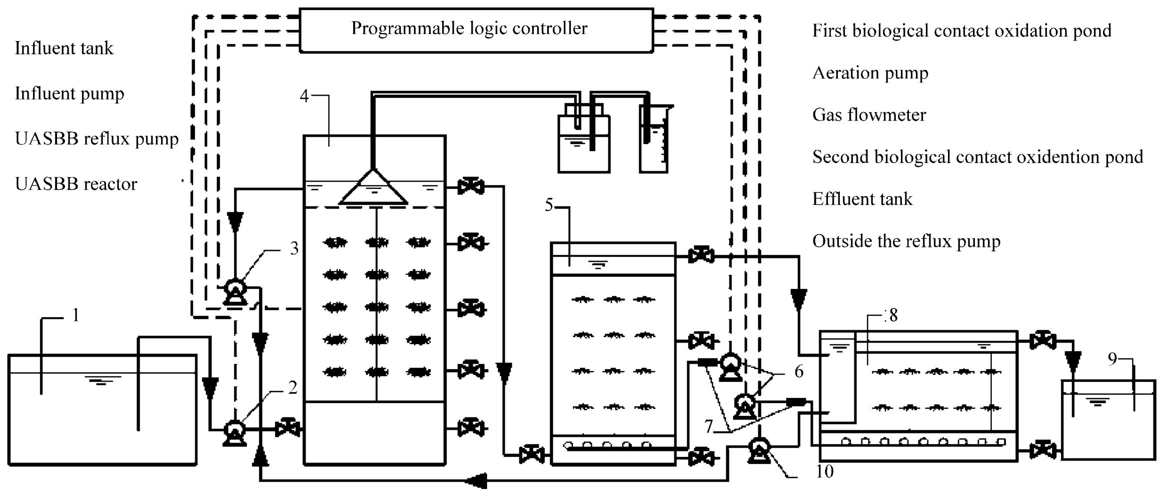

Fig. 1: Test devices and coupling system process

Table 1: Composition of the simulated wastewater

Composition	Content (mg L^{-1})
COD (Glucose)	ND
KH_2PO_4	3.04
$NaHCO_3$	1000
NH_4Cl	ND
$NaNO_2$	ND
Trace elements (ml/L)	1

Trace elements: EDTA, 10.0 g L^{-1}; ND: COD, NH_4Cl and $NaNO_2$ concentration increased over time

bottom of these ponds. The concentration of the dissolved oxygen in the reactor was adjusted through the amount of aeration.

Test water: The composition and content of the simulated wastewater are shown in Table 1. The experimental raw pig wastewater and biogas slurry were sourced from a large-scale pig farm in Nanchang City, China.

Analytical methods: The test water quality indicators include COD, pH, T, NH_4^+-N, NO_3^--N, NO_2^--N, TN and DO. Analysis carried out according to standard methods.

Test methods: Start-up and performance of the UASBB reactor. Reducing the start-up period of anaerobic reactors is one of the key parameters for increasing their competitiveness. The inoculation sludge was obtained by mixing 3 L of anaerobic sludge and 2 L of denitrification sludge. The inoculated sludge had a high concentration (38.68 g L^{-1}) of suspended solids. Once the UASBB reactor completed its start-up procedure, NH_4Cl and $NaNO_2$ were added to the influent to realize simultaneous anaerobic ammonia oxidation, methanation and denitrification progressively. The influent flow was 10 L/d, the back flow was 50 L day^{-1} and the hydraulic retention time was 24 h.

Start-up and performance of the Biological contact oxidation tank. The inoculation sludge was obtained from the oxidation ditch of a sewage treatment plant. The sludge concentration was 1500 mg L^{-1}. SV30 and SVI were both 40, 100. The pH of the test water was maintained at 6.7 to 7.5, the temperature at 20.3 °C to 23.7 °C and the dissolved oxygen at 1.5-3 mg L^{-1}.

Coupling phases of the system: In the first biological contact oxidation pond, shortcut nitrification was achieved, after which the effluent was recycled to the UASBB as an electron acceptor for the UASBB anammox reaction. The second-stage biological contact oxidation further removed ammonia from the wastewater, thus ensuring the ammonia removal efficiency of the system. The coupled system first dealt with the simulated wastewater to determine the best outside reflux ratio and then gradually increase the load. Finally, the actual swine wastewater was treated.

RESULTS AND ANALYSIS

Start-up and performance of the UASBB reactor: The microorgamisms were domesticated in simulated wastewater at temperatures ranging from 31-35°C. After more than 40 day, the influent in the reactor met the required design load [organic volume load of 0.727 kg/(m^3 d)], the COD removal rate stabilized at 85% or more and run mud did not appear, indicating a successful start-up of the UASBB reactor.

Once the UASBB reactor completed its start-up, NH_4Cl and $NaNO_2$ were added to the influent to achieve simultaneous anaerobic ammonia oxidation, methanation and denitrification progressively. During the operational phase, pH, reactor temperature, influent flow, back flow, hydraulic retention time and upflow velocity were the same as those during the start-up phase. The UASBB reactor start-up succeeded after 145 d. The COD, NH_4^+, NO_2^- and Total Nitrogen (TN) removal rates were 80- 90, 24-35, 90 and 50-60%, respectively. the internal synchronization of anammox, methanation and denitrification were gradually achieved in the UASBB reactor.

Start-up and performance of the biological contact oxidation pond: Controlling aeration intensity is key to the stuffy exposure phase, during which a specific stirring action must be guaranteed to avoid excess aeration (Carrera *et al*., 2004; Wang and Yang, 2004). In this study, the aeration rate was maintained at 200 mL min^{-1}. The dissolved oxygen in the reactor was also kept at 1.2-1.6 mg L^{-1}. After 20 d of continuous operation, the COD and NH_4^+ removal rates stabilized at 95 and 85%,

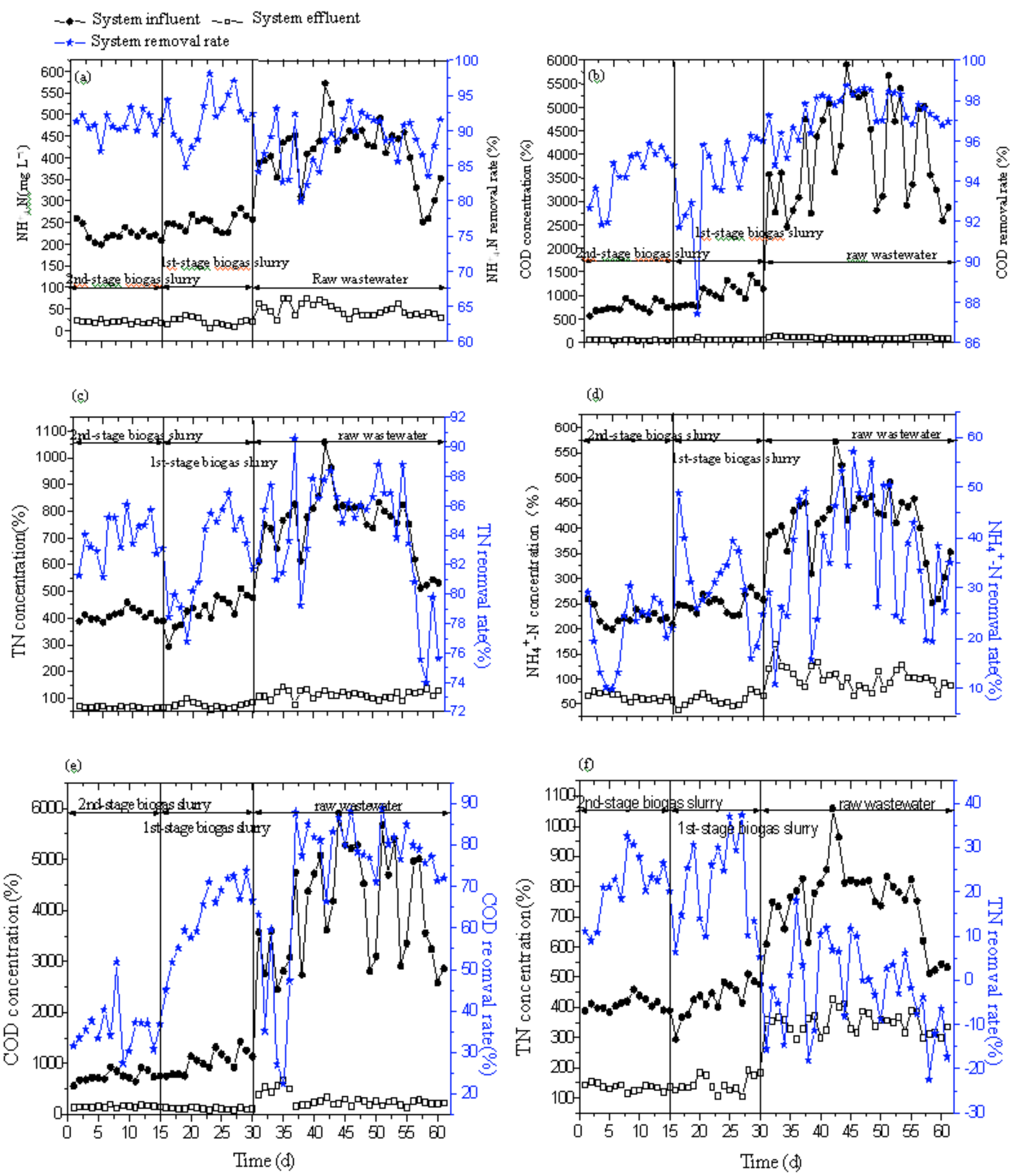

Fig. 2(a-j): Continue

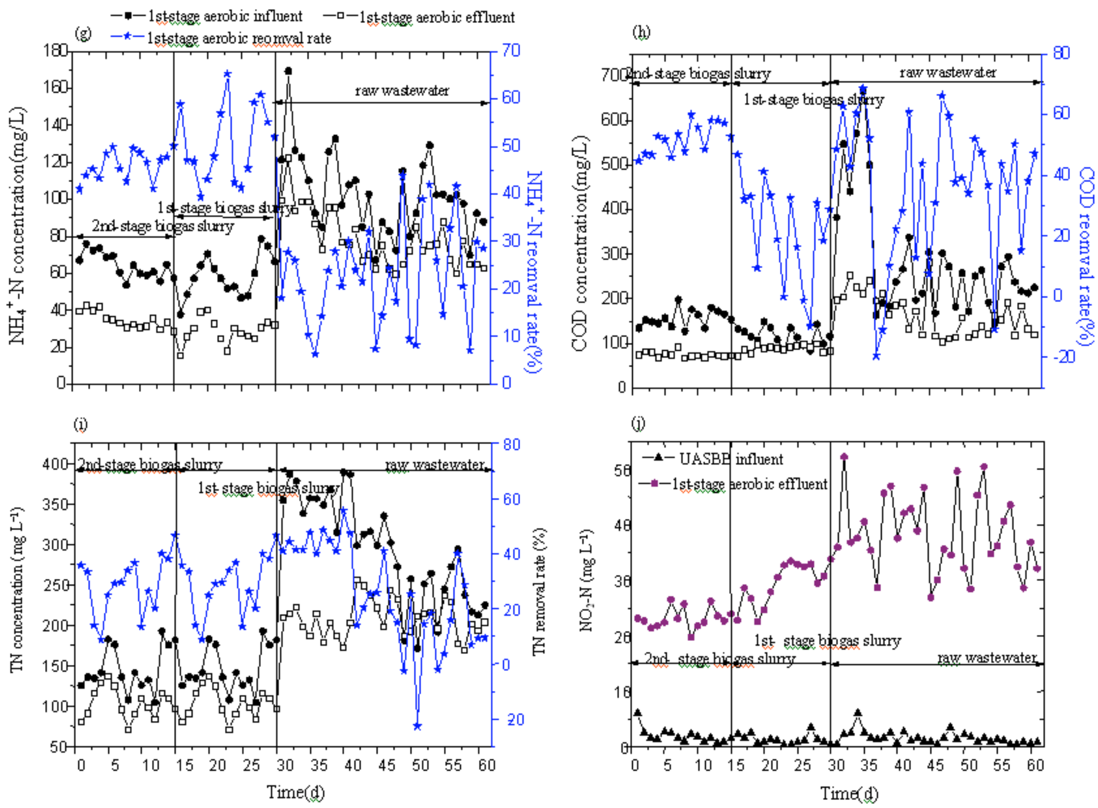

Fig. 2(a-j): Coupling system treatment of swine wastewater, (a) NH_4^+-N removal via., the coupling system, (b) COD removal via., the coupling system, (c) TN removal via., the coupling system, (d) NH_4^+-N removal via., UASBB, (e) COD removal via., UASBB, (f) TN removal via., UASBB, (g) NH_4^+-N removal via., first-stage biological, (h) COD removal via., first-stage contact process biological contact process, (i) TN removal via first-stage biological and (j) NO2⁻-N concentration in UASBB contact process and first-stage biological contact process

respectively, showing that the hanging film of the biological contact oxidation tank had started successfully.

Performance of actual wastewater treatment: During this pilot phase, actual wastewater was treated and the running performance of the coupled system was studied. Actual wastewater was added to the second-stage biogas slurry, first-stage biogas slurry and raw wastewater. The running parameters are shown in Fig. 2.

As shown in Fig. 2a-c, at an influent NH_4^+-N load of 0.3 kg/(m^3 d), the average NH_4^+-N removal rate for raw wastewater, first-stage biogas slurry and second-stage biogas slurry reached 88.2, 91.9 and 91%, respectively. At an influent COD load of 3 kg/(m^3 d), the average COD removal rate for raw wastewater, first-stage biogas slurry and second-stage biogas slurry reached 97, 94 and 94.4%, respectively. At an influent TN load of 0.51 kg/(m^3 d), the average TN removal rate for raw wastewater, first-stage biogas slurry and second-stage biogas slurry reached 84.2, 82.5 and 83.8%, respectively.

As shown in Fig. 2d, the ammonia nitrogen removal in the UASBB reactor changed in the range of 10-60%, more specifically, between 30 and 40%. Figure 2g-i show that the ammonia nitrogen removal of the first-stage biological contact oxidation pond had a closer relationship with wastewater type, exhibiting better biogas slurry processing effects than raw wastewater. As shown in Fig. 2j, the nitrite nitrogen accumulation of the biological contact oxidation tanks increased with the ammonia nitrogen concentration in the influent. This process provided a matrix that enabled UASBB anaerobic ammonia oxidation to remove the ammonia.

Technical and economic analysis: Anammox, short-range denitrification and methanation occurred simultaneously

Table 2: UASBB reactor economy verification

Status	Saved O_2 (kg/m^3 d)	Saved COD (kg/m^3 d)	RecoveredCH_4 (L/m^3 d)
Short-range denitrification	0.208	0.208	/
Anammox	0.312	0.63	/
Methanation	/	/	40.51
Total	0.52	0.838	40.51

in the UASBB reactor. These processes were calculated to save more O_2, COD and CH_4 than conventional activated sludge, as shown in Table 2.

CONCLUSIONS

- Proposed system combined UASBB and two biological contact oxidation processes. Partial nitrification and accumulation of nitrite nitrogen were achieved in the first contact oxidation pool, after which the effluent was returned to the UASBB reactor, where it supplied nitrite nitrogen for anammox and short-range denitrification. The optimal external reflux ratio was determined to be 300%
- For the raw water, at a reflux ratio of 300%, the total COD load removal rate was 1.493 kg/(m3 d), the TN load removal rate was 0.297 kg/(m^3 d) and the total ammonia load removal rate was 0.173 kg/(m^3 d)
- System was used to treat actual swine wastewater. When the COD load reached 3 kg/(m^3 d), the average removal efficiency of COD from raw pig farm wastewater, first-stage biogas slurry and second-stage biogas slurry were 97%, 94% and 94.4%, respectively. When TN load reached 0.51 kg/(m^3 d), the above removal rates were 84.2%, 82.5% and 83.8%, respectively. When the ammonia load reached 0.3 kg/(m^3 d), the above removal rates were 88.2%, 91.9% and 91%, respectively. The coupled system can save 0.52 kg/(m^3 d) of oxygen and 0.838kg/(m^3 d) of COD as well as recover 40.51 L/(m^3 d) of CH_4

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