

Supporting information

Section S1 The operation of inoculation period

For all inoculation, ~3 L of returned sludge from Nanhai wastewater treatment plant (China) and concentrated nutrients was added into said reactor (Fig. 1) to make the final ingredient concentrations in the sludge mixture the same as that in the corresponding wastewater (Table 1). The microbial community of the inoculation sludge was analyzed by 16S rRNA amplicon sequencing. The abundances of each bacteria were determined and then were used for bacteria fraction parameters of the following model. Detailed information can be found in SI.

The inoculation period lasted for 10 days for each test (Table 1 T1, C1–C4 or S1–S4) with the supernatant of the mixture daily replenished by the concentrated nutrient to maintain the concentrations of the ingredients. After 10-day inoculation, the biofilm was expected to form on the non-woven polyester fabric module. The liquid mixture was then replaced by the corresponding wastewater under each scenario. The performance of the biofilm reactor on treating organic matter and ammonia was evaluated after the inoculation.

Table S1 Kinetic and stoichiometric parameters for the PAD system

Type	Parameter	Description	Values	Unit	source
Stoichiometric parameters	Y_{AH}	Yield coefficient for AH	0.6	g VSS/g COD	(1)
	Y_{AnAH}	Yield coefficient for AnAH	0.053	g VSS/g COD	(1)
	Y_N	Yield coefficient for NB	0.3	g VSS/g COD	(1)
	Y_D	Yield coefficient for DB	0.71	g VSS/g COD	(2)
	O_2_COD	Ratio of O_2 to COD used by AH	0.473	–	(4)
	$O_2_NH_4_N$	Ratio of O_2 to NH_4 -N used by NB	3.65	–	(4)
	$COD_NO_3_N$	Ratio of COD to NO_3 -N used by DB	5.81	–	(4)
Aerobic heterotroph (AH)	k_{AH}	Maximum growth rate of AH	4.9	1/d	(3)
	b_{AH}	Decay rate coefficient of AH	0.6	1/d	(1)
	K_{COD}^{AH}	COD half saturation rate for AH	24	g COD/m ³	(1)
	$K_{O_2}^{AH}$	O_2 half saturation rate for AH	0.15	g O_2 /m ³	(4)
	K_H	Salt inhibition constant of AH	41906	g NaCl/m ³	This study
Anaerobic heterotroph (AnAH)	k_{AnAH}	Maximum growth rate of AnAH	3.27	1/d	(4)
	b_{AnAH}	Decay rate coefficient of AnAH	0.03	1/d	(1)
	K_{COD}^{AnAH}	COD half saturation rate for AnAH	29	g COD/m ³	(4)
	$K_{O_2}^{AnAH}$	O_2 half saturation rate for AnAH	0.15	g O_2 /m ³	(4)
Nitrifying bacteria (NB)	k_N	Maximum growth rate of NB	8.85	1/d	This study
	b_N	Decay rate coefficient of NB	0.05	1/d	(1)
	$K_{NH_4}^{NB}$	NH_4 -N half saturation rate for NB	1.4	g N/m ³	(1)
	$K_{O_2}^{NB}$	O_2 half saturation rate for NB	0.4	g O_2 /m ³	(5)
	K_N	Salt inhibition constant of NB	10000	g NaCl/m ³	This study
Denitrifying bacteria (DB)	k_D	Maximum growth rate of DB	1.024	1/d	This study
	b_D	Decay rate coefficient of DB	0.04	1/d	(1)
	K_{COD}^{DB}	COD half saturation rate for DB	13.7	g COD/m ³	(6)

$K_{O_2}^{DB}$	O ₂ half saturation rate for DB	0.15	g O ₂ /m ³	(4)
$K_{NO_3}^{DB}$	NO ₃ -N half saturation rate for	0.2	g N/m ³	(1)
DB				
K_D	Salt inhibition constant of DB	28076	g NaCl/m ³	This study

Source: (1) Metcalf et al., 1991; (2) Naidoo et al., 1998; (3) Chen et al., 1988; (4) Shanahan and Semmens, 2004; (5) Bagley and Broadkorb, 1999; (6) Rittmann and Manem, 1992

Table S2 Process rate equations for the PAD system

Process description	Rate equation
1. Growth of AH	$k_{AH}X_{AH} \frac{S_{COD}}{S_{COD} + K_{COD}^{AH}} \frac{S_{O_2}}{S_{O_2} + K_{O_2}^{AH}}$
2. Decay of AH	$b_{AH}X_{AH}$
3. Growth of AnAH	$k_{AnAH}X_{AnAH} \frac{S_{COD}}{S_{COD} + K_{COD}^{AnAH}} \frac{K_{O_2}^{AnAH}}{S_{O_2} + K_{O_2}^{AnAH}}$
4. Decay of AnAH	$b_{AnAH}X_{AnAH}$
5. Growth of NB	$k_N X_{NB} \frac{S_{NH_4}}{S_{NH_4} + K_{NH_4}^{NB}} \frac{S_{O_2}}{S_{O_2} + K_{O_2}^{NB}}$
6. Decay of NB	$b_N X_{NB}$
7. Growth of DB	$k_D X_{DB} \frac{S_{NO_3}}{S_{NO_3} + K_{NO_3}^{DB}} \frac{S_{COD}}{S_{COD} + K_{COD}^{DB}} \frac{K_{O_2}^{DB}}{S_{O_2} + K_{O_2}^{DB}}$
8. Decay of DB	$b_D X_{DB}$
9. Switch from denitrifying bacteria to aerobic heterotrophs	$\frac{S_{O_2}}{K_{O_2}^{AH} + S_{O_2}} \frac{X_{DB}}{0.001}$
10. Switch from aerobic heterotrophs to denitrifying bacteria	$\frac{S_{NO_3}}{S_{NO_3} + K_{NO_3}^{DB}} \frac{X_{AH}}{0.001} \frac{K_{O_2}^{DB}}{S_{O_2} + K_{O_2}^{DB}}$
11. Hydrolysis of lysed cells	$k_{AH} \frac{S_{CODc}}{K_X}$

Table S3 Stoichiometric matrix for the PAD system

Process	O ₂	NH ₄ -N	NO ₃ -N	COD _c	COD	X _{AH}	X _{AnAH}	X _{NB}	X _{DB}
1	$-\frac{O_2-COD}{Y_{AH}}$				$-\frac{1}{Y_{AH}}$	1			
2				1.42		-1			
3					$-\frac{1}{Y_{AH}}$		1		
4				1.42			-1		
5	$-\frac{O_2-NH_4-N}{Y_N}$	$-\frac{1}{Y_N}$	$\frac{1}{Y_N}$					1	
6				1.42				-1	
7			$\frac{1}{Y_D}$		$-\frac{O_2-NO_3-N}{Y_D}$				1
8				1.42					-1
9				-1	1				
10						1			-1
11						-1			1

Section S2 Model assumptions and simplifications

To better fit the experimental conditions and simplify the model, the following assumptions have been made.

- In each simulation, the initial biofilm thickness was set at 1 μm to get close to the real non-woven polyester fabric without biofilm.
- Initial biofilm density was set as the inoculated sludge concentration (8000 mg/L). According to the 16S rRNA results of the inoculation sludge, aerobic heterotroph, anaerobic heterotroph, nitrifying bacteria and denitrifying bacteria account for 23%, 15%, 6% and 6% of the total population, respectively; other unidentified bacteria are assumed to have no effect on the biofilm.
- Oxidation of nitrite to nitrate takes place immediately after oxidation of ammonia, and the intermediate products (e.g., nitrite and nitrous oxide) are not considered during denitrification (Shanahan and Semmens, 2004). Besides, the concentrations of nitrite detected in each effluent were also close to 0 mg/L (data not shown).
- because the biofilm detachment did not occur in a 10-day inoculation, the biofilm detachment was not considered in this study.
- Reactor volume and non-woven polyester fabric area were set as the same as the experimental values. Partial pressure of oxygen in the non-woven fabric was maintained at 0.21 atm and this is reasonable considering the total gas pressure was 1.03 atm.
- To simplify and illustrate the microbial community, we assumed that the simulation results of the biomass distribution represented the real microbial community after the model was calibrated and validated. Other assumptions were made as the same as a previous study (Shanahan and Semmens, 2004).

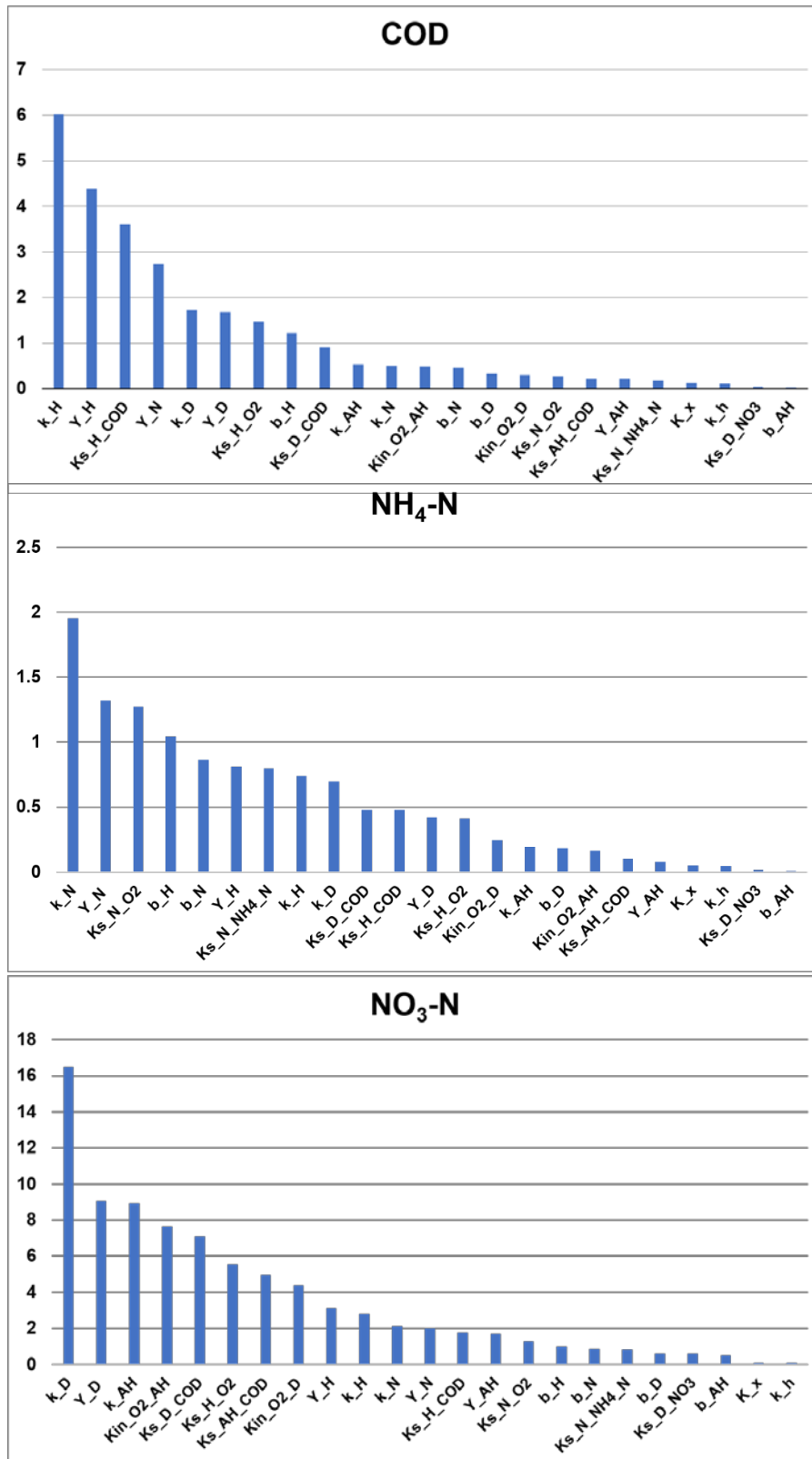


Fig. S1 Sensitivity analysis for COD, NH₄-N and NO₃-N removal in the PAD

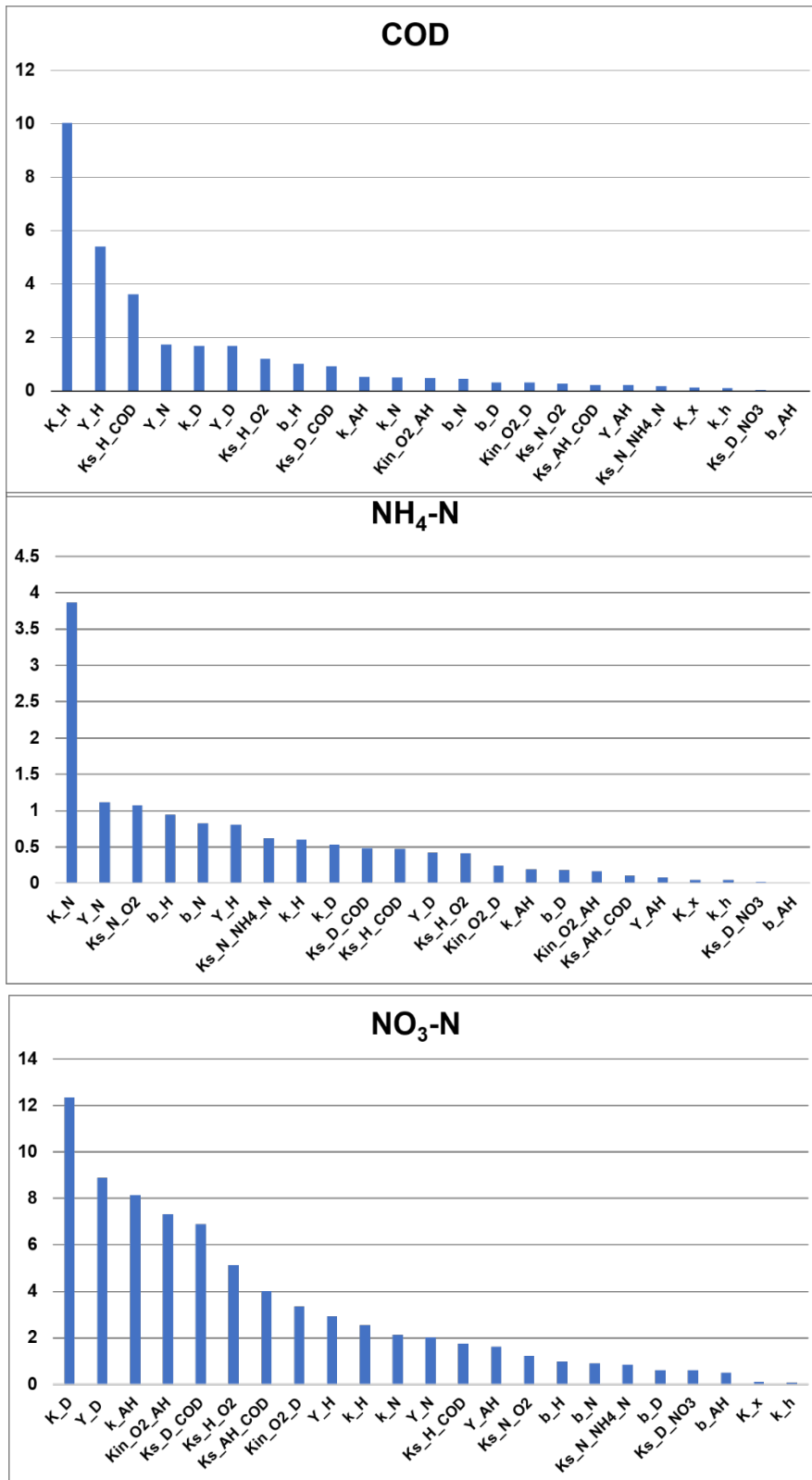


Fig. S2 Sensitivity analysis for COD, NH₄-N and NO₃-N removal with salinity in the PAD

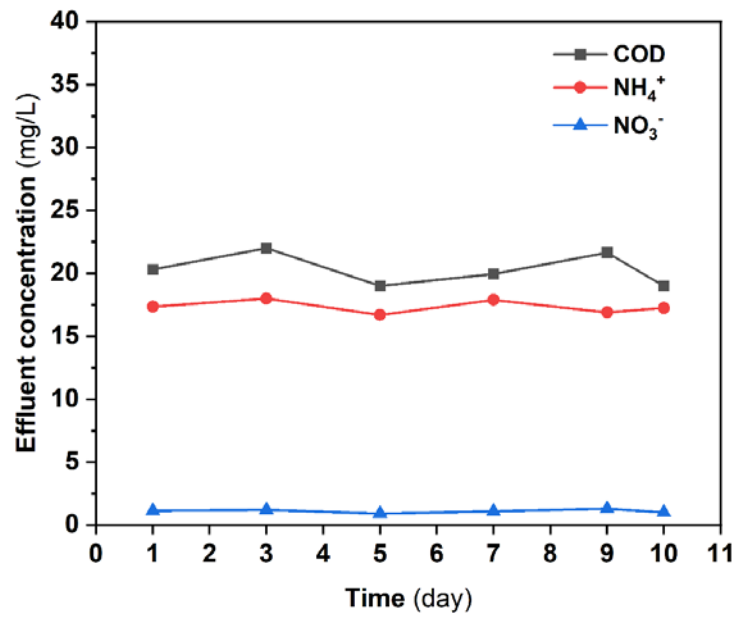


Fig. S3 Continuous effluent concentrations of PAD in scenario C3 (C/N ratio of 4 and 0% salinity)

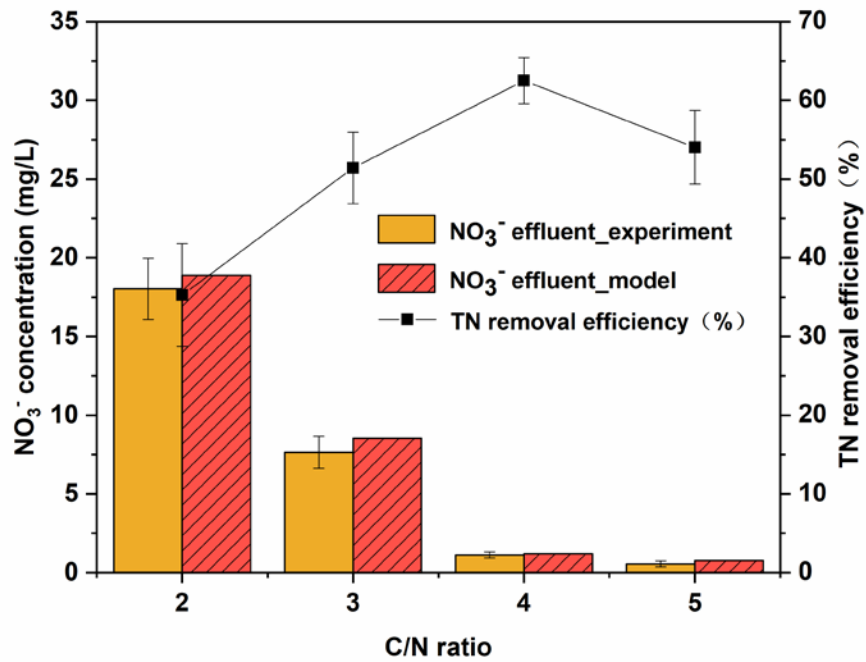


Fig. S4 The experimental and model results of the effluent concentration of NO₃⁻ and removal efficiency under different C/N ratios

Table S4 The Pearson coefficient results of the salinity and biofilm thickness

Correlation type	test value
Correlation coefficient	0.894
<i>P</i> value	0.005**

Notes: Strong correlation ($p < 0.05$) *; Significant correlation ($p < 0.01$) **

Table S5 Experimental and model results of effluent NO₃-N concentration under different salinities

Salinity (%)	Effluent concentration (mg/L)	
	NO ₃ ⁻ _experiment	NO ₃ ⁻ _model
blank	0.84 ± 0.06	0.91
0.2%	0.29 ± 0.05	0
0.5%	0.55 ± 0.02	0
1%	0.48 ± 0.03	0
2%	0.31 ± 0.02	0

References

- Bagley B M, Brodtkorb T S (1999). Modeling microbial kinetics in an anaerobic sequencing batch reactor-model development and experimental validation. *Water Science and Technology*, 71(7): 1320–1332
- Chen G H, Ozaki H, Terashima Y (1988). Modeling of the simultaneous removal of organic substances and nitrogen in a biofilm. *Water Science and Technology*, 39: 914–922
- Metcalf L, Eddy H P, Tchobanoglous G (1979). *Wastewater Engineering: Treatment, Disposal, and Reuse*. New York: McGraw-Hill
- Naidoo V, Urbain V, Buckley C A (1998). Characterization of wastewater and activated sludge from European Municipal Wastewater Treatment Plants using the NUR test. *Water Science and Technology*, 38(1): 303–310
- Rittmann B E, Manem J A (1992). Development and experimental evaluation of a steady-state, multispecies biofilm model. *Biotechnology and Bioengineering*, 39(9): 914–922
- Shanahan J W, Semmens M J (2004). Multipopulation model of membrane-aerated biofilms. *Environmental Science & Technology*, 38(11): 3176–3183 doi:10.1021/es034809y PMID:15224752