Supplementary materials

Enhancement of mainstream nitrogen removal via simultaneous partial nitrification, anammox and denitrification by gel entrapment technique

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Table S1 Wastewater compositions for batch tests of activated sludge, anammox biofilm and BSgel system

Batch test	Wastewater compositions
Activated sludge	50 mg/L NH_4Cl-N, 0-100 mg/L sucrose, 27 g/L KH_2PO_4, 500 mg/L $NaHCO_3$, 180 mg/L $CaCl_2 \cdot 2H_2O$, 300 mg/L $MgSO_4 \cdot 7H_2O$.
Anammox biofilm	50 $mg \cdot L^{-1}$ NH_4Cl-N, 50 $mg \cdot L^{-1}$ $NaNO_2$-N, 27 $mg \cdot L^{-1}$ KH_2PO_4, 500 $mg \cdot L^{-1}$ $NaHCO_3$, 180 $mg \cdot L^{-1}$ $CaCl_2 \cdot 2H_2O$, and 300 $mg \cdot L^{-1}$ $MgSO_4 \cdot 7H_2O$. The Trace elements were added (1 $mL \cdot L^{-1}$) into the synthetic wastewater. The trace element solution contained 625 $mg \cdot L^{-1}$ EDTA, 190 $mg \cdot L^{-1}$ $NiCl_2 \cdot 6H_2O$, 430 $mg \cdot L^{-1}$ $ZnSO_4 \cdot 7H_2O$, 220 $mg \cdot L^{-1}$ $NaMoO_4 \cdot 2H_2O$, 240 $mg \cdot L^{-1}$ $CoCl_2 \cdot 6H_2O$, 990 $mg \cdot L^{-1}$ $MnCl_2 \cdot 4H_2O$, and 250 $mg \cdot L^{-1}$ $CuSO_4 \cdot 5H_2O$.
BSgel system	50 $mg \cdot L^{-1}$ NH_4Cl-N, 100 mg/L sucrose, 27 $mg \cdot L^{-1}$ KH_2PO_4, 500 $mg \cdot L^{-1}$ $NaHCO_3$, 180 $mg \cdot L^{-1}$ $CaCl_2 \cdot 2H_2O$, and 300 $mg \cdot L^{-1}$ $MgSO_4 \cdot 7H_2O$.Trace elements were added (1 $mL \cdot L^{-1}$) into the synthetic wastewater. The trace element solution contained 625 $mg \cdot L^{-1}$ EDTA, 190 $mg \cdot L^{-1}$ $NiCl_2 \cdot 6H_2O$, 430 $mg \cdot L^{-1}$ $ZnSO_4 \cdot 7H_2O$, 220 $mg \cdot L^{-1}$ $NaMoO_4 \cdot 2H_2O$, 240 $mg \cdot L^{-1}$ $CoCl_2 \cdot 6H_2O$, 990 $mg \cdot L^{-1}$ $MnCl_2 \cdot 4H_2O$, and 250 $mg \cdot L^{-1}$ $CuSO_4 \cdot 5H_2O$.

Table S2. Definition of components in the model

Number	Component	Definition	Unit
Model dissolved components			
1	S_O	Dissolved oxygen	g O_2 m^{-3}
2	S_S	Readily degradable organic substrate	g COD m^{-3}
3	S_{NH4}	Ammonium nitrogen	g N m^{-3}
4	S_{NO2}	Nitrite nitrogen	g N m^{-3}
5	S_{NO3}	Nitrate nitrogen	g N m^{-3}
Model particulate components			
6	X_{AOB}	Aerobic ammonium-oxidizing bacteria	g COD m^{-3}
7	X_{AMX}	Anaerobic ammonium-oxidizing bacteria	g COD m^{-3}
8	X_{NOB}	Nitrite-oxidizing bacteria	g COD m^{-3}
9	X_H	Heterotrophic bacteria	g COD m^{-3}

10	X_I	Inert, non-biodegradable organics	g COD m^{-3}

Table S3. Process kinetic rate equations for the model

Process	Kinetics rates expressions
1. Growth of AOB	$\mu_{AOB}\frac{S_{O2}}{K_{O2}^{AOB}+S_{O2}}\frac{S_{NH4}}{K_{NH4}^{AOB}+S_{NH4}}X_{AOB}$
2. Decay of AOB	$b_{AOB}X_{AOB}$
3. Growth of NOB	$\mu_{NOB}\frac{S_{O2}}{K_{O2}^{NOB}+S_{O2}}\frac{S_{NO2}}{K_{NO2}^{NOB}+S_{NO2}}X_{NOB}$
4. Decay of NOB	$b_{NOB}X_{NOB}$
5. Growth of Anammox	$\mu_{AMX}\frac{K_{O2}^{AMX}}{K_{O2}^{AMX}+S_{O2}}\frac{S_{NH4}}{K_{NH4}^{AMX}+S_{NH4}}\frac{S_{NO2}}{K_{NO2}^{AMX}+S_{NO2}}X_{AMX}$
6. Decay of Anammox	$b_{AMX}X_{AMX}$
7. Aerobic growth of X_H	$\mu_H\frac{S_{O2}}{K_{OH1}+S_{O2}}\frac{S_S}{K_{S1}+S_S}X_H$
8. Anoxic growth of X_H with nitrite reduction	$\mu_H\eta_{H1}\frac{K_{OH2}}{K_{OH2}+S_{O2}}\frac{S_{NO3}}{K_{NO3}^{HB}+S_S}\frac{S_S}{K_{S2}+S_S}X_H$
9. Anoxic growth of X_H with nitrate reduction	$\mu_H\eta_{H2}\frac{K_{OH3}}{K_{OH3}+S_{O2}}\frac{S_{NO2}}{K_{NO2}^{HB}+S_{NO2}}\frac{S_S}{K_{S3}+S_S}X_H$
10. Decay of X_H	b_HX_H

Table S4. Kinetic and stoichiometric parameters of the model

Parameter	Definition	Values	Unit	Source
Aerobic ammonium oxidizing bacteria (AOB)				
Y_{AOB}	yield coefficient for AOB	0.15	g COD g^{-1} N	Wiesmann, 1994
μ_{AOB}	maximum growth rate of AOB	0.0854	h^{-1}	Wiesmann, 1994
b_{AOB}	decay rate coefficient of AOB	0.0054	h^{-1}	Wiesmann, 1994
K_{O2}^{AOB}	S_{O2} affinity constant for AOB	0.6	g DO m^{-3}	Wiesmann, 1994
K_{NH4}^{AOB}	S_{NH4} affinity constant for AOB	2.4	g N m^{-3}	Wiesmann, 1994
Nitrite oxidizing bacteria (NOB)				
Y_{NOB}	yield coefficient for NOB	0.041	g COD g^{-1} N	Wiesmann, 1994
μ_{NOB}	maximum growth rate of NOB	0.0604	h^{-1}	Wiesmann, 1994
b_{NOB}	decay rate coefficient of NOB	0.0025	h^{-1}	Wiesmann, 1994

K_{O2}^{NOB}	S_{O2} affinity constant for NOB	2.2	g DO m^{-3}	Wiesmann, 1994
K_{NO2}^{NOB}	S_{NO2} affinity constant for NOB	5.5	g N m^{-3}	Wiesmann, 1994
Anaerobic ammonium oxidizing bacteria (Anammox)				
Y_{AMX}	yield coefficient for Anammox	0.159	g COD g^{-1} N	Strous et al., 1998
μ_{AMX}	maximum growth rate of Anammox	0.0030	h^{-1}	Koch et al. 2000
b_{AMX}	decay rate coefficient of Anammox	0.00013	h^{-1}	Hao et al., 2002
K_{O2}^{AMX}	S_{O2} inhibiting coefficient for Anammox	0.01	g DO m^{-3}	Strous et al., 1998
K_{NH4}^{AMX}	S_{NH4} affinity constant for Anammox	0.07	g N m^{-3}	Strous et al., 1998
K_{NO2}^{AMX}	S_{NO2} affinity constant for Anammox	0.05	g N m^{-3}	Hao et al., 2002
Heterotrophic bacteria (HB)				
Y_H	yield coefficient for X_H	0.6	g COD g^{-1} COD	Henze et al., 2000
μ_H	maximum growth rate of X_H	0.26	h^{-1}	Koch et al., 2000
b_H	decay rate coefficient of X_H	0.008	h^{-1}	Wiesmann, 1994
η_{H1}	anoxic growth factor for nitrate reduction	0.28	—	Hiatt et al., 2008
η_{H2}	anoxic growth factor for nitrite reduction	0.16	—	Hiatt et al., 2008
K_{OH1}	S_{O2} affinity constant for aerobic growth	0.1	g DO m^{-3}	Hiatt et al., 2008
K_{OH2}	S_{O2} inhibit constant for nitrate reduction	0.1	g DO m^{-3}	Hiatt et al., 2008
K_{OH3}	S_{O2} inhibit constant for nitrite reduction	0.1	g DO m^{-3}	Hiatt et al., 2008
K_{S1}	S_S affinity constant for aerobic growth	20	g COD m^{-3}	Hiatt et al., 2008
K_{S2}	S_S affinity constant for nitrate reduction	20	g COD m^{-3}	Hiatt et al., 2008
K_{S3}	S_S affinity constant for nitrite reduction	20	g COD m^{-3}	Hiatt et al., 2008
K_{NO3}^{HB}	S_{NO3} affinity constant for HB	0.2	g N m^{-3}	Hiatt et al., 2008
Other stoichiometric parameters				
i_{NBM}	Nitrogen content of biomass	0.07	g N g^{-1} COD	Henze et al.,

				2000
i_{NXI}	Nitrogen content of X_I	0.02	g N g^{-1} COD	Henze et al., 2000
i_{NXS}	Nitrogen content of X_S	0.04	g N g^{-1} COD	Henze et al., 2000
f_I	Fraction of X_I in biomass decay	0.10	g COD g^{-1} COD	Henze et al., 2000

Table S5. Stoichiometric matrix for the model

Variable	S_{O2}	S_S	S_{NH4}	S_{NO2}	S_{NO3}	S_{N2}	X_S	X_H	X_{AOB}	X_{NOB}	X_{AMX}	X_I
Process	O_2	**COD**	**N**	**N**	**N**	**N**	**COD**	**COD**	**COD**	**COD**	**COD**	**COD**
1	$-\frac{3.43-Y_{AOB}}{Y_{AOB}}$		$-i_{NBM}-\frac{1}{Y_{AOB}}$	$\frac{1}{Y_{AOB}}$					**1**			
2			$i_{NBM}-i_{NXI}f_I$				$1-f_I$		**-1**			f_I
3	$-\frac{1.14-Y_{NOB}}{Y_{NOB}}$		$-i_{NBM}$	$-\frac{1}{Y_{NOB}}$	$\frac{1}{Y_{NOB}}$					**1**		
4			$i_{NBM}-i_{NXI}f_I$				$1-f_I$			**-1**		f_I
5			$-i_{NBM}-\frac{1}{Y_{AMX}}$	$-\frac{1}{Y_{AMX}}-\frac{1}{1.14}$	$\frac{1}{1.14}$	$\frac{2}{Y_{AMX}}$					**1**	
6			$i_{NBM}-i_{NXI}f_I$				$1-f_I$				**-1**	f_I
7	$-\frac{1-Y_H}{Y_H}$	$-\frac{1}{Y_H}$	$-i_{NBM}$					**1**				
8		$-\frac{1}{Y_H}$	$-i_{NBM}$	$-\frac{1-Y_H}{1.71Y_H}$		$\frac{1-Y_H}{1.71Y_H}$		**1**				
9		$-\frac{1}{Y_H}$	$-i_{NBM}$		$-\frac{1-Y_H}{2.86Y_H}$	$\frac{1-Y_H}{2.86Y_H}$		**1**				
10			$i_{NBM}-i_{NXI}f_I$				$1-f_I$	**-1**				f_I

Table S6. Bacterial community diversity index of three samples

	SS	Biofilm	BSgel
Sequences	71928	65824	72038
OTUs	492	566	542
Coverage	0.999	0.999	0.999
Chao1	531.48	616.32	605.42
ACE	532.23	613.73	604.78
Shannon	5.08	5.72	5.59
Simpson	0.916	0.954	0.950

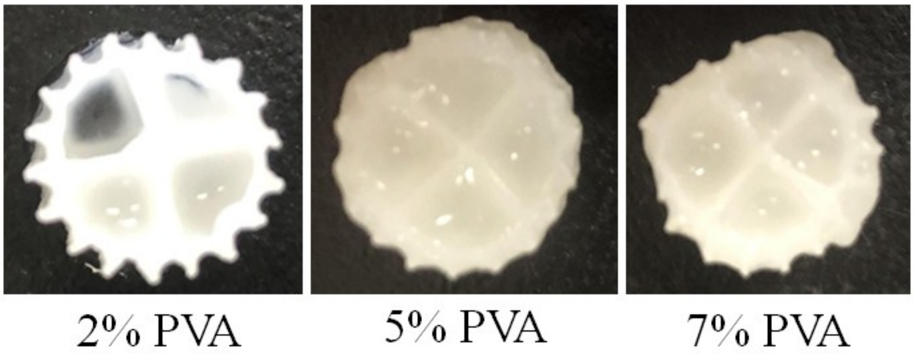

Figure S1 Images of BSgel system prepared by 2%, 5% and 7% PVA concentrations

Additional References

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