Supplementary information

Enhancing mainstream nitrogen removal by employing nitrate/nitrite-dependent anaerobic methane oxidation processes

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Table S1. Overview of the lab- and pilot-scale mainstream anammox studies. Three key control strategies, namely out-selection of NOB, adaption to the low temperature and high organic carbon loading, have been highlighted.

Scale	Configuration		T °C	Influent source	NRR kg N n^{-3} d^{-1}	TN removal efficiency %	Strategies for out-selecting NOB	Strategies for low temperature	Strategies for organic carbon	Reference
Lab-scale	One-stage	SBR	25	Real wastewater: 20 mg NH_4^+-N L^{-1} 22~58 mg COD L^{-1}	0.01-0.04	20~70	✓ DO control: 0.3~1.5 mg O_2 L^{-1} ✓ Intermittent aeration	N/A	Pre-treated by CEPT and HRAS	(Han et al., 2016)
		SBR	15	Real wastewater: ~50 mg NH_4^+-N L^{-1} ~12 mg COD L^{-1}	~77	77	✓ Seeding from sidestream ✓ DO control: 0.17~0.25 mg O_2 L^{-1} ✓ Increasing the settling velocity	Temperature decreased gradually	Diluted supernatant	(Morales et al., 2016)
		SBR	10	Synthetic wastewater: ~60 mg NH_4^+-N L^{-1}	0.1	50	✓ DO control: 0.5~2.5 mg O_2 L^{-1}	Temperature decreased gradually from 20 to 10	Synthetic wastewater	(Lotti et al., 2014a)
		SBR	12	Synthetic wastewater: 70 mg NH_4^+-N L^{-1}	0.06	90	✓ DO control	Temperature decreased gradually from 25 to 12	Synthetic wastewater	(Hu et al., 2013)
		MBBR	15	Real wastewater: 21 mg NH_4^+-N L^{-1} 69 mg COD L^{-1}	20~40	70	✓ Seeding from sidestream ✓ DO control: 0.15~0.18 mg O_2 L^{-1}	Temperature decreased gradually	Aerobically pre-treated	(Laureni et al., 2016)
		MBBR	22	Real wastewater: 50 mg NH_4^+-N L^{-1} 45 mg COD L^{-1}	33	80	✓ DO control: 0.1~0.4 mg O_2 L^{-1} ✓ Seeding from sidestream	Temperature decreased gradually from 35 to 12.5 in short term	Diluted reject water	(Kouba et al., 2016)
		MBBR	10	Synthetic wastewater: 50 mg NH_4^+-N L^{-1}	~12	~68	✓ Seeding from sidestream ✓ DO control: 0.1~0.5 mg O_2 L^{-1}	Temperature decreased gradually from 20 to 10	Synthetic wastewater	(Gilbert et al., 2014)
		IFAS*	30	Synthetic wastewater: 45 mg NH_4^+-N L^{-1} 400 mg COD L^{-1}	~100	~50	✓ Intermittent aeration	N/A	Synthetic wastewater	(Gu et al., 2017)
		SBR and MBBR	10	Real wastewater: 49 mg NH_4^+-N L^{-1} 29 mg COD L^{-1}	SBR: 10 MBBR: 31	~50	✓ Seed from sidestream ✓ DO control: 0.18 mg O_2 L^{-1} (SBR) 0.44 mg O_2 L^{-1} (MBBR)	Temperature decreased gradually from 20 to 10	Pre-treated by HRAS	(Lackner et al., 2015)
		SBR and MBBR	10	Synthetic wastewater: 50 mg NH_4^+-N L^{-1}	~30	~50	✓ Seeding from sidestream ✓ DO control: ~0.10 mg O_2 L^{-1} (SBR) ~0.25 mg O_2 L^{-1} (MBBR)	Temperature decreased gradually from 20 to 10	Synthetic wastewater	(Gilbert et al., 2015)
		MABR*	25	Synthetic wastewater: 70 mg NH_4^+-N L^{-1} 40 mg COD L^{-1}	85	81	✓ Control DO by modifying intra-membrane pressure: ~0.6 mg O_2 L^{-1}	N/A	COD addition did not improve the nitrogen removal performance	(Li et al., 2016)
		MBR	25	Synthetic wastewater: 80 mg NH_4^+-N L^{-1} Real wastewater: 88 mg NH_4^+-N L^{-1} 300 mg COD L^{-1}	970	81	✓ DO control: 0.1~0.2 mg O_2 L^{-1}	NA	Synthetic wastewater	(Zhang et al., 2013)
		Rotating biological contactor	15	Synthetic wastewater: 55~60 mg NH_4^+-N L^{-1}	500	40	✓ DO control: 1.1~3.1 mg O_2 L^{-1}	Temperature decreased gradually from 29 to 15	C/N ratio increased from 0 to 2	(De Clippeleir et al., 2013)

		Rotating biological contactor	25	Synthetic wastewater: 29~66 mg NH_4^+-N L^{-1}	380~440	46~53	✓ DO control: 1.2~1.4 mg O_2 L^{-1}	N/A	Synthetic wastewater	(De Clippeleir et al., 2011)
		SBR	25	Real wastewater: 40.1 mg NH_4^+ -N L^{-1} 70.5 mg COD L^{-1}	90	79	✓ DO control: 0.12~0.32 mg O_2 L^{-1}	N/A	Pre-treated by enhanced biological phosphorous removal (EBPR)	(Yang et al., 2018)
		IFAS	25	Synthetic wastewater: 50 mg NH_4^+-N L^{-1} 50-100 mg COD L^{-1}	50	72	✓ Intermittent aeration ✓ DO control: 0~0.4 mg O_2 L^{-1}	N/A	N/A	(Wang et al., 2018)
		SBR	30	Real wastewater: 59 mg NH_4^+ -N L^{-1} 60-150 mg COD L^{-1}	95	77	✓ Intermittent aeration ✓ DO control: 0.8~1.2 mg O_2 L^{-1}	N/A	Pre-treated by aerobic section and stepwise increase C/N ratio	(Miao et al., 2018)
		SBR	15	Synthetic wastewater: 70 mg NH_4^+-N L^{-1}	10	30	✓ Intermittent aeration ✓ DO control: <1 mg O_2 L^{-1}	Temperature decreased from 25 to 15	Synthetic wastewater	(Akaboci et al., 2018)
	Two-stage	Up-flow fluidized granular sludge reactor	10	Real wastewater: secondary effluent 60 mg (NH_4^++NO_2^-)-N L^{-1} 58 mg COD L^{-1}	340	57	N/A	Temperature decreased gradually from 20 to 10	Pre-treated from aerobic process	(Lotti et al., 2014b)
		Granular UASB*	16	Real wastewater: secondary effluent 16.87 mg NH_4^+-N L^{-1} 20.57 mg NO_2^--N L^{-1} 13.97 mg NO_3^--N L^{-1} 25.54 mg COD L^{-1}	2280	~50	N/A	Temperature decreased gradually from 30 to 16	Pre-treated from secondary clarifier	(Ma et al., 2013)
		Up-flow fixed-bed biofilm reactor	12	Real wastewater: 24 mg NH_4^+-N L^{-1} 25.54 mg COD L^{-1}	830	80	N/A	Temperature decreased gradually from 35 to 12	anaerobic pre-treated real wastewater	(Gao et al., 2014)
		Granular gaslift reactor	10	Synthetic wastewater: 61 mg (NH_4^++NO_2^-)-N L^{-1}	27	N/A	N/A	N/A	Synthetic wastewater	(Hendrickx et al., 2014)
		Granular gaslift reactor	20	Mixture of synthetic and UASB effluent: 69 mg (NH_4^++NO_2^-)-N L^{-1}	121	86	N/A	N/A	Synthetic and pre-treated by UASB	(Hendrickx et al., 2012)
		Upflow anaerobic biofilter	23	Synthetic wastewater: 47 mg NH_4^+-N L^{-1} 61 mg NO_2^--N L^{-1}	2260	~70	N/A	Temperature decreased gradually from 23 to 15	Synthetic wastewater	(Taotao et al., 2015)
		SBR	12.5	Real wastewater: ~20 mg NH_4^+-N L^{-1} ~25 mg NO_2^--N L^{-1} ~47 mg COD L^{-1}	46	N/A	N/A	Temperature decreased gradually from 29 to 12.5	Aerobically pre-treated	(Laureni et al., 2015)
		Granular UASB	26	Synthetic wastewater: 70 mg (NH_4^++NO_2^-)-N L^{-1}	1700	78	N/A	Temperature decreased gradually from 32 to 26	Synthetic wastewater	(Reino and Carrera 2017)
		MBBR	30	Synthetic wastewater: ~30 mg TN L^{-1}	90	74	N/A	N/A	Synthetic wastewater	(Gu et al., 2018)
		Granular UASB	11	Real wastewater: ~30 mg NH_4^+-N L^{-1} ~40 mg NO_2^--N L^{-1} ~47 mg COD L^{-1}	1200	40	N/A	Temperature decreased gradually from 22 to 11	N/A	(Reino et al., 2018)
		SBR	20	Real wastewater: ~32 mg NH_4^+-N L^{-1} ~79 mg NO_2^--N L^{-1}	--	80	N/A	Temperature decreased gradually from 35 to 20	Pre-treated by anaerobic section	(de Almeida Fernandes et al., 2018)

				~97 mg COD L^{-1}						
		Granular UASB	30	Synthetic wastewater: ~27 mg NH_4^+-N L^{-1} ~31 mg NO_2^--N L^{-1}	1800	80	N/A	N/A	Synthetic wastewater	(Zhu et al., 2018)
Pilot-scale	One-stage	MBBR	13	Real wastewater: ~45 mg NH_4^+-N L^{-1} ~48 mg COD L^{-1}	7	12	✓ DO control: 0.4~1.0 mg O_2 L^{-1}	N/A	Diluted supernatant	(Persson et al., 2016)
		MBBR and IFAS	15	Real wastewater: ~45 mg NH_4^+-N L^{-1} 43.6~71.0 mg COD L^{-1}	10	51	✓ DO control: 0.4~1.5 mg O_2 L^{-1} ✓ Intermittent aeration	N/A	Diluted supernatant	(Trojanowicz et al., 2016)
		MBBR	25	Real wastewater: ~31 mg NH_4^+-N L^{-1} ~37 mg COD L^{-1}	12	35	✓ Intermittent aeration ✓ Seeding from sidestream	N/A	Pre-treated in UASB	(Malovanyy et al., 2015b)
		IFAS	25	Real wastewater: 35~50 mg NH_4^+-N L^{-1} 44~88 mg COD L^{-1}	~55	52~70	✓ Intermittent aeration ✓ DO control: 0.7~1.5 mg O_2 L^{-1}	N/A	Pre-treated in UASB	(Malovanyy et al., 2015a)
		Granular plug-flow reactor	19	Real wastewater: ~26.8 mg NH_4^+-N L^{-1} ~62.1 mg COD L^{-1}	182	38.3	✓ Seeding from sidestream ✓ DO control: 1~2 mg O_2 L^{-1}	N/A	Aerobically pre-treated	(Lotti et al., 2015)
		Granular completely mixed tank	13.4	Real wastewater: ~30 mg NH_4^+-N L^{-1} 15~75 mg COD L^{-1}	97	~30	✓ Seeding from sidestream ✓ DO control: <1 mg O_2 L^{-1}	Seasonal temperature variation from 10 to 25	Pre-treated in A-stage	(Hoekstra et al., 2018)

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