

Supplementary Material

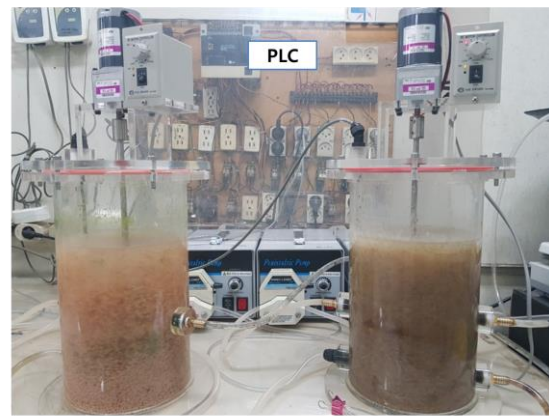
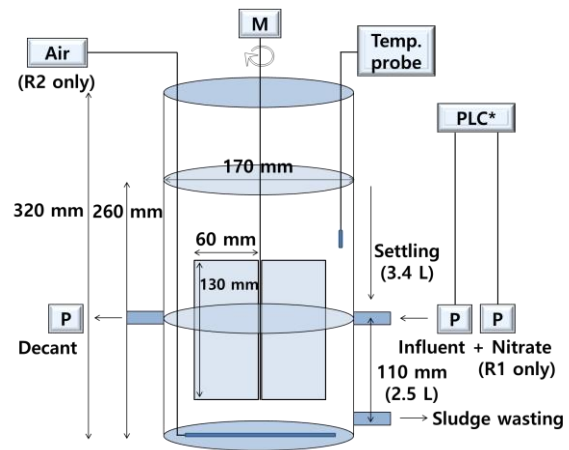
Factors Affecting the Morphology of Granular Sludge in Phosphorus-Accumulating Organism (PAO) and Denitrifying PAO (DPAO) Sequencing Batch Reactors

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An-Ax (R1)

An-Ox (R2)

Figure. S1. Diagram(left) and image(right) of lab-scale SBRs

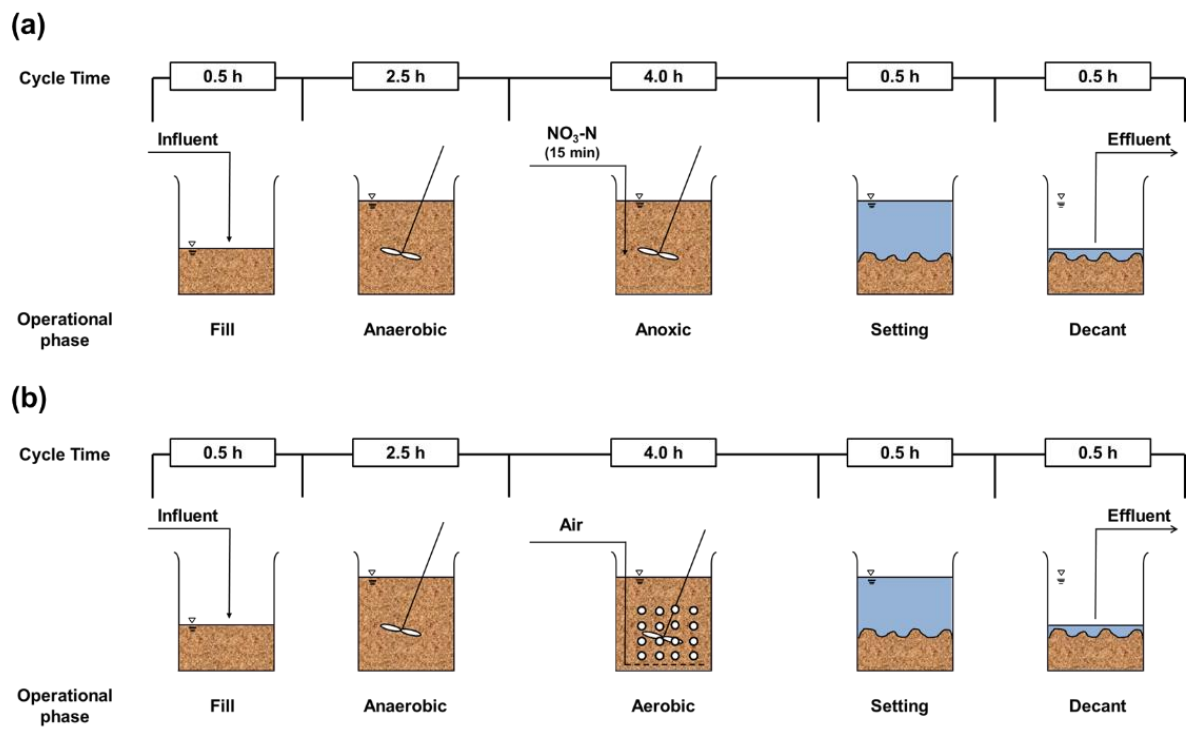


Figure. S2. Schematic of lab-scale SBRs operational condition for biological nutrient removal in (a) the An-Ax SBR and (b) the An-Ox SBR.

Table S1. Composition of synthetic wastewater

	Chemicals	Concentration	
		An-Ax SBR	An-Ox SBR
Carbon source	CH ₃ CH ₂ COONa	0.15 g/L (150 mg COD/L)	0.15 g/L (150 mg COD/L)
Nitrogen source	KNO ₃	7.21 g/L (15 mg NO ₃ ⁻ -N/L)	-
	NH ₄ Cl	0.038 g/L (10 mg NH ₄ ⁺ -N/L)	0.095 g/L (25 mg NH ₄ ⁺ -N/L)
Phosphorus source	KH ₂ PO ₄	0.0175 g/L (6 mg PO ₄ ³⁻ -P/L)	0.0175 g/L (6 mg PO ₄ ³⁻ -P/L)
Trace metal solution	*	0.1 mL/L of influent	0.1 mL/L of influent

Table S2. Summary of 34 references and operating results of this study

NO	Process	Condition	BNR type	OLR (kg/m ³ ·d)	SVI (mL/g)	MLSS (mg/L)	SRT (day)	HRT (h)	H/D ratio	Settling time* (min)	Aeration intensity (cm/s)	F/M ratio	Granule size (mm)	EPS conc. (mg/g vss)	Reference
1	SBR	Ox	Nitrification	6.0	51-85	5,900	7	8.0	24	20	2.5	0.34	2.4		Tay et al. (2001)
	SBR	Ox	Nitrification	6.0	50-80	8,600	9	8.0	24	20	2.5	0.23	1.1		
2	SBAR	Ox	Nitrification	2.5			45	5.6	22.5	3	2.2		2.5		Beun et al. (2002)
	SBAR	Ox	Nitrification	4.6				0.67	22.5		2.2		0.56		
	SBAR	Ox	Nitrification					1.0	22.5		2.2		0.75		
	SBAR	Ox	Nitrification	1.0				0.67	22.5		2.2		1.41		
3	SBR	Ox	Nitrification					3.0	24	30	3		0.12		Tay et al. (2002)
	SBR	Ox	Nitrification					6.0	24	30	3		0.22		
	SBR	Ox	Nitrification					12.0	24	30	3		0.24		
	SBR	Ox	Nitrification					24.0	24	30	3		0.08		
4	SBR	An/Ox	PAO	1.3	70	3,400	10			30		0.19	2.75		Dulekgurgen et al. (2003)
5	SBR	Ox/Ax	Nitrification	2.5	70-90	6,000		15.0	15	45	0.42	0.11	1.15		Jang et al. (2003)
6	SBR	An/Ox	PAO		33			12.0	24.0	5	2.5		1.65		Lin et al. (2003)
	SBR	An/Ox	PAO		32			12.0	24.0	5	2.5		1.22		
	SBR	An/Ox	PAO		25			12.0	24.0	5	2.5		1.03		
	SBR	An/Ox	PAO		20			12.0	24.0	5	2.5		0.6		
	SBR	An/Ox	PAO		12			12.0	24.0	5	2.5		0.42		
7	SBR	An/Ox	PAO	0.9	80	2,980		5.0	2.5	30		0.13	0.1		Kim et al. (2004)
	SBR	An/Ax/Ox	PAO, dPAO	0.9	80	2,980		5.0	2.5	30		0.13			
	SBR	An/Ax/Ox	PAO, dPAO	0.9	65	2,980		5.0	2.5	30		0.13	2.5		
	SBR	An/Ax/Ox	PAO, dPAO	0.9	95	2,980		5.0	2.5	30		0.13			
8	SBR	Ox	Nitrification	2.4	46	9,000			11.1	2	1.2		Compact		McSwain et al. (2004a)
	SBR	Ox	Nitrification	2.4	60	6,800			11.1	2	1.2		loose		
	SBR	Ox	Nitrification	2.4	114	3,200			11.1	2	1.2		loose		
9	SBR	Ox	Nitrification	2.4	60	3,000				10	1.2		0.8	58	McSwain et al. (2004b)
	SBR	Ox	Nitrification	2.4	63	8,800				2	1.2		3.0	82	
10	SBR	Ox	Nitrification	2.5				6.0	13.3	20	2.4		0.51		Yang et al. (2004)
	SBR	Ox	Nitrification	2.5				6.0	13.3	20	2.4		0.32		
	SBR	Ox	Nitrification	2.5				6.0	13.3	20	2.4		0.25		
	SBR	Ox	Nitrification	2.5				6.0	13.3	20	2.4		0.1		
	SBR	Ox	Nitrification	2.5				6.0	13.3	20	2.4		0.1		
11	SBR	Ox	Nitrification	4.14	53	10,000		7.0		1		0.12	2.5		Yun et al (2004)
12	SBR	Ox	Nitrification	2.4	60	3,000		4.0	11.1	10	1.2	0.27		58	McSwain et al. (2005)

	SBR	Ox	Nitrification	2.4	63	8,800		4.0	11.1	2	1.2	0.09	2.0	84	
13	SBR	Ax/Ox	Nitrification				20	12.0		45			0.55		Carvalho et al. (2006)
14	SBAR	Ox	Nitrification	1.0				5.6	14.4		2.5		1.1		de Kreuk and Van Loosdrecht.(2006)
15	SBR	Ox	Nitrification	4.0				8.0	1.4	3	0.4		2.0		Sun et al. (2006)
	SBR	Ox	Nitrification	4.0				8.0	1.4	3	0.4				
	SBR	Ox	Nitrification	4.0				8.0	1.4	3	0.4		0.5		
	SBR	Ox	Nitrification	4.0				8.0	1.4	3	0.4				
16	SBR	Ox	Nitrification	4.0	43	7,800	20	4.5	17.0	5		0.10	1.5	48	Wang et al. (2006)
17	SBR	Ox	Nitrification		52				13.0		0.6		0.35	201.2	Adav et al. (2007)
	SBR	Ox	Nitrification		35				13.0		1.2		3.25	591.3	
	SBR	Ox	Nitrification		61				13.0		1.8		1.25	637	
18	SBR	Ox	Nitrification	6.0	50.3			8.0		5			0.4	39	Zheng and Yu. (2007)
	SBR	Ox	Nitrification	6.0	46.8			8.0		5			0.75	53	
	SBR	Ox	Nitrification	6.0	45.1			8.0		5			1.2	57	
19	SBR	An/Ox	PAO	1.6		3,400	9	1.18		10	0.24	0.24	0.62		Dulekgurgen et al. (2008)
	SBR	An/Ox	PAO	1.6		3,000	9	1.18		5	0.49	0.27		252.7	
	SBR	An/Ox	PAO	1.6		850	9	1.18		3	1.76	0.94		162.4	
20	SBR	Ox	Nitrification		50	2,500	3		25.4	30	2.5	0.20	0.3		Li et al. (2008b)
	SBR	Ox	Nitrification		50	3,400	6		25.4	30	2.5	0.15	0.23		
	SBR	Ox	Nitrification		50	4,500	9		25.4	30	2.5	0.11	0.23		
	SBR	Ox	Nitrification		50	5,500	12		25.4	30	2.5	0.09	0.21		
	SBR	Ox	Nitrification		50	8,000	40		25.4	30	2.5	0.06	0.18		
21	SBR	Ox	Nitrification	8.0	60	9,000		3.0	20.0	5	2.4	0.11	1.5		Liu and Tay. (2008)
	SBR	Ox	Nitrification	3.0	30	7,000		8.0	20.0	5	2.4	0.14	0.9		
	SBR	Ox	Nitrification	1.5	50	3,000		16.0	20.0	5	2.4	0.33	0.6		
22	SBR	Ox	Nitrification	2.4		6,000				2	1.2				McSwain and Irvine (2008)
	SBR	Ox	Nitrification	2.4						2	1.2				
23	SBR	Ox	Nitrification	3.0				4.0	13.3	2	2.4		0.5	142.6	Xiao et al. (2008)
24	SBR	Ox	Nitrification					0.5	5.5				0.9		Belmonte et al. (2009)
25	SBR	Ox	Nitrification	1.8	20								1.8	106	Li et al. (2009)
	SBR	Ox	Nitrification	1.8	20								2.9	141.4	
26	SBR	Ox	Nitrification		17	3,100	12.5	24.0	1.7	10	0.07	0.97	0.55		Wan et al. (2009)
	SBR	Ox	Nitrification		33	3,100	12.5	24.0	1.7	10	0.07	0.97	0.55		
27	SBR	An/Ax/Ox	PAO, dPAO	0.76	59		12	19.5	1.6	1.8			0.8		Coma et al. (2010)
28	SBR	Ox	Nitrification	2.0	46	4,000	10		8.3	2	0.66	0.25	1.0	35	Sheng et al. (2010)
	SBR	Ox	Nitrification	2.0	48	5,000	10		8.3	2	0.70	0.20	2.2	45	
29	SBR	An/Ox	PAO		80-100	4,500	16	8.0	6.0	35	0.42	0.07	0.74	115.3	Wu et al. (2010)

30	SBAR	Ax/Ox	dPAO	2.82	15			8.5	7.0	30			0.8		Angela et al. (2011)
31	SBR	Ox	Nitrification	0.45	50		56		2.1	5	0.6		1.9		Cydzik-Kwiatkowska and Wojnowska-Baryła(2011)
32	SBR	Ox	Nitrification		27	2,000	15		4.23	30		0.3	1.5	80	Li et al. (2011)
	SBR	Ox	Nitrification		36.8	2,000	8		4.23	30		0.7	2.8	75	
	SBR	Ox	Nitrification		42.5	2,000	5		4.23	30		1.1	4.5	100	
	SBR	Ox	Nitrification		29.2	2,000	15		4.23	30		1.1	3	85	
33	SBR	An/Ox	PAO	0.8	27.5			8.0		10			0.6		Zhang et al. (2011)
34	SBAR	Ox	Nitrification	2.4	100	9,420			12.8	5	2.4		1.78	30.3	Zhu et al. (2012)
	SBAR	Ox	Nitrification	0.8	100	8,530			12.8	5	2.4		1.19	35.2	
35	SBR	An/Ox	PAO	0.74	84	2,812	34	13.9	1.9	30	1.46	0.09	0.41	23.93	This study
36	SBR	An/Ax	dPAO	0.74	97	2,226	40	13.9	1.9	30		0.12	2.2	36.7	This study

Note - SBR: sequencing batch reactor SBAR: sequencing batch airlift reactor *Settling time in one SBR operation