Simultaneous nitrogen and phosphorus removal from domestic wastewater in an aerobic granulation system operated at different anaerobic-aerobic duration

Calculations for nitrogen assimilated

The percentage of nitrogen assimilated by the biomass was calculated based on the following equation as described by Wan *et al.* (2009):

$$N_{assimilation}\ (g_N\ d^{-1}) = f_N\ (\Delta XV + VSS_{out}Q_{out}) \quad (1)$$

$$\eta_{assimilation}\ (\%) = (N_{assimilation} / NH_4^{+}\text{-}N_{in}) \times 100 \quad (2)$$

where:

f_N = nitrogen fraction of the sludge ($mg_N.mg^{-1}VSS$)

*The value was assumed to be equal to 0.1 $mg_N.mg^{-1}VSS$ as suggested by Lee *et al.* (2007) and Wan *et al.* (2009)

ΔXV = slope between two measurements of sludge concentration inside the SBR over time ($g_{vss}\ d^{-1}$)

VSS_{out} = solid concentration present in the effluent ($g_{vss}\ L^{-1}$)

Q_{out} = flow rate of effluent ($L\ d^{-1}$)

$\eta_{assimilation}$ = assimilation efficiency (%)

$NH_4^{+}\text{-}N_{in}$ = concentration of NH_4^{+}-N in influent

Table S1: Raw data for nitrogen assimilation calculations for (a) M1; (b) M2 and (c) M3

(a)

Day	**ΔXV**	**VSS_{out}**	**Q_{out}**	**$N_{assimilation}$**	**NH_4^+-N_{in}**	**$\eta_{assimilation}$**
349	2.16	0.023	16.4	0.25	26.1	0.96
350	2.02	0.034	16.4	0.26	19.7	1.32
351	2.88	0.025	16.4	0.33	20.3	1.63
355	1.77	0.032	16.4	0.23	16	1.44
356	1.75	0.020	16.4	0.21	10	2.10

(b)

Day	**ΔXV**	**VSS_{out}**	**Q_{out}**	**$N_{assimilation}$**	**NH_4^+-N_{in}**	**$\eta_{assimilation}$**
393	2.98	0.045	16.4	0.37	20.8	1.78
394	3.04	0.039	16.4	0.37	20.8	1.78
398	3.11	0.048	16.4	0.39	23.5	1.66
399	2.99	0.050	16.4	0.38	19.8	1.92
400	3.25	0.046	16.4	0.40	20.5	1.95

(c)

Day	**ΔXV**	**VSS_{out}**	**Q_{out}**	**$N_{assimilation}$**	**NH_4^+-N_{in}**	**$\eta_{assimilation}$**
349	2.33	0.032	16.4	0.29	25.3	1.15
350	2.56	0.037	16.4	0.32	23.3	1.37
351	2.79	0.035	16.4	0.34	29.8	1.14
355	2.44	0.040	16.4	0.31	23.5	1.32
356	2.49	0.037	16.4	0.31	22.8	1.36

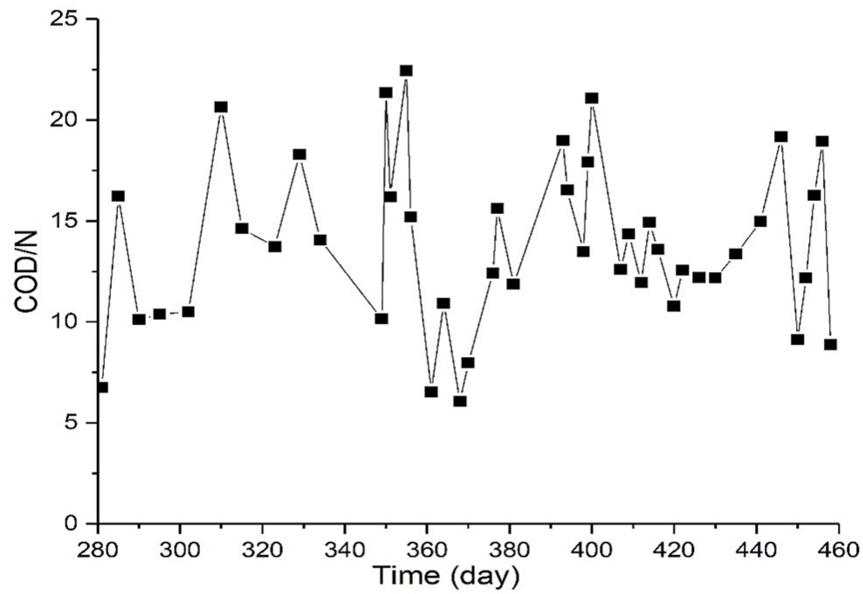


Figure S1: Profile of COD/N in the influent feed during M1, M2 and M3

Table S2: Raw data for SND calculations for (a) M1; (b) M2 and (c) M3

(a)

Day	NH_4^+-N start-aerobic*	NH_4^+-N end-nitrification*	NO_2^--N influent*	NO_2^--N end-nitrification*	NO_3^--N influent*	NO_3^--N end-nitrification*	NH_4^+-N removed*	NO_x^--N accumulated*	NO_x^--N denitrified*	SND (%)
349	24.8	6.2	3	9	3	6.2	18.6	9.2	9.4	50.5
350	17.8	6.7	2	6	0	0.4	11.1	4.4	6.7	60.4
351	16	6.8	5	9	4	4	9.2	4.0	5.2	56.5
355	15.3	4.3	3	7	3	4.8	11.0	5.8	5.2	47.3
356	8.5	2.9	3	1	2	6.6	5.6	2.6	3.0	53.6

(b)

Day	NH_4^+-N start-aerobic*	NH_4^+-N end-nitrification*	NO_2^--N influent*	NO_2^--N end-nitrification*	NO_3^--N influent*	NO_3^--N end-nitrification*	NH_4^+-N removed*	NO_x^--N accumulated*	NO_x^--N denitrified*	SND (%)
393	21.3	17.5	3	8	3	0.8	3.8	2.8	1.0	26.3
394	21.8	16.3	4	10	2	0.1	5.5	4.1	1.4	25.5
398	24.4	19.3	0	3	0	0.8	5.1	3.8	1.3	25.5
399	21.5	15.8	2	6	0	0.2	5.7	4.2	1.5	26.3
400	23.2	16.5	4	11	3	0.9	6.7	4.9	1.8	26.9

(c)

Day	NH_4^+-N start-aerobic*	NH_4^+-N end-nitrification*	NO_2^--N influent*	NO_2^--N end-nitrification*	NO_3^--N influent*	NO_3^--N end-nitrification*	NH_4^+-N removed*	NO_x^--N accumulated*	NO_x^--N denitrified*	SND (%)
450	24.1	8.8	2	7	1	5.7	15.3	9.7	5.6	36.6
452	22.4	7.8	4	12	3	5.0	14.6	10.0	4.6	31.5
454	28.2	8.0	5	14	6	13.9	20.2	16.9	3.3	16.3
456	21.9	6.3	3	9	3	7.7	15.6	10.7	4.9	31.4
458	19.7	4.3	4	11	4	5.9	15.4	8.9	6.5	42.2

* Unit mg/L

Calculations for free nitrous acid (FNA) production

The FNA concentration was calculated using the equation as described by Anthonisen *et al.* (1976).

FNA concentration (µg/L) = [NO_2^--N concentration / 10^{pH} x exp (-2300 / (273 + T))] x 1000

where:

NO_2^--N concentration = Nitrite nitrogen concentration in the SBR at the end of aerobic(mg/L)

pH = pH of the bulk solution in SBR

*The value was assumed to be equalled to 7.6 for M1, 6.2 for M2 and 7.3 for M3, based on the average value as presented in Table 1

T = Temperature (°C)

*The value was assumed to be equalled to 25 as the experiment was conducted at room temperature

Table S3: Raw data for FNA concentration calculations for (a) M1; (b) M2 and (c) M3

(a)

Day	**NO_2^--N (mg/L)**	**FNA concentration (µg/L)**
349	9	0.51
350	6	0.34
351	9	0.51
355	7	0.40
356	1	0.05

(b)

Day	**NO_2^--N (mg/L)**	**FNA concentration (µg/L)**
393	8	11.35
394	10	14.19
398	3	4.28
399	6	8.51
400	11	15.61

(c)

Day	**NO_2^--N (mg/L)**	**FNA concentration (µg/L)**
450	7	0.79
452	12	1.35
454	14	1.58
456	9	1.01
458	11	1.24

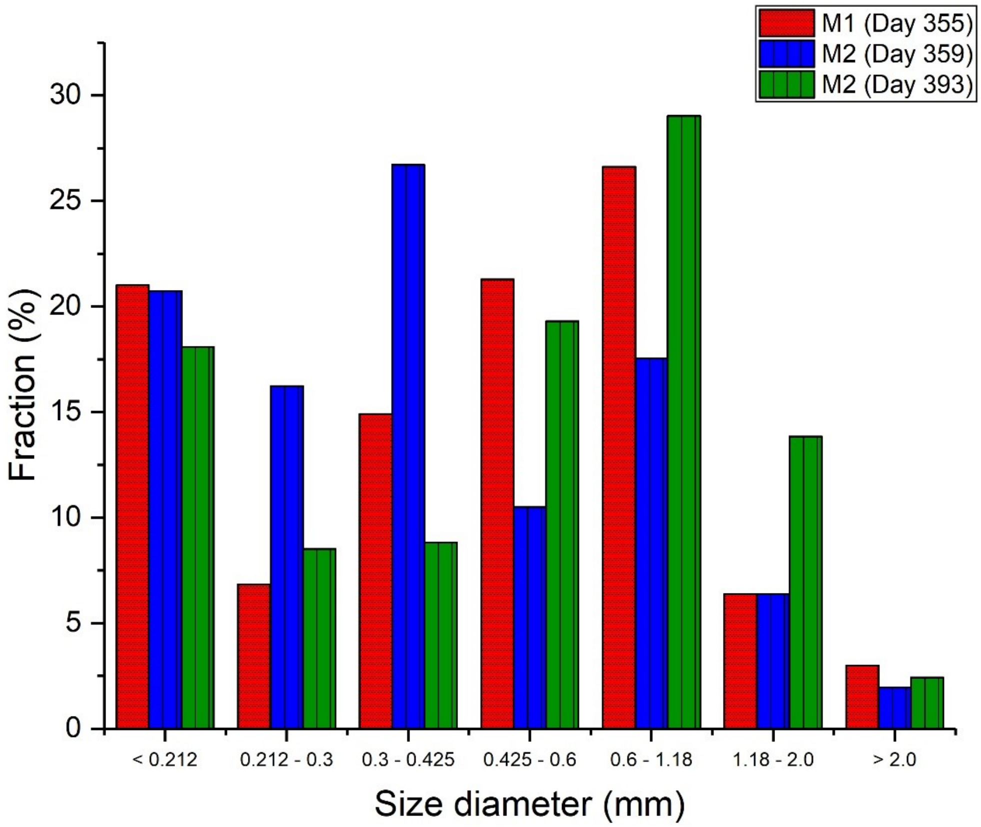


Figure S2: Size distribution formed during M1 (Day 355) and M2 (Day 359 and Day 393)

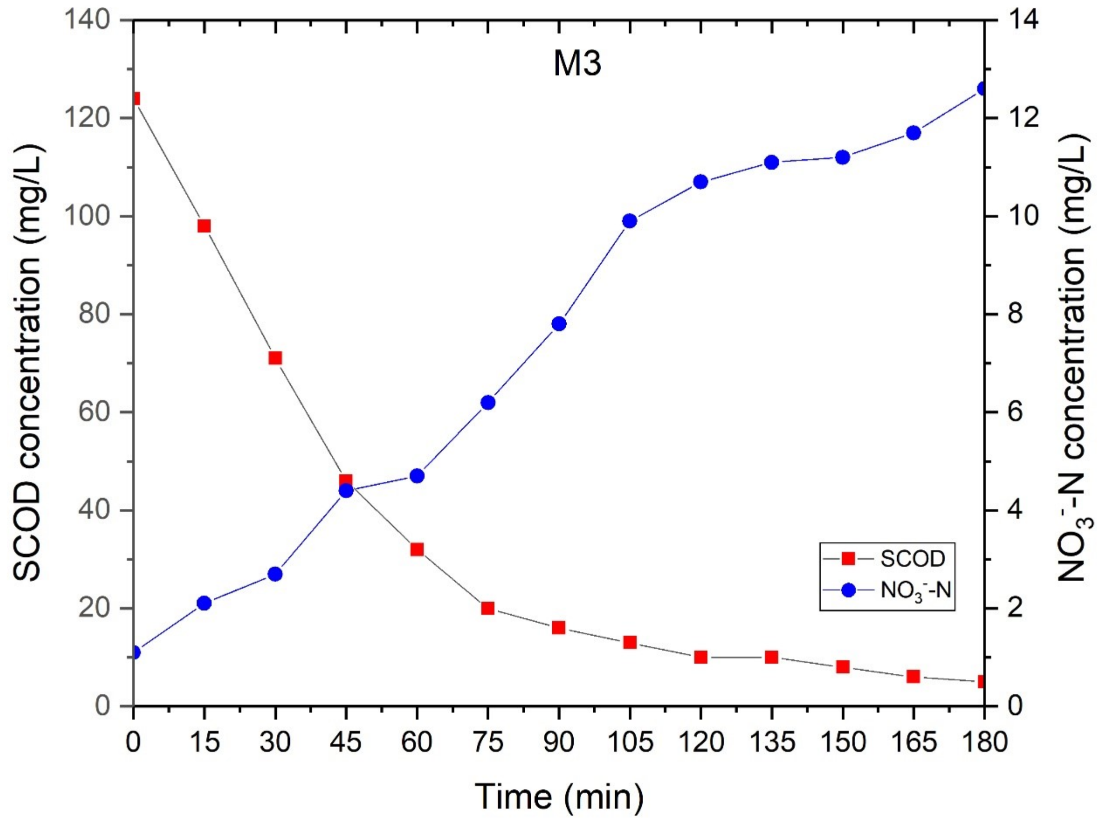
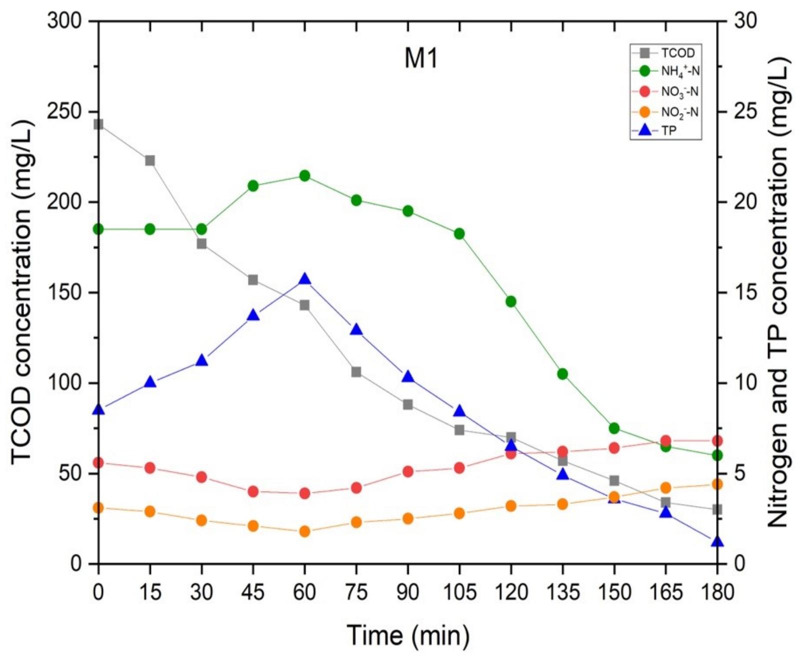
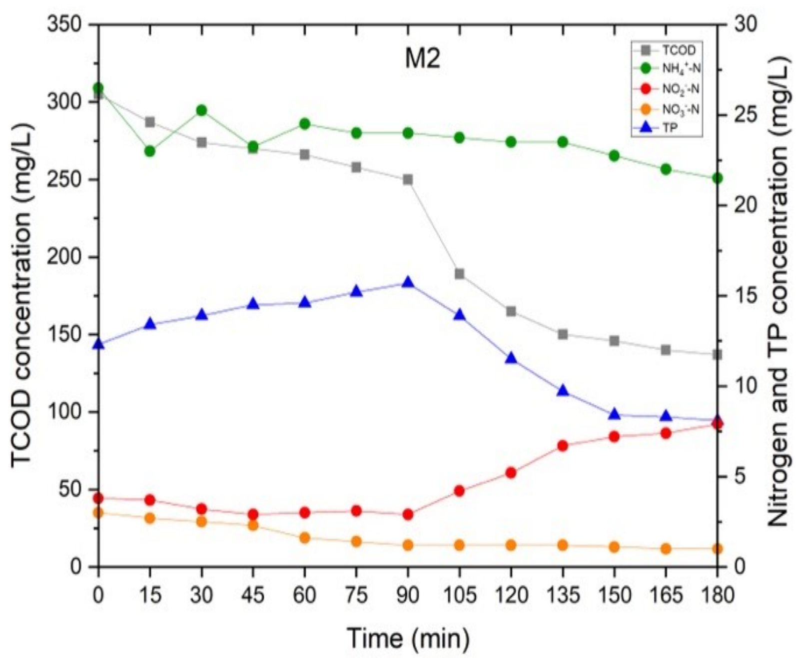


Figure S3: Cycle profile for SCOD and NO_3^--N concentration during M3 on Day 454

(a)


M1
TCOD
NH4+-N
NO3--N
NO2--N
TP
TCOD concentration (mg/L)
Nitrogen and TP concentration (mg/L)
Time (min)
0
15
30
45
60
75
90
105
120
135
150
165
180
0
50
100
150
200
250
300
0
5
10
15
20
25
30

(b)


M2
TCOD
NH4+-N
NO2--N
NO3--N
TP
TCOD concentration (mg/L)
Nitrogen and TP concentration (mg/L)
Time (min)
0
15
30
45
60
75
90
105
120
135
150
165
180
0
50
100
150
200
250
300
350
0
5
10
15
20
25
30

(c)

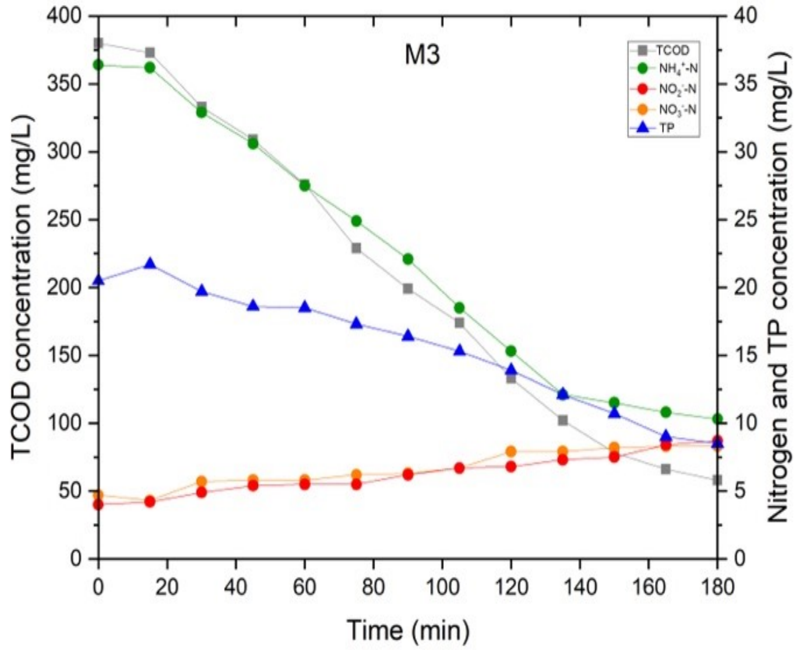


Figure S4: Cycle profile for TCOD, nitrogen and TP concentration during (a) M1 (Day 353), (b) M2 (Day 396) and (c) M3 (Day 455)

References

A. C. Anthonisen, R. C. Loehr, T. B. S. Prakasam and E. G. Srinath, Inhibition of nitrification by ammonia and nitrous acid, *J. Water Pollut. Control Fed.*, 1976, **48**, 835-852.

J. K. Lee, K. H. Lee and S. B. Yim, Optimization of nitrogen removal in a sequencing batch reactor system by variation of the time distribution, *J. Environ. Sci Health, Part A, Toxic/Hazardous Substances and Environmental Engineering*, 2007, **42**(11), 1655-1663.

J. Wan, Y. Bessière and M. Spérandio, Alternating anoxic feast, aerobic famine condition for improving granular sludge formation in sequencing batch airlift reactor at reduced aeration rate, *Water Research*, 2009, **43**(20), 5097-5108.