Theoretical Evaluation of Nitrogen Removal in Anoxic-oxic-anoxic-oxic Process

Byung-Dae Lee

***Abstract*—**Generally anoxic-oxic-anoxic-oxic processes for nitrogen removal were known as popular domestic sewage treatment plants. These processes were evaluated in this study by theoretical calculation based on nitrification and denitrification reaction. Total nitrogen removal efficiency depends on n (return sludge ration) and r (portions of influent to the second anoxic tank). The maximum total nitrogen removal efficiency could be found to be (n+b+bn)/{(1+n)(1+b)} when a portion is 1/{1+0.35*(substrate COD)/(NH_4^+-N)} of influent is introduced into the second denitrification tank.

***Keywords*—**Maximum nitrogen removal, (De)nitrification, calculation, optimal influent allocation ratio.

I. Introduction

NITOGEN in nature has various forms and the pathway also complicated. Most of the nitrogen in fresh water is primarily combined in proteinaceous matter and urea. It is readily decomposed by bacteria to ammonia. In an aerobic environment, bacteria oxidize the ammonia to nitrite and nitrate. These inorganic nitrogen are reused by algae and other aquatic plants to form plant proteins. Some of plant proteins are also transferred to animal proteins by feeding of consumers. Death and decomposition of the plant and animal proteins again yield ammonia [3].

The total nitrogen concentration in untreated wastewater various from 20 to 85 mg/L. Nitrogen in wastewater can be divided into four form: organic nitrogen, ammonia nitrogen, nitrite nitrogen and nitrate nitrogen. Organic nitrogen and ammonia nitrogen are dominant in untreated wastewater and occupy about 40% and 60% of total nitrogen. Consequently, when a large amount of nitrogen in wastewater is discharged to the environment without being treated, depletion of receiving-water oxygen resources can occur as the ammonia is oxidized to nitrate. This depletion of oxygen can be eliminated if the ammonia is first oxidized to nitrate by nitrification reaction before it is discharged. Denitrification is the process followed by nitrification, and is used to remove nitrogen from the effluent of nitrification process. Though nitrate is less troublesome than ammonia, it promotes the eutrophication of lake. Therefore, the removal of nitrogen is also recommended for the advanced treatment.

This study conducted a theoretical calculation of anoxic-oxic-anoxic-oxic processes to investigate the maximum nitrogen removal with known values (i.e., influent water qualities, sludge return ration, and influent allocation ratio).

II. Methods

This process consists 4 reactors: anoxic, oxic, anoxic, and oxic reactor as shown in Fig. 1. Some portion of influent are fed to the second anoxic reactor. Also some portions of nitrate nitrogen from recycled mixed liquor can be converted to nitrogen gas in the first anoxic reactor by denitrification process with carbon source from influent. The influent ammonia nitrogen is converted to nitrate in the first oxic reactor by nitrification process and then nitrate nitrogen converts into nitrogen gas in second anoxic reactor by denitrification process with some portions of carbon source from the influent.

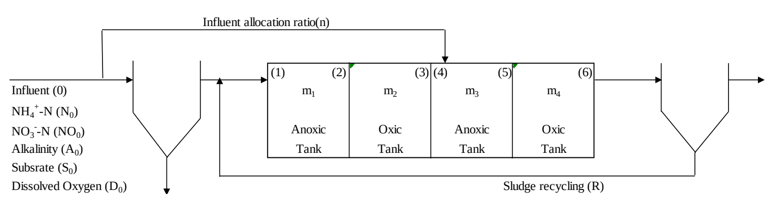

Fig. 1 System configuration of anoxic-oxic-anoxic-oxic process.

The parameters considered in this system are also the same as in the previous, i.e., concentration of ammonia nitrogen (NH_4^+), nitrate nitrogen (NO_3^-), alkalinity (A), and substrate (COD), To make simplify the equations we consider the parameters in influent as NH_4^+ = 1 m/L, NO_3^- = 0 mg/L, alkalinity = a*3.57 mgCaCO3/L and substrate = b*2.86 mgCOD/L. The concentration of reacted nitrogen in each reactor is m1, m2, m3 and m4. The symbols of this parameter at different position in the system are shown in Table 1.

Byung-Dae Lee is with the Department of Health Management, Uiduk University, 261 Donghaedaero, Gandong, Gyeongju, Gyeongbuk, 780-713, Republic of Korea (phone: +82-54-760-1702; fax: +82-54-760-1179; e-mail: bdlee@uu.ac.kr).

TABLE I
PARAMETERS IN ANOXIC-OXIC-ANOXIC-OXIC PROCESS

Parameters	Influent (0)	Mixture anoxic tank	After aoxic reactor (2)	After oxic reactor (3)
NH_4^+-N	1	N1	N2	N3
NO_3^--N	0	NN1	NN2	NN3
S-COD	b	S1	S2	S3
Alkalinity	a	A1	A2	A3
Parameters	Mixture anoxic tank (4)	After aoxic reactor (5)	After oxic reactor (6)	
NH_4^+-N	N4	N5	N6	
NO_3^--N	NN4	NN5	NN6	
S-COD	S4	S5	S6	
Alkalinity	A4	A5	A6	

III. RESULTS AND DISCUSSION

From the theoretical nitrogen balance of nitrification and denitrification processes, we can express N0 to A6 with the influent components, the return sludge ratio (n), influent ration to second anoxic tank ®, and the concentrations of reacted nitrogen (m1, m2, m3, and m4) as shown in Table 2.

TABLE II. GENERAL PARAMETERS AT DIFFERENT POSITIONS IN THE ANOXIC-OXIC-ANOXIC-OXIC PROCESS

Parameters	Influent (0)	Anoxic reactor (1)	After anoxic reactor (2)	After oxic reactor (3)
NH_4^+-N	1	1-nm2-{(1+2)nm4/(1+n-r)}	1-nm2-{(1+2)nm4/(1+n-r)}	1-(1+n)m2-{(n(1+n)m4/(1+n-r)}
NO_3^--N	0	n(m2-m1)+{n(1+n)(m4-m3)/(1+n-r)}	nm2-m1(1+n)+{n(1+n)(m4-m3)/(1+n-r)}	(1+n)(m2-m1)-{n(1+n)(m4-m3)/(1+n-r)}
S-COD	b	b(1-r)/(1+n-r)	{b(1-r)/(1+n-r)} –m1	0
Alkalinity	a	a+n(m1-2m2)+{n(1+n)(m3-2m4)/(1+n-r)}	a+2nm2+m1(1+n)+{n(1+n)(m3-2m4)/(1+n-r)}	a+(1+n)(m12m2)+{n(1+n)(m3-2m4)/(1+n-r)}
Parameters	Mixture anoxic reactor (4)	After anoxic reactor (5)	After oxic reactor (6)	
NH_4^+-N	1-(1+n-r)m2nm4	1-(1+n-r)m2nm4	1-(1+n-r)m2nm4	
NO_3^--N	(1+n-r)(m2-m1)+n(m3-m4)	(1+n-r)(m2-m1)+nm4-(1+n)m3	(1+n-r)(m2-m1)+(1+n)(m4-m3)	
S-COD	rb/(1+n)	rb/(1+n)-m3	0	
Alkalinity	a+(1+n-r)(m1-2m2)+n(m3-2m4)	a+(1+n-r)(m1-2m2)+n(m3-2m4)	A+(1+n-r)(m1-2m2)+n(m3-2m4)	

To get the concentration at different positions, we can do the same procedure as in previous calculation (anoxic, oxic, anoxic, and oxic reactors) then the concentration of each case can be calculated.

By solving the four equations in each reactor from Table 1 and Table 2, we can get concentration of nitrogen (m1, m2, m3, and m4) in each tank for each case. From the analysis the cases that never occur are also existed.

From the all cases that can occur, the zones of all cases obtained by changing the ratio of incoming influent to the second anoxic tank (r) from 0 to 1, the same way as in the previous calculation. To simplify the equation, we used the return sludge ratio at 25% (n=0.25). The seven zones can be obtained as shown in Fig. 2.

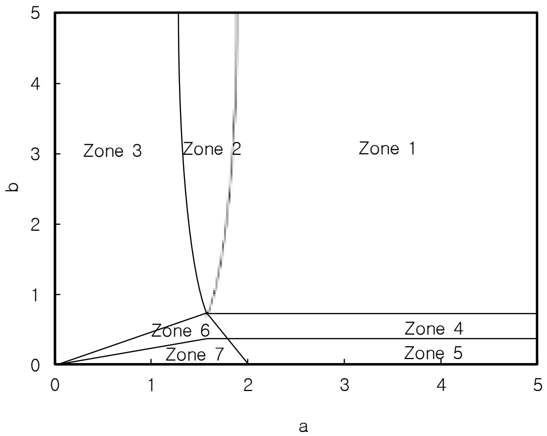

Fig. 2 Zone analysis of all cases of anoxic-oxic-anoxic-oxic process.

This figure shows the relationship between influent components (a and b) and zones. In each zone has it's the following own characteristics:

Zone 1: All of nitrification and denitrification reactions completely occur in all tanks and effluent substrate from second anoxic tank becomes zero.

Zone 2: Only nitrification in first oxic tank does not completely occurs.

Zone 3: Denitrification in both anoxic tanks completely occurs but the nitrification in both oxic tanks do not completely occur.

Zone 4: Nitrification in both oxic tanks completely occurs but only denitrification in first anoxic tank completely occurs.

Zone 5: Nitrification in both oxic tanks completely occurs but denitrification in both anoxic tanks does not completely occur.

Zone 6: Only denitrification in first anoxic tank completely occurs but the nitrification in both anoxic tanks do not completely occurs.

Zone 7: All of the reaction in both anoxic and both oxic tanks do not completely occur.

From the relationship between r and removal efficiencies of total nitrogen and ammonia nitrogen of all seven zones, we can summarize r values that can get maximum ammonia and total nitrogen removal efficiency as shown in the Table 3.

TABLE III
SUMMATION OF REQUIRED R VALUES FOR MAXIMUM AMMONIA AND TOTAL NITROGEN REMOVAL EFFICIENCY FOR ALL ZONES

Zone	Minimum r required for maximum NH_4^+-N and TN removal	Efficiency of maximum TN removal	Efficiency of maximum NH_4^+-N removal
1	1/(1+b)	{100(n+b(1+n))/{(1+2)(1+b)}	100
2	(a+an-n)/(2b+a)	{100b(n+a)+an(1+b)}/{(1+n)(2b+a)}	100
3	{2a(1+n)}/(4b+3nb+2a+an)	{100a(2b+an+3bn)}/(2a+4b+an+3bn)	{100a((a+3b)(1+n))/(2a+4b+an+3bn)
4	(b+bn-n)/b to (1+n)(1-b)	100b	100
5	0	100b	100
6	(2b+bn-an)/2b to (a-b+2an-bn)/(a+b)	100b	50(a+b)
7	0	100b	50(a+b)

From this calculation, we found that r value has some relationship with the ammonia and total nitrogen removal efficiency in all zone.

Therefore from Table 3, we can draw Fig. 3 with the relationship between the removal efficiencies, influent ration to second anoxic reactor (r) and influent composition.

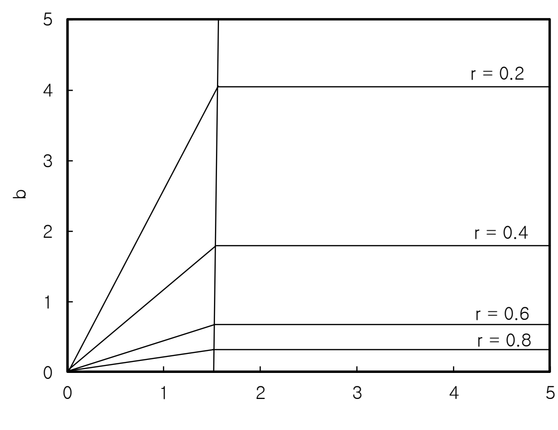

Fig. 3 Minimum required r values for maximum total nitrogen removal efficiency

This figure shows the r values for maximum ammonia and total nitrogen removal efficiency. From the analysis, we consider r value 2 cases as follows:

In zone 1, 2, and 3: At a is greater than 2, we find that maximum ammonia and total nitrogen removal efficiency depends on b value and return sludge ratio (n) by the equation {(1+n)b+n}/{(1+n)(1+b)}. For example, if we have influent component of a = 3 and b = 4 and sludge reture ration (n) = 50%, we can get the maximum ammonia nitrogen removal efficiency of 100% and maximum total nitrogen removal efficiency of 87% at r value equal to 0.2.

In zone 4 and 6: If we have influent at a = 3 and b = 0.2, we can get the maximum ammonia removal efficiency 100% and maximum total nitrogen removal efficiency 20% at r value equal to 0.4.

IV. Conclusion

The theoretical calculation in anoxic-oxic-anoxic-oxic process appears to be highly effective for removal nitrogen. The main results are as follows:

(1) Total nitrogen removal efficiency depends on the substrate, alkalinity and ammonia nitrogen in the influent to the wastewater treatment plant.

(2) In general domestic wastewater, the substrate and alkalinity is considered to be enough for denitrification and nitrification in wastewater treatment plant.

For anoxic-oxic-anoxic-oxic system, the total nitrogen removal efficiency depend on n (return sludge ration) and r (portion of influent to the second anoxic tank). The maximum total nitrogen removal efficiency for the anoxic-oxic-anoxic-oxic process can be found to be {(n+b+bn)/(1+n)(1+b)} when a portion is 1/{1+0.35*(substrate COD)/(NH_4^+-N)} of influent is introduced into the second denitrification tank.

(3) The alkalinity and substrate in the influent to the nitrogen treatment plant are not enough for complete denitrification and nitrification reaction, the total nitrogen removal efficiency is different depending on the zone in which they are located.

(4) Anoxic-oxic-anoxic-oxic process is one of the effective method for nitrogen removal. This process can be done by both new treatment plants and upgrading the existing sewage treatment plants.

V. Recommendations

From the theoretical calculation for nitrogen removal efficiency, the following items are recommended to be taken into consideration

- The theoretical calculation of nitrogen removal efficiency for anoxic-oxic-anoxic-oxic processes which have more than two series of anoxic and oxic tanks should be further studied.

- The theoretical calculation for biological phosphorus removal should be taken into consideration as well as the nitrogen removal process.

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