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Theoretical Analysis for Nitrogen Removal in Step Feed Oxic-Anoxic-Oxic Process

Byung-Dae Lee† · Il-Chool Kim*

†*Division of Health, Uiduk University, Gyeongju 780-713, Korea*
**Department of Cosmetic Science, Joongbu University, Kumsan, Chungnam 312-702, Korea*
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Abstract : One of the popular domestic sewage treatment process (called step feed oxic-anoxic-oxic process) for nitrogen removal was analyzed in this study by theoretical analysis based on the nitrification and denitrification reaction. Total nitrogen removal efficiency was suggested by considering influent qualities(i.e., ammonia, nitrite, nitrate, alkalinity, and COD). Total nitrogen removal efficiency depends on r (influent allocation ratio). In the case that all influent components are enough, the total nitrogen removal follows equation 100·b/(1+b), when r is 1/(1+b). Finally, it can be concluded that step feed oxic-anoxic-oxic process could be effective for nitrogen removal.

Keywords : Nitrification, Denitrification, Calculation, Maximum nitrogen removal, Optimal influent allocation ratio.

1. INTRODUCTION

Recently, rapid increase of population and man's activities have caused continuing degradation of the natural resources, such as air, land and water. As a result, it is more emphasized to treat wastewater before discharging to receiving waters[1]. In addition, the stream standards imposed on treatment systems sometimes require expansion and upgrading of present plants as well as high treatment efficiency of new treatment plants. Hence, treatment requirements become more stringent in terms of the allowable concentration of nitrogenous substances in the effluent from wastewater treatment plants[2]. Nitrogen may deplete dissolved oxygen level in receiving waters, stimulate eutrophication, reduce chlorine disinfection efficiency and affect the suitability of wastewater for reuse. In turn, these facts require advanced wastewater treatment facilities[3-5].

The modification of conventional activated sludge process ha been well developed for removing nitrogenous substances as well as carbonaceous substances from wastewater[6-10]. Nitrogen in wastewater is present in many forms such as ammonia, nitrate, nitrite, soluble organic and suspended organic materials, Among them, predominant species are ammonia nitrogen so that biological processes are used for nitrification and denitrification reactions. Nitrification is the oxidation processes of ammonia to nitrite and nitrate in the presence of oxygen and

† Corresponding author
(e-mail : bdlee@uu.ac.kr)

alkalinity while denitrification process is an anoxic condition to reduce nitrite and nitrate to nitrogen gas with the presence of carbon source[11-13]. Both reactions are affected by many factors such as dissolved oxygen, temperature, pH, alkalinity, concentration of ammonia nitrogen, organic substrate and nitrifying bacteria[14-18].

Among these factors, alkalinity for nitrification process and carbon source for denitrification process are essential components. In some case, these components in influent are not enough for completion of both reactions, resulting in low efficiency of nitrogen removal. The theoretical analysis must be developed to predict the nitrogen removal efficiency in terms of influent components.

However, this approach is not easy because the combination of two totally different reactions request us to design very complicated flow sheets if chemicals are not added externally. In addition research work for this modification has provided us many different methods, resulting in much difficulty of the comparison of these methods. Until now a few theoretical research were reported to predict optimal reactor volume ratio for maximum nitrogen removal [19-20]. As a result, theoretical analysis for practical nitrification-denitrification process has not been developed yet. For the prediction of the effluent quality, another way is through theoretical calculation which can help us in designing advanced wastewater process, and suggest the best efficiency in different situations.

2. Methods

2.1.Theoretical calculation

This system consist of three reactors which are oxic, anoxic and oxic reactor as shown in Fig. 1. The influent is fed to anoxic reactor in some ratio (r). To simplify the equations, it can be assumed that the effect of return sludge is neglected.

The parameters considered in this process are concentrations of ammonia nitrogen, nitrate nitrogen, substrate and alkalinity. The same as in the previous case m_1 is the nitrate nitrogen produced by nitrification in the first oxic tank, and m_2 is nitrogen gas from denitrification in anoxic tank, and m_3 is nitrate nitrogen produced by nitrification in the last oxic tank. The symbols of these parameters at different positions in anoxic and oxic tanks are shown in Table 1.

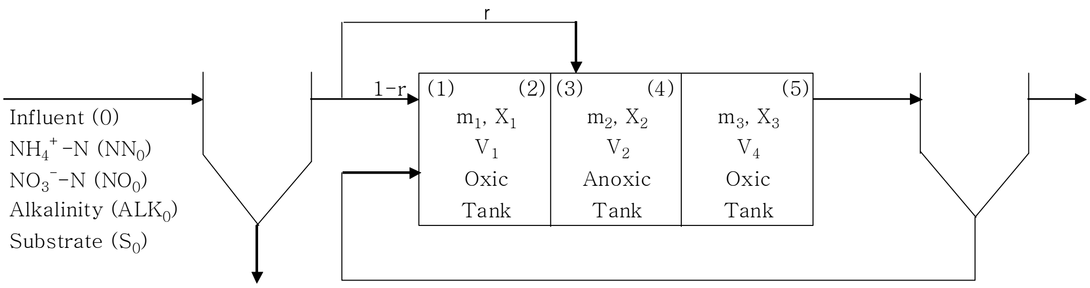


Fig. 1. System configuration of oxic-anoxic-oxic process.

m_1, m_2, m_3 : Concentration of nitrogen reacted in V_1, V_2 or V_3
X_1, X_2, X_3 : Concentration of MLVSS in oxic, anoxic or oxic tank
V_1, V_2, V_3 : Volume of oxic, anoxic or oxic tank

Table 1. Parameters in oxic-anoxic-oxic process

Parameters	Influent	Oxic reactor	After oxic reactor	Mixture anoxic reactor	After anoxic reactor	Effluent from oxic reactor
NH_4^+-N	N_0	N_1	N_2	N_3	N_4	N_5
NO_3^--N	$NN_0=0$	NN_1	NN_2	NN_3	NN_4	NN_5
S-COD	S_0	S_1	S_2	S_3	S_4	S_5
Alkalinity	A_0	A_1	A_2	A_3	A_4	A_5

Table 2. General parameters at different positions in the oxic-anoxic-oxic process

Parameters	Influent	Oxic reactor	After oxic reactor	Mixture anoxic reactor	After anoxic reactor	Effluent from oxic reactor
NH_4^+-N	N_0	N_0	N_0-m_1	$N_0-m_1(1-r)$	$N_0-m_1(1-r)$	$N_0-m_1(1-r)-m_3$
NO_3^--N	$NN_0=0$	0	m_1	$m_1(1-r)$	$m_1(1-r)m_2$	$m_1(1-r)-m_2+m_3$
S-COD	S_0	S_0	0	$r{\cdot}S_0$	$r{\cdot}S_0-2.87m_2$	$A_0-7.14m_l(l-r)+$
Alkalinity	A_0	A_0	$A_0-7.14m_1$	$A_0-7.14m_1(1-r)$	$A_0-7.14m_1(1-r)+3.57m_2$	$3.57m_2-7.14m_3$

Form the nitrogen balance and stoichiometric balance of nitrification and denitrification processes, it can express N_0 to A_5 with the influent compositions, ratio of influent to anoxic reactor (r) and the concentrations of nitrogen (m_1, m_2, and m_3) as shown in Table 2.

3. Results and Discussion

3.1. Case analysis

The influent components, substrate COD and alkalinity, may affect the removal efficiency of nitrogen. Sometimes, the alkalinity or substrate is not enough to perform reactions completely. In this system, the cases to be considered are 8 cases as shown in Table 3.

To get the parameters at different positions, the parameters of each case can be calculated. From the analysis the cases that never occur are case 2 and case 4. Table 4 shows summary of process effluent, removal efficiency and condition effluent for all cases that can occur.

Table 4 shows that the ammonia nitrogen removal efficiency can reach 100% in case 1 and 7. All of these cases have enough alkalinity to complete nitrification. The other cases, alkalinity is not enough to perform the nitrification in both oxic tanks resulting in limitation of ammonia nitrogen removal efficiency.

The above table shows that the removal efficiencies of ammonia and total nitrogen depend on r value and we consider this value in zone analysis.

Table 3. Case analysis of oxic-anoxic-oxic process

Case	Tank 1 oxic tank	Tank 2 anoxic tank	Tank 3 oxic tank
1	N	DN	N
2	N	DN	IN
3	N	IDN	N
4	N	IDN	IN
5	IN	DN	N
6	IN	DN	IN
7	IN	IDN	N
8	IN	IDN	IN

N: Complete nitrification
DN: Complete denitrification
IN: Incomplete nitrification
IDN: Incomplete denitrification

Table 4. Summation of plant effluent, removal efficiency and conditions of influent for oxic-anoxic-oxic process

Items	Parameters	Case 1	Case 3	Case 5	Case 6	Case 7	Case 8
Rate (mg·N/1)	m_1	N_0	N_0	$0.14A_0$	$0.14A_0$	$0.14A_0$	$0.14A_0$
	m_2	$N_0(1-r)$	$0.35r \cdot S_0$	$0.14A_0(1-r)$	$0.14A_0(1-r)$	$0.35r \cdot S_0$	$0.35r \cdot S_0$
	m_3	$r \cdot N_0$	$r \cdot N_0$	$N0-0.14A_0(1-r)$	$0.07A_0(1+r)$	$N_0-0.14A_0(1-r)$	$0.14r \cdot A_0+0.175r \cdot S_0$
Effluent	NH_4^+-N	0	0	0	$N_0-0.14A_0(1.5-0.5r)$	0	$0.14A_0-175r \cdot S_0$
	NO_3^--N	$r \cdot N_0$	$N_0-0.35r \cdot S_0$	$N_0-0.14A_0(1-r)$	$0.07A_0(1+r)$	$N_0-035r \cdot S_0$	$0.14A_0-0.175r \cdot S_0$
	S-COD	0	0	0	0	0	0
	Alkalinity	$A_0-3.57 \cdot N_0(1+r)$	$A_0-7.14N_0+1.2r \cdot S_0$	$A_0(1.5-0.5r)7.14N_0$	0	$A_0-7.14N_0+1.25r \cdot S_0$	0
	Total Nitrogen	$r \cdot N_0$	$N_0-0.35r \cdot S_0$	$N_0-0.14A_0(0-r)$	$N_0-0.14A_0(0-r)$	$N_0-0.35r \cdot S_0$	$N_0-0.35r \cdot S_0$
Removal efficiency(%)	NH_4^+-N	100	100	100	$\frac{21A_0-7r \cdot A_0}{N_0}$	100	$\frac{14A_0+17.5r \cdot S_0}{N_0}$
	Total Nitrogen	$100(1-r)$	$\frac{35r \cdot S_0}{N_0}$	$\frac{14(1-r)A_0}{N_0}$	$\frac{14(1-r)A_0}{N_0}$	$\frac{35r \cdot S_0}{N_0}$	$\frac{35r \cdot S_0}{N_0}$

3.2. Zone analysis

From the conditions of influent in three tanks, it can be drawn figures from the condition of all cases that can occur as in anoxic and oxic system, by using the ratio of a (0.35·alkalinity/ammonia) and b (0.28·alkalinity/ammonia).

To analyze the zones, it can be drawn figures from conditions of all cases by varying r values from 0.2, 0.4, 0.6, and 0.8, then Fig. 2 can be obtained.

From this figure, 3 transition areas can be obtained that r values vary from 0 to 1. Each transition area can make a zone. The zone can be divided as follows:

Zone 1 is the transition area of case 1 and 3. When the r value is small, case 1 occupies in this zone and changes to case 3 as r values increase.

Zone 2 is the transition area of case 6 and 8. When the r value is small, case 6 occupies in this zone and changes to case 8 as r values increase.

Zone 3 is the transition area of case 5, 6, 7 and 8. When the r value is small, case 6 occupies in this zone and changes to case 5,7,and 8 respectively as r values increase.

Each zone has its own characteristic for ammonia and total nitrogen removal efficiencies.

3.3. Relationship between return sludge ratio and nitrogen removal efficiency

The relationship between the influent ratio to the anoxic reactor (r) and nitrogen removal efficiencies in each zone 1 is shown in Fig. 3.

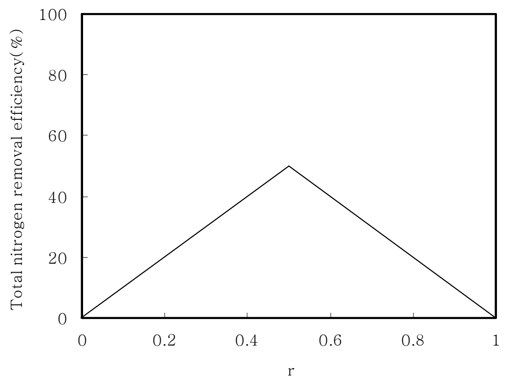
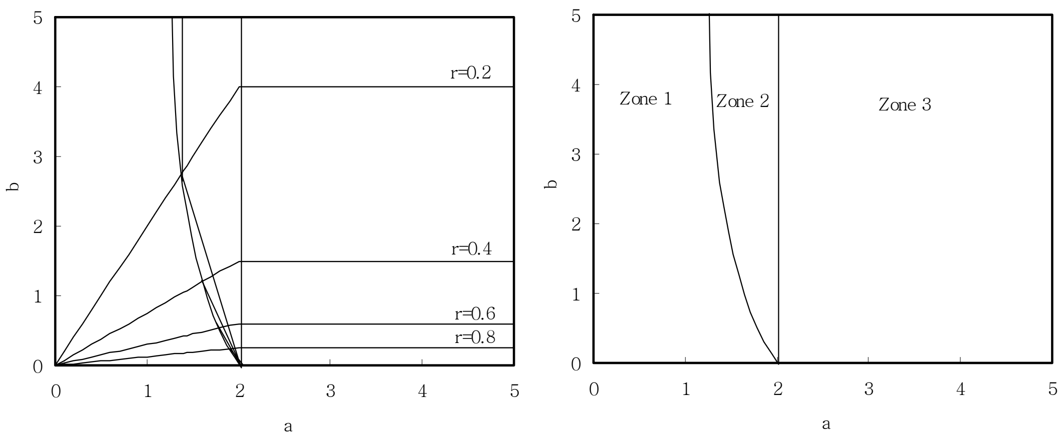


Fig. 3. Relationship between r and total nitrogen removal efficiency for zone 1.



(a) (b)

Fig. 2. Zone analysis of all cases of oxic-anoxic-oxic process (a) and simplified zone (b).

The total nitrogen removal efficiency in this zone depends on r values. If r value is less than 1/(1+b), the total nitrogen removal efficiency follows the equation r·b. At r value is greater then 1/(1+b), the total nitrogen removal efficiency decreases by the equation (1-r)b. The ammonia nitrogen removal efficiency in this zone is independent of r value. Meanwhile other zone (i.e., zone 2 and 3) analysis were omitted because most of all domestic sewage influent correspond to zone 1.

From relation between r and removal efficiency of total nitrogen and ammonia nitrogen of all 3 zones, it can be summarized the r values that can get maximum total nitrogen removal efficiency and r values for maximum ammonia nitrogen removal efficiency is all zones as Table 5.

From this analysis, it can be found that r values have some relationship with the total and ammonia nitrogen removal efficiency in all zones. In zone 1, total nitrogen maximum removal efficiency follows equation b/(1+b) at r value is equal to 1/(1+b). In zone 2 and 3, maximum total nitrogen removal efficiency follows equation (ab/(2b+a)) at r value is equal to a/(2b+a).

3.4. Optimal operation conditions and removal efficiency

From Table 5, we can draw Fig. 4 and Fig. 5 for relationship between removal efficiency, influent ratio to anoxic tank (r) and influent compositions. In zone 1, r value is constant at 1/1+b and in zone 2 and 3, r value is increased when alkalinity increases as equation a/(2b+a), For example, if domestic sewage have influent data at a = 3 and b = 4, the maximum total nitrogen removal efficiency should be followed by equation a/(2b+a) that is equal to 80% (Fig. 5) and the maximum ammonia removal efficiency is 100%, at r value is equal to 0.2 (Fig. 4).

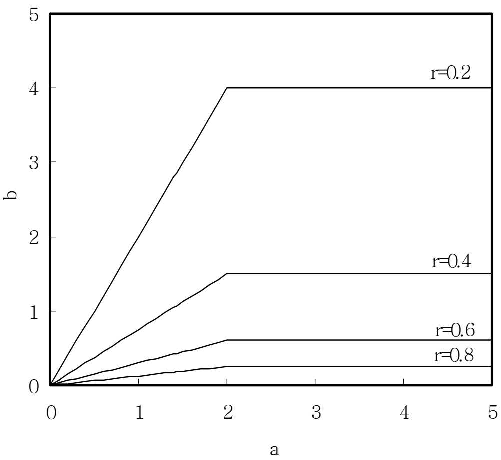


Fig. 4. r value required for maximum total nitrogen removal efficiencies of oxic-anoxic-oxic process.

Table 5. Summation of r value for maximum nitrogen removal efficiency of oxic-anoxic-oxic process

Zone	Minimum r required for maximum total nitrogen removal efficiency	Maximum total nitrogen removal efficiency (%)
1	$\frac{1}{1+b}$	$\frac{100b}{1+b}$
2	$\frac{a}{2b+a}$	$\frac{100ab}{2b+a}$
3	$\frac{a}{2b+a}$	$\frac{100ab}{2b+a}$

The total nitrogen removal efficiency follows equation a·b/(2b+a) at the a value is lower than 2 and become constant by the equation b/(1+b) when a value is greater than 2.

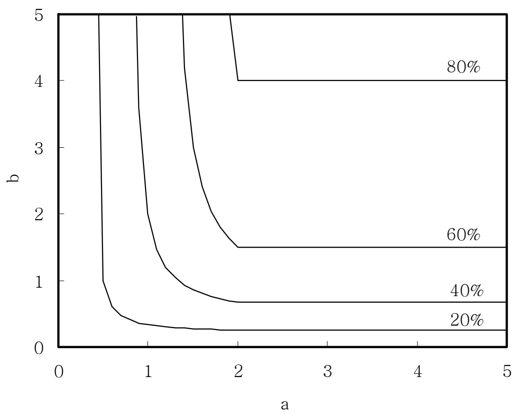


Fig. 5. Relationship between influent compositions and maximum total nitrogen removal efficiency.

4. Conclusions

The proposed theoretical analysis in step feed 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 domestic sewage plant.
2. Total nitrogen removal efficiency depend on r(influent allocation ration). In the case that all components are enough, the removal efficiency of total nitrogen follows equation 100·b/(1+b).
3. The alkalinity and substrate in the influent to the nitrogen treatment plant are not enough for complete denitrification and nitrification reactions, the total nitrogen removal efficiency is different depending on the zone in which they are located.
4. The step feed oxic-anoxic-oxic process in one of effective method for nitrogen removal. This process can be done by both new treatment plant and up grading the existing sewage treatment plants.

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