J. of the Korean Oil Chemists' Soc.,
Vol. 28, No. 1. March, 2011. 6~9

Estimation of Optimal Operation Conditions in Step Feed Processes Based on Stoichiometric Nitrogen Removal Reactions

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(Received November 14, 2010 ; Accepted December 20, 2010)

Abstract : Step feed process was analyzed stoichiometrically for the optimal operation conditions in this study. In case of optimal operation conditions, minimum R (sludge recycling) value, r (internal recycling ratio) value, and n (influent allocation ratio) value for the step feed process to acquire the maximum TN removal efficiency were identified by theoretical analysis. Maximum TN removal efficiency, based on stoichiometric reaction, can be obtained by controlling n value for the step feed process.

Keywords : Nitrification, Denitrification, Stoichiometric Calculation, Maximum Nitrogen Removal, Optimal Sludge Recycling Ratio

1. INTRODUCTION

Rapid civilization and upgrading of living standards have increased production of pollutants, and consequently the role of wastewater treatment plants is more emphasized for the treatment of these pollutants[1-2]. Due to the lack of understanding of the basic concept behind the nitrogen removal, selection of optimal conditions on wastewater treatment plants (WWTPs) in traditional methods has sometimes led to lower removal efficiencies[3-5]. From the design and operation experience of WWTPs, it has become evident that comprehensive influent conditions and reaction mechanisms are required to optimize the design of WWTPs for nitrogen removal[6-8].

Therefore, it is conceded that the study, the exploring the optimal conditions for nitrogen removal in total wastewater treatment plants, is quite meaningful. Selection of waste water plants should be made to optimize the whole system. The requirements are important especially for the processes intended for biological nitrogen removal

2. BASIC ASSUMPTION AND STOICHIOMETRIC REACTIONS

Several water quality items have very important role on the nitrogen behavior under

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Table 1 System parameters and relevant key influent water quality items considered to study the nitrogen behavior

Key influent quality items	System parameters
Substrate(ß), NH_4^+-N(N), NO_3^--N(NN),Alkalinity(α)	Influent allocation ratio to the second anoxic tank(n), Internal recycling ratio from second oxic tank to the first anoxic tank(r), Return sludge ratio or recycling ratio (R) (Fig. 1)

Note, Symbols of each item are given in parenthesis

both system configurations[9]. Table 1 shows system parameters and relevant key influent water quality items considered in each system. Three non-dimensional variables (α, ß and D), which represent substrate and alkalinity respectively, were introduced for the simplification of calculation and will be used in zone analysis section.

α=0.28·[influent alkalinity (mg $CaCO_3$/L)/ Influent NH_4^+-N(mgN/L)]
ß=0.35·[influent substrate (mg COD)/Influent NH_4^+-N(mgN/L)]
D=0.28·[dissolved oxygen (mg O_2/L)/Influent NH_4^+-N(mgN/L)]

3. RESULTS AND DISCUSSION

From the stoichiometry of nitrification-denitrification reactions, it can be estimated the concentration of effluent ammonium nitrogen, nitrate nitrogen, substrate and alkalinity in each tank. In this research, the TN removal efficiency was expressed as a function of influent components and design/operation conditions on the basis of stoichiometric nitrification and denitrification. Influent water quality can mainly effect on nitrogen removal efficiency in the activated sludge system. The most important items are alkalinity for nitrification and substrate for denitrification. Therefore, if one or both of items in the influent are not enough for the nitrification and denitrification, removal efficiency becomes lower.

The following assumption are used in this research

(1) Ammonium nitrogen and alkalinity are not taken or produced by microorganism,
(2) Detention time in each reactor is long enough to complete reactor,
(3) Ammonium nitrogen passes through anoxic reactor without any reaction,
(4) In case of Anoxic-oxic system, aerobic decomposition of substrate in the anoxic tank caused by DO from return sludge or mixed recycling flowrate occurred first, after that substrate remained in the influent was utilized in the denitrification reaction. And DO can be kept a certain value (D mg/l) in the oxic tank,
(5) Nitrate nitrogen was produced only from ammonium nitrogen,
(6) Substrate is completely consumed in the each oxic tank by aerobic bacteria

Many modified processes are reported for nitrogen removal. Generally, the biological nitrogen removal process using activated sludge needed at least two reactors. However, systems upto 12 tanks also has been reported. The Fig 1 shows the basic concept of nitrogen removal in step feed anoxic oxic process.

Stoichiometric reaction in denitrification tank is :

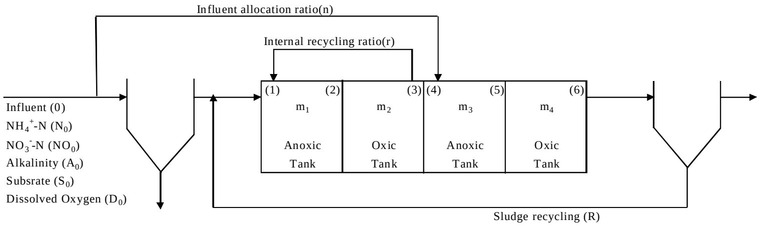

Fig. 1. The basic concept of step feed anoxic oxic process

Note, 0 : Influent; 1 : Mixture of influent and recycling flowrate; 2 : After anoxic tank; 3 : After oxic tank; Symbols of item are given in parenthesis

$$NO_3^- + 1.25C + 0.5H_2O \rightarrow \quad 0.5N_2 + HCO_3^- + 0.25CO_2 \qquad (1)$$

The above equation expresses 1mol of NO_3^--N reacts with 1.25 mole of carbon. 2.86mg(=(32·1.25)/14) of substrate(COD) are needed to perform the complete denitrification and 3.57mg(=50/14) of alkalinity are produced for 1mg of NO_3^--N. So following two equations can be deduced from the Eq1.

$$2.86\cdot(NN_1-NN_2)=S_1-S_2 \rightarrow$$
$$NN_1-NN_2=0.35\cdot(S_1-S_2) \qquad (2)$$

This equation expresses the relationship between the amounts of nitrate nitrogen reduced and substrate consumed.

$$3.57\cdot(NN_1-NN_2)=A_2-A_1 \rightarrow$$
$$NN_1-NN_2=0.28\cdot(A_2-A_1) \qquad (3)$$

This explains the relationship between the amounts of nitrate nitrogen reduced and alkalinity produced.

On the other hand, stoichiometric reaction in nitrification tank is:

$$NH_4^+ + 2O_2 + 2HCO_3^- \rightarrow NO_3^- + 3H_2O + 2CO_2 \qquad (4)$$

This equation proposes that theoretically 7.14mg (100/14) of alkalinity are required for 1mg of NH_4^+-N oxidized. From the above stoichiometric relationship (Eq 4), the following equation can be obtained.

$$7.14\cdot(N_2-N_3)=(A_2-A_3) \rightarrow N_2-N_3=0.14\cdot(A_2-A_3) \qquad (5)$$

From the mass balance concept, total amount of nitrogen (=ammonium nitrogen + nitrate nitrogen) from the position 2 to position 3 must be equal resulting Eq (6) will be acquired.

$$N_2+NN_2=N_3+NN_3 \qquad (6)$$

The Eqs (1) and (4) express theoretical reactions in biological nitrogen removal processes and show that the stoichiometrical ratio, α(=0.28· Alkalinity/NH_4^+-N) must be equal to or more than 2(=7.14·0.28) for complete nitrification, and that the ratio, ß(=0.35·Substrate COD/NH_4^+-N) must be equal to or more than 1(=2.86·0.35) for complete denitrification. Within the range of R values 0 to infinity in step feed anoxic oxic process, following Fig. 2 can be obtained.

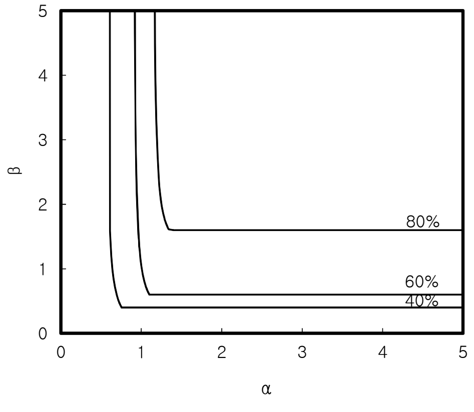

Fig. 2. Stoichiometric maximum TN removal

efficiency in step feed anoxic oxic process (R=0.5 and r=1.5)

The influent water quality in most of WWTPs were $\alpha > 2$ and $\beta > 1$. Therefore based on above Eq(1) to (6), the maximum TN removal efficiency can be obtained as

$$\frac{50(\beta R+R+\beta-\beta r+G)}{(R+1)(\beta+1)} \quad \text{when n value equals} \quad \frac{\beta R+\beta+\beta r+R+2-G}{2(\beta+1)}.$$

Where: $G = (R^2+2\beta R+\beta^2R^2+2\beta R^2+2\beta^2R+\beta^2+4\beta r+2\beta^2r+\beta^2r^2+2\beta^2Rr+2\beta rR)^{0.5}$

4. CONCULSIONS

Theoretical TN and $NH4^+$ -Nremoval efficiency at the minimum required R (return sludge or mixed liquor recycling ratio) and n value (influent allocation ratio to the second anoxic tank) as optimal operation condition were found out and compared with reported value the in step feed anoxic oxic process.

The maximum TN removal efficiency can be obtained as

$$\frac{50(\beta R+R+\beta-\beta r+G)}{(R+1)(\beta+1)} \quad \text{when n value equals} \quad \frac{\beta R+\beta+\beta r+R+2-G}{2(\beta+1)}.$$

Where: $G = (R^2+2\beta R+\beta^2R^2+2\beta R^2+2\beta^2R+\beta^2+4\beta r+2\beta^2r+\beta^2r^2+2\beta^2Rr+2\beta rR)^{0.5}$

β = (0.35·influent COD)/influent NH_4^+-N

D = DO concentration in last oxic tank

r = internal recycling ratio(from first oxic tank to first anoxic tank)

The maximum NH_4^+-N removal efficiency also can be achieved 100% even n equal zero.

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