Research on nitrification and denitrification kinetics of three-phase biological fluidized bed with four step-feed process

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Abstract. Step-feed nitrogen removal process, as a new sewage treatment technology, was concerned by scholars domestically and abroad in recent years. Three-phase biological fluidized bed with four step-feed process combined step-feed nitrogen removal with biological fluidized bed. In fact,there were many advantages, such as high nitrogen removal efficiency, saving the return facility and so on. Based on the classic dynamic model of activated sludge, simultaneous nitrification and denitrification kinetics of three-phase biological fluidized bed step-feed process were studied. Dynamic model of SND was established and to guide the test and the actual project.

Introduction

In recent years, the phenomenon of sewage putted into water had grown year by year, sewage has seriously affected industry and agriculture. Currently the cities' sewage mainly used the traditional process, but water quality was not up to standard, it was a major problem of operation, so on the basis of energy conservation, upgrading of the sewage treatment technology was a serious problem.

Three-phase biological fluidized bed with four step-feed process was a new biological nitrogen removal process. There were many advantages, such as high nitrogen removal efficiency, saving the return facility, no external carbon source, improving the system resistance and increasing the concentration of activated sludge [1–3]. However, this process in our country was not yet mature, there was still a lot of research work to be done.

Experiment equipment

Experiment equipment was adopted the volume of 20L transparent plexiglass, equipment was shown in Figure 1. Long was 500mm, width was 200mm , high was 300mm. The experiment was divided into four A/O, each volume was equal and made with aerobic zone and anoxic zone.
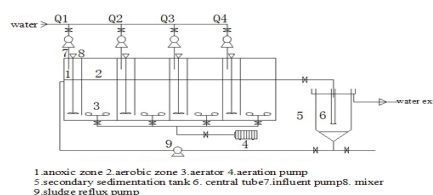

1.anoxic zone 2.aerobic zone 3.aerator 4.aeration pump
5.secondary sedimentation tank 6. central tube7.influent pump8. mixer
9.sludge reflux pump

Fig.1 Test device flowchart

The test results and discussion

SND phenomenon

In test, the decrement of NH_4^+-N was 0.64g/d in the first section of aerobic zone, the formation of NO_3^--N was 0.27g/d. The decrement of NH_4^+-N was 0.58g/d in the second section , the formation of NO_3^--N was 0.34g/d.The decrement of NH_4^+-N was 0.52g/d in the third section , the formation of NO_3^--N was 0.4g/d. The decrement of NH_4^+-N was 0.50g/d in the fourth section , the formation of NO_3^--N was 0.36g/d. The results showed that the decrement of NH_4^+-N was higher than the formation of NO_3^--N, especially in the first and second section, it could inferred that SND

phenomenon occurred in system. In the step- feed process, sludge only returned to the first section of anoxic zone and the sewage was extended into the segments, so there was gradient distribution of the concentration of sludge in the reaction. In the process of growth and metabolism of microorganisms needed to consume a portion of nitrogen to synthesize their own material, so it occurred loss of nitrogen phenomenon. Whether SND phenomenon occurred in the system or not, it should first deduct the amount of anabolic nitrogen effect of sludge[4].

The microorganisms empirical formula can be estimated the nitrogen used for consumed for assimilation[5], as shown in Table 1. The results showed the decrement of NH_4^+-N in the system was significantly greater than the amount of nitrogen for cell synthesis.

Table1　Nitrogen consumed for assimilation

Number	Sludge emissions(g/d)	Nitrogen consumed for assimilation(g/d)	The total amount of nitrogen loss(g/d)
1	3.388	0.406	0.650
2	3.307	0.396	0.877
3	3.382	0.413	0.911

In test, supposed the growth of microbial cells and sludge emissions were flatted and estimated the amount of nitrogen needed for microbial assimilation. The results of comparison of the nitrogen used for consumed for assimilation and the decrement of NH_4^+-N in the system were shown in Fig.2, it showed that nitrogen used for consumed for assimilation significantly less than the decrement of NH_4^+-N in the system. The decrement of NH_4^+-N in the aerobic zone was not caused by the nitrogen used for consumed for assimilation, so SND phenomenon occurred in the system[6].
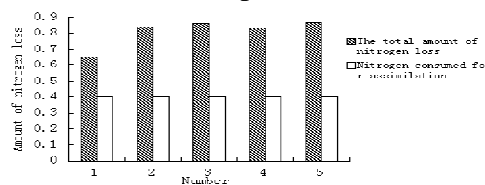

Fig.2 Comparison of the nitrogen used for consumed for assimilation and the TN loss in the aerobic zone

Model assumptions

Before the derivation of model , assuming the following conditions were satisfied:

(1)The mixture in the reactor was completely in mixed state.

(2)Nitrification and denitrification were independent and meet with Monod equation.

(3)Keeping the number of microorganisms was constant.

(4)Ignore nitrogen consumed for assimilation.

SND kinetics

In nitrificated ammonia of biological sewage treated process, nitrite was easily be oxidized, so it can approximate that the final product of ammonification was nitrated in the system.

Material balance to NO_3^--N , get:

$$\frac{dD}{dt} = \left(\frac{dD}{dt}\right)_{\text{Nitrificat ion}} + \left(\frac{dD}{dt}\right)_{\text{Denitrific ation}} + \left(\frac{dD}{dt}\right)_{\text{Assimilati on}} \tag{1}$$

Above formula $\frac{dD}{dt}$ ——NO_3^--N degradative rate（mg/(L·d)）;

Ignore the low concentrations of nitrite nitrogen, so:

$$\left(\frac{dD}{dt}\right)_{\text{Nitrificat ion}} = -\left(\frac{dN}{dt}\right)_{\text{Nitrificat ion}} \tag{2}$$

By assumption (4),

$$\left(\frac{dD}{dt}\right)_{\text{Assimilati on}} = 0 \tag{3}$$

In reactions, microbial growth and substrated degradation can be expressed as:

$$Y_n = -\frac{dX_n}{dN} = -\frac{\dfrac{dX_n}{dt}}{\dfrac{dN}{dt}} = \frac{r}{v} = \frac{\dfrac{r}{X_n}}{\dfrac{v}{X_n}} = \frac{m_n}{q_n} \tag{4}$$

Above formula Y_n——Nitrobacteria yield coefficient（gVSS/gNH$_4^+$-N）；

r —— Nitrobacteria proliferative rate（gVSS/d）；

v —— NH$_4^+$-N degradative rate（gNH$_4^+$-N/d）；

q_n ——NH$_4^+$-N ratio oxidative rate（gNH$_4^+$-N/(gVSS·d)）

μ_n—— Nitrobacteria ratio growth rate（g/g·d）.

By assumption (3)

$$\frac{X_A}{X} = m \tag{5}$$

Above formula m—The proportion of nitrobacteria accounting on the total amount of microbes

Put（4）and（5）into（2）, get:

$$\left(\frac{dD}{dt}\right)_{\text{Nitrificat ion}} = \frac{1}{Y_n} m_{n,m} \frac{N}{K_n + N} \times \frac{C_O}{K_O + C_O} mX \tag{6}$$

By the nitration process may be deduced for the denitrificative process:

$$\left(\frac{dD}{dt}\right)_{\text{Denitrific ation}} = -\frac{1}{Y_d} m_{d,m} \frac{D}{K_d + D} \times \frac{S}{K_S + S} \times \frac{K_O}{K_O + C_O} nX \tag{7}$$

Above formula Y_d ——Denitrifiers yield coefficient（gVSS/gNO$_3^-$-N）；

n ——The proportion of denitrifiers accounting on the total amount of microbe（%）.

Put（6）and（7）into（2）, ignore of assimilation,

$$\frac{dD}{dt} = \frac{1}{Y_n} m_{n,m} \frac{N}{K_n + N} \times \frac{C_O}{K_O + C_O} mX - \frac{1}{Y_d} m_{d,m} \frac{D}{K_d + D} \times \frac{S}{K_S + S} \times \frac{K_O}{K_O + C_O} nX \tag{8}$$

The formula (8) could be simplified to,

$$\left(\frac{dD}{dt}\right)_{\text{Nitrificat ion}} = \frac{N}{K_n + N} \times A \tag{9}$$

Above formula $A = \frac{1}{Y_n} m_{n,m} \frac{C_O}{K_O + C_O} mX$, it was a constant.

Because N was much larger than K_n , so

$$\frac{N}{K_n + N} \approx 1 \tag{10}$$

So it can get,

$$\frac{dN}{dt} = -\left(\frac{dD}{dt}\right) = -A \tag{11}$$

Considered $\frac{S}{K_s + S}$ as a constant, so the formula (7) could be simplified into,

$$\left(\frac{dD}{dt}\right)_{\text{Denitrific ation}} = -B\frac{D}{K_d + D} \tag{12}$$

Put（9）and（12）into（8）, get,

$$\frac{dD}{dt} = A - B\frac{D}{K_d + D} \tag{13}$$

The formula (13) on both sides had to be integrated,

$$t = \frac{D}{A - B} + \frac{BK_d}{(A - B)^2}\ln\left[\frac{AK_d}{AK_d + (A - B)D}\right] \tag{14}$$

A could be obtained by testing, under the conditions that C/N was 8, influent split ratio was 1.18, the results were shown in Fig.3 . A was 3.0822 from the slope of figure. Put A into formula(14) and it could obtain that B was 2.81 and K_d was 4.9, and put them into formula(14), get:

$$\frac{dD}{dt} = 3.0822 - \frac{2.82D}{4.79 + D} \tag{15}$$

From the model can be seen that K_d was 4.7mg/L, which was much larger than the constant saturation of single-stage denitrificative process. When the dynamic model of SND was established, it used the mixture of NO_3^--N concentration to instead of real NO_3^--N concentration of anoxic zone, but in aerobic zone, the main force of matrix diffusion existed from aerobic zone of biofilm to the internal anoxic zone, the NO_3^--N concentration in actual anoxic zone was lower than the NO_3^--N concentration of mixture, which lead to a higher K_d.
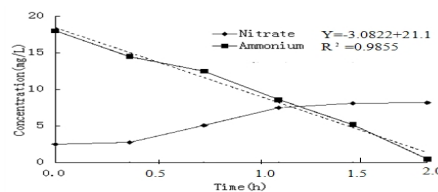

Fig.3 Change of ammonium and nitrate

Conclusion

（1）SND phenomenon existed in three-phase biological fluidized bed with four step-feed process of the aerobic zone;

（2）Dynamic model of SND was established,R^2 =0.9855;

（3）Dynamic modeling could be used to guide test and actual project,which fully into account in the phase of operational requirements design of the system .

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