2010 International Conference on Biology, Environment and Chemistry
IPCBEE vol.1 (2011) © (2011) IACSIT Press, Singapore

Effect of shear stress on activated sludge granular in Sequencing Batch Reactor

Xiaoling-Zhang
School of Environmental Science and Engineering
Chang'an University
Xi'an, China
Zhangxiaoling101@126.com

Shan-Liu
School of Environmental Science and Engineering
Chang'an University
Xi'an, China
liushchd@163.com

Abstract—**The cultivation of aerobic granular sludge with the capacity of removing phosphorus was performed in the Sequencing Batch Reactor(SBR) using conventional flocculent activated sludge as seeding sludge and synthetic municipal wastewater. The results showed that the aerobic granular sludge had the good settling-ability, the high biomass retention and the regular structure with a diameter of 1.0 to 2.0mm, SVI of which was 20~22mL/g. Moreover, the effect of shear stress on granulation, morphology and bioactive of granules were all investigated. The results showed that within the range of 4.2～7.7N/m2 of shear stress, the lager the shear stress was, the denser, the more regular and the more bioactive of granules was. When shear stress is between 4.2 and 6.5N/m2, the larger the shear stress was, the faster the sludge granulation process and the larger the cultivated granular sludge size was. However, excessive shear force （7.7N/m2） would slow down the process of sludge granulation and the size of cultivated sludge particles would become smaller. In addition, Aerobic granular sludge which had the capacity of removing nitrogen and phosphorus simultaneously was successfully induced by gradually increasing ammonia nitrogen concentration in the influent. The removal efficiencies of the aerobic granular sludge on TN and PO4-P were 89.8% and 94.5%, respectively.**

Key words-low DO; aerobic granular sludge; shear stress; the capacity of removing nitrogen and phosphorus simultaneously.

I. INTRODUCTION

Aerobic granules is recognized to be a recent promising biotechnology, which is superior to activated sludge floc in terms of settling ability, compactness, high activity, withstanding the organic shock loading, etc [1]. During the last 20 years, extensive research has been made on aerobic granular sludge [2,3,4]. It appeared that the successful cultivation for granules was confined to specific operational parameters, such as seed sludge, substrate composition, organic loading, reaction design, feeding strategy, settling time, exchange ratio and hydrodynamic shear force (aeration intensity)[1].

In biological reactors detachment force resulting from gas or liquid flow and particle to particle collision was a key factor that influenced the formation, structure and stability of granules [5]. So far, the aerobic granules were almost cultivated in pneumatically agitated reactors, in which hydrodynamic shear force were usually decided by aeration intensity. Adav reported that the granulation processes in three identical reactors fed with phenol-containing wastewater and aerated at different intensities (1~3 L air/min). At low aeration intensity (1 Lair/min), no granules were formed. At high aeration rate (3L air/min), mature and stable granules (1~1.5mm) with compact interiors were formed. An intermediate intensity (3~3.5mmLair/min) led to the formation of granules with overgrowth of filaments [6]. It means that high aeration intensity was benefit to forming compact aerobic granules.

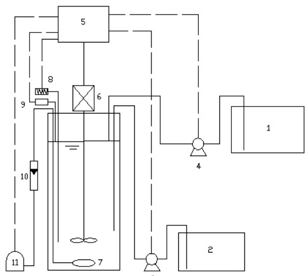
As a matter of fact, aeration exerted its influence on granules by not only supply of hydrodynamic shear force, but also oxygen supply. Independent effect of oxygen and shear force on granules has seldom studied. It's important for cultivating stable granules to maintain High shear force. High aeration rate meant high energy consumption, which limited the application of aerobic granular sludge. At the same time, comparative low dissolved oxygen concentration in SBR which obtained by decreasing aeration intensity was necessary to optimize the removal of nitrogen via denitrification. Mosquera-corral reported that an oxygen saturation of 40% increased the nitrogen removal efficiency due to an increased denitrification. Granules, however, broke up due to low oxygen concentration [7]. Picioreanu postulated that the low ratio of biomass growth rate versus diffusive transport resulted in the development of smooth biofilms [8]. Recent study showed that selection for slow growing organisms, such as PAOs, led to stable granular sludge at low oxygen concentrations [9].

In this paper, aerobic granules with the capacity of removing phosphorus were cultivated in an SBR, firstly. Next, effect of shear stress on activated sludge granular in anaerobic-low dissolved oxygen SBR was studied. At last Aerobic granular sludge which had the capacity of removing nitrogen and phosphorus simultaneously was induced.

II. MATERIAL AND METHODS

A. Reactors

A completed stirred laboratory scale Sequencing Batch Reactor (SBR) was set up and operated at 25℃ constant temperature. The working volume of SBR was 10L and the air compressors were used for aeration. The DO concentration was controlled by adjusting airflow rate. During the operation at low aeration level or the compressors were not working, A mechanical stirrer was used to ensure sufficient shear force for cultivating aerobic granular sludge. Peristaltic pumps were employed for influent feeding and effluent withdrawing. The reactor was operated on 6h-cycles, consisting of 5-min influent feeding (no mixing, no aeration), 120-min anaerobic phase (mixing), 205-min aerobic phase (mixing, aeration), 30-min sludge settling and 25-min withdrawing. Figure 1 showed the schematic of the SBR system.



1. influent box 2.effluent box 3. effluent pump 4.influent pump 5.automatic control device 6. mechanical stirrer 7.diffuser 8.heating system 9.fluid level control 10.rotameter 11.air compressor

Figure 1. The schematic of the SBR systems

B. Substrate Compositions

The plant was inoculated with activated sludge from a full scale plant treating combined industrial and domestic sewage. The synthetic feeding in the experiments was shown in table 1, which was prepared with piped water. Sodium acetate was used as organic substrate (as COD).

Microelement solution was added, composition of the microelement solution was shown in table 2.

TABLE 1 COMPOSITION OF SUBSTRATE

Substrate	Concentration
$CH_3COONa.3H_2O$	200-800mgCOD/L
NH_4Cl	10mgN/L(Ⅰ~Ⅲ), 40 mgN/L(Ⅳ)
KH_2PO_4	10±1mgP/L
Microelement solution	1cm^3/gNH_3-N

TABLE 2 COMPOSITION OF THE MICROELEMENT SOLUTION

$CaCl_2.2H_2O$	4890mg/L
$MgCl_2.6H_2O$	16710mg/L
$FeCl_3.6H_2O$	3200mg/L
$MnCl_2.4H_2O$	687mg/L
$ZnCl_2.2H_2O$	67 mg/L
$CuCl_2.4H_2O$	74.7 mg/L
$NaMoO_4.2H_2O$	1.67 mg/L

C. Operating Procedure

The operating procedures of the SBR were given in table 3.

TABLE 3 OPERATING PHASE OF THE SBR

Phase	HRT	OLR (kgCOD/(m^3·d)	NLR (kgNH_3-N/(m3·d)	SRT (d)	Operating days(d)
Ⅰ	10	0.482～0.986	0.024	20	40
Ⅱ	8.6	2.218～2.263	0.024	10	30
Ⅲ	10	1.113～1.182	0.024	20	20
Ⅳ	10	1.113～1.182	0.096	20	25

D. Analytical methods

Samples of effluent were withdrawn periodically and immediately filtered through 0.45μm pore size syringe filler. COD, NH_4^+-N, NO_2^--N, NO_3^--N were determined according to the standard methods issued by the Environmental Protection Agency (EPA) of China (1989).

III. RESULTS AND DISCUSSIONS

A. Cultivation of Aerobic Granules with The Removal of Phosphorus

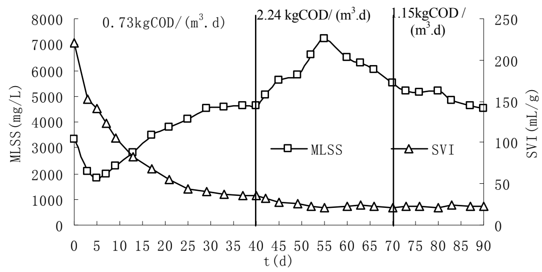


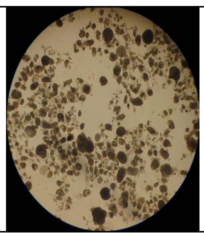
Figure 2. Variations of SVI and MLSS on the phase of cultivation of granules

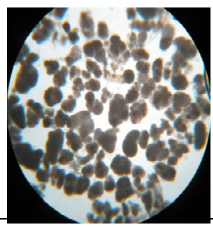
The SBR reactor alternated in anaerobic / low DO concentration conditions, the DO concentration of 1~ 2mg / L in the aerobic period controlled by the less aeration intensity of 0.33 L / min. The cultivation of aerobic granules with Phosphorus removing was divided into three periods: low organic loading (0.73 kgCOD/ (m^3.d)) period, high organic loading phase (2.24 kgCOD/ (m^3.d)) period, and intermediate organic loading phase (1.15 kgCOD/ (m^3.d) period. The changes of the sludge SVI were shown in

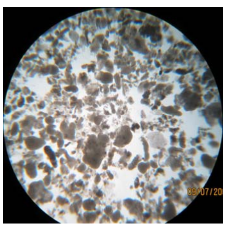
Figures 2, the morphological changes of granular sludge were showed in Figure 3.

In the early 5 days of cultivation process, the sludge concentration decreased from 3300mg / L to 1800mg / L, due to washout of light sludge, the formation of granular sludge began on the 6th day, and sludge concentration in SBR have increased from 1800mg / L to 7100mg / L until the 58th day. But the concentration of sludge decreased after that, because of the larger size of granules limiting the penetration of dissolved oxygen and nutrients, stopping the growth of microorganisms and the secretion of extracellular polymers within particles. The large granules broke up to small pieces, which washed out with effluent. By reducing organic loading rate, the sludge concentration in SBR recovered to about 5000mg/L. The initial seed sludge for the SBR operation had a SVI of 225mL/g, and then the SVI had deeply decreased to 50mL/g in 25 days, at last the SVI stabilized between 20~30 mL/g. Which was much lower than the values of 80~/100 ml/g reported by Peng et al. (1999).

Figure 3 showed Morphological observation of sludge during cultivation. On the organic loading rate of 0.73 kgCOD/ (m^3.d), only a small amount of regular shape formed, the sludge in the SBR was the mixture of a majority of activated sludge floc and a small quantity of round-shaped, as shown in figure 3(a). The process of granulation was firstly accelerated when the organic loading rate reached 2.24 kgCOD/ (m^3.d). in figure3(b)，the percentage of granules in SBR rose to 90%, the size of granules was mainly between 0.8mm~1mm. Granules tend to be irregular, broke up, during the late time of high organic lading rate (2.24kgCOD/(m^3.d)), as shown in figure3(c) . This situation was relieved when the organic loading rate lowed to 1.15kgCOD / (m^3.d); stable granules come into being, as showed in figure3 (d). The morphological observation in figure 3 coincided with the variation of SVI in figure 2.


The 40th day of experiment


The 50th day of experiment


The 70th day of experiment

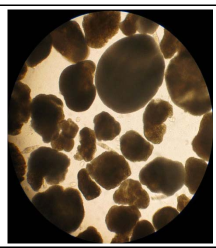

The 85th day of experiment

Figure 3. Morphological observation of sludge

B. The Effects of Shear Force on Aerobic Granules

Four SBR were set up to study the effects of shear force on granules. These SBR were operated under the identical parameters, such as, seed sludge, aeration, temperature, settling time, influent except for shear force. The four SBR were labeled with A, B, C and D.

1) The effects of shear force on granulation

The shear stress and the beginning of granules occurred in four SBR were showed in table 4.

TABLE 4 THE SHEAR STRESS AND THE BEGINNINGOF GRANULES

The number of SBR	A	B	C	D
Shear stress(τ,N/m2）	4.2	5.3	6.5	7.7
The beginning of granules occurred	8th	6th	3rd	5th

As can be seen from Table 4, first, granular sludge occurred in SBR C, second, occurred in SBR D, and then , in SBR B, at last, in SBR A. The order of the time for fulfilling granulation was vice verse.

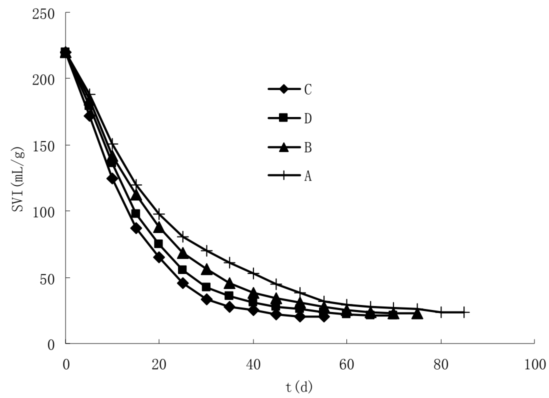


Figure 4. Variations of SVI under different shear stress

Variations of SVI under different shear stress were showed in Figure 4. In the A group ~ D group, the SVI of 4 groups gradually decreased and stabilized 20 ~ 22mL / g on the end. In the A group ~D set of experiments, the stabilized time of SVI is in order for the C, D, B, and A. it was showed that the effect of shear stress on granulation was that, in a certain range shear force of 4.2 ~ 6.5 N/m^2, the higher shear stress was, the faster the process of sludge particles was. While the excessive shear stress of 7.7 N/m^2 slowed down the process of granulation.

2) The effects of shear force on characteristics of granules

Shear stress in the four different conditions, can all develop a mature granular sludge, the shape of granules close to round, the color of granules is orange. Examination

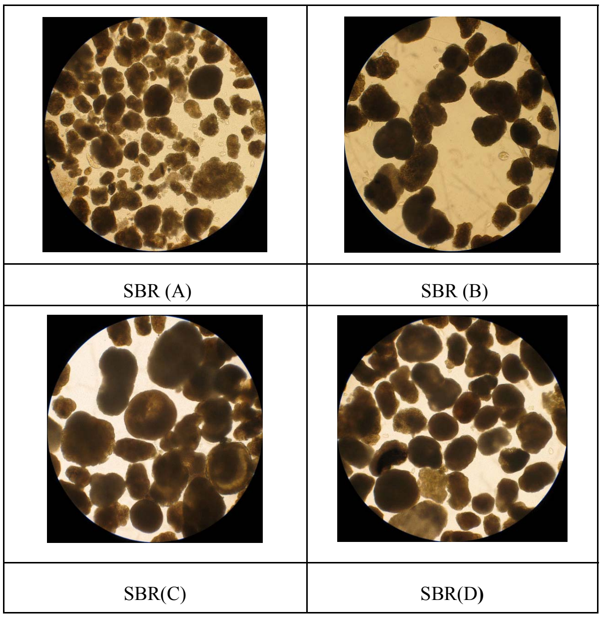


Figure 5. the mature aerobic granular sludge of different shear stress

under a microscope showed that the mature individual form of aerobic granular sludge dominated by oval-shaped external outline clearly, different shear stress conditions, Under the conditions of shear stress in each group form granular sludge in Figure 5.

C. *The Simultanueous Removal of Nitrogen and Phosphorusaerobic with Granules*

When the granules with the capacity of removing phosphorus developed well, the removal of nitrogen and phosphorus at the same time was highlighted by increase the concentration of ammonia nitrogen in influent gradually. The results showed that a significant removal efficiency of the Total Nitrogen (TN) and phosphorus in the SBR. The end of the aeration phase, TN removal efficiency reached 89.8%. The removal efficiency of phosphorus reached 94.5%.

IV. CONCLUSION

Firstly, the best OLR for cultivating aerobic granules was about1.15 kgCOD/ (m3.d) on the condition of 1~2mg/L DO in the SBR's aerobic time. Secondly, Shear stress has great effects on the process of granulation and the characteristic of mature granules. Thirdly, the aerobic granules with the capability of removing of nitrogen and phosphorus were induced.

ACKNOWLEDGMENT

This work was supported in part by grants from Special funds of basic scientific research of Central Colleges (CHD2009JC001).Ministry of land and natural resources in arid and semi-arid areas of open water resources and environmental research laboratory.

REFERENCES

[1] Sunil S, Adav SS, Duu-Jong Lee, Kuan-Yeow Show, Joo-Hwa Tay. Aerobic granular sludge: Recent advances. Biotechnology Advances. vol. 26, pp. 411-422, 2008.

[2] Morgenroth E,Sherden T, van Loosdrecht MCM,Heijnen JJ, Wilderer PA.Aerobic granular sludge in a sequencing batch reactor. Wat. Res. Vol.31(1997), pp. 91-3194.

[3] H. Linlin, W. Jianlong, W. Xianghua, Q. Yi. "The formation and characteristics of aerobic granules in sequencing batch reactor (SBR) by seeding anaerobic granules," Process Biochem. vol. 40, pp.1-7, 2005.

[4] J. J. Beun, M. C. M. van Loosdrecht, J. J. Heijnen, "Aerobic granulation in a sequencing batch airlift reactor." Water Res. vol. 36, pp.702-712, 2002.

[5] J.H.Tay,Q.S.Liu, The effects of shear force on the formation, structure and metabolism of aerobic granules,Appl.Microbiol.Biotechnol.57(2001):227-233.

[6] Adav SS, Lee DJ, Lai JY Effects of aeration intensity on formation of phenol-fed aerobic granules and extracelluar polymeric substances," Appl microbiol Biotechnol , vol. 77 pp. 175-182, 2007.

[7] A. Mosquera-Corral, M. K. de Kreuk, J. J. Heijnen, M. C. M. van Loosdrecht, "Effects of oxygen concentration on N-removal in an aerobic granular sludge reactor," Wat. Res., vol. 39 pp. 2676-2686, 2005.

[8] Picioreanu C,van Loosdrecht MCM, Heijnen JJ. Mathematical modeling of biofilm structure with a hybrid differential-discrete celluar automation approach. Biotechnol. Bioeng. Vol.58(1998), pp. 101-116.

[9] M. K. De Kreuk, M. C. M van Loosdrecht. "Selection of slow growing organisms as a means for improving aerobic granular sludge stability," Wat.Sci.Tech., vol. 49(2004), pp. 9-17.

[10] Y. Q. Liu, J. H. Tay, "The essential role of hydrodynamic shear force in the formation of biofilm and granular sludge," Wat. Res., vol. 36 pp. 1653-1665, 2002.

[11] Bui Xuan Thanh, Chettiyappan Visvanathan, Roger Ben Aim Characterization of aerobic granular sludge at various organic loading rates

[12] , J. H. Tay, "Cultivation of aerobic granules in a buuble column and an airlift reactor with divided draft tubes at low aeration rate," Biochenmical engineering journal., vol. 11 pp. 338-346, 2006.

[13] L. Tijhuis, M. C. M van Loosdrecht, J. J. Heijnen, "Formation and growth of heterotrophic aerobic biofilms on small suspended particles in airlift reactors," Biotech. Bioen., vol. 44 pp. 595-608, 1994.

[14] L. Bond, J. Keller, L. L. Blackall, "Characterisation of enhanced biological phosphorus removal activated sludges with dissimilar phosphorus removal performances," Water Sci. Technol. Vol. 37, pp. 567–571.