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Effects of properties on formation of aerobic granular sludge under different organic loadings

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ABSTRACT

With the other operating conditions kept stable, the morphology and pollutant removal performance of aerobic granular sludge (AGS) were tested under different influent organic loadings to analyze its adaptable growth. Results showed that the sludge, with an average particle diameter of 4.0 mm and a good settling ability, was spherical or ellipsoidal and had a smooth and dense surface. The findings also revealed that when the influent organic loading was more than 400 mg/L, this novel form of active sludge removed more than 96, 94, and 90% of ammoniacal nitrogen (NH_3-N), total phosphorus (TP), and chemical oxygen demand (COD) in wastewater, respectively. When the organic loading was reduced from 400 to 100 mg/L, the sludge gradually disintegrated into a rice-like AGS, but the granules maintained their smooth surface and good settling performance. In this case, however, the NH_3-N, TP, and COD removal effects significantly decreased. When the influent organic loading dropped to 100 mg/L, the biomass in the reactor significantly reduced. Correspondingly, the efficiencies of the sludge in removing NH_3-N, TP, and COD were reduced to 60, 55, and 60%, respectively.

Keywords: Aerobic granular sludge; Organic loading; SBAR; Performance

1. Introduction

Aerobic sludge granulation is a promising wastewater treatment process because it can treat various wastewaters (e.g. paper mill effluent [1]), and serves as a potential adsorbent for the removal of Cu^{2+} and sunset yellow FCF [2,3]. However, the formation of aerobic granular sludge (AGS) is constantly influenced by many factors (e.g. shear force, dissolved oxygen, microelement, setting time, and extracellular polymeric substances) regardless of the reactor involved or the existing environmental condition [4–11]. Organic loading is also an important factor that affects the formation of AGS [12–15]. Aerobic sludge granulation technology can hardly be used for treating organic compounds in water because the chemical oxygen demand (COD) of urban sewage is low and constantly

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changing. Therefore, the influence of organic loading on the formation and performance of AGS should be investigated. In this experiment, COD concentration was reduced to examine the performance and decontamination ability of AGS under different organic loadings in a sequencing batch airlift reactor (SBAR). These conditions were set to build a foundation for the further analysis of the application of AGS in wastewater treatment engineering. SBAR is a highly efficient biological treatment reactor that has good heat and mass transformation, excellent mixing performance, and compact structure, as well as it does not require sludge recycling [16].

2. Materials and methods

2.1. Experimental installation

The effective volume of SBAR reactor was set as 3 L, and water changing rate per cycle was 50%. The rise velocity of gas was regulated and controlled between 0.90 and 1.66 cm/s according to the operation of the treatment system, which was automatically controlled with a programmable logic controller. The system was run for eight cycles daily, in which each cycle included influent water (6 min), aeration (140–169 min), precipitation (1–30 min), and effluent water (4 min).

Fig. 1 illustrates the schematic diagram of the SBAR reactor.

2.2. Experimental materials

The artificial simulated wastewater was considered as experimental water. $C_6H_{12}O_6$ and CH_3COON were used as comprehensive carbon sources, and $NaHCO_3$ was adopted as pH regulator. pH was maintained at 7, and the COD, ammoniacal nitrogen (NH_3-N), and total phosphorus (TP) were simultaneously maintained at 1,200, 50, and 10 mg/L, respectively, to provide the essential trace elements for the growth of micro-organisms. With the gradual reduction of the organic matter concentration in the experiment, the COD, NH_3-N, and TP steadily decreased from 1,200 to 100 mg/L, from 50.00 to 4.12 mg/L, and from 10.00 to 0.82 mg/L, respectively.

Inoculated sludge was obtained from the activated sludge of an A/O aeration tank in the Lanzhou Qilihe-Aning Sewage Treatment Plant, which produces polluted, light brown mud. Consequently, 1.5 L of this sludge was placed in a beaker to which nutrients were added. The recovered sludge was inoculated after 2 h of aeration. Numerous micro-organisms, which had good and high activity in the inoculated sludge, were observed through microscopic examination. These microorganisms had a relatively clear appearance (transparent) and structure. The value of the mixed liquor volatile suspended solids (MLVSS)/mixed liquor suspended solids (MLSS) was 0.625.

2.3. Experimental process

After the AGS was obtained, the setting time was kept at 3 min. The organic loading of influent water was gradually reduced under the stable operation of the system to investigate the morphological feature and decontamination capability of the sludge. The attempt was also aimed at determining the relationship among the biological populations of AGS and exploring its growth adaptability under different organic loadings.

Table 1 lists the change tendency of organic loading.

2.4. Analytical methods

COD, NH_3-N, and TP were measured using the national standard methods [17,18]. The morphological changes in the sludge were recorded by a digital camera. The wet sieving method was used to determine the particle size distribution of granular sludge [19,20].

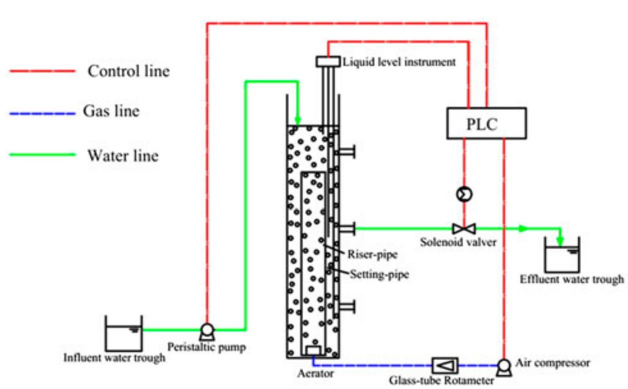

Fig. 1. Schematic diagram of SBAR.

Table 1
The change of the organic loading

Time	COD_{cr} (mg/L)	Time	COD_{cr} (mg/L)
1st–10th d	1,200	41th–50th d	400
11th–20th d	1,000	51th–60th d	300
21th–30th d	800	61th–70th d	200
31th–40th d	600	71th–80th d	100

3. Results and discussion

3.1. Particle size distribution of AGS under different organic loadings

Fig. 2 shows the particle size distribution of AGS under different organic loadings.

The particle size distribution of the sludge was diverse under various organic loadings. When the organic loading of influent water gradually decreased from 1,200 to 800 mg/L, the particle size of AGS slightly increased. The proportion of the sludge, whose particle size varied between 2 and 5 mm remained at approximately 80%, and that of the sludge with the size of 5 mm increased from 8 to 10%. When the loading was 600 mg/L, the proportion of the particle size between 2 and 5 mm reached the highest value of 88%, but the proportion of the particle size above 5 mm decreased to 4%. With the further decrease in organic loading, the particle size of the sludge considerably changed, in which its entire proportion exhibited a decreasing trend. When the loading decreased from 400 to 100 mg/L, the proportion of the particle size less than 2 mm increased from 30 to 70%. However, the proportion of the sludge above 3 mm decreased from 24 to 8%. These results revealed that the particle size of the sludge in higher organic loading was larger than that in lower loading.

3.2. Morphology of granular sludge under different organic loadings

Fig. 3 illustrates the morphological feature of AGS under different organic loadings.

When the loading of influent water was 1,200 mg/L, the particle size of AGS was large, and the particle had a smooth surface, high strength, good setting ability, and a khaki color. Considering that granules generally exhibit sustainable growth under high loading conditions, the particle size of AGS continuously increased, and it exhibited a good setting capability when the loading varied between 1,000 and 800 mg/L. However, the color of the granule changed from khaki to white. When the organic loading was 600 mg/L, flocs appeared on the surface of the granule, and the setting ability gradually worsened as evidenced by the formation of cavitation. When the loading was further decreased to 400 mg/L, cleavages emerged in large granules whose surfaces were filled with several flocs. Likewise, numerous small rice-like particles were formed. Nonetheless, the granule maintained a good setting ability and displayed a khaki color. When the loading was 300 mg/L, the number of large granules was reduced, but the volume of rice-like particles increased, and their color deepened. In this case, the setting ability of the system was improved. When the loading was 200 mg/L, the 3 mm spherical particles hardly

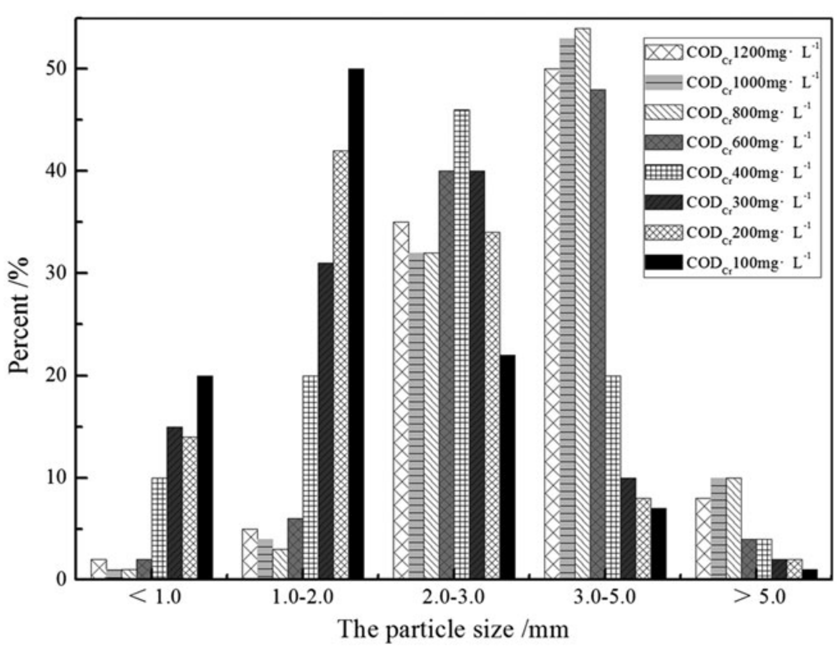

Fig. 2. The particle size distribution of granules.

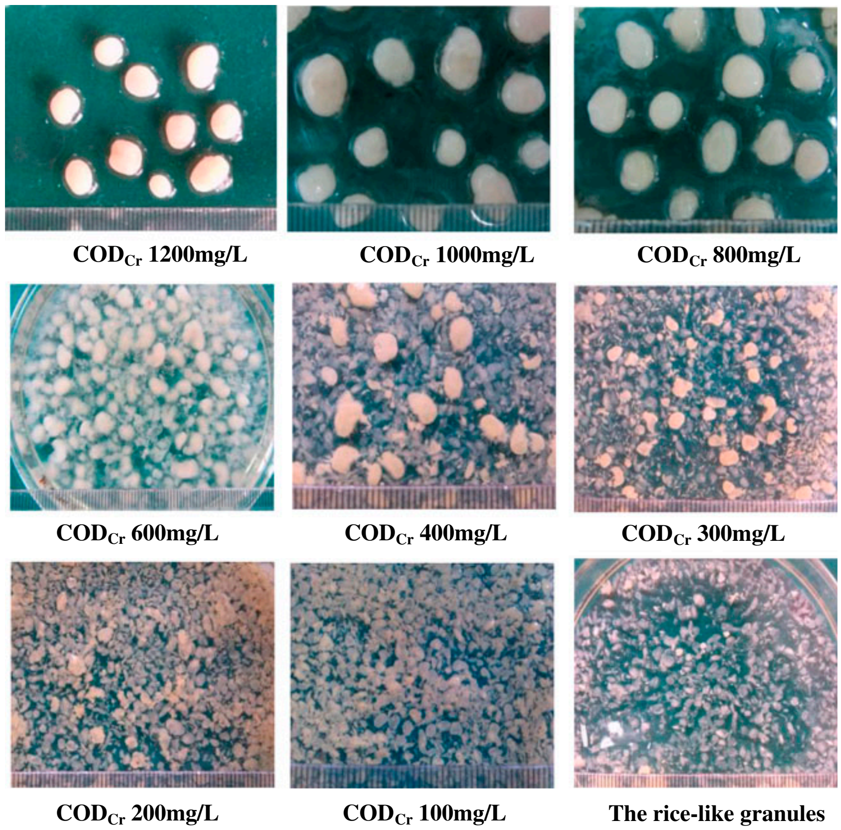

Fig. 3. The morphology of granular sludge.

existed, the volume of rice-like particles with the deepest color increased to the highest value, and the effect of sewage treatment was satisfactory. When the organic loading finally decreased to 100 mg/L, the color of rice-like particles changed to white, and their volume and density gradually decreased. In this condition, the effect of sewage treatment was aggravated.

3.3. *Decontamination efficiency of granular sludge under different organic loadings*

Fig. 4 displays the decontamination efficiency of AGS under different organic loadings.

Fig. 4(a) illustrates that when the organic loading of influent water was above 400 mg/L, the efficiency of AGS in removing NH_3-N was maintained above 90%. However, this removal rate was reduced when the organic loading gradually decreased. When the loading was 200 mg/L, the removal rate of NH_3-N was reduced to 80%, and when the loading was 100 mg/L, the removal rate was approximately 60%. When the organic loading was above 300 mg/L, the granule mainly consisted of spherical or ellipsoidal granular sludge with large particle diameter. Moreover, the space of aerobic-oxygen-anaerobic was large, and its distribution was significant. Several nitrifying and denitrifying bacteria were also observed. As such, the metabolism speed of these bacteria was quick when the amount of nutrients was enough. This condition was the reason why the removal rate of NH_3-N in wastewater was high when the loading was above 300 mg/L. When the organic loading dropped to 200 mg/L because of the decreased amount of nutrients, no spherical particles existed in the reactor and only rice-like particles emerged. These particles were small and of irregular shape. The advantages of the structure of aerobic-oxygen-anaerobic were not obvious, and the nitrifying rate of NH_3-N gradually decreased. Thus, the removal rate of NH_3-N was reduced. When the loading was 100 mg/L, in which the amount of nutrients was insufficient, the particle size of the sludge continuously decreased, and the zones of anoxic and anaerobic narrowed, thereby further decreasing the removal rate of NH_3-N. The effects of different organic loadings of influent water on NH_3-N in effluent water were not generally significant.

Fig. 4(b) demonstrates that when the organic loading was above 400 mg/L, the efficiency of AGS in

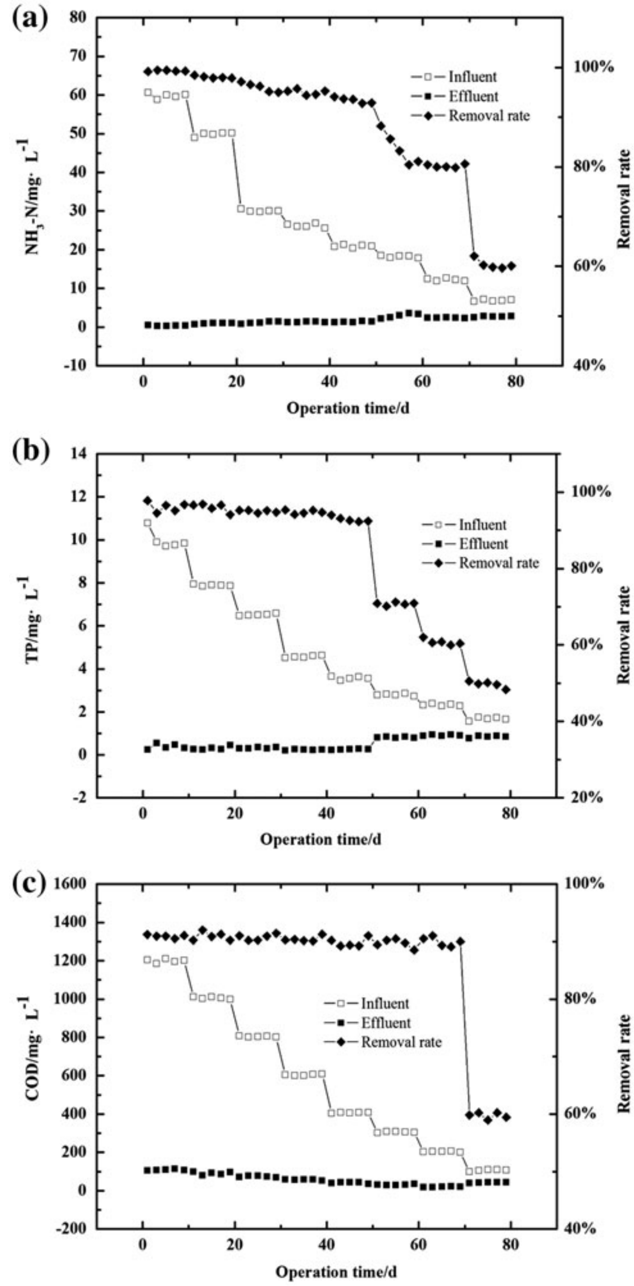

Fig. 4. The decontamination efficiency of granular sludge. (a) NH_3-N, (b) TP, and (c) COD.

removing TP was kept above 94%. Nonetheless, when the loading was below 400 mg/L, the removal rate gradually decreased. When the loading dropped to 300, 200, and 100 mg/L, the removal rates of TP were approximately 70, 63, and 50%, respectively. When the organic loading of influent water was above 400 mg/L, the growth speed of AGS was fast, and the amount of exhausted mud was high. Moreover, numerous phosphorus-accumulating organisms, which had absorbed a large amount of phosphorus, were discharged from the treatment system with exhausted mud. Under such condition, the removal rate of TP was satisfactory. When the organic loading was under 400 mg/L because of inadequate amount of nutrients, the growth speed of micro-organisms slowed down. Correspondingly, the amount of exhausted mud of the reactor gradually decreased, and the phosphorus absorption capacity of AGS was not enough. Therefore, the removal rate of TP worsened. The above discussion implied that all TPs of effluent water were under 1 mg/L in different organic loadings.

Fig. 4(c) illustrates that when the organic loading of influent water was above 200 mg/L, the efficiency of AGS in removing COD was above 88%. However, when the loading dropped to 100 mg/L, the removal rate of COD also decreased to 60%. The COD of effluent water was approximately 40 mg/L. When the organic loading was above 400 mg/L, the amount of nutrients was sufficient. As such, the micro-organisms rapidly grew, and their metabolic rates were high. These conditions were the reasons for the high removal rate of COD. When the loading was reduced to 300 and 200 mg/L because of insufficient nutrients, the micro-organisms absorbed as many nutrients in water for their continuous growth. Therefore, the COD of effluent water was cut down to 20 mg/L. When the amount of nutrients further decreased and the organic loading was 100 mg/L, the activity and metabolic rates of micro-organisms were reduced. In this event, the COD of effluent water was improved to 40 mg/L.

4. Conclusion

The form of AGS changed under different organic loadings. In particular, the spherical sludge became rice-like particles. When the organic loading was high, the sludge primarily consisted of spherical or elliptical particles and presented a khaki color. When the loading was below 400 mg/L, the sludge was divided into small smooth particles, which were schistose, rice-like, and of irregular shapes. The particle size distribution of the sludge also varied under different organic loadings.

The effects of the efficiency of AGS in removing NH_3-N, TP, and COD in wastewater were not obvious under different organic loadings. Notably, the removal rates for these compounds did not significantly vary. However, when the organic loading of influent water was reduced to 100 mg/L, the results changed. The findings presented in this paper could be used to set up the foundation for further analysis of the application of AGS in wastewater treatment engineering.

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