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Anaerobic Biological Treatment of High Concentration Wastewater

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Granular sludge is the key to the efficient operation of the UASB reactor, which directly affects the treatment efficiency of the reactor. The ordinary flocculent sludge is lighter, and it is easy to be flushed out of the reactor under the action of the influent water flushing in the UASB reactor and the gas scouring generated by the anaerobic reaction of the reactor sludge layer, resulting in reducing in the sludge concentration in the reactor, thus affecting the removal effect. Granular sludge has good settle ability and is not easily lost in the UASB reactor. In this paper, the performance of seed sludge inoculated by two different UASB process is studied to propose the best seed sludge inoculated under the condition of no anaerobic reactor sludge inoculation, which provides references for anaerobic biological treatment of high concentration wastewater.

1. Introduction

The anaerobic granular sludge is a mixture consisted of methanogens, acetogens, hydrolyzed fermenting bacteria, and other microorganisms, it's tight in structure and has good settle ability, which can improve the treatment efficiency of the reactor (Bong et al., 2018; Chojnacka et al., 2011). The anaerobic sludge technology has the advantages of wide application range, low energy consumption, high load and less residual sludge during wastewater treatment (Xiang and Yang 2009). However, the anaerobic sludge cultivation time is long and its requirement on temperature is high. The cultivation time and temperature of the anaerobic granular sludge are one of the current research hotspots. Based on the actual engineering requirement, this paper uses the activated sludge from the sewage treatment plant and the river sediment as the seed sludge to study the granulation performance of the two types of seed sludge, which provide references for the engineering UASB biological treatment start-ups.

2. Experimental methods and main equipment

2.1 Experimental devices

The UASB reactor in the test is a self-made simple UASB reactor with a diameter of 190 mm, made of polymethyl methacrylate (PMMA), it's columnar in shape and equipped with a three-phase separator. The three-phase reactor adopts the form of mud-water separation, the mud-water mixture mainly inflows from the channel in the middle, and the sludge precipitated in the sedimentation zone flows back from the backflow seam in the lower part to the sludge layer, the mud-water separation can minimize the mutual interference between the inflow water and the backflow sludge, thus reducing the sludge loss and maintaining the sludge concentration in the sludge area. At the same time, there is a gas chamber on the side wall of the reactor for collecting gas and completing the three-phase separation. There is a uniform water distribution device at the bottom of the reactor. The test device is shown in Figure 1.

2.2 The water used in the experiment and the seed sludge

2.2.1 The water used in the experiment

This research comes from an actual need: to treat the wastewater generated during the deep processing of jujube. This kind of wastewater is one of the most polluted waste liquids in the food industry, with high CODcr concentration and low pH value. In practical application, there's few research and application on the jujube processing wastewater, so this paper designs and uses coagulation sedimentation-UASB-anoxic-contact oxidation process to treat the high concentration jujube processing wastewater, therefore, the water used in this experiment is the effluent of the simulated jujube processing wastewater after coagulation and sedimentation, and the water is prepared according to the average water quality of the jujube processing wastewater. Main components of simulated jujube processing wastewater are: sucrose, glucose, ammonium chloride, potassium dihydrogen phosphate, sodium chloride, citric acid, sodium sulfate, potassium chloride, calcium chloride, magnesium chloride, manganese chloride, cobalt chloride, ferrous sulfate, aluminum chloride, sodium molybdate, boric acid, nickel chloride, copper chloride, zinc sulfate, disodium EDTA, and so on. The first stage of sludge inoculation uses the prepared nutrient solution, which is rich in nutrients and trace elements such as carbon, nitrogen and phosphorus. The carbon source is $C_6H_{12}O_6$, the nitrogen source is NH_4Cl, the phosphorus source is KH_2PO_4, C:N:P=1000:5:1, which is suitable for the growth of microorganisms.

Figure 1: UASB device

2.2.2 Seed sludge and pretreatment

The choice of seed sludge is the key to the successful start-up of the UASB reactor. Selecting seed sludge with high activity and adaptability can shorten the start-up time of the reactor and improve the treatment ability of the reactor. Because there is no sludge digestion facility around and there is no operating example of the UASB process, the selection range of seed sludge is small. In order to compare the performance of different kinds of seed sludge in the granulation cultivation process, and choose best seed sludge for the test, this test selected seed sludge from the anaerobic pool of Lugang Wastewater Treatment Plant in Baoding City and from the river sediment of Fuhe River in Baoding City.

The anaerobic pool of the sewage treatment plant has less impurities, high activity and it’s convenient to take the sludge from it. The sewage treatment plant mainly deals with domestic sewage, which is rich in nutrients such as nitrogen and phosphorus and other trace elements that is suitable for microbial growth. The sludge contains abundant microbial species and has high activity. The anaerobic pool sludge concentration is about 4000~5000mg/L, and the sludge is grayish black. Compared with the sludge concentration in the UASB reactor, the sludge concentration is lower and it needs to be pretreated. In this test, after repeated precipitation, the supernatant was removed, and the concentration of the seed sludge was increased to about 20,000 mg/L. For the river sediment sludge from the Fuhe River in Baoding City, because it has been deposited at the bottom of the river for a long time, it has strong adaptability to the environment. The river sediment is located below 1 m water depth and has a high anaerobic level. The nutrients contained in the water of Fuhe River in Baoding City are sufficient for the growth of microorganisms in the river sediment. According to the microscopic examination of the river sediment, the sludge contains a large number of microorganisms, and its activity is high. In conclusion, it is suitable as the seed sludge for the UASB reactor. However, there are many impurities in the bottom of the city river. In this test, the river sediment sludge is first elutriated through a large-diameter sieve, removing large particulate substances, such as domestic garbage and branches and leaves, and then elutriated through a small-diameter sieve to remove sand with smaller particle size. At last, after elutriated for several times, high-activity sludge would take main part in the whole sludge. The elutriated river sediment sludge has a higher concentration, dilute it appropriately so that the sludge concentration is about 20,000 mg/L.

2.3 Experimental methods

2.3.1 Temperature control

Since the ambient temperature during the test period was below 30°C, which cannot meet the temperature condition suitable for the growth of seed sludge in the UASB reactor. Therefore, the temperature in the reactor was maintained by heating the influent and applying thermal insulation materials to the outer layer of the reactor. The heating device is mainly composed of a heater, a temperature display, a contactor and a contact for sensing temperature. The temperature of the temperature display is set to 40°C. After the influent is heated, the water enters the reactor via a peristaltic pump, the temperature loss of the influent water entering the reactor is about 3-4 °C. The outer insulation layer is made of aluminum foil rubber insulation cotton with a thickness of 10mm, which can keep the temperature inside the reactor at about 35°C.

2.3.2 Stage control

Yue and Joo (1997) believe that the sludge granulation process can be divided into three stages: accumulation stage, granulation stage and maturity stage. Schmidt and Ahring (1996). believe that the process of sludge granulation is divided into the following stages, that is, the bacteria move to the surface of inert substances or other bacteria; they are reversibly adsorbed together or adsorbed onto the inert substances by physicochemical action; and the bacteria are irreversibly adhered together or on to the inert substances by the action of the microbial appendage (Hung et al., 2011). The start-up of the UASB in this test is divided into the sludge adaptation stage, the load increase stage, and the acclimation stage. After the anaerobic pool sludge of sewage treatment plant, and the sludge of the river sediment are pretreated and added to the UASB reactor, and the amount of seed sludge accounts for one-third of the effective volume of the reactor. In order to rapidly complete the granulation cultivation of the seed sludge, the remaining two-thirds of the volume in the UASB reactor of this test was filled with the pre-formulated nutrient solution. The static cultivation stage of the sludge is to adapt the seed sludge to the new environment quickly. When the CODcr in the reactor drops significantly and the removal rate increases, it indicates that the seed sludge has adapted to the new environment and begins the next stage. In the load increase stage, the influent volume load is increased by increasing the influent CODcr, for the concentration of influent CODcr, taking 400 to 1000 mg/L as each step, it gradually increased to about 5000 mg/L. At this stage, the granular sludge has undergone three stages of startup initial stage, granular sludge formation period, and granular sludge layer formation period; the acclimation stage is carried out by using the laboratory prepared high-concentration jujube processing wastewater, and the influent CODcr is gradually increased from 5000mg/L to about 20,000 mg/L. During the test, to stabilize the pH in the reactor, the influent water was added with NaOH to keep the influent pH at around 8; the reactor operation HRT was designed to be 24h.

3. Experimental results

3.1 Adaptation stage

In the static seed sludge cultivation stage, add nutrient solution into the reactor so that the CODcr of the mixture in the reactor is close to 1200 mg/L and the water temperature in the reactor can be maintained at about 25°C. As the static cultivation progresses, the pH of the mixture in the reactor gradually decreases. At this time, add NaOH solution into the reactor to adjust the pH of the mixture in the reactor to about 7.5. In the static cultivation stage, the change of CODcr in the UASB reactor with different seed sludge is shown in Figures 2.

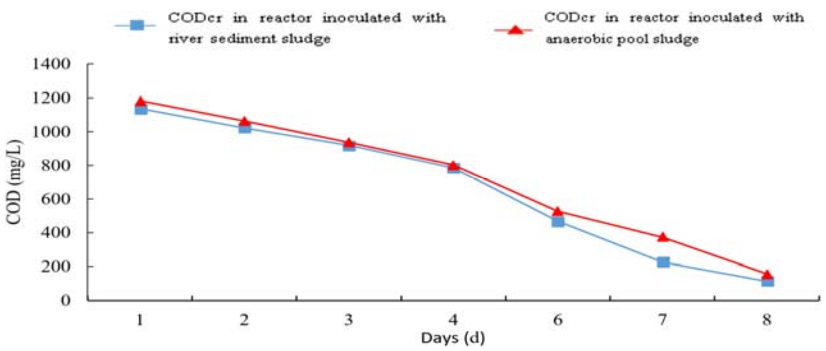

Figure 2: Change of CODcr in two UASB reactors during the adaptation stage

It can be seen from Figures 2 that the CODcr of the mixture in the two reactors gradually decreases since the first day, from the 4th day, the CODcr increases more dramatically, until the 8th day of the reaction, the CODcr in reactor inoculated with river sediment sludge decreases from 1138mg/L to 114mg/L, while the CODcr in reactor inoculated with anaerobic pool sludge decreases from 1184mg/L to 158mg/L; In both reactors, the removal rate of CODcr increases with the proceeding of the reaction, and from the 4th day the removal rate increases more dramatically, the CODcr removal rate in reactor inoculated with river sediment sludge increases from 10% on the first day to the 50% on the 7th day; while the CODcr removal rate in reactor inoculated with anaerobic pool sludge increases from 10% on the first day to the 58% on the 7th day.

In both reactors, from the 4th day, the CODcr decreases more dramatically, it's because in both reactors the seed sludge begins to adapt to new living environment from the 4th day, and the microbial activity in the sludge increases and the microorganisms begin to proliferate. The reason why the CODcr removal rate in the reactor gradually increases is that as the reaction progresses, the concentration of CODcr in the reactor gradually decreases, and the microorganisms in the sludge start to proliferate, and the amount of carbon source consumed gradually increases, so in the last few days the CODcr removal rate increases significantly.

3.2 Load increase stage

The load increase stage is mainly to complete the cultivation of granular sludge. After 8 days of seed sludge adaptation, fill water into the two UASB reactors continuously and the influent water heating device is turned on, adjust the pH of the influent water and open the influent peristaltic pump. The influent CODcr concentration is about 1200mg/L, gradually increase the influent CODcr concentration to increase the influent volume load. The influent and effluent CODcr and their removal rate in the two reactors are shown in Figures 3 and 4.

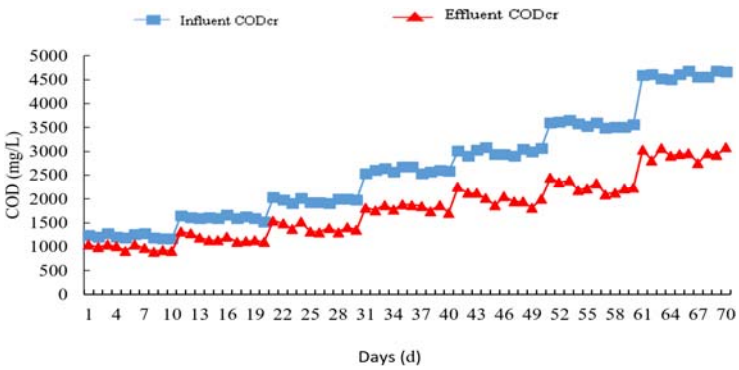

Figure 3: Change of influent and effluent CODcr in reactor inoculated with river sediment sludge

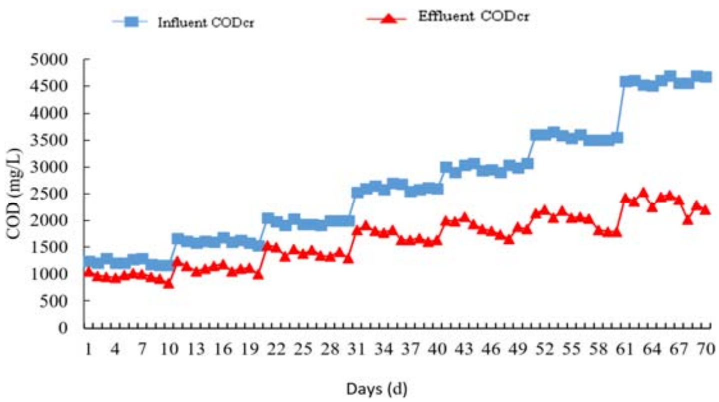

Figure 4: Change of influent and effluent CODcr in reactor inoculated with anaerobic pool sludge

It can be seen from the above figures that, in both reactors, the effluent CODcr increases with the increase of influent CODcr. For the reactor inoculated with river sediment sludge, from the 1st day to the 10th day, the influent CODcr is about 1200mg/L, and the effluent CODcr is about 900mg/L. On the 61st to the 70th day of the reaction, the influent CODcr increases to about 4600mg/L, and the effluent CODcr is also increasing, reaching about 2900mg/L; for the reactor inoculated with sludge from anaerobic pool of sewage treatment plant, from the 1st day to the 10th day, the influent CODcr is also about 1200mg/L, and the effluent CODcr can also reach about 900mg/L. On the 61st to the 70th day of the reaction, the influent CODcr is around 4600mg/L, and the effluent CODcr is around 2100mg/L. For the reactor inoculated with river sediment sludge, in the initial reaction period, the CODcr removal rate is between 10% and 20%, and the removal rate is gradually stabilized at 35% to 40% in the later period of the reaction; for the reactor inoculated with sludge from anaerobic pool of sewage treatment plant, in the initial reaction period, the CODcr removal rate is also between 10% and 20%, in the later reaction period, the removal rate is stabilized at about 50%. When the influent volume load in the two reactors increases, the CODcr removal rate decreases in the first few days, but the decrease is small. When the volume load increases, the CODcr removal rate gradually increases and tends to be stable.

Although in the reactor, the effluent CODcr increases with the increase of influent CODcr, the reactor's CODcr removal rate is gradually increasing, indicating that in the reactor the anaerobic microorganisms in the seed sludge grew well and proliferated faster. As the influent volume load increases, the seed sludge in the reactor undergoes a brief adaptation stage and then returns to normal. In the whole load increase stage, the reactor inoculated with sludge from anaerobic pool of sewage treatment plant has a CODcr removal rate obviously higher than that of the reactor inoculated with river sediment sludge. Therefore, it can be judged that the sludge from anaerobic pool of sewage treatment plant is more suitable as seed sludge for the UASB reactor, its activity is higher and the treatment ability is stronger. The reactor inoculated with sludge from the anaerobic pool of sewage treatment plant is taken as the reactor for the acclimation stage to conduct the test.

During the 70 days of the load increase stage, anaerobic granular sludge gradually formed. The reactor inoculated with river sediment sludge was observed on the 45th day of the reaction, and a small amount of granular sludge with a particle size of 0.6-0.8 mm was found. The reactor inoculated with sludge from the anaerobic pool of sewage treatment plant was observed on the 38th day of the reaction, and a small amount of granular sludge with a particle size of 0.5-0.8 mm was found. As the reaction progressed, the particle size of the granular sludge increased continuously, and the amount of granular sludge continues to increase as well. At the final stage of the reaction, that is, on the 70th day, samples were taken from the sludge layer of the two reactors, and large particles were observed. In the reactor inoculated with river sediment sludge, the largest particle size was 2.6 mm, while in the reactor inoculated with sludge from the anaerobic pool of sewage treatment plant, the largest particle size was up to 3.2 mm. In the sludge, there appeared many granular sludge particles that were regular and similar to oval in shape, and in the reactor inoculated with sludge from the anaerobic pool of sewage treatment plant, the regular-shaped sludge particles were significantly more than that of the reactor inoculated with river sediment sludge. It can be seen from the formation process of granular sludge that the sludge from anaerobic pool of sewage treatment plant is more suitable as the seed sludge for the UASB reactor.

3.3 Acclimation stage

The acclimation stage of the seed sludge is to gradually adapt the seed sludge to the influent water quality. In the load increase stage of the seed sludge, this test used a nutrient solution suitable for seed sludge growth to successfully cultivate granular sludge in two reactors in 70 days, and selected the reactor inoculated with sludge from anaerobic pool of sewage treatment plant as the reactor for the test of this stage. In this stage, the influent water was high-concentration jujube processing wastewater prepared in the laboratory. The water quality was similar to that of the actual high-concentration jujube processing wastewater after coagulation and sedimentation, and contained the necessary nutrients and trace elements. The highest concentration of CODcr was about 20000mg/L. The test conducted the acclimation by gradually increasing the influent CODcr. In the acclimation stage, the influent and effluent CODcr are shown in Figures 5.

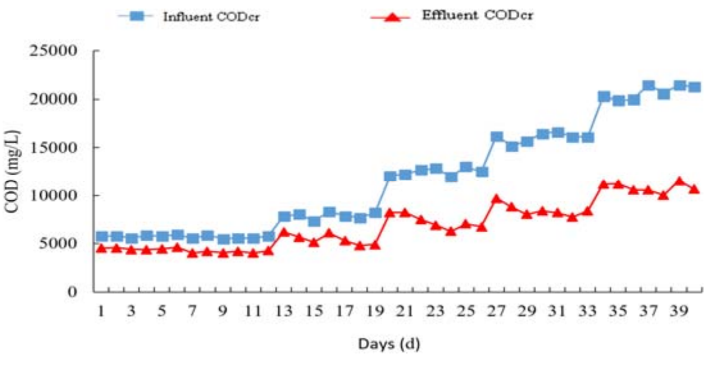

Figure 5: Change of influent and effluent CODcr in the reactor

The results show that with the increase of influent CODcr, the effluent CODcr of the reactor increased. The influent CODcr was about 5500mg/L in the first few days, the effluent CODcr was about 4000~4400mg/L, and the lowest was 4005mg/L. By the end of the acclimation stage, the influent CODcr was about 21000mg/L, the effluent CODcr was about 11000mg/L, and the lowest can reach 10013mg/L; when the influent CODcr increased, the effluent CODcr increased first and then decreased; generally, the reactor's CODcr removal rate increased, and in the first few days, the removal rate was 20%~30%, and at last the removal rate reached 50%. From the 29th day, the removal rate was stabilized at 50%. When the influent CODcr increased, the removal rate first decreased and then increased, and tended to be stable in the last few days.

The reason for the increase of effluent CODcr is the increase of influent CODcr; in first few days of acclimation stage, the reactor's CODcr removal rate was 20%~30%, which was significantly lower than the final CODcr removal rate in the load increase stage. The reason is that the influent of the reactor was changed from the nutrient solution suitable for the growth of microorganisms in the seed sludge to the high-concentration jujube processing wastewater prepared in the laboratory. The living environment of the microorganisms in the sludge had undergone changes, and it took a certain time for the seed sludge to adapt to the new influent water environment and to restore its activity. The high-concentration jujube processing wastewater prepared in the laboratory was relatively complex in water impurities, and the microbial decomposition and absorption was relatively difficult; on the 14th day of the reaction, the removal rate of CODcr in the reactor began to increase, indicating the seed sludge had begun to adapt to the influent water quality, restore activity, and proliferate a lot; in the acclimation stage, when the CODcr increased, the reactor's CODcr removal rate decreased slightly, and the reason is also that the seed sludge needs a certain adaption period for the increase of influent CODcr; at last the test influent CODcr is stabilized at 21000mg/L, and the CODcr removal rate was stable at about 50%, the test ran stably and the acclimation stage was completed.

4. Conclusion

This paper performed granulation cultivation on river sediment sludge and anaerobic pool sludge of municipal sewage treatment plant, and concluded that the UASB reactor inoculated with anaerobic pool sludge of sewage treatment plant took less time to form granular sludge and the performance of the granular sludge was better, and it had a higher CODcr removal rate on the influent water. The anaerobic pool sludge of sewage treatment plant is more suitable as the seed sludge of the UASB reactor.

This paper used a laboratory-prepared nutrient solution suitable for microbial growth for the granulation cultivation of seed sludge and successfully cultivated granular sludge within 70 days, and the reactors ran stably.

The high-concentration jujube processing wastewater prepared by the laboratory was used to acclimate the granular sludge as the influent. The reactor's CODcr removal rate increased from about 21% to about 50%, and the effluent was stable.

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