Biotechnology and Bioprocess Engineering **2004**, 9: 519-522 ©KSBB

Quantitative Study of the Reformation of Excess Sludge by Intense Aeration Under Nutrient-poor Conditions

Guangwei Li[1], Liming Chen[1], Kiyoshi Toda[2], and Shuting Zhang[1]*

[1] School of Environmental Science and Technology, Tianjin University, Tianjin 300072, China
[2] Department of Applied Chemistry and Biotechnology, Niigata Institute of Technology, Kashiwazaki, Niigata 945-1195, Japan

Abstract In the course of anaerobic storage of excess sludge, odors due to chemicals such as hydrogen sulfide are produced. These odors cause many problems. Many methods have been developed to eliminate odors, but all current methods are not only costly, but also largely ineffective. In this paper, we investigate the process of transformation of sludge microorganism cultures through intense aeration under nutrient-poor conditions, in terms of the selective adjustment and control of microorganism culture. The aerated sludge is subsequently returned to the adjusting pool, where the microorganisms inhibit odors, thus the excess sludge itself will act as an odor inhibitor. The process can be verified in terms of viability, in that the degradation capacity of the sludge was maintained after the intensely-aerated sludge was returned to the treatment system.

Keywords: biological sludge, hydrogen sulfide, intense aeration, nutrient-poor, odors, sludge storage tank

Aerobic microorganisms are used during the treatment of organic wastewater, and a large amount of excess sludge is usually generated [1]. In the course of treatment, odor is often produced in two phases. (1) The wastewater must be quantitatively and qualitatively equalized in an adjusting pool before entering the aeration tank. Due to the high concentration of organic material, the wastewater is prone to decay, and produces odor in the adjusting pool. Aeration is insufficient to ameliorate the anaerobic metabolic processes inherent in this production of odor. (2) The excess sludge must be reserved in the sludge storage tank for some time, before it is subjected to ultimate treatment, such as incineration or relocation to a landfill. In the course of anaerobic storage of excess sludge, odors are produced by chemicals such as hydrogen sulfide. The odor pervades the treatment facility, pollutes the air, and causes a general deterioration in working conditions. What's more, the odor influences the performance of successive treatment units. In practice, deodorizing equipments and chemical adsorption treatment are used to eliminate H_2S produced by sludge decay [2-5]. Thus, treatment cost increases, although the damage caused by H_2S can't be completely ameliorated. Therefore, it is necessary to develop method for the inhibition of initial H_2S production. In this paper, we make a study of the changes in the sludge microorganism culture during intense aeration under nutrient-poor conditions, in terms of selective adjustment and control of the microorganisms' culture. Then the aerated sludge is returned to the adjusting pool, the microorganisms are used to inhibit odor, and the excess sludge should itself function as an odor inhibitor. The vindication of this process is that the degradation capacity of the sludge was maintained after the intensely-aerated sludge was returned to the treatment system. In this experiment, we studied decay characteristics under anaerobic conditions, the sludge's degradation capacity on organic matter under aerobic and anaerobic conditions, and the mechanism by which intense aeration induced odor inhibition. The primary results were achieved, and presented briefly as follows.

Sludge was from a reclaimed water station in Tianjin University (Chemical oxygen demand (COD) of sludge supernatant remained under 50 mg/L). The sludge was settled for 1.5 h at a standstill to concentrate, and used as excess sludge in the experiment. The characteristic values of the excess sludge were controlled at pH 7.50~7.70 and COD 34~46 mg/L, ORP 45~60 mV, MLSS 8,000~10,000 mg/L, NH_4^+-N 105~130 mg/L.

The excess sludge was put into a 30-L container. The six sandy aerators were laid evenly at the bottom of the container to produce sufficiently intense aeration. The dissolved oxygen (DO) in the sludge was controlled at 6.8~7.0 mg/L, and the temperature was controlled at 25 ± 1°C. The samples were taken separately at aeration times of 0, 8, 24, 48, and 72 h to measure some parameters. Before the samples were taken, the sludge, which had adhered to the container wall, was scraped into the mixed liquor. Meantime, distilled water, which

***Corresponding author**
Tel: +86-22-87402075 Fax: +86-22-27402075
e-mail: stzhang@tju.edu.cn

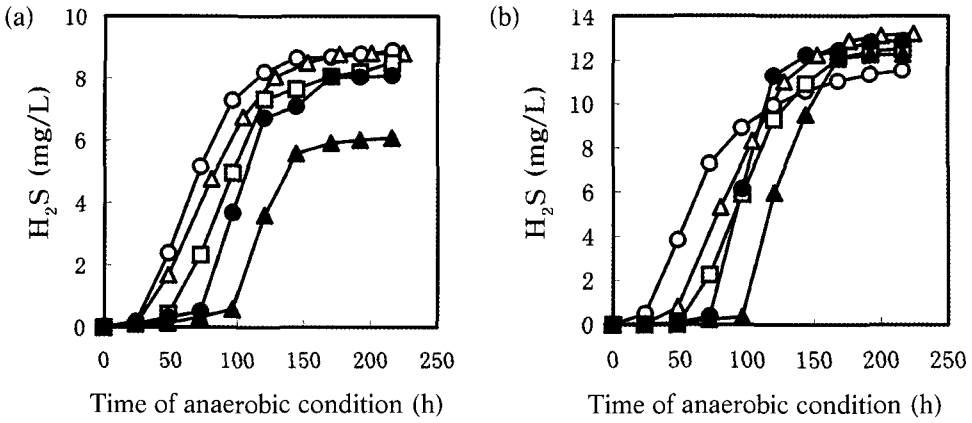

Fig. 1. The cumulative quantity of H_2S production under anaerobic condition. Circles, triangles, rectangles, closed circles and closed triangles show H_2S production, under anaerobic conditions, for the sludge at aeration times of 0, 8, 24, 48, and 72 h. Fig. 1a shows the experiment without addition of substrate, Fig. 1b shows the experiment with the addition of substrate.

had been oxygen-saturated by aeration, was injected to supplement the water lost due to aeration and evaporation, in order to keep constant volume in the sample.

Two series of parallel experiments were carried out. In the first experiment, 1 L of excess sludge, aerated intensively, was put into a 1.2-L column glass bottle, and then the change of the related traits under anaerobic conditions was observed. The other series comprised the simulation of the mixed liquor when the aerated sludge was returned to the adjusting pool. We mixed the excess sludge with concentrated synthetic wastewater. The concentrated synthetic wastewater was mainly composed of glucose, ammonia, phosphates and other trace nutrients such as iron, calcium and magnesium, at a carbon-nitrogen-phosphorous ratio of 100:5:3, and was wholly fed to the sludge in one application. The sludge was also fed with 500 mg/L SCOD. 1 L of mixed liquor was put into a 1.2-L column glass bottle at 34 ± 1°C, and then we observed changes of the related traits under anaerobic, nutrient-rich conditions.

During the experiment, the cumulative quantities of produced H_2S, ORP, and, MLSS were determined.

To assess changes in the capability of aerated sludge to degrade organic matter, the aerated excess sludge was mixed with concentrated synthetic wastewater. Then the SCOD levels of the mixed liquor were determined at a certain time interval, under both aerobic and anaerobic conditions.

During the experiment, the ORP level was determined with a system composed of a calomel electrode and a platinum electrode. The COD level was determined by the potassium dichromate method, and expressed as COD_{Cr}. The H_2S level was determined by measuring the quantity of iodine consumed [6].

The changes in the cumulative quantity of H_2S produced under anaerobic conditions without substrate by the intensely-aerated sludge, at different times prior to the experiment, are shown in Fig. 1a. The sludge produced no H_2S during the early phase, as the sludge was not anaerobic. After a certain lag period, though, H_2S was copiously produced. H_2S level increase slowed down after about 4~7 days. On the other hand, as the aeration time of the sludge was increased, the starting time of H_2S production was delayed. For the sludge that was not previously aerated, the lag time prior to H_2S production was approximately 20 h. But for the sludge aerated for 8, 24, 48, and 72 h, the lag times were 30, 45, 65, and 90 h respectively.

Changes in the cumulative quantity of H_2S by the intensely-aerated sludge, incubated under anaerobic conditions with substrate, was similar to those of the sludge incubated without substrate, as is showed in Fig. 1b. The initial production time of H_2S was obviously delayed as aeration time increased, as in the case without the addition of substrate. But the total quantity of H_2S produced with the addition of substrate was larger (30% higher on the average) than it without added substrate. The higher H_2S production may be attributed to peptone in the synthetic wastewater.

ORP is associated with sludge decay. So ORP was monitored to determine when the sludge became anaerobic. The initial value and decrease rate of ORP were different from sludge to sludge. But trends in the change of ORP levels were consistent (Figure omitted). ORP levels in the intensely-aerated sludge decreased rapidly under anaerobic conditions, irrespective of the presence of substrate. And when ORP levels reached a certain value, they began to decrease slowly. What's more, the more time the sludge was aerated, the more slowly ORP decreased, and the higher the initial ORP levels of the sludge became. The initial ORP levels in the sludge that was aerated for 72 h was higher than that of sludge that was not aerated, by about 270 mV. Due to the intense aeration, the DO of the mixed liquor was high and diffused into the floc particles; hence the activity of anaerobic bacteria was restrained. At the same time, high DO also helped to convert the reducible matter into oxidizable matter, *i.e.*, the transformation of NH_4^+ to NO_3^-.

With the addition of substrate, ORP levels in the aerated sludge decreased rapidly under anaerobic conditions

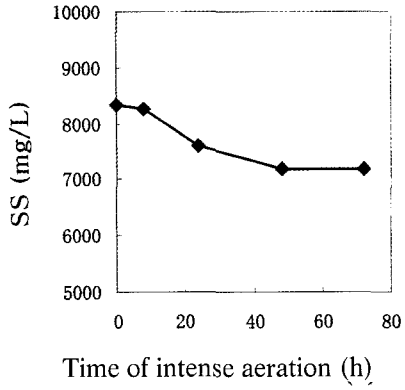

Fig. 2. Change of MLSS with increases in aeration time.

but the initial time of H_2S production was not altered, nor was the production velocity of H_2S, compared to sample without substrate. These results are not consistent with the opinion that pure microorganisms produce H_2S at less than −100 mV of ORP. This indicates that the numerical relation between H_2S and the ORP value is difficult to quantify in a mixed sludge sample. It is possible that it changes with alterations in the relative proportions and relative activity of different kinds of microorganisms. Perhaps under nutrient-poor conditions, the intense aeration deeply inhibited the activity of the microorganisms that produces H_2S, and the activity took some time to resume.

The change of sludge color was consistent with the change of ORP. The more time the sludge was aerated intensely, the more time it took for the sludge to blacken. For the sludge that was aerated for 72 h, with and without substrate, lag time for sludge blackening was 1 day and 3 days, respectively. But the sludge that wasn't aerated became black within 2~4 h, irrespective of the presence of substrate. The following may be presumed: that the intense aeration slowed decrease in ORP levels, and delayed both the blackening of the sludge, and also the initial H_2S production time.

The floc concentration was expressed as mixed liquor suspended solid (MLSS). The change in MLSS of the aerated sludge is shown in Fig. 2. When the sludge was aerated intensely for 8 h, MLSS exhibited no significant changes. Subsequently, as aeration time increased, MLSS decreased significantly, from 8,300 mg/L to 7,200 mg/L, and remained constant after 48 h. When the concentrated sludge was put into the aeration reactor, we observed a jet-black mixed liquor, with uniform texture. As aeration time of the sludge increased, the sludge gradually became dust-coloured and reduced. Floc particles dispersed. We conjecture that the decrease of MLSS may be attributed to the degradation of the organic matter within the sludge flocs. The intense aeration caused oxygen to diffuse into the flocs, and expanded the aerobic region of the bio-flocs. So organic matter could have been hydrolyzed and degraded, under aerobic conditions, within the flocs. As volatile suspended solids (VSS) were reduced, sludge decreased [7].

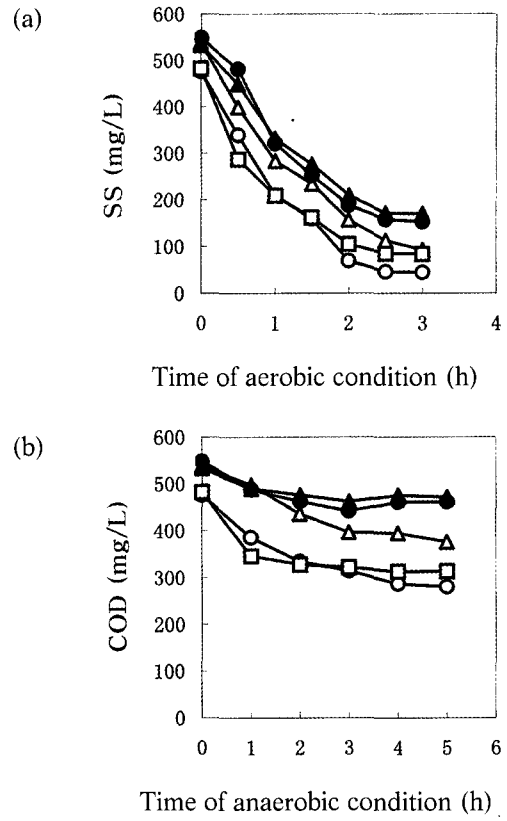

Fig. 3. Change of COD with addition of substrate. Circles, triangles, rectangles, closed circles and closed triangles show COD variations for the sludge at aeration times of 0, 8, 24, 48, and 72h. Fig. 3a shows the experiment under aerobic conditions, Fig. 3b shows the experiment under anaerobic conditions.

The intensely-aerated sludge to degrade organic matter was studied in the experiment. The changes of COD levels in the mixed liquor of the sludge and the synthetic wastewater were monitored, and are shown in Figs. 3a (aerobic conditions) and 3b (anaerobic conditions). COD levels in the mixed liquor decreased rapidly with increases in aeration time. After some time, the decrease velocity became slow, and at the end achieved a stable value. But with increases in aeration time, the stable value became higher.

We made a further study of the capacity of the intensely-aerated sludge to degrade organic matter. The ratio of difference in COD levels from initial levels to later levels (3 h with aeration, 5 h without aeration), to unit quality of microorganisms, per unit time, was used to express the sludge's degradation capacity. The specific rate of COD degradation, which was defined as the amount of COD degraded per unit quantity of MLSS per unit time, correlates with the intense aeration time of the sludge. The ratio of specific rates of COD degradation for the sludge, which was aerated intensely for 0 and 72 h, was calculated. The ratio, under aerobic conditions, is 0.973, and 0.478 under anaerobic conditions. Fig. 3 and the ratios indicate that the degradation ca-

pacity of the aerated sludge didn't change significantly under aerobic conditions, while the degradation capacity decreased under anaerobic conditions. In other words, intense aeration inhibited the activity of anaerobic microorganisms, but did not affect aerobic microorganisms. We conjecture that the intense aeration was responsible for the high dissolved oxygen content of the sludge under nutrient-poor conditions. The high DO inhibited the activity of anaerobic microorganisms, and changed the sludge microorganism culture. So, when the aerated sludge was returned to the aeration tanks, the sludge maintained good degradation capacity. After the sludge was returned to the adjusting pool, which was also subjected to intense aeration, odors was not produced at levels higher than at the hydraulic detention time, under nutrient-rich and anaerobic conditions. It is also conceivable that the excess sludge should function as an odor inhibitor, after the intensely-aerated sludge was relocated to the aeration tank.

The effect of intense aeration treatment, under nutrient-poor conditions, on sludge microorganism cultures was studied. The main conclusions are as follows:

1) Pretreatment of the excess sludge by intense aeration under nutrient-poor conditions significantly delayed H_2S production in the sludge under anaerobic conditions, and decreased total production of the harmful gas.

2) Pre-aeration of the excess sludge delayed the time at which ORP levels became negative, and blackening of the sludge under anaerobic conditions. The phenomena were consistent with the delay of H_2S production.

3) Intense aeration of the excess sludge for 72 h caused a small decrease in MLSS, approximately 14%.

4) After intense aeration of the excess sludge, the sludge's degradation capacity on supplemented synthetic wastewater didn't significantly change under aerobic conditions, but decreased under anaerobic conditions. This shows that, in fact, the intense aeration changed the activity of the microorganisms to inhibit H_2S production by the inhibition of the activity of anaerobic microorganisms.

The above results establish a foundation for the treatment process by which the intensely-aerated sludge was returned to the adjusting pool. The process may inhibit H_2S production, produce sludge with the capacity to inhibit odors, and ameliorate the sludge's capacity to degrade organic matter. Certainly, further study is indicated.

NOMENCLATURE

DO	dissolved oxygen
MLSS	mixed liquor suspended solid
ORP	oxidation-reduction potential
SCOD	soluble chemical oxygen demand

REFERENCES

[1] Liu, Y. and J.-H. Tay (2001) Strategy for minimization of excess sludge production from the activated sludge process. *Biotechnol. Advan.* 19: 97-107.

[2] Allen, E. R. and Y. Yang (1991) Biofiltration control of hydrogen sulfide emissions. *Proceedings of the 84th Annual Meeting of the Air and Waste Management Association.*

[3] Ottengraf, S. P. P. (1986) Exhaust gas purification. *Biotechnology* 8: 426-452.

[4] Leson, G. and A. M. Winer (1991) Biofiltration: an innovative air pollution control technology for VOC emission. *J. Air Waste Manage. Assoc.* 41: 1045-1054.

[5] Deshusses, M. A. and G. Hamer (1993) The removal of volatile ketone mixtures from air in biofilters. *Bioprocess Eng.* 9: 141-146.

[6] Fusheng Wei (1989) *The method on Monitoring and Analysis of Water and Wastewater.* 3rd ed., pp.331-332. China Environmental Science Press, Beijing, PRC, China.

[7] Abbassi, B., S. Dullstein, and N. Rabiger (2000) Minimization of excess sludge production by increase of oxygen concentration in activated sludge flocs: Experimental and theoretical approach. *Wat. Res.* 34: 139-146.

[Received May 20, 2004; accepted November 18, 2004]