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# Effect of different sludge reduction methods on sludge reduction rates, performance of activated sludge process and urban planning

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ABSTRACT

Effect of biological methods (aerobic digestion, anaerobic digestion, and predation by *Tubifex tubifex*), physical methods (addition of uncoupling agent), and chemical methods (addition of ozone, chlorine) on the efficiency of sludge reduction was compared, so was the effect of different sludge reduction methods on the performance of activated sludge process with respect to the content and nature of organic matters. It was concluded that the best sludge reduction technology was using uncoupling agent with sludge reduction efficiency at 60%, followed by ozone, chlorine, micro-biological, aerobic biological, and anaerobic biological, which was the worst with efficiency at 36%. All of the molecular weight (MW) distribution of supernatant in activated sludge processes was changed to some extent under different sludge reduction methods. The change of the MW distribution would play a certain impact on the biodegradable ability of the organics, thus affecting the efficiency of sludge reduction rate. Finally, the impacts of final disposal method on urban environment were analyzed, and some recommendations related to urban planning were made.

*Keywords:* Sludge treatment methods; Sludge reduction; Activated sludge process; Urban environment; Urban planning

## 1. Introduction

Nowadays, the biological treatment was widely used in municipal wastewater treatment, but large amounts of residual sludge would be produced inevitably during this process [1]. Due to the complexity of sewage treatment, there was a considerable amount of toxic and hazardous substances in residual sludge [2–6], such as parasite eggs, pathogenic microorganisms, heavy metals. In addition, it could also generate a certain amount of unstable organic matter when the management of sewage treatment process was not proper. For large amounts of sludge produced by municipal sewage treatment plants, if there were no scientific treatment or disposal methods, it would be a harmful pollution source to the urban environment directly or potentially and then generated certain negative effects on urban planning and development [7].

In this study, effect of different techniques on the specific rate of sludge reduction and the rate of sludge reduction was analyzed in the laboratory. Therefore, comprehensive comparisons were conducted for effect of the sludge reduction technologies on the performance of activated sludge processes, and the harm to the environment and impact on urban planning were also analyzed.

## 2. Materials and methods

### 2.1. Experimental setup

As shown in Fig. 1, the experimental system consisted of seven identical completely mixed activated sludge processes that were operated in parallel. The effective volume of aeration tank and sedimentation tank was 6.5 and 3.2 L, respectively. Feed water was pumped from feed water tank to aeration tank at a volume loading of about 1 L/h, where laboratory-made air diffuser was placed, and was degraded by active sludge and then overflow to the sedimentation tank.

### 2.2. Experimental materials and methods

In this study, in order to keep the consistency of water used in this experiment, synthetic wastewater was adopted, and the concentration of organic matter and ammonia nitrogen was similar to those in urban sewage. The characteristics and constituents of the feed water are shown in Table 1.

In this study, the seven completely mixed activated sludge process that operated in parallel, including uncoupling agent, ozone, chlorine, microbiological, aerobic biological, and anaerobic biological, and an activated sludge process as a control test without any agent was operated at the same time. 3,3′,4′, 5- tetrachlorosalicylanilide (Acros company, Canada), served as uncoupling agent, was added to completely mixed activated sludge process. The concentration of ozone was 13–15 mg/L; and the dosage of chlorine was 14 mg chlorine per gram dry sludge.

### 2.3. Analytical methods

Mixed liquor suspended solids (MLSS) were measured using gravimetric method. The procedures for extracellular polymeric substances (EPS) were measured according to the methods described in the literature [8]; ultrafiltration membrane method was used to determine the molecular weight (MW) distribution [9]. The specific oxygen uptake rate (SOUR) was measured according to the methods described in the literature [10].

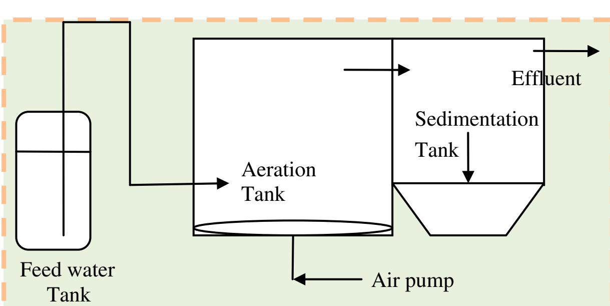


Fig. 1. Schematic diagram of the experimental setup.

Table 1
Components and characteristics of artificial wastewater

| Components | Concentration (mg/L) | Components | Concentration (mg/L) |
|---|---|---|---|
| Starch | 250 | $NaHCO_3$ | 80 |
| Glucose | 200 | $CaCl_2$ | 8 |
| Peptone | 150 | $KH_2PO_4$ | 50 |
| Beef extract | 70 | $(NH_4)_2SO_4$ | 110 |
| Carbamide | 10 | $FeSO_4$ | 0.2 |
| $MgSO_4$ | 70 | $MnSO_4$ | 5 |

### 2.4. Evaluation indices for sludge reduction

The specific rate of sludge reduction ($R$), which is the rate of sludge reduction per unit time, can be calculated according to:

$$R = (S_i - S_{i+1}/(t \times S_i) \quad (1)$$

where $S_i$ is the concentration of sludge before reduction, $S_{i+1}$ is the concentration of sludge through reduction in $t$ days, $R$ is the reduction in sludge per unit mass per unit time (to measure the ability of the methods used on the reduction in per unit sludge), units: mg/mg/d.

The rate of sludge reduction ($E$), reflecting the reduction in sludge quantity within the reactor per unit time, with the units of mg/d, can be described as:

$$E = (S_i - S_{i+1})/(t) \quad (2)$$

The proportion of sludge reduction represents the proportion of the final amount of a certain amount of sludge, with the unit of %:

$$R_r = (S_i - S_{i+1})/(S_i) \quad (3)$$

## 3. Results and discussion

Before carrying out the sludge reduction experiments, seven groups activated sludge systems running in parallel were stabilized, which had been continuously operated for 50 days.

### 3.1. Effect of different methods on sludge reduction rate

The effect of different methods on the rate of sludge reduction was investigated, with the initial

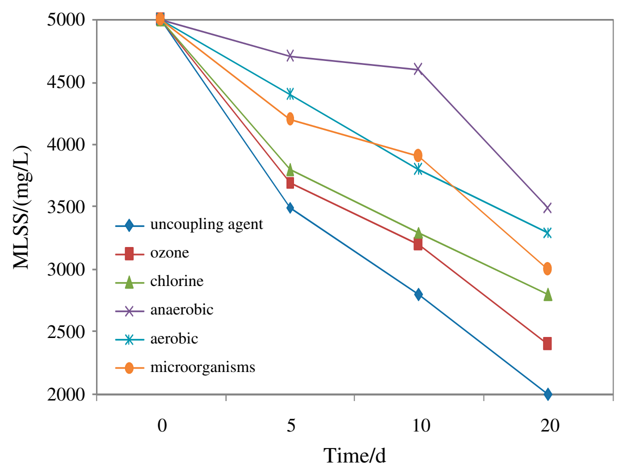


Fig. 2. Effect of different methods on sludge reduction within 20 days.

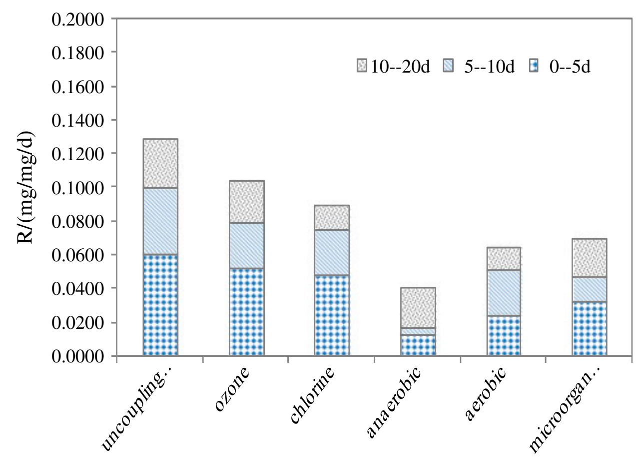


Fig. 3. Effect of different sludge reduction methods on the specific rate of sludge reduction.

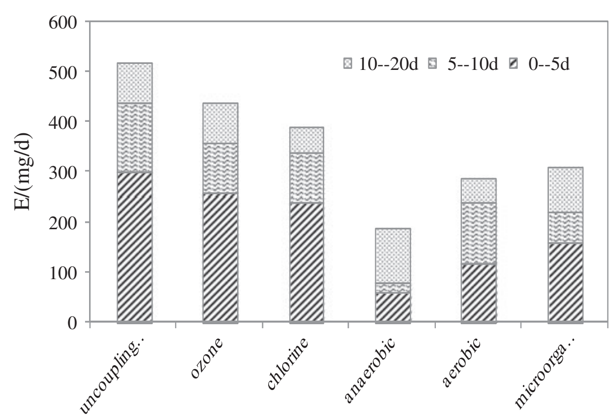


Fig. 4. Effect of different sludge reduction methods on sludge reduction rate.

sludge concentration at about 5 g/L. The operating conditions of the original activated sludge did not change through the experiment period, and the effect on sludge reduction within 20 days was shown in Fig. 2. It can be seen from Fig. 2, for sludge reduction, the effect of uncoupling agent was the best, followed by ozone, chlorine, micro-biological, aerobic biological, and anaerobic biological. Five of the six sludge reduction methods applied in this experiment were related to the principle of biological degradation except uncoupling agent method. Mechanisms of ozone and chlorine oxidation were stated as following: The reaction of agents and organic matter in the cell membrane mainly changed the MW of organic matter, and thus, organic matter was opt to be biological degradable, thereby reducing the yield of sludge. However, the binding of uncoupling agent and hydrogen ions reduced the resistance of the hydrogen ions from the cell membrane, and then, uncoupling agent went through the cell membrane carrying hydrogen ion, making the proton gradient of both sides decrease; the decreased proton gradient was not sufficient to drive ATP synthase to synthesize ATP, thus reducing the amount of the ATP synthesis by oxidative phosphorylation, so the energy generated in the oxidation process eventually released as heat.

During the 20-day experiment of sludge reduction, the activated sludge concentrations were detected three times: on days 5, 10, and 20. The specific rate of sludge reduction, the rate of sludge reduction, and the proportion of sludge reduction using different treatment techniques could be calculated, and the results are shown in Figs. 3–5, respectively. Uncoupling agent relied on the chemical action, it would be fast and direct, so at the initial stage of sludge reduction, the rate of sludge reduction and the proportion of sludge reduction using uncoupling agent were much higher than the other reduction methods.

It can also be seen from Figs. 3–5 that the changing trends of sludge concentration of several sludge reduction methods with time were different. But in general, it was larger in the initial 0–5 days and the reduction rates decreased with time for all the specific rates of sludge reduction and the rates of sludge reduction except anaerobic biological method, which was consistent with the previous report [11].

### *3.2. Effect of different sludge reduction methods on organic matter behavior in activated sludge process*

The EPS and MW distribution of supernatant in activated sludge with different methods were measured on 20th day, and the percentages of EPS

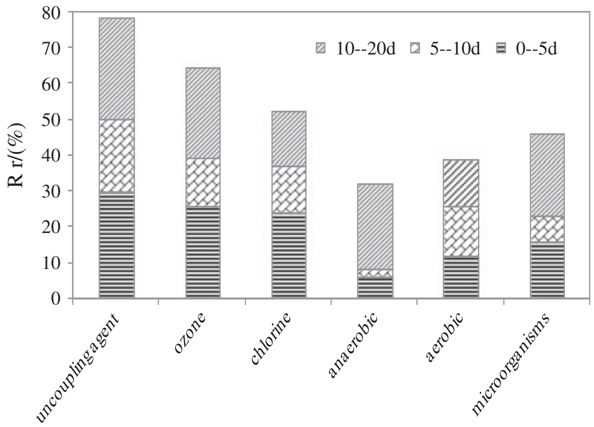


Fig. 5. Effect of different sludge reduction methods on sludge reduction proportion.

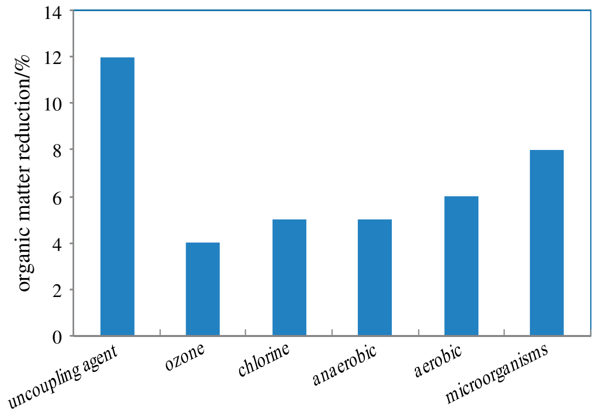


Fig. 6. The percentages of EPS reduction and MW distribution with different sludge reduction methods.

reduction with different sludge reduction methods and MW distribution of supernatant in activated sludge systems are shown in Figs. 6 and 7, respectively. As illustrated in Fig. 6, the addition of uncoupling agent significantly reduced the EPS content in the system. However, the impact of ozone on EPS content was the smallest. But ozone had the most obvious impact on MW distribution of EPS in the system, especially the organics with MW <3 kDa (Fig. 7). It was postponed that high MW EPS of supernatant in activated sludge was degraded into low MW organics. Studies have shown that low MW organics were more easily biodegradable.

### 3.3. *Effect of different sludge reduction methods on performance of activated sludge process*

During the stable operation of the activated sludge systems, removal of TOC and $NH_3$–N under different processes is shown in Table 2. It can be seen that the

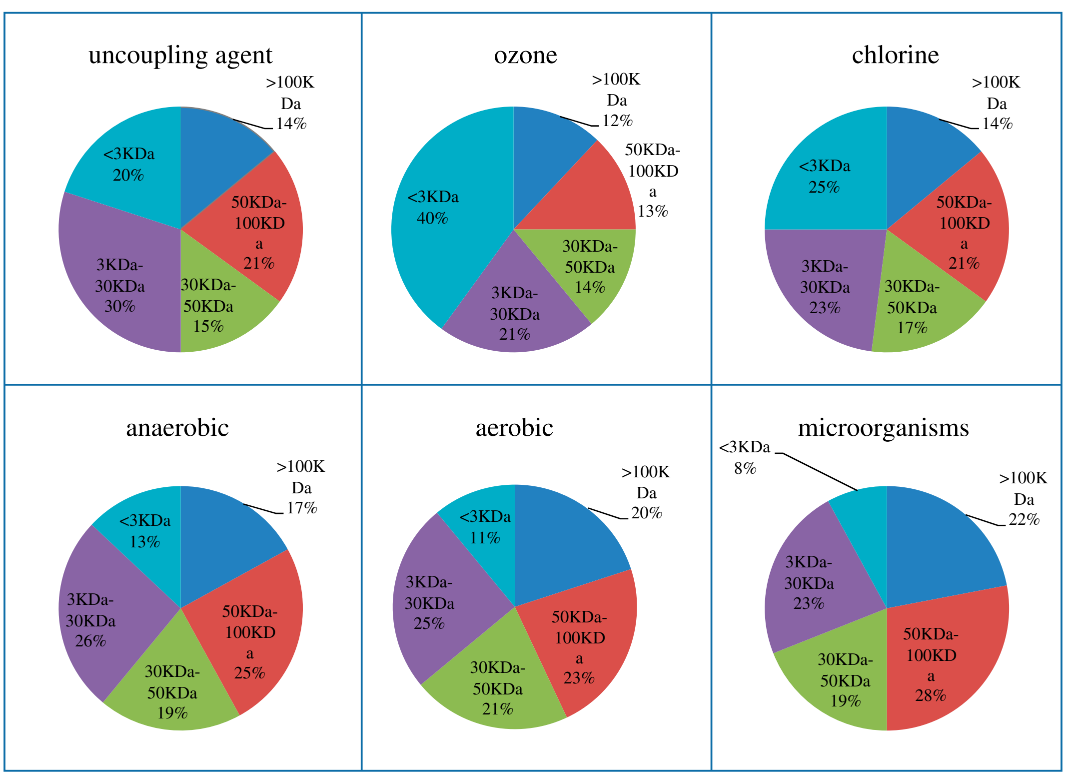


Fig. 7. MW distribution of supernatant in activated sludge systems.

Table 2
Average removal of organic matter and ammonia during the operation of sludge reduction

| Items | Removal rate (%)[a] | |
|---|---|---|
| | TOC | $NH_3$–N |
| Activated sludge process | 85 | 80 |
| Uncoupling agent | 83 | 71 |
| Ozone | 87 | 76 |
| Chlorine | 81 | 72 |
| Anaerobic biological | 78 | 79 |
| Aerobic biological | 79 | 81 |
| Micro-biological | 83 | 83 |

[a]$n = 10$.

introduction of different sludge reduction methods had no significant effect on the removal of organic matter. This shows that the activated sludge was still able to maintain high organic removal efficiency, although the sludge concentration had a significant reduction during the stable operation period. This is consistent with the results drawn by previous researchers [12,13].

Meanwhile, ammonia removal of different processes (Table 2) shows that addition of uncoupling agent, ozone, or chlorine would have a certain inhibition effect on $NH_3$–N removal. The addition of uncoupling agent could possibly improve the concentration of proton ionophore, and thus, nitrogen in the reducing sludge was released to the water, so the nitrogen concentration in the effluent increased. However, the addition of ozone or chlorine might damage the biological activity of activated sludge. Different from the above, the introduction of three biological sludge reduction technologies (anaerobic biological, aerobic biological, and micro-biological methods) had no significant effect on $NH_3$–N removal.

SOUR values of different processes with time during the stable operation of the activated sludge systems are shown in Fig. 8. It can be seen that SOUR had a significant increase as the addition of uncoupling agent, which was similar to the phenomena observed by Mayhew [14]. Because there was no association between the increase and growth of SOUR, so the existing compounds in activated sludge system might generated energy uncoupling. It meant that more energy was consumed in the system for metabolic as the addition of uncoupling agent, which is just the essential reason of sludge reduction.

### 3.4. Effect of final disposal of activated sludge on urban environment and planning

At present, sludge reduction or reuse has become a hot research topic in the fields of environment and

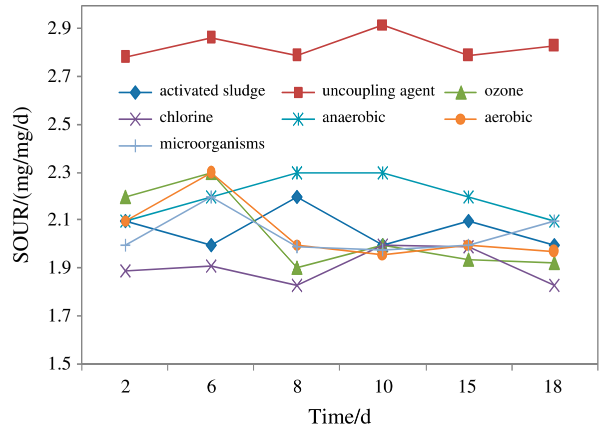


Fig. 8. SOUR values of different processes with time.

urban planning. However, under the current technology level, it is impossible to achieve zero sludge production for sewage treatment process, so it should be closely related with people's living standards for further disposal (or final disposal) after sludge reduction. Sludge reduction technology also requires further study, and subsequent disposal (or final disposal) of sludge will play a great role on urban environment and the overall planning.

In this study, the optimal sludge reduction technology is uncoupling agent. But uncoupling agent is usually a compound which is much difficult to be biodegraded or has great toxicity. So biological degradation of uncoupling agent is incomplete, which would certainly bring new pollution for subsequent disposal of sludge, and also bring some harm to the health of the people. Therefore, the application of uncoupling agent has the risk of endangering the urban environment. Besides, the addition of ozone or chlorine will also generate a certain degree of oxidation by-products [15,16], and subsequent treatment of this part of the by-products will directly affect the urban water environment.

Different from the addition of uncoupling agent, ozone, or chlorine, the technical feasibility of biological treatment technology is poor, but it does not need extra energy and has the advantages of lower operating costs, almost no by-products. Therefore, optimization and engineering of the biological treatment methods would not only improve the sludge reduction efficiency, but also would minimize energy consumption and the output of by-products.

## 4. Conclusions

Several sludge reduction technologies for activated sludge system were studied by bench-scale experiments. It was concluded that the optimal sludge reduction technology was uncoupling agent with efficiency at 60%, followed by ozone, chlorine, micro-biological, aerobic biological, and anaerobic biological, which was the worst with efficiency of 36%. All the MW distribution of supernatant in activated sludge was changed to some extent using different sludge reduction methods. The change of the MW distribution of organics would play a certain impact on the biodegradation in the sludge, thereby affecting the efficiency of sludge reduction. The introduction of different sludge reduction technologies almost had no impact on the pollutant removal efficiency.

In addition, the impact of sludge reduction measures on the urban environment should be taken into account when developing the sludge reduction technology, and treatment and disposal methods of sludge should also be considered in the planning of the entire city.

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