New approaches to minimize excess sludge in activated sludge systems


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Abstract This paper presents three new approaches to reduce excess sludge production in activated sludge systems: 1) modification of conventional activated sludge process with insertion of a sludge holding tank in the sludge return line; 2) chlorination of excess sludge so as to minimize excess sludge production; and 3) utilization of a metabolic uncoupler, 3, 3', 4', 5-Tetrachlorosalicylanilide (TCS) to maximize futile activity of sludge microorganisms thereby leading to a reduction of sludge growth. Pilot study was carried out to evaluate this modified activated sludge process (OSA). It has been confirmed that the OSA process is effective in reducing excess sludge; particularly when the ORP level in the sludge holding tank was kept at –250 mV, more than 50% of the excess sludge was reduced. This process can maintain the effluent quality and even perform with a better sludge settleability than a conventional system. Experimental work on the second approach showed that chlorination treatment of excess sludge at a chlorine dose of 0.066 g Cl₂/g MLSS reduced the excess sludge by 60%, while concentration of THMS was found below 200 ppb in the treated sludge. However, such sludge chlorination treatment sacrificed sludge settleability. Thus, it is not feasible to introduce the chlorination step to a conventional system. The third approach confirmed that addition of TCS could reduce sludge growth effectively if the TCS concentration is greater than 0.4 ppm. A 0.8-ppm concentration of TCS actually reduced excess sludge by 45%. It was also experimentally demonstrated that presence of TCS increases the portion of active sludge microorganisms over the entire microbial population.

Keywords Activated sludge process; chlorination of excess sludge; excess sludge minimization; metabolic uncoupler; ORP; sludge holding tank; THMs; TCS

Introduction

Activated sludge process is the major means of treating municipal and industrial wastewaters that transforms both soluble and particulate organic pollutants into biomass or sludge. Substantial amount of excess sludge is thus generated daily. Treatment and disposal of the excess sludge eats up 40 to 60% of total operational cost of an activated sludge treatment plant (Horan, 1990). Moreover, major ultimate disposing methods of dewatered sludge in densely populated urban areas such as Hong Kong are landfilling and/or incineration. The landfilling has created environmental challenges in Hong Kong due to the shortage of landfill sites. Therefore, sludge incineration is considered as the last resort for the sludge disposal, which is, however, facing not only the escalation of construction and operational costs due to stringent air emission regulations, but also increasing public awareness of dioxin generation from solids waste incinerators. It is thus difficult to find suitable incinerator sites. To solve the sludge problem strategically, minimization of the excess sludge production is ideal. Recently various innovative approaches have been proposed (Low and Chase, 1998). This paper reports our recent studies on the development of three new approaches: 1) to reduce excess sludge reduction by passing the settled sludge of the final clarifier through a sludge holding tank thereby inducing extensive internal use of sludge carbon source and endogenous so as to reduce sludge production (Chudoba et al., 1992a,b;
Saby et al., 2001a,b; Chen et al., 2000a); 2) to use chlorine to replace ozone to minimize excess sludge because of its low cost (Saby et al., 2001c); and 3) to use a metabolic uncoupler to stimulate futile activity of sludge microorganisms so that sludge growth can be limited (Chen et al., 2000b, 2001).

**Reduction of excess sludge by a modified activated sludge process with a sludge holding tank (OSA process)**

Two identical 10-L membrane immersed bioreactors were used to cultivate the activated sludge, as shown in Figure 1. The MBR bioreactors consist of a biological reactor and a hollow fiber membrane separation module.

The membrane module has a porosity of 0.1 µm and a total surface area of 0.2 m². Synthetic wastewater mainly composed of peptone and yeast extract was continuously fed to each of the MBR bioreactors using a stepwise increase of the influent COD concentration from 100 to 330 mg/L during a two-month period. In the cultivation, the hydraulic retention time and dissolved oxygen (DO) were controlled at 6 hrs and around 7 mg/L respectively; while the MLSS and sludge age were maintained at 2,000 mg/L and 4 days. The sludge cultivation and all the following experiments were conducted in a temperature constant room at 20°C. MLSS and MLVSS in the effluent were monitored daily, and soluble COD, nitrate, phosphorous, and sulfate concentrations in the influent, the effluent, and the reactors were monitored 2–4 times per week according to the *Standard Methods* (APHA, 1998). After the two-month cultivation, the sludge production and the treated water quality became stable, both were similar in these two MBR systems. Then, one of the systems was modified as an OSA system by inserting a 4.75-L sludge holding tank between the 10-L aeration tank and a 4-L settler and, while the other one remained unmodified to serve as the reference system. In the OSA system, its settler thickened the sludge in order to supply adequate sludge to the holding tank so as to achieve a low ORP level. This step was to induce a sludge starvation under an anoxic condition. A 14-day stabilization period was provided to produce sufficient quantity of sludge in the anoxic tank in order to effectively reduce the ORP level from around +350 to +100 mV in the OSA system initially. During the OSA system operation, the COD loading rate (1.3 g.day⁻¹), DO, hydraulic retention time and MLSS concentration in the aeration tank were all maintained at the same levels as those in the operation of the reference system. The hydraulic retention times in the settler and the anoxic tank of the OSA system were kept at 2.4 and 10.4 hrs, respectively. Such a long retention time in the anoxic tank facilitated maintaining the ORP level at –250 mV with occasional injections of pure nitrogen gas that was controlled by an ORP controller (TOA). After the initial 14-day operation period, another three operation periods at a length of 40–90 days each were conducted at the corresponding ORP levels in the anoxic tank: 1) +100 mV; 2) –100 mV; and 3) –250 mV. Each operation was carried out until stable effluent quality and sludge production rate were achieved. Meanwhile, the reference system continued for the same period of time. In these operations, the influent and effluent COD concentrations in the aeration tank,
the settler, and the anoxic tank, the MLSS and MLVSS levels in the aeration tank of the OSA system were monitored daily. The sludge quantity in the settler and the sludge holding tank, the sludge volume index (SVI), the concentrations of nitrate, phosphorous, and sulfate in all the tanks in the OSA system were analyzed periodically. Sludge wasting was made daily in order to keep the MLSS level in the aeration tank of the OSA system at 2,000 mg L\(^{-1}\).

The major results are summarized in Figure 2 and Table 1. The main conclusions of this study are: 1) the insertion of a sludge holding tank into the returned sludge circuit to form an OSA process can result in a significant decrease in excess sludge production; 2) the COD removal and sludge settleability were both improved by the OSA system in all the operation periods, compared with the reference system; 3) the ORP level at the sludge holding tank plays an important role in reducing the excess sludge and a low ORP favors sludge reduction, i.e. when the ORP level was controlled at \(-250\) mV, the excess sludge can be reduced by 36% compared to that at +100 mV or by 50% compared to the reference system.

**Excess sludge reduction by chlorination treatment**

The above reference system was used to examine the sludge reduction efficiency by chlorinating excess sludge and then returning it to the system. This testing system did not alter the configuration except for addition of an additional pump to return the liquor of the chlorination reactor after the sludge chlorination, as shown in Figure 3b. This return was conducted for 20 hrs in order to lessen the impact of chlorine residuals in the liquor, which was adapted from Yasui et al. (1996) with the sludge ozonation treatment, after the sludge injection and the 10-min circulation periods. The excess sludge chlorination treatment was performed daily with approximately 4.5 g per day equivalent to the excess sludge production rate in the above reference line. The chlorination treatment was conducted at a dose of 0.066 gCl\(_2\)/g MLSS for 1 min, which followed the dose of ozone adapted by Yasui et al.
(1996). Therefore, a comparison between this study and the previous study may be possible in the light of the excess sludge reduction efficiency. During the operation of the testing system, the COD loading rate (1.3 g/day), DO, hydraulic retention time, and MLSS concentration in the aeration tank were all maintained at the same levels as those of the above reference system. This operation lasted for 35 days until the effluent quality and sludge production became stable. In the operation, the influent and effluent COD concentrations, and the MLSS and MLVSS levels were monitored daily. The sludge volume index (SVI), THM concentration, pH, chlorine residuals and the concentrations of nitrate, phosphorus, and sulfate in treated water and the sludge of each system were analyzed periodically. Sludge wasting was also done daily in order to keep the MLSS level of the aeration tank of the OSA system at 2,000 mg/L. The representative results are shown in Figures 3 and 4.

The chlorination treatment of excess sludge at the chlorine dose of 0.066 g Cl₂/g MLSS and then returning this treated sludge with a duration of 20 hrs to an activated sludge system resulted in a 60% reduction of excess sludge. The principal disadvantage to the sludge chlorination is the formation of THMs. However, less than 200 ppb THMs were only detected in the effluent of the system. Such a low THMs concentration is probably due to the volatilization of THMs during the chlorine treatment using a sprinkler system to eliminate sludge foaming. Thus, the THMs did not become an issue in this process. Furthermore, soluble COD in the sludge increased significantly in the initial stage of the operation of the system. However, after a few weeks operation, the soluble COD concentration declined but still remained too high compared with that in the effluent of the reference system without the sludge chlorination treatment. Therefore, use of the sludge chlorination step may have these operational problems, which may make it difficulties for the application of chlorination-based sludge minimization approach in conventional treatment plants. However,

![Figure 3 Sludge chlorination setup and the MBRS systems](image-url)

![Figure 4 Sludge production rates in the reference line without and the testing line with the chlorination treatment of excess sludge](image-url)
integration of a membrane filtration module in the conventional system can solve these problems.

In order to identify the effective concentration of TCS on sludge growth, batch tests using activated sludge without addition of TCS were conducted in 2-L reactors at various concentrations of TCS ranging from 0.2 to 0.8 ppm. In each test, the initial biomass concentration was kept at around 2,000 mg/L, while the initial COD concentration was 500 mg/L. These batch experiments were carried out for 3 hours with a sampling interval at 30 min. Meanwhile, control experiments without addition of TCS were also conducted in parallel. In all the batch experiments, pH and DO were kept at around 7 and over 6.0 mg/L. Analytical parameters included COD, MLSS, and MLVSS. These parameters were measured according to the Standard Methods (APHA, 1998). In addition to these experiments, batch operation of the activated sludge culture with addition of TCS was also conducted for one month since there was concern that activated sludge microorganisms might develop resistance to the TCS effect or degrade the TCS so that TCS might lose effectiveness in stimulation of energy uncoupling. Three 15-L batch reactors filled with the non-TCS added cultivated activated sludge were employed initially. The first reactor received a dose of TCS at a 0.5-ppm level, while another was added at a 1-ppm level. Both dosings were conducted once per 24-hr cycle. The last served as the control system without addition of TCS. Prior to the TCS dosing, the supernatant in those two reactors was sufficiently removed after 30-min sludge settlement. This was to prevent significant accumulation of TCS in the reactors. To start these experiments, sludge was transferred from the cultivation reactor into each of these three reactors to maintain the initial MLSS level at 2,000 mg/L. The same synthetic wastewater as that used in the cultivation was fed to all the reactors at a constant COD level of about 500 mg COD/L. The MLSS in each reactor was maintained at 2,000 mg/L by wasting excess sludge which amount was precisely determined from the MLSS and the wasting volume. During the operation, MLSS and COD were measured before the withdrawal of sludge as well as after the daily addition of wastewater in order to determine the sludge wastage precisely. All three experiments were conducted for one month at 20°C. The major results are shown in Figures 5 and 6. These results confirmed that TCS is effective in reducing sludge growth rate. The 0.4-ppm concentration is found to be the threshold for triggering the sludge production reduction. Both the 3-hr batch tests with activated sludge developed without the presence of TCS and the 30-day operation of batch activated sludge cultures with TCS added demonstrated that sludge growth can be reduced by around 40% when the TCS concentration was from 0.8 to 1 ppm. Under such TCS concentration, substrate removal capability was not affected. It has also been found that the cause of the sludge reduction is associated with the enhancement of microbial activity and the percentage of active cells over the total cell number. This enhancement was directly confirmed with the DAPI-and CTC-staining techniques. The 1-ppm TCS concentration increased the microbial activity by 42% and raised the active cell percentage by 45%. The effectiveness

![Figure 5](https://iwaponline.com/wst/article-pdf/44/10/203/424185/203.pdf)  
**Figure 5** Effect of TCS concentration on sludge growth yield

![Figure 6](https://iwaponline.com/wst/article-pdf/44/10/203/424185/203.pdf)  
**Figure 6** Effect of TCS concentration on reduction of excess sludge
of TCS can be sustained during the 30-day operation of activated sludge batch culture. Introduction of TCS concentration at a 1-ppm level does not affect the treatment performance of the activated sludge cultures. Therefore, it may be feasible to apply this uncoupler to achieve excess sludge minimization in activated sludge processes.

Conclusions
This paper studied three new approaches to reduce excess sludge in activated sludge systems. The main conclusions are: 1) the modified activated sludge process (OSA) is effective in reducing excess sludge; when ORP in the sludge holding tank was kept at $-250$ mV, more than 50% of the excess sludge can be reduced. This process is able to maintain the effluent quality of COD and SS and even perform with a better sludge settleability than a conventional system; 2) Treatment of excess sludge treatment at a chlorine dose of 0.066 g Cl$_2$/g MLSS can reduce excess sludge by 60% and did not induce higher concentration of THMS than 200 ppb in the treated water. However, sludge settleability will be sacrificed when excess sludge chlorination is introduced; and 3) addition of TCS is able to reduce sludge growth effectively when its concentration is greater than 0.4 ppm. When TCS is added at 0.8 ppm, excess sludge can be reduced by 45%.

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References