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Pursuing Simple and Low-cost Operation for Sludge Reduction via a Self-Oxidized Reduction Process in a Field-Scale Sewage Treatment Plant

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Authors' contributions

The present study was carried out in collaboration among the authors. Authors RS and ST designed, performed, analyzed, interpreted, and drafted the manuscript. Authors YH, MW, and MT provided technical support and revised the manuscript as well as supervised the research. All authors read and approved the final manuscript.

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ABSTRACT

Aims: A self-oxidized sludge reduction process was installed in a municipal sewage treatment plant at full scale in order to verify the efficiency of the process.
Study Design: A full-scale (100 m^3) self-oxidized sludge reduction tank was constructed in a municipal sewage treatment plant and was operated for collecting data.
Place and Duration of Study: The sewage treatment plant was located in a city of Toyama Prefecture, Japan. The field test was conducted from FY 2011 to 2015.
Methodology: By observing BOD, SS, and COD_{MN} and controlling them to conform to industrial wastewater discharge standards, the cost reduction of waste sludge disposal resulting from sludge mass reduction via the self-oxidized process was evaluated.

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Results: In this study, the operation cost for a local small government in charge of the plant was reduced by more than 50,000 USD per year.
Conclusions: The self-oxidized method can be an alternative sludge reduction method.

Keywords: Sewage treatment; sludge reduction; self-oxidized process; MLSS; WSSS.

1. INTRODUCTION

The activated sludge process is the main process for sewage treatment worldwide and has a long history, as more than 100 years have passed since Ardern and Lockett discovered it in England in 1914 [1]. Because it is the main process, optimal operation of the activated sludge process has been researched via modeling [2,3]. However, the stakeholders of the process always have a headache—sewage sludge disposal. The disposal cost of the sludge is a heavy burden because it comprises more than half the amount of the total sewage treatment cost.

To date, many studies have been undertaken regarding utilization and reduction of waste sludge from the activated sludge process. In terms of the utilization, production of energy, in such forms as heat, electricity, and biofuel, has been proposed [4]. Su et al. (2017) [5] used solar energy to improve energy performance at sewage treatment plants. Using sewage sludge as fertilizer through composting is still a major utilization option [6,7]. Biodiesel production from lipids in sewage sludge has been researched for energy production [8,9].

Recent papers about sludge reduction are as follows. Song et al. (2010) [10] studied aerobic sludge digestion combined with electrical pretreatment. Yasin et al. (2014) [11] reported on microbial addition for utilizing excess sludge. Upgrading a system by combining a membrane bioreactor with an up-flow anaerobic sludge blanket reactor [12] or with thermo-alkaline hydrolysis [13] was also investigated for waste activated sludge reduction. Sludge reduction technologies generally are classified into three groups: chemical, physical, and biological approaches [14]. Ultrasonic, thermal, microwave, and focused pulsed pretreatments; lysis-thickening centrifugation; stirred ball milling; and high-pressure homogenization are designated as physical approaches. Oxidation, alkaline, and free nitrous acid (FNA) pretreatments are deemed chemical approaches. For a biological approach, temperature-phased anaerobic digestion (TPAD) is reported here. All these approaches have advantages, such as improved sludge settleability, and disadvantages, such as high investment and running costs and limited applicability, e.g., only for at the lab scale [14]. According to Li et al. (2016) [15], composting and anaerobic digestion has been the most popular disposal and treatment methods for sewage sludge.

Sludge reduction is a big issue in Japan, especially for local governments. Shrinking tax income because of population decrease, such as through migration to cities, and an increase of senior population means local governments in Japan must ponder reduction of their running costs. Hopeful possibilities for the reduction in the running costs are reductions in sewage treatment costs, especially a decrease in costs from reducing waste sludge generation.

In this study, waste activated sludge was treated via a self-oxidized process at field scale for reducing its mass. The concept is the cheapest and simplest approach for the project's target entity—local governments that are not wealthy. Activated sludge mostly consists of biomass such as prokaryotes and eukaryotes [1], which comprise more than 80% of suspended solids in weight. The self-oxidized process is a starvation process that degrades the microorganisms into CO_2 [16]. Waste sludge was routed to an isolated reactor and aerated without food. Without food, microbes start to degrade. Some are preyed on by other microbes, with the predators also finally oxidized and solubilized in the water. Consequently, the sludge mass is reduced.

2. MATERIALS AND METHODS

2.1 Materials for the Sewage Treatment Process

A field experiment was conducted at the N sewage treatment plant in the city of A in Toyama Prefecture, Japan. The N plant was designed for the population of approximately 3,000 in the area and accepts 500 m^3 of dairy sewage inflow as well. This plant employs an oxidation ditch process, with a planned sewage quality of 195 and 157 mg/l for BOD and SS, respectively. The guaranteed quality of treated

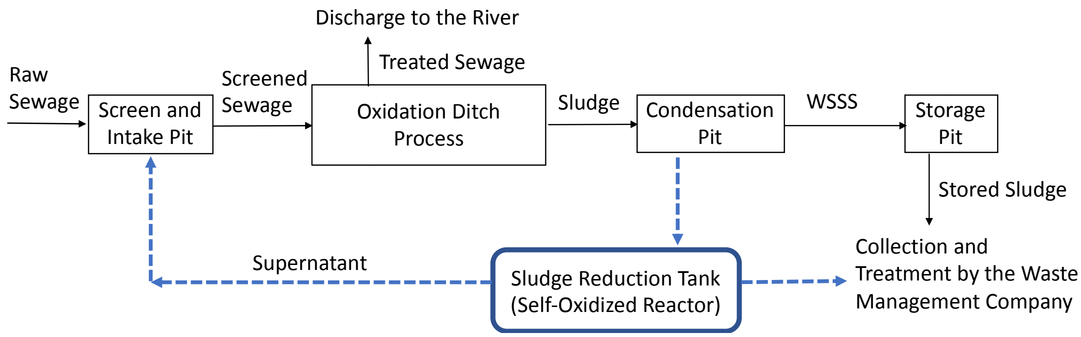

Fig. 1. Studied sewage treatment plant and self-oxidized process (solid lines indicate the plant's normal flow; dashed lines indicate the installed part and flow of the study)

water is 20 mg/l for both indicators. The plant flow is described in Fig. 1. Usually, 9 m^3 of sludge was withdrawn from the storage pit nine times per month.

2.2 Methods

2.2.1 Self-oxidized reactor

Fig. 1 shows where the part installed for the purpose of the study, i.e., the sludge reduction tank, fit into the flow of the plant. The tank was 100 m^3 in area, and waste sludge entered the tank from the condensation pit. The only aeration was supplied to the waste sludge in the tank. One m^3 per day of WSSS (waste sludge) was sent from the condensation tank to the sludge reduction tank. Figs. 2 and 3 show the sludge reduction tank when it was empty and in operation, respectively.

2.2.2 Analysis

Data were observed on a fiscal year (FY) basis. A fiscal year in Japan starts in April and ends in March of the following year. Measurements of COD_{Mn}, BOD, and SS in the effluent were done according to the Japanese Industrial Standards [17]. MLSS (activated sludge in an aeration tank) and WSSS were also measured in a routine analysis procedure following Sewage Works in Japan Standard Methods for the Examination of Water and Wastewater [18]. Average and maximum flow rates were measured directly at the intake pit.

3. RESULTS

3.1 Operation Data of the Plant

The average and maximum flow rates of the plant in FY 2015 which were supplied from the plant, are shown in Fig. 4. The daily average inflow rate ranged between 423 m^3 in October 2015 to 742 m^3 in January 2016. The highest maximum inflow rate was approximately 23,000 m^3, occurring in January 2016. The mean values of pH, temperature, BOD, COD_{Mn}, and SS of the inflow were 7.0 (range: 6.4–7.6), 19.9ºC (range: 11.8–25.3ºC), 142 mg/l (range: 91–210 mg/l), 79 mg/l (range: 60–100 mg/l), and 137 mg/l respectively, according to the data supplied from the plant.

Fig. 2. Tank when empty

Fig. 3. Tank in operation

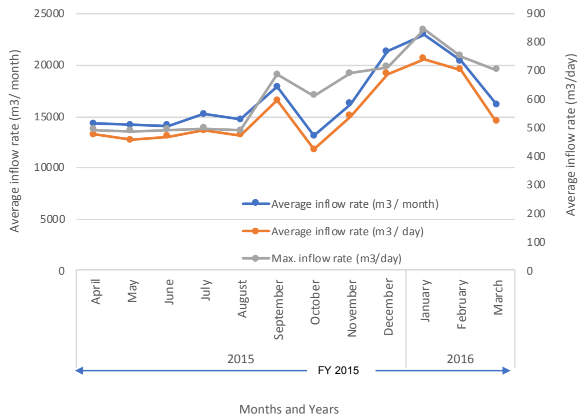

Fig. 4. Average monthly inflow rate of the plant for FY 2015

The COD_{Mn}, BOD, and SS concentrations of the effluents in FY 2015 are shown in Fig. 5. The COD_{Mn} values fluctuated from 5.2 to 8.0 mg/L, whereas the BOD values ranged from 0.8 to 4.3 mg/L. The COD_{Mn} values were always higher than those of BOD were. The SS values fluctuated from 2.0 to 5.1 mg/L. For industrial wastewater discharge, the standard values are 160, 160, and 200 mg/L for COD_{Mn}, BOD, and SS, respectively. According to the results, those three factors were well below their discharge standards.

Sludge reduction was traced from July 7 to September 12, 2013. Fig. 6 shows WSSS concentration and sludge mass reduction patterns. The highest value of 11,481 mg/l of WSSS was seen on July 15, and WSSS was reduced to 7354 mg/l by September 12, 2013. Following the WSSS decrease, the sludge mass was reduced from 747 to 518 kg during the two-month period (July 7 to September 12).

3.2 Sludge Mass Reduction

The amount of monthly sludge withdrawal and corresponding MLSS concentration in FY 2015 are shown in Fig. 7. The lowest sludge withdrawal was seen in June 2015 and was 41 tons. The highest was in November 2015 and was 77 tons. MLSS fluctuated from 2,250 mg/l in August 2015 to 4,100 mg/l in March 2016. The MLSS kept increasing in FY 2015; however, it decreased to 3,200 mg/L in FY 2016 (data not shown).

Fig. 8 shows the annual amount of sludge withdrawal in the period from FY 2005 to FY 2015. This study was started in FY 2011, and a clearly different trend was observed starting in that fiscal year. The amount was 773 tons in FY

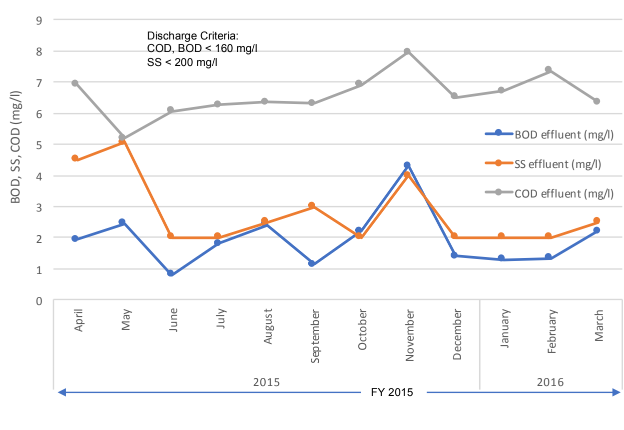

Fig. 5. BOD, SS, and COD concentrations in the effluent for FY 2015

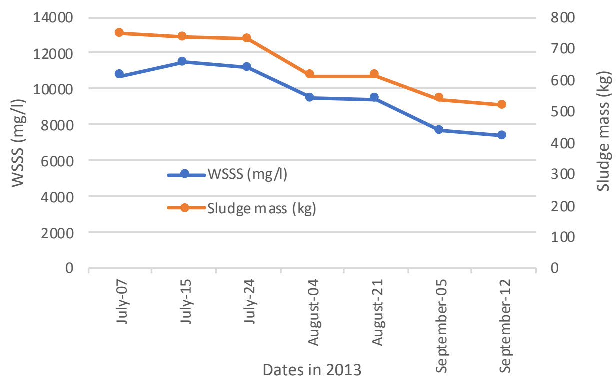

Fig. 6. WSSS concentration reduction during a period of 2013

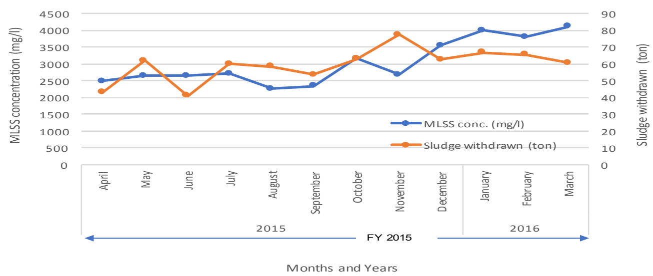

Fig. 7. MLSS concentration and sludge withdrawn in FY 2015

2005 and increased to 992 tons in FY 2010. It, however, drastically decreased to 682 tons and continued at the level until 2015.

4. DISCUSSION

Sludge reduction was observed as soon as this study started in FY 2011. Since the year, drastic reduction remained until the end of the study in 2015. WSSS was reduced by 36% during two months in 2013, and following the reduction trend, sludge mass was reduced by 30% (Fig. 6). This phenomenon implied that the self-oxidized reduction process effectively worked for reduction of the sludge. As shown in Fig. 8, the average amount of annual sludge withdrawn in the period without sludge reduction from FY 2005 to FY 2010 was 884 tons and that in the period with sludge reduction from 2011 to 2015 was 658 tons. If we assume the sludge treatment fee is 250 USD per ton, the annual cost for waste sludge treatment is 221,000 USD and 164,500 USD without and with sludge reduction, respectively. Thus, the average decrease in cost following sludge reduction is 56,500 USD. The running cost increase due to adopting sludge reduction was approximately 400 USD per month for electricity, as extra labor cost for hiring personnel to take care of the self-oxidized reactor was not necessary. Consequently, it can be said that a decrease of more than 50,000 USD (56,500 USD/year – 400 USD/month x 12 months/year) in cost annually was achieved after considering the running cost. This is a huge cost reduction for a local government.

An increase in the MLSS concentration can be expected when waste sludge is oxidized because oxidation of sludge means more nutrition is extracted into the supernatant, which is sent back to the beginning of the oxidation ditch process. As shown in Fig. 7, the MLSS concentration increased, reaching 4,100 mg/l in March 2016. In this case, the MLSS concentration decreased to the normal concentration range after the supernatant was no longer sent to the sludge reduction tank. As the MLSS concentration increased, the concentrations of BOD, SS, and COD_{Mn} in the effluent from the system remained at levels much lower than their standards, which implied that the self-oxidized sludge reduction process did not negatively affect the total sewage treatment system.

Fig. 9 shows the sludge reduction percentage and sludge retention time (SRT) for different sludge treatment methods [14,19]. For ultrasonic treatment, for example, sludge reduction was 25–91% and SRT was 8–22 days [14]. Sludge reduction and SRT were 10–100% and 28 days, respectively, for ozonation. The ranges show the variation in the results of different researchers' experiments. As illustrated in the figure, self-oxidized treatment (this study) shows a low sludge reduction percentage and the longest SRT, making it seem an inappropriate treatment method to choose for sludge reduction.

Table 1 lists the advantages and disadvantages of each treatment method [14]. Disadvantages include worsening of sludge settleability and an increase in COD of the effluent; yet, the most concerning for stakeholders is the cost. The method that shows low capital and running costs is FNA; therefore, FNA seems the optimal choice. However, its application is still only at a lab-scale level. As shown in the table, the ultrasonic and anaerobic digestion methods indicated either a low capital or running cost, yet the remaining of the two costs for each was high. Moreover, although no relationship between sludge settleability and COD in the effluent was found, an increase in COD of the effluent is a concern that stakeholders have to consider because the effluent quality must remain below the level of the discharge criteria. As displayed in the table, the self-oxidized method can be a good alternative because of its low cost and other operational advantages, even though it has a long SRT compared to the other sludge reduction methods.

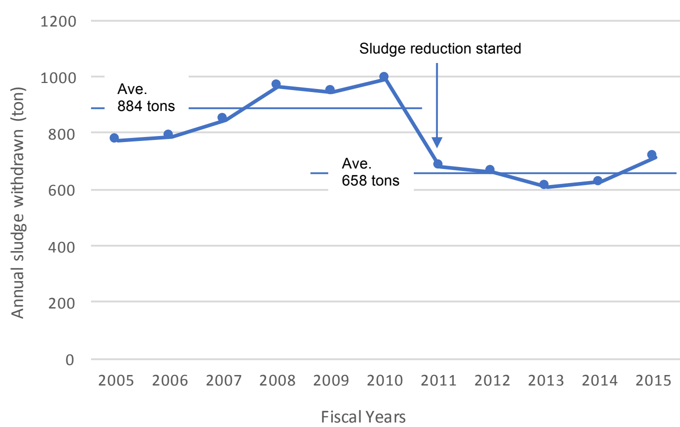

Fig. 8. Sludge reduction trend before and after sludge reduction started in 2011

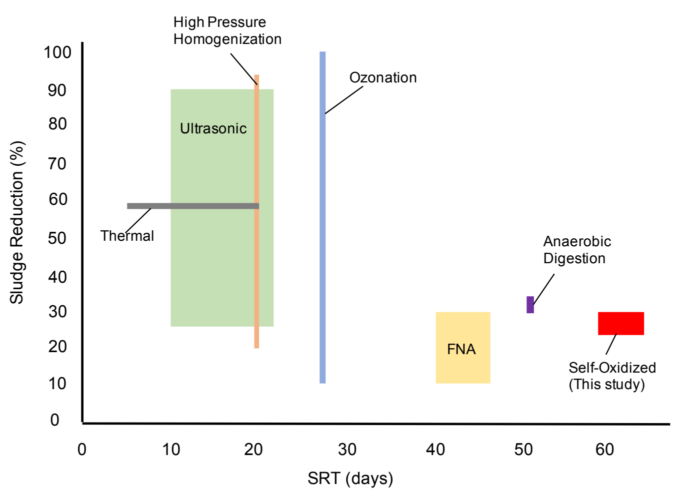

Fig. 9. SRT versus sludge reduction for different sludge treatment methods (A large box indicates a wide range of sludge reduction and SRT.)

Table 1. Advantages and disadvantages of different treatment methods

Treatment classification	Treatment method	Cost		Odor formation	Sludge settleability	COD in effluent	Operation scale
		Capital	Running				
Chemical	Ozonation	High	High	No	Improved	Increased	Full
	Free Nitrous Acid (FNA)	Low	Low	-	No effect	No effect	Lab
Physical	Ultrasonic	Low	High	No	Worsened	Increased	Full
	High-pressure Homogenization	High	High	No	Improved	Increased	Full
	Thermal	High	High	Yes	Improved	Increased	Full
Biological	Anaerobic Digestion	High	Low	Yes	-	-	Full
	Self-Oxidized (this study)	Low	Low	No	No effect	No effect	Full

Note: The symbol "–" indicates no data

5. CONCLUSIONS

The self-oxidized method was employed for sludge reduction at full scale. Although the method has some disadvantages, such as a long SRT and a low sludge reduction efficiency, it can be considered an alternative sludge reduction method. MLSS was stable during the experimental period and the quality of the treated wastewater was well below their discharge criteria. In this study, the operation cost for a local small government decreased by approximately 50,000 USD per year. The results of this study, therefore, encourages Japanese local governments in sludge reduction on their sewage management. The self-oxidized method for sludge reduction of sewage treatment should get more attention and be employed in not only Japan but also other developing countries because of its simplicity and low cost.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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