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High-pressure jet device for activated sludge reduction: Feasibility of sludge solubilization

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ABSTRACT

The objective of this study was to investigate the feasibility of a high-pressure jet device (HPJD) as an alternative technology to reduce the amount of excess activated sludge in a low-cost and simple manner. The device received concentrated activated sludge from two different ports: a horizontal port that transferred activated sludge with a jet flow via a nozzle and a side port that aspirated activated sludge with air. An investigation into the manner in which activated sludge was supplied indicated that the activated sludge conveyed by horizontal jet flow with aspiration from the elevated side port provided the highest degree of activated sludge reduction in the mixed liquor suspended solid (MLSS). The degree of reduction was 12.2% and the viable microorganisms decreased by 42.8%. The injection ratio *R* was defined as the amount of activated sludge from the side port to that of the nozzle. We found an optimum value of three with a MLSS reduction of 40%. The eluted constituents from the damaged cells or the intracellular compounds were biodegraded by the intact activated sludge. Estimation on cost and performance for activated sludge reduction, based on the energy and MLSS reduction, showed that the HPJD is twice as cost-effective as conventional technologies and that the throughput is 3.2–7.2 times as high as a high pressure homogenization device.

1. Introduction

Activated sludge systems are important in industrial and municipal wastewater treatment plants (WWTPs) [1]. Activated sludge systems produce excess sludge because of excess growth of microorganisms incorporating organic carbon and nitrogen compounds dissolved in incoming wastewater. The cost of excess sludge treatment accounts for 18–57% of the total operational cost of WWTPs, and this is, therefore, an engineering challenge [2]. This challenge warrants the development of a system to reduce the amount of excess activated sludge.

A mechanism of excess activated sludge reduction is generally destruction of bacterial cell walls and membranes by a sludge reduction technology, which releases organic carbon to be mineralized into carbon dioxide by metabolisms of intact microorganisms in a bioreactor. Several technologies, based on chemical, physical and biological methods to reduce excess activated sludge production, have been developed. Ozonation is one of the most broadly used chemical treatment technologies [3–6]. Alternative chemical technologies for excess activated sludge reduction are chlorination [7–10] and alkali-thermal treatment, and these technologies have previously been investigated [11–13]. Milling treatment [14], thermal processing [15], and ultrasonic treatment [16–18] are representative physical treatment technologies for excess activated sludge, which have been intensively investigated due to their high throughput and simplicity. However, the disadvantages of these chemical treatments are the high cost of chemical agents and the cost of electricity for the generation of ultrasonic waves and heat to solubilize microorganism cells [19]. On the other hand, anaerobic or aerobic sludge digestion, a representative biological method, is

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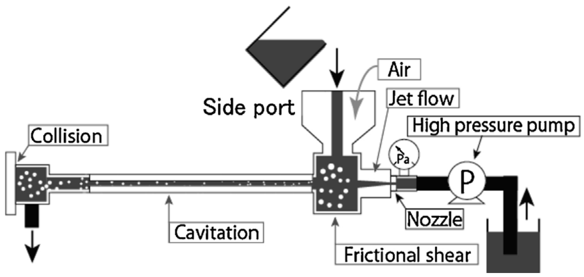

Fig. 1. Conceptual high-pressure jet device, the HPJD. Some activated sludge is transferred to a nozzle by a high-pressure pump and conveyed horizontally to the HPJD whereas the other is drawn from the top (side) port and mixed with air.

an option to reduce excess activated sludge. However, biological treatment requires stringent operational conditions, e.g., temperature, solid retention time, volumetric organic loading rate, pH and so on, to sustain stability of activated sludge reduction performance [20–22].

To reduce excess activated sludge in a cost-effective and high-throughput manner, a high-pressure jet device (HPJD) was developed. This device has originally been applied for washing of soil contaminated with insulation oil, resulting in high washing performance of the soil in an extremely short time [23]. This technology potentially broadens the applicability to excess activated sludge reduction. The HPJD consists of a high-pressure pump, which transfers the activated sludge, and pipes of different diameters together with a collision plate at the edge (Fig. 1). Two influent ports are used for activated sludge injection in a jet flow manner through a nozzle and the sludge is drawn at the top of the pipe (side port). Jet flow is generated by lateral flow through the nozzle and this enhances the negative pressure in a HPJD so that activated sludge from the side port is taken with air, resulting in intensive mixing in the pipe. The accepted mechanisms of activated sludge solubilization are (1) cavitation, (2) frictional shear and (3) collision. Cavitation is caused by the transport of activated sludge into a zone with a narrower diameter pipe in which the formed fine bubbles collapse, resulting in a significant increase in temperature [24]. Frictional shear likely occurs at the point where the activated sludge that falls vertically from the top port contacts the laterally transferred sludge. The high velocity of the activated sludge expectedly leads to a compression of microorganism cells on the steel plate at the end of the pipe. These multiple effects potentially enhance the solubilization of the microorganism cells leading to excess activated sludge reduction. In addition, the forced sludge aspiration accelerates the throughput capacity of the activated sludge to be treated. A similar device without a side port from which activated sludge is fed has been designed for the enhancement of cavitation for water sterilization [25], pretreatment for anaerobic digestion [26] and activated sludge reduction [27]. However, the application of a HPJD device where multiple factors are at work in addition to cavitation has not been investigated to date. Because of these multiple factors, which are distinct from a high pressure homogenization (HPH) where cavitation is a main factor for cell destruction [27], a HPJD is a promising simple, high-throughput and chemical-free sludge reduction technology. Additionally, it can be installed into the return of a sludge line in an activated sludge system.

This study was therefore, undertaken to evaluate the effectiveness of a HPJD to reduce the volume of activated sludge from a municipal wastewater treatment plant by batch experiments. Specifically, the manner and degree of activated sludge supply from the two ports were investigated by measuring the magnitude of the reduction effect, the viability of bacterial cells and the availability of treated activated sludge as a substrate after HPJD application.

2. Materials and methods

2.1. High-pressure jet device (HPJD)

Activated sludge was injected into the HPJD, *a.k.a.* the DEM® (Dojo-Kankyo Process Institute, Yokohama, Japan). The HPJD has two influent lines where activated sludge is supplied as shown in Fig. 1. One of the two lines was supplied horizontally and the other vertically. The activated sludge that was added horizontally was transferred using a nozzle and a high pressure pump (HPJ-160, Tsurumi Manufacturing Co., Ltd. Osaka, Japan). Because of waste activated sludge handling issues, two HPJDs with different throughput capacities were made: one was used to investigate the effect of activated sludge on the degree of solubilization and it had a total length of 1.5 m, a nozzle diameter of 2.5 mm and a high pressure pump flow rate of 27 L/min, which ensured a maximum pressure of 4.5 MPa, whereas the other had a total length of 1 m, a nozzle diameter of 0.7 mm and a high pressure pump flow rate of 10 L/min, ensuring a maximum pressure of 6 MPa.

2.2. Source of activated sludge

The activated sludge used in this study was obtained from a line of concentrated activated sludge from a secondary clarifier in the full-scale municipal WWTP (Kitatama Ichigo Water Reclamation Center, Tokyo, Japan). This WWTP employed a conventional activated sludge system, continuously receiving municipal wastewater with average pH, COD_{Mn}, BOD, NH_4^+, total phosphorus and suspended solid (SS) concentrations of 7.61 ± 0.29, 100 ± 19 mg/L, 153 ± 38 mg/L, 18.3 ± 2.3 mg-N/L, 3.3 ± 0.4 mg-P/L and 153 ± 70 mg/L, respectively. Hydraulic and solid retention times of the aeration tank were controlled at 7.8 h and 8 day, respectively, resulting in mixed liquor suspended solid (MLSS) and mixed liquor volatile suspended solid (MLVSS) concentrations of 1300–1500 mg/L and 1100–1200 mg/L. The initial MLSS concentration used in this experiment differed depending on purposes and days when concentrated activated sludge was taken, i.e., 4000 mg/L in the experiment 2.3 and 6000–11,000 mg/L in the experiment 2.4. Before the HPJD experiments, the sludge was subjected to intense mixing to completely detach any bubbles generated mainly by denitrification.

2.3. Effect of the HPJD's operating conditions on the degree of solubilization

To determine the effect of manner of sludge supply on the degree of activated sludge reduction, three types of HPJD configuration were used, as shown in Fig. 2. The three methods used to supply activated sludge were, Run 1: supply of activated sludge in the horizontal direction by high-pressure jet, Run 2: supply of activated sludge in the horizontal and vertical upper directions, Run 3: supply of activated sludge in the horizontal and vertical lower directions. The latter direction employs the suction of activated sludge from the bottom of the HPJD (Run 2) and the top of the HPJD (Run 3). In addition to the aspiration effect from Run 2, the configuration in Run 3 allows air to be sucked downwards as fine bubbles, which potentially dissipates by cavitation. The experiment was initiated by the supply of 80 L of activated sludge to the nozzle in Run 1 and 40 L of activated sludge to both the nozzle and the lower or upper ports in Run 2 and Run 3, respectively. The discharged activated sludge from each HPJD was subjected to a maximum of five HPJD treatments. After each treatment, 50 mL of the activated sludge was taken for measurement of MLVSS whereas the rest of the samples were used for further analysis. Microorganism cell viability in the treated activated sludge, as an indicator of the degree of activated sludge solubilization upon HPJD treatment, was performed