Effect of Ozonation on Reduction of Volume and Mass of Waste Activated Sludge

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Abstract: The effect of ozonation on sludge treatment was investigated. The main objective of this research was to assess the effectiveness of different ozone doses on sludge disintegration and mineralization, for which the parameters of TS, TSS, VS and settleable solids were chosen. The results indicate that the ozone at doses between 0.125 to 2 gO3/gTS reduced TS, TSS and VS between 15.4% to 80.7%, 8.3% to 47.9% and 5.8% to 45.9%, respectively. It can be concluded from these results that the ozone could mineralize a high fraction of volatile solids so that the minimum reduction of VS in waste activated sludge required by EPA was achievable via ozonation. Ozonation also improved the settleability of the sludge which resulted in reducing the sludge volume. Reduction of sludge volume can decrease the cost of its handling.

Key words: Biological wastewater treatment, sludge, stabilization, ozonation, solid disintegration

INTRODUCTION

Biological treatment is the most used technology in wastewater purification[1]. As a biological technology, activated sludge system has been employed to treat a wide variety of wastewater, and over 90% of the municipal wastewater treatment plants use it or one of its modifications as the core part of the treatment process[3]. A considerable volume of sludge is generated during operation of activated sludge, a part of which should be withdrawn and disposed in order to maintain appropriate level of biomass concentration in the aeration basin[1]. It must be noted that the excess sludge generated from the biological treatment process is a secondary solid waste that must be disposed of in a safe and cost-effective way[2]. Processing and disposal of excess sludge is one of the most serious problem encountered in wastewater treatment in terms of environment, finance and technology[4] so that it accounts for 50–60% of the total expense of wastewater treatment plant[8,5].

The conventional disposal methods such as landfill or ocean dumping may cause secondary pollution problems and are strictly regulated in many countries[3]. Therefore, prior to safe disposal solids and biosolids are stabilized to reduce pathogens, eliminate offensive odors and inhibit and reduce or eliminate the potential for putrefaction[6].

A conventional treatment to stabilize excess activated sludge is the aerobic digestion process; however, due to the complicated, non-homogeneous nature of sludge, it requires long retention times to meet sludge reduction efficiencies as well as large construction cost. In order to maximize the reduction efficiency in digesters, solids contained in sludge need to be destructed and converted to readily degradable substance[7]. A number of processes including thermal energy[8], ozonation[9,10], alkaline[11,12], high pressure[13], mechanical disintegration[14,15], acidification[16] and ultrasound[17,18] have been investigated for decomposition and pre-treating waste sludges. Among these processes, ozonation is of special interest because it has high oxidation potential, no oxidant residues are remaining and no increase in salt concentration occurs[19]. Muller reported that the ozonation of sludge was the most cost effective as well as reached the highest degree of disintegration among several developing disintegration methods[20].

Scheminski et al.[21] reported that sludge particulates were transformed into soluble composition regarding protein, lipid, and polysaccharide at an ozone dose of 0.05-0.5 gO3/gDS and there is a phenomenon of mineralization for higher ozone dose[19,22]. When sludge is kept contact with ozone in the ozonation unit, it reacts with solids in two different ways: the direct and the indirect reaction, both reactions occurring simultaneously[19].

Nevertheless, most studies on the sludge ozonation processes have focused either on the degradation and pretreatment of activated sludge, or on reduction of excess sludge in activated sludge systems[10], and only a few have applied to the stabilization of sludge.
The main purpose of this research was investigating the effectiveness of ozone dose on stabilizing waste activated sludge in a laboratory scale system. This paper presents the results of the effect of ozone dose on destruction of solids in sludge and on volume reduction of sludge.

MATERIALS AND METHODS

Characteristics of Waste Activated Sludge: Experiments were carried out on waste activated sludge taken from a local municipal wastewater treatment plant in Tehran, Iran. The sludge samples were taken from the return activated sludge line in activated sludge system. The sample bulk was stored at 4°C to prevent from changing the characteristics. The main characteristic of the tested waste activated sludge is given in Table 1.

**Experimental Apparatus and Procedure:** The schematic of set-up used in this experiment is given in figure 1. As illustrated in Fig. 1, the experimental set up consisted of a glass custom made cylindrical sparger as the ozone contactor, an ozone generator (ARDA, model COG-0M, type 1A), a diffuser to supply ozone to the sludge, an oxygen cylinder equipped with the regulator and flowmeter, a recirculation pump (Vicounte VHF-110P) and spry nozzle to break the foams that were generated during ozonation of sludge, an ozone off-gas destruction system, and valve and tubing. Ozone contactor was a 50 mm i.d. annular glass tube with the total volume of 2 L that in each run 1.5 L sludge was poured into it and ozonated. The experiment carried out at different batch runs consisted of several ozone doses between 0.125 to 2 gO3 gTS-1. Ozone-laden gas flow rate was fixed at 1 L min-1 in which ozone inlet concentration was about 0.45 g h-1. Hence, the ozone dose expressed as the mass of ozone consumed per unit mass of dried solids (gO3 gTS-1) varied by changing injection time of ozone-containing air. At each run, 1.5 L activated sludge was poured into the ozone contactor and was ozonated to the predetermined ozonation time. Ozone gas stream was introduced to the contactor at the through the diffuser located at the bottom of reactor. Each run was repeated three times and average of parameters was considered to evaluate the ozonation efficiency. Ozone concentration in gas phase, before and after reaction with sludge, was measured in order to calculate the amount of O3 that was transferred and consumed. The ozone transfer efficiency was found to be about 94% regardless of ozone doses.

**Analytical Methods:** In order to study the performance of the ozonation process in reduction of solids and volume of sludge, it was sampled before and after ozonation to analyze for total solids (TS), total suspended solids (TSS), volatile solids (VS), volatile suspended solids (VSS) and settleable solids. All these measurements were carried out on samples, according to Standard Methods. The pH of samples was measured using a pH-electrode. Ozone concentration in inlet and outlet gas streams was sampled by sparging a measured volume of the air into 250 ml of KI solution. The solution in the sparger was then analyzed by titration against sodium thiosulfate (Na2S2O3). The pH --- 7.3

<table>
<thead>
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<tr>
<td>TS</td>
<td>mg L-1</td>
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<td>VS</td>
<td>% of TS</td>
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<tr>
<td>TSS</td>
<td>mg L-1</td>
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</tr>
<tr>
<td>VSS</td>
<td>mg L-1</td>
<td>5910</td>
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<td>Settles solids</td>
<td>mL L-1</td>
<td>940</td>
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<tr>
<td>pH</td>
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**RESULTS AND DISCUSSIONS**

Solids Destruction and Reduction: The digestion processes are usually employed to reduce the volume and mass of sludge. To improve digestion efficiency, the most logical approach is to disrupt the microbial cells in the sludge. Figure 2 shows the effect of ozone dose on total and suspended solids content of the waste activated sludge. As it can be seen, the mass reduction of suspended solids in sludge increased with the increasing the rate of ozonation in where the attained destruction efficiency of TSS for ozone doses of 0.125, 0.25, 0.5, 1 and 2 gO3 gTS-1 was 15.4%, 34.3%, 56.5%, 70.1% and 80.7 %, respectively. The greater the ozone dose, the higher reduction in suspended solids was obtained. The main reason for mass reduction of sludge during the ozonation might be to rupture the cell wall and to release of extracellular and intracellular matter[8, 21]. The high disintegration percentage of the suspended solids of the sludge in ozonation reactor can be attributed to the high oxidation potential of ozone. Park et. al.[16] investigated the feasibility of ozonation process for treatment of waste activated sludge in a pilot-scale reactor and reported mass reduction of 70% at a dose of 0.5 gO3 gDS-1. Reduction of solids content of a sludge is caused to reducing cost of its handling. As ozonation proceeds, the destructed and solubilized solids can undergo further aqueous phase oxidation reactions as the supplying ozone is continued and become mineralized.

Effectiveness of ozonation in reduction of TS in sludge is also given in figure 2. TS reduction and hence sludge mineralization increased from 8.3 % to
Fig. 1: Schematic of the experimental set up

Fig. 2: Effect of dose of ozone on TS and TSS reduction

47.9% when ozone dose was increased from 0.125 gO₃ g⁻¹TS to 2 gO₃ g⁻¹TS. Fraction of TS lost represents the mineralization fraction of soluble organic matter, both initial and those produced from solid destruction, due to subsequent oxidation with ozone to carbon dioxide. Mineralization of soluble organic matter present in sludge liquor decrease the organic load added on treatment plant when the supernatant is returned to the head of the treatment plant for processing.

The result of the increasing solubilization and mineralization versus ozone dose obtained in this study is in accordance with the literature [24,27].

Reduction of Volatile Solids (Stabilization of Sludge): Volatile solids content of sludge is an indication of sludge its stability and reduction of VS used for assessing the effectiveness of a process in stabilizing a sludge. Variation of volatile solids of the waste activated sludge at several ozone doses was
investigated. Figure 3 shows the change in reduction of VS content of the sludge versus applied ozone dose. According to Figure 3, 5.8%, 12.2%, 23.3%, 34.5% and 45.9% of the sludge volatile solids concentration was reduced at ozone doses of 0.125, 0.25, 0.5, 1 and 2 gO₃ g⁻¹TS, respectively. Volatile solids destruction is an important indication in vector attraction reduction requirements promulgated by the EPA. EPA states that for proper vector attraction reduction, the volatile solids should be reduced by 38%.

Comparing the results obtained in this experiment with the EPA requirements demonstrate that the ozonation process could achieve the minimum 38% volatile solids reduction limitation set by EPA for reducing vector attraction at the ozone dose of less than 2 gO₃ g⁻¹TS, hence is a technical viable process for stabilization of sludge. In addition, these results confirm the conclusion drawn for mineralization of biomass. Except for a few article (such as 9), reduction of volatile solids of sludge in ozonation reactor has been reported by many researchers.

**Reduction of Sludge Volume:** Settleability of sludge is a key parameter in operation of sludge handling facilities in particular thickeners. The ideal case would result in a layer of biosolids with a layer of supernatant on top of the sludge. The supernatant could be returned to the head of the treatment plant and the biosolids could be disposed or utilized in various applications if the solids are properly stabilized. In this
experiment the parameter of settleable solids was used to evaluate the effect of ozone on sedimentation properties of the sludge. Results of settleable solids analysis is given in figure 4. As figure 4 depicts, ozonation drastically improved the sedimentation properties of the sludge particularly in doses lower than 1 gO\textsubscript{3}/gTS in where settleable solids of the sludge decreased from 950 mL L\textsuperscript{-1} (before ozonation) to 234 mL L\textsuperscript{-1}. When the dose of ozone was increased to 2 gO\textsubscript{3}/gTS the quantity of settleable solids reduced to 110 gO\textsubscript{3}/gTS.

At the end of each ozonation experiment, the ozonated sludge quickly settled to a small layer of biosolids, with a cloudy layer of supernatant. Boehler and Siegrist\cite{29} concluded that the reason for the improvement of the settling properties is the disintegrative properties of ozone. When sludge flocs are oxidized, they break apart into smaller pieces. This evens out the particle distribution, making the sludge easier to sediment. Improvement of sludge settlability resulted in reduction of sludge volume which in turn diminish its handling cost.

**Conclusion:** The feasibility of utilizing ozone to reduce mass and volume of the waste activated sludge was studied. It has been found that ozone with the dose of lower than 2 gO\textsubscript{3}/gTS could reduced a high fraction of solids in sludge as well as it volume. The reduction of solids in sludge contained disintegration and mineralization processes. Ozone mineralized around 50% of the VS at the dose of 2 gO\textsubscript{3}/gTS and thus achieved the reduction requirement set by EPA for proper vector attraction reduction (38%) at the dose of less than 1.5 gO\textsubscript{3}/gTS. It is concluded from the present work that the ozonation is a feasible and effective process for treatment of excess biological sludge in terms of reduction of solids and volume.

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**REFERENCES**