

Application of Dissolved Air Flotation Process for Industrial Sludge Thickening: A Laboratory-scale Study

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Abstract

Aims: Increasing population density in cities has led to an increase in industrial and municipal wastewater sludge generation volume. Dissolved air flotation (DAF) can widely be used for water and wastewater treatment. The aim of our study is to evaluate some DAF design parameters on biological sludge thickening which generated from an industrial wastewater treatment plant. **Materials and Methods:** This experimental research had been carried out as a laboratory-scale study on DAF process to thickening of the biological sludge. The required amount of sludge was taken once from the Amikabir industrial town wastewater treatment plant in Kashan, Iran. After determination of optimal recycling rate, pH, and coagulant dose, effects of pressure (3, 5, and 7 atm), flotation time (5 and 10 min), and coagulant addition were evaluated on DAF process efficiency. **Results:** According to this investigation results, the optimal pH and dose of coagulant were obtained 7.5 and 200 mg/L, respectively. Maximum process efficiency for the reduction of total dissolved solids (TDSs), total solids (TSs), and turbidity parameters was 61.01%, 84.02%, and 97%, respectively. Furthermore, the results showed that in contrast to time, coagulant addition and pressure have significant effect on DAF process. **Conclusion:** DAF process had suitable thickening efficiency to removal of TDS, TS, and turbidity on biological activated sludge.

Keywords: Flotation, industrial wastewater treatment, sludge disposal, thickening

INTRODUCTION

Increasing population density in cities has led to an increase in industrial and municipal wastewater sludge generation volume.^[1] Findings of the study in other countries have shown that countries such as the United States of America, China, Brazil, India, Indonesia, Russia, and Japan are involved to produce nearly 50% of world wastewater.^[2] Generated wastewater in various industrial portions contains significant amounts of organic pollutants.^[3] Hence, the widespread use of activated sludge process in wastewater treatment leads to an increase of industrial and domestic wastewater sludge production.^[4] These sludges contain trace elements, heavy metals, synthetic organic substances, pathogens, and parasites, and if they discharge to the environment without any treatment or used in agriculture, they can lead to contamination of water, soil, and agricultural products and finally create a serious risk to human health.^[5-7]

Although the sludge treatment and disposal is one of the priority issues but it is expected that its production will increase due to the intensification of current environmental legislation.^[8] For

example, organic sludge discharging into the ocean occurred from 77% in 2005 to 47% in 2009 and then to 14% in 2013.^[1] The cost of sludge treatment included 50%–60% of all wastewater treatment costs.^[8] Therefore, due to rise of these costs, it is essential to optimize mechanical equipment that are condensed on thickening and dewatering of sludges. Sludge thickening by different methods such as gravity settling, filter presses, belt filter press, vacuum filters, centrifuges, chemical processes, and dissolved air flotation (DAF) had been done.^[9]

DAF is a conventional wastewater treatment process since the 1950s. Application of this process in large plants is economical. Several studies have reported that the effluent of DAF process does not include any solid materials.^[10] Flotation

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is a physicochemical process that had advantages such as high speed, low space requirements, flexibility, and low costs. Although the flotation had different types, the application of DAF in water and wastewater treatment had been growing in the last three decades.^[11] DAF process had been used primarily for the removal of suspended and colloidal solids, such as fine particles, by lowering their density. This process can widely be used associated with water treatment and purification of municipal and industrial wastewater.^[12] Coagulation and flocculation are the essential processes for the removal of colloidal particles in water and wastewater treatment.^[13] Many coagulants can be applied in DAF systems, including alum, poly aluminum chloride, aluminum chloride, poly aluminum sulfate, ferric chloride, bentonite, and organic polymers.^[14] Many studies were investigated the effect of coagulation on DAF efficiency.^[15-18] A study reported that DAF process with magnesium coagulation had high efficiency to removal of *Chlorella zofingiensis* microalgae.^[19] Aluminum salts and iron salts are the conventional used coagulants. Due to public health concerns about residual alum ions,^[13] ferric chloride was selected in this study. In the DAF process, compressed air was injected into the wastewater tank. As a result, composed air bubbles attached the fine particles inside the tank and made them float on the water surface.^[20]

Amirkabir industrial town is located at the southeast of Kashan in Iran. This industrial town is composed of several units that most of them produce chemicals and foods. Amirkabir industrial town wastewater treatment plant (AITWTP) simultaneously treats the sanitary and processed wastewater and had 1112 square meters foundation, an area of 1.5 hectares, and a daily treatment capacity of 350 cubic meters. Few studies have been conducted on sludge thickening with DAF method. Considering the high volume of sludge generation and its related problems, such as treatment, transport, and environmental risks, we had tried to examine the effect of DAF process with and without coagulants addition on biological sludge thickening in our study.

MATERIALS AND METHODS

Dissolved air flotation laboratory-scale system

This experimental study was carried out on a batch laboratory scale on DAF process for thickening of biological sludge which withdrawn from the AITWTP in Kashan, Iran. All analyses were carried out according to the standard method in Research laboratory of Public Health School, Kashan University of Medical Sciences.^[21] The system consists of a flotation tank, pressure tank, and air compressor. Flotation tank had dimensions of 10 cm × 10 cm × 35 cm which filled by 3 L water (freeboard = 5 cm). At a distance of 3 cm from the bottom of the tank, a sampling valve was embedded. In addition, the pressure tank had a height of 45 cm and diameter of 35 cm with 173 L capacity. The DAF system is operated based on a batch reactor including coagulation, flocculation, and flotation steps in the flotation vessel, respectively.

Coagulant dosage and pH optimization

To determine the dosage and optimum pH, jar test was used, such a way that first, ferric chloride (Merck Company) was added as coagulant in different doses to determine the best coagulant dose effect on DAF efficiency by turbidity measurement from supernatant samples. Then, this test was done again in various pH ranges. Finally, maximum efficiency was obtained in specific pH and coagulant dose as optimum.

Recycling flow rate

Flotation system efficiency can be explained by the air-to-solids (A/S) ratio (usually considered in the range of 0.005–0.06 mg/ml in wastewater solid thickening) that effective for solid–bubble collision and separation.^[22] According to equation 1, recycling flow rate (R) was calculated at three pressures (3, 5, and 7 atm) and measured total suspended solids (TSSs):^[23]

$$\frac{A}{S} = \frac{1.3 S_a (fP - 1) R}{S_u} \quad (\text{Equation 1})$$

Where S_a is air solubility (18.7 ml/l at 20°C), R is recycling rate (%), f is fraction of air dissolved at pressure P (usually 0.5), P is pressure (atm), and S_u is suspended solids (mg/l).

According to equation 2, recycling flow rate can be defined by divided of saturated water volume (r) to raw wastewater volume (v).^[24]

$$R = \frac{r}{v} \quad (\text{Equation 2})$$

Equation 1 was used to calculate the recycling flow rate; in this manner, all parameters except pressure and recycling rate have been defined. The recycling flow rate depends on pressure. Hence, based on the pressure of 3, 5, and 7 atm, the recycling flow ratio was calculated 400%, 135%, and 87%, respectively. The theoretical size of the produced bubbles was determined in the range of about 40–140 μm according to specified pressures.^[25]

Experimental methods

Sludge sample was taken from the return activated sludge line in AITWTP, transferred to laboratory, and stored in refrigerator at 4°C. Sludge analysis including pH, TSS, TSSs, turbidity, and total dissolved solids (TDSs) was performed at room temperature according to the American Public Health Association (2540 B).^[21]

To determine the effect of DAF on sludge thickening, first, a certain volume of water was dumped into the pressurized tank under three pressures (3, 5, and 7 atm) for 30 min. At the same time, a certain amount of sludge sample according to the calculated recycling rates was dumped into the flotation vessel. Then, coagulation (1 min detention time and 180 rpm) and flocculation process (30 min detention time and 30 rpm) were applied. Next, the flow of saturated water with an average of 0.317 m³/h (SOR = 31.7 m³/m²/h) discharged into the flotation vessel, up to 3 L. Finally, after flotation process (2-pdf), samples

were taken at interval of 5 and 10 min from the supernatant and analyzed for TS, turbidity, and TDS parameters comparing with control samples to assess the efficiency of DAF process. The times of 5 and 10 min and pressures of 3 and 5 atm were selected according to prior studies; however, pressure of 7 atm was selected as a novelty and has not been seen in previous studies. Finally, according to sampling method, reduction of three parameters in supernatant was assumed as increasing in process efficiency. All experiments were repeated three times and the average values were used for statistical analysis.

Statistical analysis

First, Kolmogorov–Smirnov test was used for checking the data normality. Then, ANOVA test was used to analyze the results ($P < 0.05$). All the analyses were applied with SPSS Version 16.0. (Chicago, SPSS Inc).

RESULTS

To determine the optimal dose and pH, jar test was used. The results of this test showed that coagulation and flocculation process in pH = 7.5 and coagulant dose of 200 mg/l had the highest efficiency. The results of this study are summarized in Table 1.

Results of DAF process efficiency during detention time are shown in Figure 1. Based on data in Figure 1, it is obvious that DAF efficiency for TS in 5 and 10 min is 70.76% and 70.62%; for TDS it is 44.38% and 45.5%; and also for turbidity it is 91.64% and 89.66%, respectively.

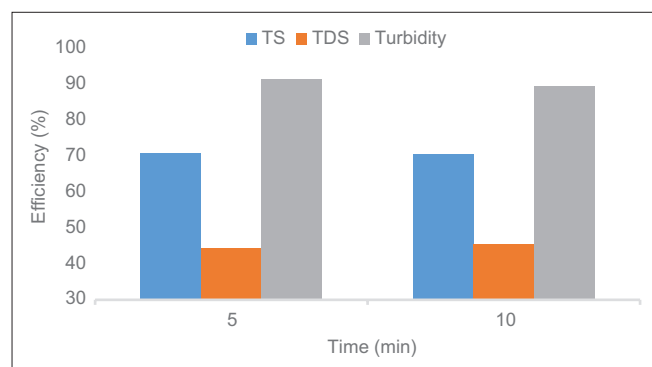


Figure 1: The effects of detention time on dissolved air flotation efficiency for sludge thickening

The effects of pressure on DAF removal efficiency for sludge thickening are shown in Figure 2. As shown in Figure 2, the average removal rate at 3, 5, and 7 atm was 77.6%, 76.33%, and 58.12% for TS; 56.85%, 47.15%, and 30.8% for TDS; 92.59%, 96.59%, and 82.76% for turbidity, respectively.

In our study, effect coagulant addition on DAF efficiency was determined. As shown in Figure 3, with coagulant addition, DAF has efficiency of 73.45%, 45.01%, and 93.94% for TS, TDS, and turbidity, respectively. Furthermore, without coagulant addition, these efficiencies were obtained 67.93%, 44.87%, and 87.37%, respectively.

DISCUSSION

The present study aimed to determine the effect of DAF process on waste activated sludge thickening of wastewater treatment plant of Kashan's Amirkabir industrial town. Maximum removal of TS was obtained under conditions of coagulant addition, 5 min of detention time, and pressure of 3 atm that was equal to 84.02%. Maximum TDS removal was determined 61.01% at coagulant addition, 5 min of detention time, and pressure of 3 atm. Furthermore, the best removal for turbidity was achieved 97.89% without coagulant addition, 10 min, and 5 atm.

As shown in Figure 1, efficiency removal of TS, TDS, and turbidity parameters, with and without coagulant addition, has little changes, and they have insignificant relationship over the time ($P > 0.05$) that is not consistent with the findings

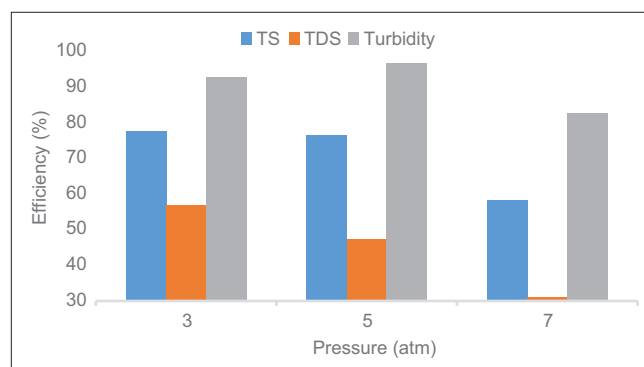


Figure 2: The effects of pressure on dissolved air flotation efficiency for sludge thickening

Parameter	Time (min)	Coagulation status, pressure (atm)					
		With coagulant			Without coagulant		
		3	5	7	3	5	7
TS	5	84.02±2.85	76.58±1.6	68.05±2.09	77.85±1.54	71.56±1.02	46.48±6.84
	10	73.64±1.16	78.43±1.15	59.97±8.8	74.91±1.53	78.77±0.85	58.01±1.79
TDS	5	55.19±6.56	47.13±2.1	27.91±1.51	56.13±9.91	46.68±0.62	33.23±3.2
	10	61.01±5.1	47.31±0.03	31.51±3.76	55.09±9.67	47.51±2.5	30.57±7
Turbidity	5	97.51±0.93	96.81±0.86	96.1±2.22	96.41±2.08	96.18±1.55	66.85±2.13
	10	89.2±9.2	95.5±2.39	88.5±9.23	87.26±2.01	97.89±0.61	79.61±0.46

TDS: Total dissolved solid, TS: Total solid

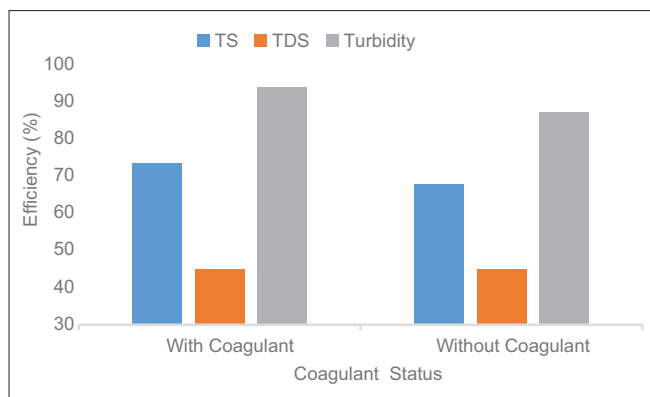


Figure 3: The effects of coagulant addition on dissolved air flotation efficiency for sludge thickening

of other studies.^[11,26-28] Typically, in these studies, increasing of efficiency was seen. The reason of this stability can be attributed to the detention time of less than 5 min. In addition, heavy flocs formation can be one of the effective factors on decreasing of DAF flotation ability over the time.

According to Figure 2, TS and TDS removal efficiency under conditions of various pressures and with/without coagulant addition significantly decreased ($P < 0.05$); however, pressure of 5 atm has maximum removal of turbidity, significantly. According to equation 1, the solubility of air in liquid increases with increasing pressure theoretically. In a study, with increasing of pressure from 0.1 Mpa to 0.5 Mpa, TS content of domestic wastewater reduced from 25 mgL⁻¹ to 12 mgL⁻¹.^[29] In addition, in the previous study which we done for thickening of hospital wastewater treatment plant sludge, increasing of pressure from 5 to 7 atm, caused to removal improvement of turbidity and EC, however, TS had little changes.^[30] This direct relationship between pressure and removal efficiency is also observed in several other studies.^[26,27] Considering the low application of DAF in studies related to sludge thickening, the reason of this inverse relationship can be attributed to the high concentration of TS in sludge and thus limitation of A/S ratio resulting from that concentration.

Except for the TDS parameter, coagulant addition caused to insignificant increasing of TS ($P > 0.05$) and significant increase of turbidity removal efficiency ($P < 0.05$). The stability of TDS can be due to the presence of coagulant salt in sludge. However, effect of coagulant absence in comparing with coagulant addition is appropriate. The results of one study showed that without using of chemical pretreatment, the removal of suspended solids and oil and grease increased 57% and 60%, respectively.^[31] In our study, cause of this phenomenon can be attributed to extracellular polymeric materials which have accounted 60%–80% of sludge. Many investigations have proved importance of these materials on the flocculation, settling, and dewatering characteristics of the sludge.^[32] In a study, coagulant addition leads to an increase in suspended solids removal from 82% to 99% that is consistent with our study results.^[15] In general, it can be concluded that

the efficiency of the process with the coagulant is higher than without coagulant addition.

CONCLUSION

According to our study findings, it can be concluded that DAF process is efficient for TS and turbidity removal for the industrial wastewater sludge thickening, but more study is necessary for final decision in this regard. In addition, maximum efficiency was obtained in the pressure of 5 atm, time of 5 min, and addition of coagulant. Therefore, considering the limitations of A/S, in future studies, it can be recommendable to the use of less concentrated sludge in the DAF process for the thickening. Furthermore, pressure of 7 atm not only economically but also in terms of efficiency has not been efficient and high-pressure levels application are not recommended. According to low difference in the efficiency of the process in the presence and absence of coagulant, it is suggested not to use coagulant for decreasing of operating costs.

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Conflicts of interest

There are no conflicts of interest.

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