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Removal of turbidity from water by dissolved air flotation and conventional sedimentation systems using poly aluminum chloride as coagulant

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ABSTRACT

Flotation is a method in which particles in liquid phase are transported to the surface by air bubbles. In this experimental study, a comparison has been made between conventional sedimentation and dissolved air flotation (DAF) systems to remove turbidity from water. Initially, optimal operational conditions for each system utilized using water artificially turbid with Kaolin. For each system, samples were taken at 20-min interval after the system reached its optimal operational conditions. Parameters, such as turbidity, alkalinity, temperature, pH, and total suspended solids, were measured. For 20, 30–50 and 90–110 NTU, turbidity average removal efficiencies in DAF system were 14.7, 11.1 and 10.9%, respectively, larger than the conventional sedimentation system. The effect of coagulant dose indicated that DAF system with lower dosage of coagulant have higher removal efficiency. On the other hand, the results showed that due to increased efficiency of DAF system, solid concentration of sludge produced in this system was more than the sedimentation system ($p < 0.01$). However, operation of DAF system needs accurate control devices and experienced technical staff to operate the system.

Keywords: Water treatment; Dissolved air flotation (DAF); Sedimentation; Turbidity; Poly aluminum chloride (PAC)

1. Introduction

Surface waters are considered as the most significant water supply sources, especially in large communities [1]. Surface waters in their path dissolve different types of impurities that need to be treated. Treatment chain would be selected based on raw water quality conditions, the level of treatment, and the type of consumption [2]. To remove particles and other impurities various technologies such as sedimentation, filtration, and flotation could be used [3].

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In sedimentation system, particles settle due to their weight (gravity force). In contrast, in flotation system, particles are transferred to the surface taking the advantage of bouncy force. The main advantage of flotation over sedimentation is that small and light particles could be eliminated faster [4]. Therefore, in flotation process, no need to have high-density floccules. In another word, low-intensity floccules are required to enhance flotation. The most considerable methods of flotation include air flotation, vacuum flotation, and dissolved air flotation (DAF).

In DAF system, air is dissolved in water or wastewater by pressurized air in a saturator. The saturated liquid is injected at the base of contact zone via a set of air diffuser [5,6]. Upon the injection of saturated flow, air bubbles with sizes between 10 and 100 µm are produced. In DAF system of low recharge rate, the whole system may be under pressure. In large units, a proportion of water or output wastewater (5–12%) is returned to saturator which in this case becomes half-saturated [7]. Returned flow would mix with main flow at the entrance to the saturator.

Sedimentation is defined as an operational unit in which colloids are separated due to their weight. This process is commonly used to treat drinking water and wastewater. The main prospects of this approach in treatment of water could be categorized to: preliminary sedimentation of surface water before slow sand filter, sedimentation of suspended particles before rapid filtration, sedimentation of floccules in lime-soda softening unit, and sedimentation of suspended particles in manganese/ferro removal unit. It has been demonstrated that DAF as in comparison with settling unit is more effective in separating low-density particles, and water containing algae, natural color, or low mineral water turbidity [5,8].

Jafarzadeh et al. [9] used DAF system for pretreatment of Karoon River water in Iran. He demonstrates that flotation system is not adequate to remove turbidity from Karoon water and a presedimentation system is needed. In his experiments, lack of control on the injection of coagulant materials was one of the limitations. Shahmansouri et al. [10] used DAF system to separate ionic detergent from surface water in Isfahan Water Treatment Plant and a satisfactory result was obtained. Kordmostafapour et al. [11] studied the removal of arsenic and aluminum from raw water using a DAF system using poly-aluminum-chloride (PAC) as a coagulant. They were able to achieve a removal efficiency of 99 and 99.1% for arsenic and aluminum, respectively.

Comparison between DAF and conventional sedimentation system showed that DAF is much more efficient in removing turbidity, especially when the water temperature is low [12]. In these experiments, the flotation time in DAF and sedimentation systems was 5 and 20 min, respectively. It has been shown that for flotation and sedimentation systems, there is no difference in the amount of required coagulant [12,13]. However, flotation system does not require polyelectrolyte as supplementary coagulant. A flotation system requires flocs that are porose with low density which can float easily.

The aim of this study was to investigate the efficiency of DAF system against conventional sedimentation system to remove turbidity.

2. Materials and methods

Schematic view of DAF and sedimentation systems used in this study are shown in Figs. 1 and 2, respectively. The DAF system consists of a rapid mixing unit of 20 cm (L) × 15 cm (W) × 15 cm (H) with a hydraulic retention time of 1 min, a two-stage flocculation unit of 26 cm (L) × 35 cm (W) × 62 cm (H) with a hydraulic retention time of 11 min, flotation unit of 96 cm (L) × 35 cm (W) × 62 cm (H) with a hydraulic retention time of 12–17 min (depending on the return flow), and saturation units of cylinder shape of 170 cm (H) and 30 cm diameter.

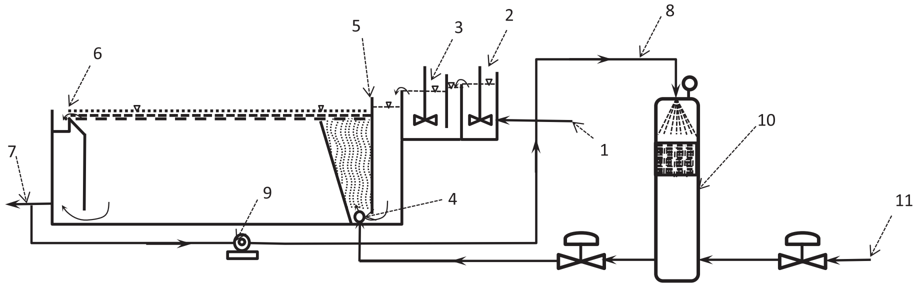

Fig. 1. DAF system used in this study: 1-feed water; 2-rapid mixing; 3-flocculants; 4-air sparger; 5-underflow baffles; 6-outlet weir; 7-clean water; 8-recycled water; 9-recycled pump; 10-saturator and 11-compressed air.

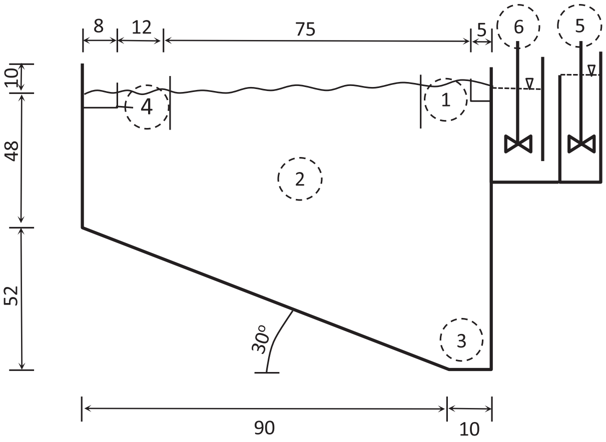

Fig. 2. Sedimentation system used in this study: 1-Entrance region; 2-Sludge region; 3-Sedimentation region; 4-Exit region; 5-Rapid mixing; 6-Slow mixing (Flocculant). (All units in centimeter).

In the rapid mixing part of DAF system, water and poly aluminum chloride (PAC) as coagulant was mixed and entered to slow mixing section to allow formation of flocs. Table 1 shows the characteristics of PAC was used in this study. Upon formation of flocs water was entered to flotation region of the system and mixed with saturated water containing small size air bubbles (water was saturated using an air compressor). The flocs were attached to the air bubbles and brought to surface due to buoyancy forces. The system was operated in continues mode having a discharge rate of 0.6 m^3/h. Four different pressures 3, 4, 5, and 6 atmospheres with three different recycle flows (recycle rate) 10, 20, and 30% were tested.

As indicated in Fig. 2, the sedimentation system consists of flocculation and sedimentation units. The flocculation unit was shared between DAF and sedimentation systems. The discharge rate for the sedimentation system was 0.1 m^3/h.

As part of this study, optimum operational conditions for DAF and sedimentation systems were obtained. The water used in this study was sourced from a bore located in the main campus of the University of Isfahan. Water was stored in a 2-m^3 tank and supplied to both systems after its turbidity was artificially adjusted. Parameters such as turbidity, alkalinity, temperature, PH and total suspended solid were measured according to standard methods for water and wastewater experiments [14]. Table 2 shows the quality of raw water used in this study.

Table 1
Characteristics of PAC

Parameter	Unit	Value
Appearance		Yellow powder
Content of Al2O3	% by mass	17.5 ± 1.0
Basicity	% by mass	45.0 ± 5.0
Chloride content	% by mass	20.5 ± 1.5
Specific gravity at 25°C		1.37 ± 0.02
pH of 5% solution	w/v	1.8–4.5

Turbidity level in both systems was artificially adjusted using Kaolin ($H_2Al_2Si_2O_8$–H_2O) which was purchased from Merck Company. For each level of turbidity, a certain mass of Kaolin was mixed in one liter backer and its turbidity was measured, then the mass of Kaolin for 2 m^2 of water was estimated and added to the supply tank. Three ranges of turbidities 20, 30–50 and 90–110 NTU were experimented. PAC doze was varied from 4 to 11 mg/l at 1 mg/l step using jar test. Table 3 shows condition under which jar tests were conducted.

The sedimentation and DAF systems were operated under an equilibrium conditions and samples were collected at 20 min intervals at the influent and effluent sections of both systems. The samples were analyzed in the water laboratory of Isfahan University of Medical Science.

3. Results and discussion

In order to access turbidity removal in DAF system, different saturation pressures and coagulant concentration have been studied. Fig. 3 shows the removal efficiency of DAF system for turbidity of 25 NTU for 10, 20, and 30% recycled flow. In these experiments,

Table 2
pH, alkalinity, and turbidity of raw water used in this study

Parameter	Minimum	Maximum	Average
pH	7.3	8.3	7.9
Alkalinity (mg/l $CaCO_3$)	130	180	150
Turbidity (NTU)	0	0.2	0.1

Table 3
Characteristics of jar test

Unit	Flotation unit (min)	Sedimentation (min)
Time for rapid mixing (380 rpm)	1	1
Time for slow mixing (30 rpm)	11	35
Time for sedimentation	30	30

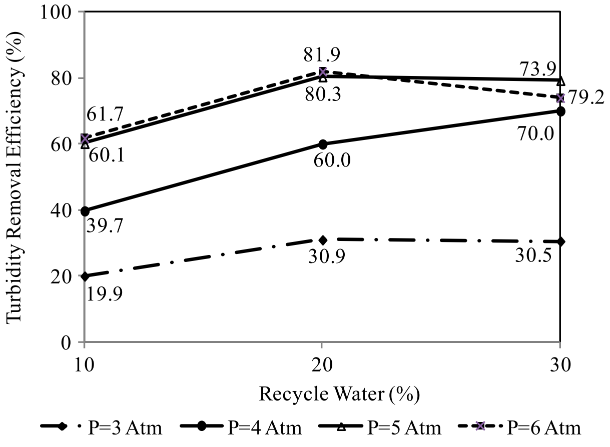

Fig. 3. Removal efficiency of DAF system.

concentration of PAC was fixed at 4 mg/l, but pressure was increased from 3 to 6 atm at 1 atm step. The results on this figure show that for P ⩾ 4 atm and recycle water 20%, maximum removal efficiency has occurred. Removal efficiency has not significantly changed when the pressure changes from 5 to 6 atm. It was noticed that when the recycle flow increases to 30%, due to instability in the flow, the removal efficiency slightly reduces. Based on these results, it was decided to operate the DAF system for 5 atm pressure and 20% recycle flow.

Furthermore, removal efficiency of both systems for various PAC concentrations was assessed and the results are presented in Fig. 4. Results show that, in overall, removal efficiency of DAF system is higher than the sedimentation system. For 20, 30–50 and 90–110 NTU, average removal efficiencies in DAF system were, respectively, 14.7, 11.1, and 10.9% larger than the conventional sedimentation system. Comparison of results from DAF and sedimentation systems shows that at low concentration of coagulant (PAC), the removal efficiency in DAF system is higher. However, as coagulant concentration exceeds 7 mg/l, for turbidity greater than 30 NTU, removal efficiency in DAF system decreases. It is likely that zeta potential of kaolin used in this study become less negative as PAC concentration increased. This might have been because the coagulation mechanism changed from one of charge neutralization to sweep coagulation [15]. It is interesting to note that for turbidity 30–50 NTU, removal efficiency in DAF system has not significantly influenced by concentration of coagulant. The results in this study provide information on the fact that DAF has higher efficiency with almost half dosage of PAC required in the conventional (sedimentation) system.

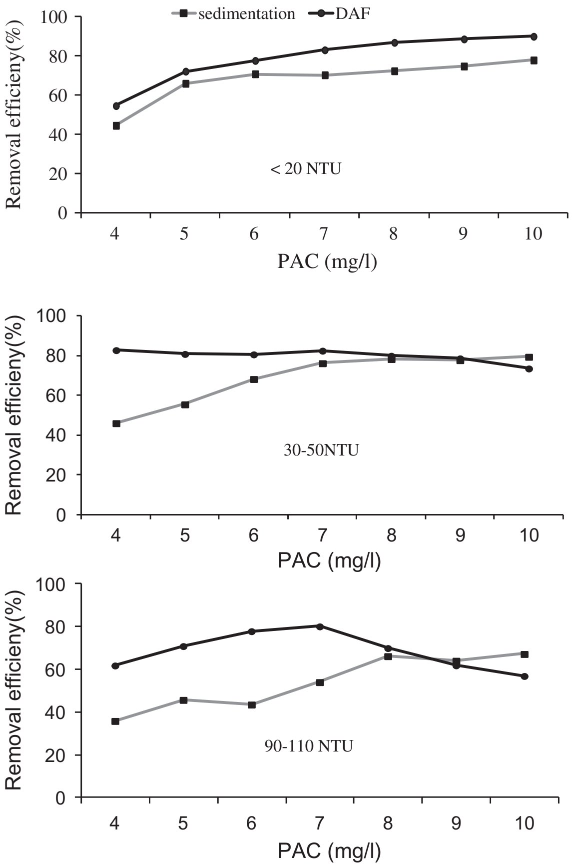

Fig. 4. Variation of removal efficiency with concentration of PAC in both DAF and sedimentation systems.

One of the advantages of DAF system over conventional sedimentation system is the amount of solid sludge that is removed in this system. Fig. 5 compares the percentage of the solid sludge is removed by these systems. As can be seen from this

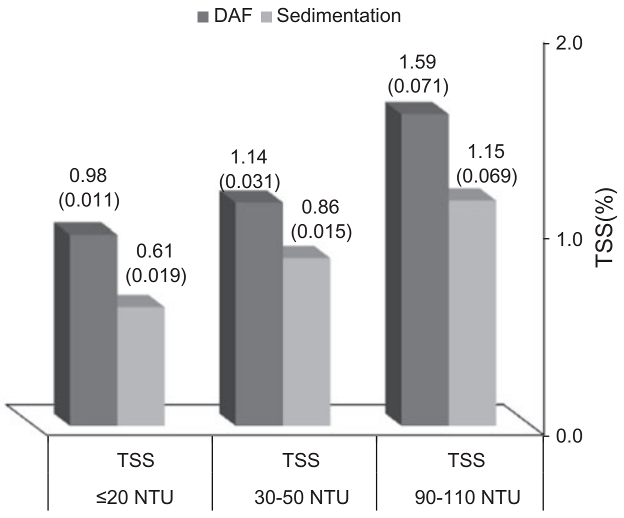

Fig. 5. Comparison of average solid sludge in DAF and sedimentation system (numbers in the bracket are standard deviation which is based on three runs, $p < 0.01$).

figure, for all level of turbidity was tested, solid sludge produced in DAF system is larger by about 30%.

4. Conclusion

In this study, DAF and conventional sedimentation systems were compared. The results indicated that DAF system has higher removal efficiency and needs less coagulant as in comparison with conventional sedimentation systems. However, accurate control devices and operational technique is needed to operate the system.

References

[1] S.R. Qasim, E.M. Motley, G. Zhu, Water Works Engineering: Planning, Design, and Operation, Prentice Hall, Upper Saddle River, NJ, 2000.

[2] H.J. Kiuru, Development of dissolved air flotation technology from the first generation to the newest (third) one (daf in turbulent flow conditions), Water Sci. Technol. 43 (2001) 1–7.

[3] J.W. Patterson, Industrial Wastewater Treatment Technology, Butterworth Publishers, Stoneham, MA, 1985.

[4] J. Rubio, M.L. Souza, R.W. Smith, Overview of flotation as a wastewater treatment technique, Miner. Eng. 15 (2002) 139–155.

[5] J.K. Edzwald, Dissolved air flotation and me, Water Res. 44 (2010) 2077–2106.

[6] T. Schofield, Dissolved air flotation in drinking water production, Water Sci. Technol. 43 (2001) 9–18.

[7] J.D. Farmerie, Dissolved Air Floatation as a Cost-effective Alternative for Potable Water Clarification. F B Leopold Co., 2005. Available from: https://awwoa.ab.ca/home/pdfs/Dissolved%20Air%20Flotation.pdf (accessed March 20, 2013).

[8] S.P. Liu, Q.S. Wang, W.J. He, H.D. Han, X.H. Fan, T.J. Geng, Comparison of dissolved air flotation and sedimentation in treatment of typical north china source water, Process Eng. 7 (2007) 283–287.

[9] N. Banisaeid, N. Jafarzadeh, F. Tarkian, G. Eidan, Evaluation of dissolved air flotation (Daf) for pretreatment of the Karoon river water, Water Wastewater 63 (2007) 13–23.

[10] M.H. Mahmoudian, M.R. Shahmansoori, M.M. Amin, M. Ghasemian, Treatment spent filter backwash water using dissolved air flotation (Daf) in Isfahan Wtp, Water Pract. Technol. 3 (2008) 1–8.

[11] F. Kordmostafapour, H. Pourmoghadas, M.R. Shahmansouri, A. Parvaresh, Arsenic removal by dissolved air flotation, J. Appl. Sci. 6 (2006) 1153–1158.

[12] J.K. Edzwald, J.P. Walsh, Dissolved Air Flotation: Laboratory and Pilot Plant Investigations, AWWA Research Foundation and American Water Works Association, Denver, CO, 1992.

[13] W. Fuqi, Z. Yuemei, Z. Yiqing, Y. Jing, Application of polyaluminum in dissolved-air flotation process, Water Technol. 4 (2008) 17–24.

[14] L.S. Clesceri, A.D. Eaton, A.E. Greenberg, E.W. Rice, Standard Methods for the Examination of Water and Wastewater: Centennial Edition, 21st ed., American Public Health Association, Washington, DC, 2005.

[15] M. Han, S. Dockko, C. Park, Calculation of Collision Efficiency Factor by Trajectory Analysis in Dissolved Air Flotation, KSCE J. Civ. Eng. 2 (1998) 91–95.