Effect of Bubble Bed Depth on Water Turbidity Removal Using DAF

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Abstract

Diffused Air Flotation (DAF) has been successfully used for removal of turbidity in water treatment plants through numerous applications. The optimization of the system is dependent of several factors such as coagulant dose, flocculation time, and waterbed depth along the separation zone of the DAF. This paper addresses mainly the effect of bubble bed depth in the separation column on turbidity removal from water. Effects of varying alum coagulant dose from 5 to 45mg/l and changing the influent hydraulic loading from 1 to 4 $m^3/m^2/hr$ on DAF performance were also addressed. Results showed increased efficiency of turbidity removal with the increase of bubble depth in the separation column, as fewer particles were dragged out from the process effluent port situated at the bottom of the tank. The increase in hydraulic loading though beneficial in reducing the required surface area resulted in increased turbidity in the treated effluent.

Introduction

Low turbidity streams and rivers are usually located at upper reaches of undeveloped watershed, they still may contain high levels of Total Organic Carbon during high runoff events resulting in an increase in turbidity from biological growth or the presence of significant color. High turbidity streams and rivers tend to be located in watersheds having erodible soils, significant agricultural farming activity, or receiving urban and industrial runoff. Large reservoirs or lakes may have turbidity levels below 100 NTU, whereas some rivers can have turbidity higher than 1000 NTU. High turbidity can occur in smaller reservoirs receiving water from agricultural watershed or urban drainage area. Larger reservoirs also experience high turbidity as a result of water quality changes during annual thermal changes in the lake, and may experience high turbidity events associated with severe flooding (US EPA, 1999).

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DAF process is increasingly used in water treatment as it may offer several advantages from the followings depending on project conditions and constraints: high overflow rates, rapid start-up, high solids capture particularly finer solids (80-90%), good algae removal (50-80%) at high hydraulic loadings, reduced chemical usage, and relatively robust to hydraulic and quality variations in raw water. However a number of disadvantages may also be encountered as: complex and mechanically intensive process, requires electrical power, higher maintenance cost, separate flocculation required, besides a number of process control variables (Schofield, 2001).

Continuous development and optimization of the application of DAF process for water treatment are currently investigated through several researches and applications to achieve higher efficiencies in suspended solids and turbidity removals while maintaining or lowering both construction and operational costs. (Kempeneers et al. 2001; Hargesheimer and Watson 1996). Major developments for the process are oriented towards higher hydraulic loading rates and deeper tanks. The efficiency of turbidity removal through application of DAF process depends on several factors as hydraulic conditions controlling particles settling velocities, and chemical conditions influenced by coagulant doses and flocculation time. The particle surface charge also affects the successful interactions between particles and air bubble. Since both hydraulic and chemical conditions have their great influences on the performance and the efficiency of the DAF process, a combined action is therefore expected to prevail in the application of the process. This research aims to investigate the effect of bubble depth of the DAF separation column on the efficiency of turbidity removal under the effect of varying coagulant doses and hydraulic loadings.

Materials and Method

The current study was accomplished in the Water-First Laboratory in Seoul National University – Korea. The experimental setup used in the experiments is shown in Fig. 1 where the main components are as follows:

i) The flocculation section is composed of a 2 Liters Jar cell with a mechanical stirrer. The jar was used in preparing influent turbid water by mixing 0.5 g of kaolin clay in 2 Liters of tap water resulting in water turbidity of 240 NTU. This arbitrary turbidity value was chosen and considered to be moderate value where higher and lower values may be encountered in low turbid and high turbid streams. Coagulant stock solution was prepared using aluminum sulfate, and optimum coagulant doses were tester in the range of 5 to 45 mg/l. Rapid mixing was applied for 10 sec (at 100 rpm) followed by gentle mixing for 7 min (at 25 rpm) keeping the suspension homogeneous and unsettled.

ii) A variable speed transfer pump was used to introduce the prepared turbid water to the top of the separation column as the influent to the studied DAF process. Three sets of flow were used namely 50, 100, and

200 mL/min equivalent to hydraulic loading of 1 to 4 m/hr (related to separation column diameter as stated later).

iii) The DAF reactor is composed from the separation column (60 mm diameter x 450 mm height), and a saturator unit providing pressurized air at a flow of 70mL/min and a pressure of 6 atm. Air is introduced to the bottom of the separation column through perforated tubes. The column is fitted with an effluent port opening located at 35 mm from the column bottom from which clarified effluent can be collected. Different water heights in the column were maintained through adjusting control devices at the port opening.

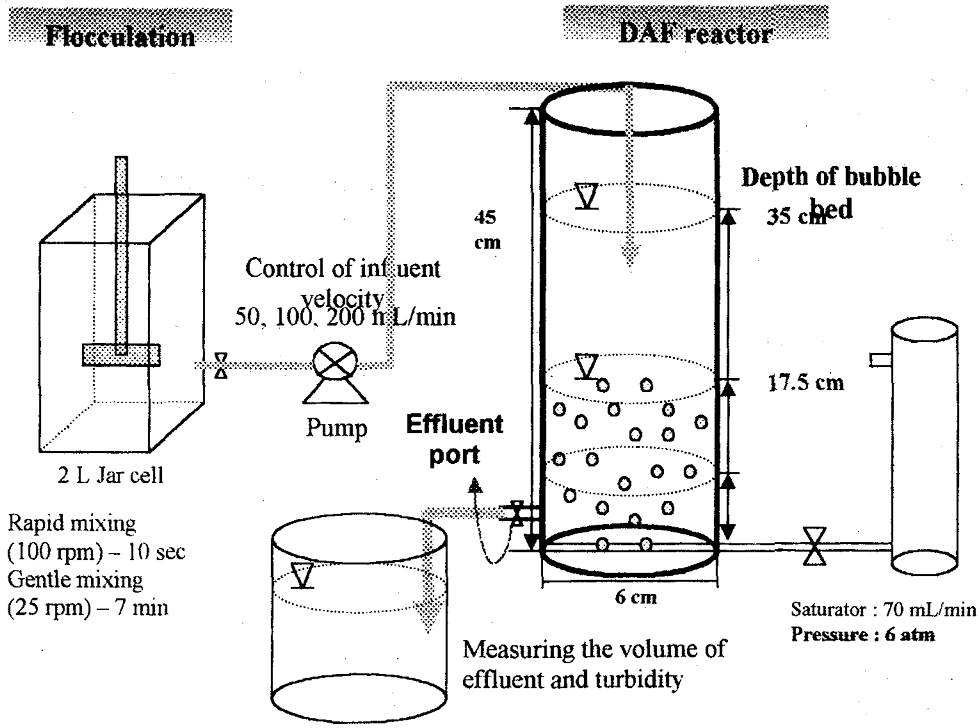

Fig. 1 Schematic representation of the experimental setup for the study

Experimental investigations were conducted at different water heights in the separation column: 8.75, 17.5, and 35 cm. Effluent turbidity was measured relative to varying alum dose and hydraulic loading. At the start of the experiments the separation column was filled with tap water then the influent was introduced at the top of the column, it took few minutes (maximum of six minutes) for the system to stabilize with less stabilizing time required with lower hydraulic loadings. DAF process is characterized by required short detention times either for flocculation as pre-treatment or in the separation zone. Therefore, flocculation time and operating time at the separation column were selected as 7 and 8 minutes respectively as obtained from preliminary setting optimization and as discussed later. Turbidity was measured using 2100P Hach turbidimeter and zeta potential was measured using a DELSA 440 SX (Beckman & Coulter, USA) detecting zeta potential differences by electrophoretic mobility measurement.

Results and Discussion

Alum was added for particles charge neutralization and for flocculation. Optimum alum dose corresponding to lowest turbidity in flocculated water ranged from 15 to 25 mg/l. Figure 2 shows particles surface charge corresponding to different alum dose measured as zeta potential. A reverse in particles surface charges (from negative to positive) occurred between 15 to 25 mg/l of alum, and zeta potential value at 15 mg/l was considerably low. Results of varying hydraulic loadings and water column depth (bubble bed depth) are shown in Figures 3 and 4. Results shown are for minimum and maximum hydraulic loadings applied in this study, using an optimum alum dose of 25 mg/l as previously discussed. For the lowest hydraulic load (inflow 50mL/min – equiv. to 1 m/hr), the system stabilizes fast that no major variation in turbidity removal efficiency was observed starting from 2 minutes of operation. Higher water column, thus bubble depth zone, resulted in the higher turbidity removal efficiencies as more agglomerated bubbles flowing upwards are expected to intercept the increasing number of introduced turbidity flowing downwards.

For the highest hydraulic loading (inflow 200mL/min – equiv. to 4 m/hr), shorter water column depth required more time to stabilize (approximately 6 minutes) while the highest water column showed robust and high removal efficiency (over 90%) from the start of experiments, adding another advantage for having higher bubble depth separation zone. Similar to the first case, higher removal efficiency was linked with higher water column depth; poor removal efficiency (60%) was obtained for the shortest depth due to particles dragging with the effluent from the short separation column that may not allow enough separation zones for the introduced air bubbles to interact with the downwards-flowing particles. An operating time of 8 minutes for the separation column was then applied and the effect of increased hydraulic loading on turbidity removal efficiency is shown in Figure 5. Results showed that removal efficiency almost linearly increased with increasing water (and bubble) bed depth in the separation zone. For the longest bed depth used (35 cm), turbidity removal efficiency only decreased from 99% to 94% while increasing the hydraulic loading rate from 50 to 200mL/min.

Figure 6 shows the effect of different alum dose on effluent turbidity for a hydraulic loading of 100mL/min (equiv. to 2 m/hr). Higher effluent turbidity was recorded for shorter bed depth. Maximum turbidity removal occurred at 25mg/l alum dose where a reverse in particles surface charge occurred. Zeta potential for air bubbles in DAF process was previously measured by Han and Dockko (1999) and found to be (-25 mV). Therefore, better particle-bubble interactions through different electrostatic charges can be expected, and particles can easily adhere to the negatively charged air bubbles. Another advantage of the deeper water and bubble bed depth is when reducing coagulant dose to 15 mg/l where effluent quality was still better than that of shorter bed using optimum alum dose of 25 mg/l, thus deeper beds are less sensitive for variations or reduction in alum dose which has its implication on process operation stability and cost. Figure 7 shows the effluent turbidity from the longest waterbed depth (35cm) at different hydraulic loadings. The optimal range of alum dose was similar as defined previously.

Conclusions

This study addressed the effect of bubble bed depth in DAF process on turbidity removal efficiency. Three different bubble bed depths were investigated (8.75, 17.5 and 35 cm) at different hydraulic loadings equivalent to 1 to 4 m/hr. The study showed that an optimum alum dose of 25 mg/l where a reverse in particles size (from negative to positive) occurred, thus better particle-bubble adherence would be expected with the negatively charged air bubbles. Higher hydraulic loadings resulted in poorer effluent quality for shorter water and bubble bed depth (as low as 60% removal). The efficiency of turbidity removal increased with increasing bubble bed depth for all studied hydraulic loadings, reaching 99% and 94% for minimum and maximum hydraulic loadings respectively, in addition to being less sensitive to lower alum doses. This has its direct impact on reducing the required surface area of flotation cells with increased hydraulic load, besides tolerating less coagulant thus less operating cost.

Acknowledgment

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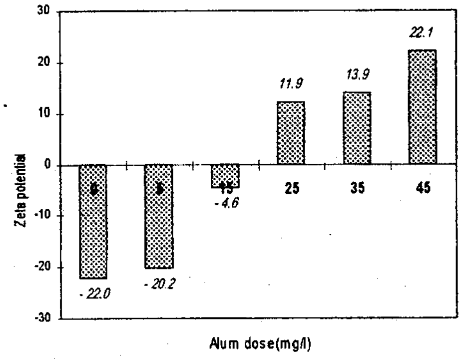

Fig. 2 Particles zeta potential vs. alum dose

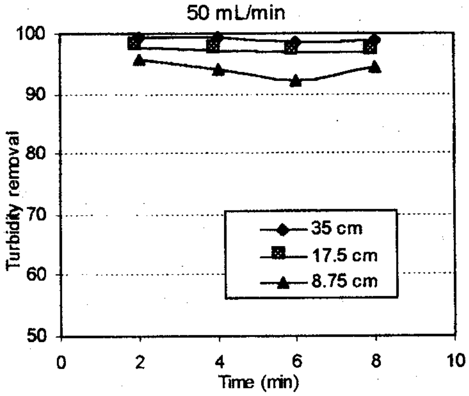

Fig. 3 Turbidity removal (low hydraulic load)

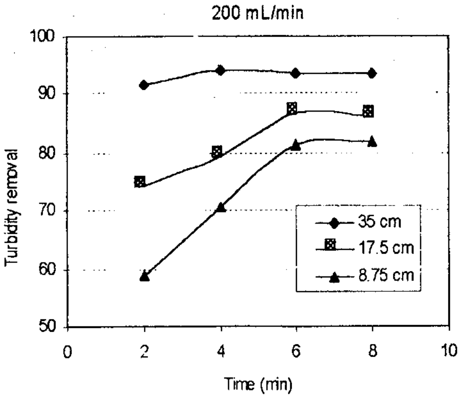

Fig. 4 Turbidity removal at high hydraulic loading

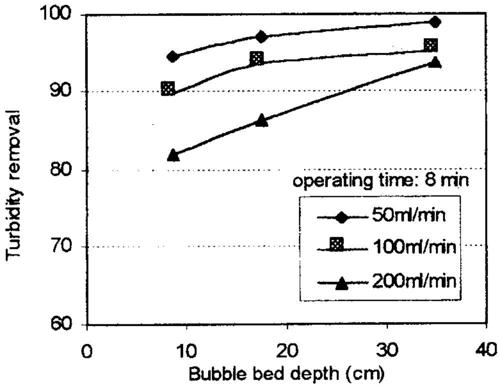

Fig. 5 Effect of bed depth on turbidity removal

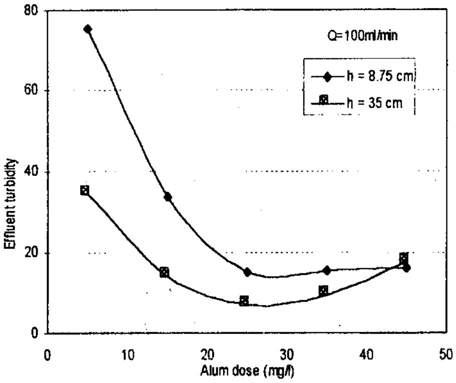

Fig. 6 Effluent turbidity vs. alum dose

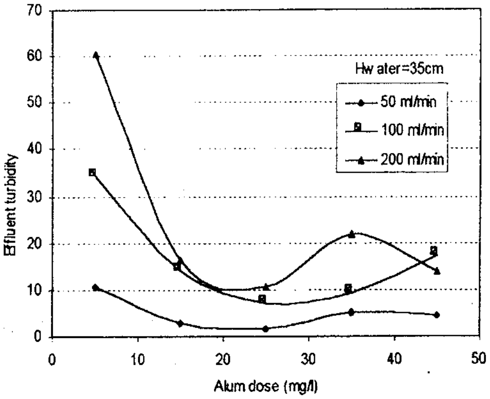

Fig 7. Effluent turbidity vs. hydraulic loading

تاثير عمق طبقه فقاعات الهواء على إزاله العكارة من المياه باستخدام عمليه الطفو-DAF

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ملخص البحث

تستخدم عمليات فصل المواد العالقة بنظرية الطفو باستخدام الهواء المضغوط على نطاق واسع وخاصة في إزالة العكارة من المياه الخام في محطات تنقية مياه الشرب حيث توجد تطبيقات عديدة لها عالميا. وتعتمد كفاءة وحدات تنقية المياه بالطفو على عدة عوامل منها تركيز المواد المروبة، زمن الترويب، وارتفاع عامود المياه الحامل لفقاعات الهواء في منطقة الفصل. ويتناول هذا البحث تأثير عمق فقاعات الهواء في العامود المائى على كفاءة فصل المواد العالقة والعكارة من المياه الخام مع دراسة تأثير تغيير جرعة المواد المروبة من ٥ إلى ٤٥ مجم/لتر وتغيير الحمل الهيدروليكي من ١ إلى ٤ متر^{٣}/متر^{٢}/ساعة. وقد دلت النتائج على أن كفاءة إزالة العكارة من المياه الخام تزداد مع زيادة عمق طبقة فقاعات الهواء مما يعوق خروج المواد الصلبة والعكارة مع المياه المعالجة من قاع الخزان. ومع أن زيادة الحمل الهيدروليكي يفيد في تقليل المساحات الكلية المطلوبة للخزانات إلا أن زيادته أدت إلى زيادة العكارة في المياه المعالجة الخارجة من الخزان.