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조류와 유기화합물의 동시제거를 위한 흡착 - DAF 복합공정

Adsorption-DAF Hybrid Process for the Simultaneous Removal of Algae and Organic Compounds

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Abstract

Dissolved air flotation (DAF) is an effective solid/liquid separation process for low density floc particles such as algal, color-alum and clay-alum flocs produced from low turbidity water. The removal of taste- and odor-causing organics (2-mthylisoboneol and geosmin) originating from algae in drinking water is a local and worldwide concern. Although DAF has been effectively applied for the removal of suspended solid, its application for the treatment of dissolved organic carbon is very limited. In this study, a new hybrid system consisting of adsorption and DAF processes was introduced for the simultaneous removal of algae and taste- and odor-causing organics. Powdered activated carbon (PAC) was used as an adsorbent. In this proposed system, the major concern of eliminating the spent PAC from the system was also addressed. It was found that zeta potential of algae and PAC was increased with coagulant dosage, and the removal efficiency in DAF was also enhanced up to 90~95% under the given experimental conditions. Based on this study, the hybrid process was found to be a promising technology for the simultaneous removal of algae and dissolved organic pollutants.

Key words: Adsorption, DAF, Algae, PAC
주제어: 흡착, 용존공기부상, 조류, 분말활성탄

1. INTRODUCTION

Dissolved air flotation (DAF) is an effective solid/liquid separation process for low density floc particles, such as algal flocs, color-alum flocs and clay-alum flocs produced from low turbidity water (Fukushi et al., 1995; Kwak, 1997; Han et al., 1997). The DAF processes for drinking water treatment are composed of the four steps namely coagulation and flocculation prior to flotation, bubble generation, bubble-floc collision and attachment in a mixing zone, and finally rising of bubble-floc

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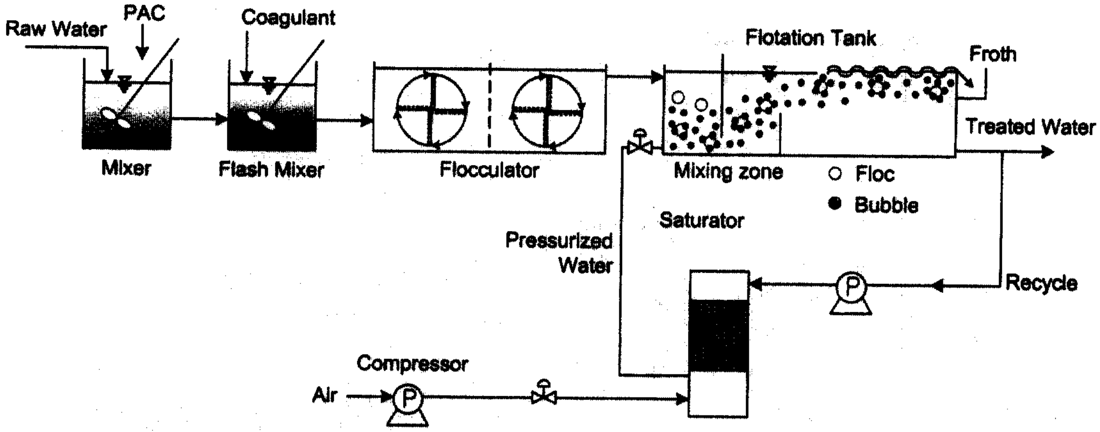


Fig. 1. Conceptual diagram of PAC-DAF hybrid process.

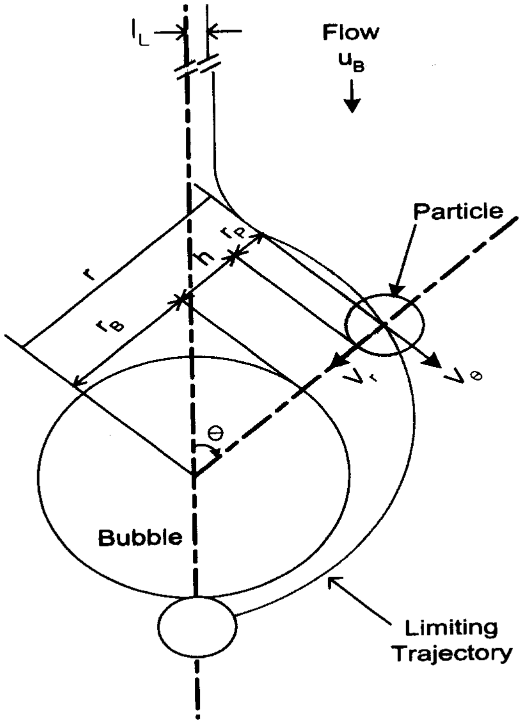
agglomerates in a flotation tank.

Blooms of blue-green algae in reservoirs often produce the musty-earthy taste and odor algal metabolites such as 2-methylisoboneol (MIB) and geosmin. MIB and geosmin are not removed by conventional water treatment and their presence in the distribution system, even at low ng/L levels, can result in consumer complaints. Recently, many researchers have reported on the effectiveness of PAC for removing taste- and odor-causing compounds from drinking water (Cook et al., 2001). Several studies have described how the effectiveness of PAC for the removal of MIB and geosmin depends very strongly on the types of activated carbon used. Another major influence on the application of activated carbon in water treatment is the competitive effect of natural organic material (NOM). They have addressed that PAC can effectively remove MIB and geosmin when the correct dose is applied (Newcombe et al., 2002)

Although DAF has been effectively applied for the removal of algae, its application for the treatment of dissolved organic compounds originating from algae is very limited. Thus, in this study, a new hybrid system consisting of adsorption and DAF processes was introduced for the simultaneous removal of dissolved organic compounds and algae. A conceptual diagram of hybrid system is shown in **Fig. 1.** The dissolved odor and taste-causing compounds from algae are adsorbed on PAC. Then, the spent PAC and algae is eliminated in the DAF process. It is essential to investigate the flotation efficiency of PAC and algae in DAF process under various conditions. In this study, zeta potential of two algae (*anabaena*, *microcystis*) and PAC derived from three different natural sources (coal, wood, coconut) was measured in terms of coagulation dosage. Flotation efficiency in DAF was estimated theoretically and was compared with the experimental results. Collision efficiency was calculated by trajectory analysis for the mathematical models proposed by Leppinen (1999) and Okada (1990). The effects of van der Waals forces and electrostatic forces as well as hydrodynamic interaction between a rising bubble and dropping particle during flotation were also included in the model in order to account practical behaviors in the DAF process.

2. ANALYSIS OF THE PARTICLE TRAJECTORY

To analyze the particle trajectory on the bubble surface when the particles and bubbles were both charged, Okada et al. (1990) proposed the following equations under certain assumptions described in the reference (Okada, 1990). By introducing the dimensionless parameters, $H = h/r_p$, and $R = r_p/r_b$, the velocity of the particle normal and tangential to the bubble surface are represented,



respectively, as follows:

$$V_{r,i} = r_{p,i}\frac{dH_i}{dt} = \frac{F_{n,i}f_{1,i}}{6\pi\mu r_{p,i}} \tag{1}$$

$$V_{\theta,i} = r_{p,i}\frac{d\theta_i}{dt} = \mu_{\theta,i}f_{1,i} \tag{2}$$

In Eq. (1), F_n is the total force acting on the particle normal to the bubble surface. Here, F_n was the sum of various forces as follows:

$$F_n = F_{el} + F_{vdw} + F_{H/r} \tag{3}$$

$$F_{el} = \pi\varepsilon r_p k\xi_p\xi_b\left[\frac{4\exp(-kr_pH)}{\{1+\exp(-kr_pH)} - \frac{2(\xi_p-\xi_b)^2\exp(-2kr_pH)}{\xi_p\xi_b\{1-\exp(-2kr_pH)\}}\right] \tag{4}$$

$$F_{vdw} = -\frac{A}{6r_pH^2} \tag{5}$$

$$F_{H/r} = -\frac{3R^2(H+1)^2}{2(1+HR+R)^2}\times 6\pi\mu r_p u_b\cos\theta f_2 \tag{6}$$

The resultant model equation for motion of the particle can be obtained as below:

$$\frac{dH}{d\theta} = \frac{2(1+HR+R)^2}{3R^2(H+1)}\frac{f_1}{6\pi\mu r_p u_B\sin\theta f_3}\times \left\{-\frac{A}{6r_pH^2} + 4\pi\varepsilon r_p k\xi_p\xi_b\frac{\exp(-kr_pH)}{1+\exp(-kr_pH)} - \frac{3R^2(H+1)^2}{2(1+HR+R)^2}\times 6\pi\mu\varepsilon r_pU_B\cos\theta f_2\right\} \tag{7}$$

The ordinary differential equation (Eq. 7) with respect to angle, was integrated by using DVODE of the International Mathematics and Science Library.

3. EXPERIMENTAL

A DAF experiment was carried out in a batchwise manner to obtain the flotation efficiency. Water quality of raw water obtained Dong Hwa Dam had in the following characteristics: pH 7.54, turbidity 2NTU, alkalinity 1.5mg/L as $CaCO_3$, COD 2.1mg/L, and SS 2.5mg/L. The solution pH was adjusted by using hydrogen chloride and potassium hydroxide. Clay (SiO_2 0.46, FeO_3 0.02, Al_2O_3 0.35, CaO 0.03) was used to adjust turbidity of water. Polyaluminumchloride was used as a coagulant. Zetasizer 2000 (Malvern) instrument was used for the measurement of zeta potential and HACH 2001AN was employed to analyze the solution turbidity. Algae such as *anabaena* and *mycrocystis* were chosen and three kinds of PAC having different diameters and sources (coal-, wood-, coconut-based) were used as the model particles. The physical properties of three PAC adsorbents measured by a Micromeritics ASAP 2000 automatic analyzer were

Table 1. Characteristics of Powdered Activated Carbons.

Spcifications	PAC-CB	PAC-WB	PAC-Coconut
Type	coal based	wood based	coconutshell based
Surface area, m^2/g	915	882	1,199
Bulk density, kg/m^3	100-300	290-390	350-500
Mean particle diameter, μm	10.9	19.72	64.2
Mean pore diameter, Å	24.2	30.6	30.4
Micropore volume, cc/g	0.19	0.34	0.067
Iodine number, mg/g	800	900	900
Ash content, %	5	6	3
Moisture content, %	8	5	10

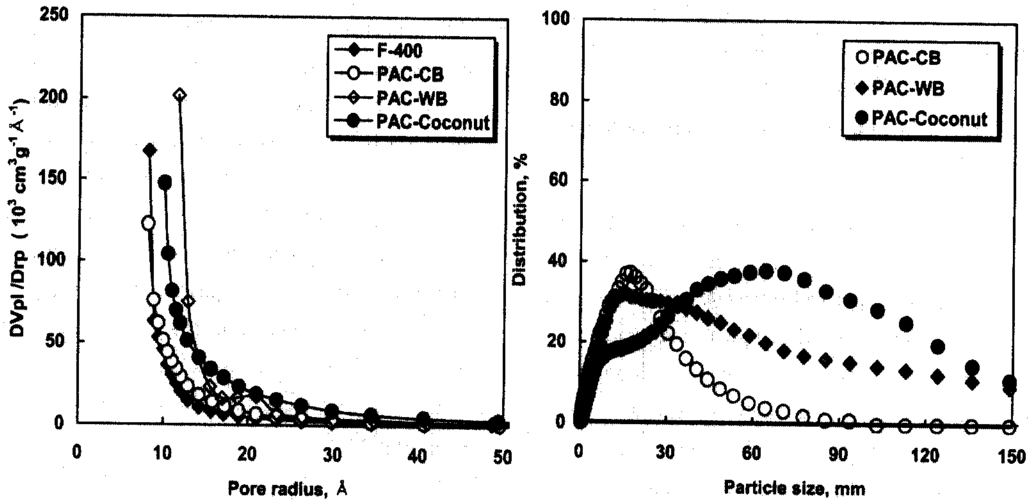


Fig. 2. Pore and particle size distributions of three PACs.

shown in **Table 1**. Prior to measurement, the samples were outgassed at 623K for 10 hour. **Fig. 2(a)** shows the pore size distribution calculated by BJH (Barrett, Joyner and Halenda) method from nitrogen adsorption isotherms of PAC-CB, PAC-WB, and PAC-Coconut. Also, **Fig. 2(b)** presents the particle size distribution of PACs measured by particle size analyzer (Malvern PSA). The mean particle diameter of three PACs including PAC-CB, PAC-WB, and PAC-Coconut is 10.9, 19.7, and 64.2μm, respectively.

4. RESULTS AND DISCUSSION

The determination of optimum condition for the removal of taste-and odor-causing compounds such as geosmin and 2-mthylisoboneol using PAC is important in the adsorption-DAF hybrid system. It has been reported that a PAC dosage as low as 5-20mg/L could be reduce commonly occurring concentrations of these organics (10-20ng/L) to acceptable levels. The spent PAC adsorbed organic compounds together with algae could be eliminated by DAF. The effectiveness of the hybrid system depends on how to float the spent PAC. Generally, the flotation efficiency in DAF is highly dependent on the properties of particle, bubble, and water. Moreover, the surface charges of bubble and particle are very important in DAF. **Fig. 3** shows the influence of coagulant dosage on zeta potential and removal efficiency of clay as a model particle for inorganic solids in the absence of algae and PAC.

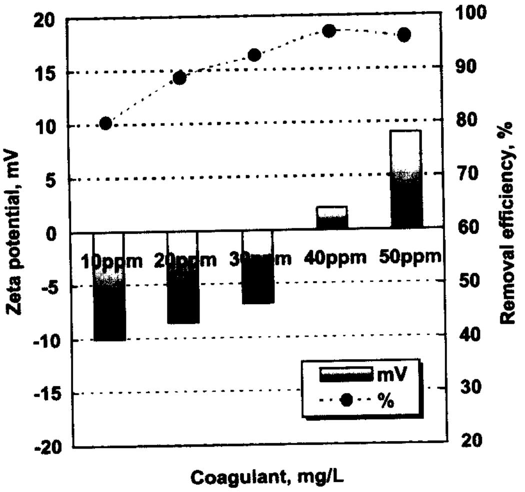


Fig. 3. Influence of coagulant dosage on zeta potential and removal efficiency.

When the coagulant dosage was increased (10~50 mg/L), the zeta potential of clay was in the range of -10~10mV and the removal efficiency was 80~95%. These results suggest that the appropriate quantity of coagulant was required to achieve the high removal efficiency over 90%. The musty-earthy taste and odor-causing compounds in water mainly originated from the blooms of blue-green algae. Fig. 4 shows the picture of algae (*anabaena*, *microcystis*) originated from blue-green algae.

Figs. 5 and 6 show the comparison of the removal efficiencies of *anabaena* and *microsystis*, respectively, by DAF and sedimentation in terms of coagulant dosage. Both turbidity and chlorophyl-a were measured. It was found that upon increasing the coagulant dosage, the removal efficiency by sedimentation and DAF for two algae was increased although its tendency was changed when the coagulation dosage is over 40mg/L. The results suggest that the optimal dosage must be determined according to the types of algae and other conditions such as turbidity, pH, and temperature. It was confirmed that the DAF was an efficient method for the removal of algae.

Fig. 7 shows the variation of zeta potential of two algae for *anabaena* and *microcystis* in terms of solution pH with coagulant dosage. It was observed that the zeta potential was increased with coagulant dosage and hydrogen concentration (at lower pH). The value of zeta potential ranged between approximately -15~25mV under our experimental conditions of coagulant dosage (10-50mg/L) and pH (4-9). The zeta potential slightly varied according to the types of algae. For *anabaena*, the values were almost independent with the coagulant dosage (30-50mg/L) in the range of pH 4-9.

In order to verify the DAF methodology to float PAC, the efficiency of sedimentation and flotation of three different PACs were compared in the absence and

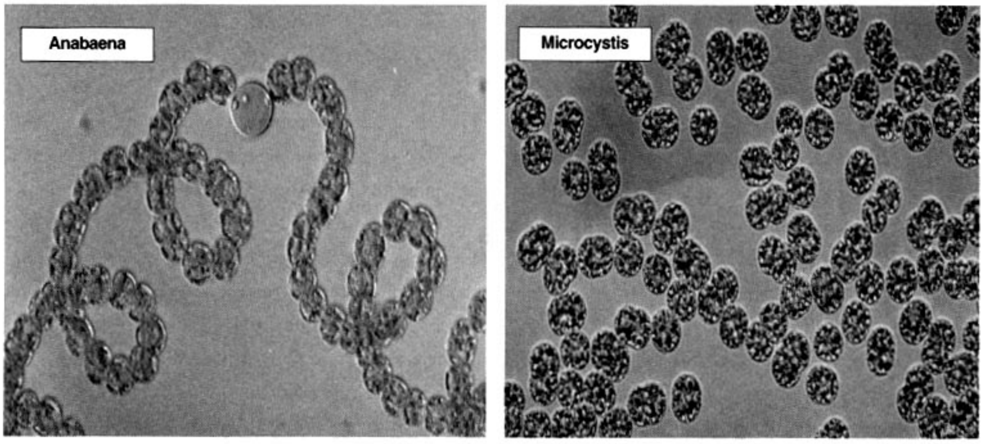


Fig. 4. Photos of algae for anabaena and microcystis.

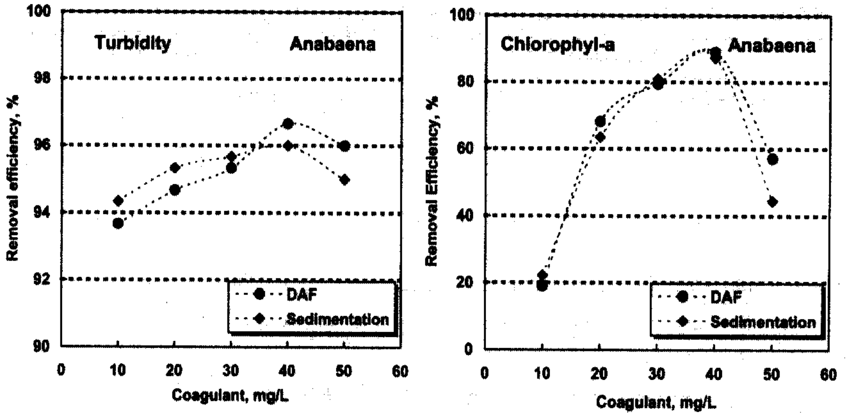


Fig. 5. Comparison of the removal efficiency of anabaena by DAF and sedimentation in terms of coagulant dosage.

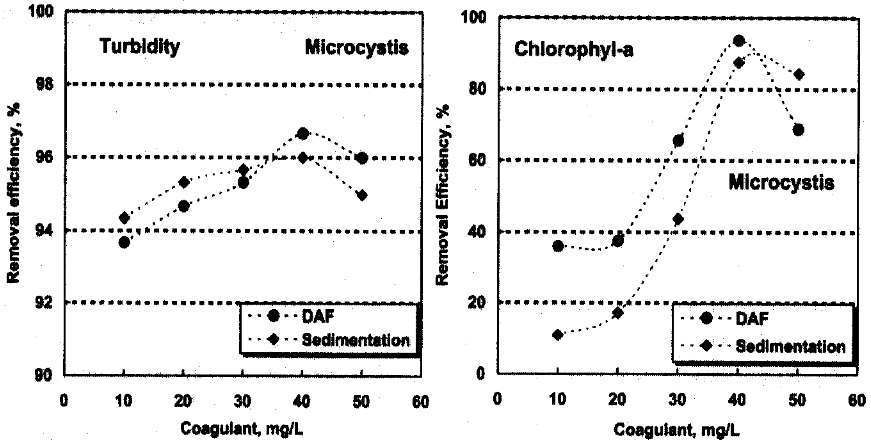


Fig. 6. Comparison of the removal efficiency of microcystis by DAF and sedimentation in terms of coagulant dosage.

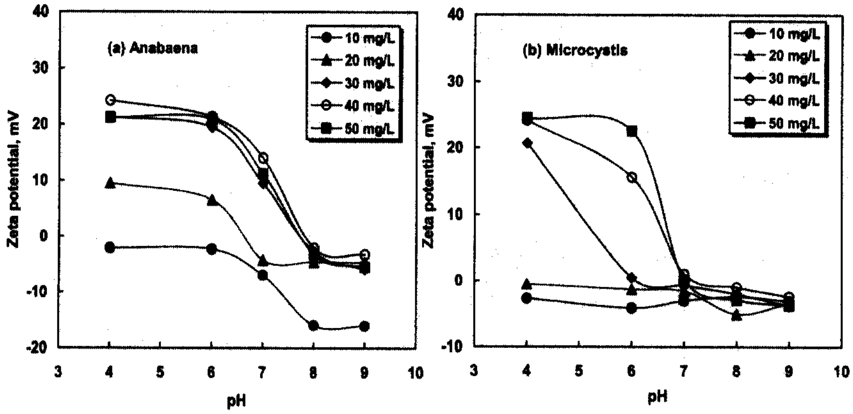


Fig. 7. Zeta potential of *anabaena* and *microcystis* in terms of coagulant dosage.

Table 3. Removal Efficiency of PACs by Sedimentation and DAF. (unit:%)

Adsorbent	without coagulant		with coagulant	
	Sedimentation	DAF	Sedimentation	DAF
PAC-CB	1.7	9.7	77.5	94.6
PAC-WB	3.8	5.3	72.9	94.2
PAC-Coconut	1.5	6.0	69.5	93.6

presence of coagulant. **Table 3** lists the removal efficiency of PACs. The removal efficiency by sedimentation and DAF without coagulant dosage was very low (< 10%), while the efficiency was highly increased with coagulant dosage up to approximately 70% for sedimentation and 95% for DAF, respectively.

5. CONCLUSION

As a simultaneous removal technology for algae and PAC adsorbed organic pollutants, a new hybrid process of adsorption and DAF was investigated. The collision efficiency factor of bubble and particle in DAF was calculated from trajectory analysis using the hydrodynamic and interparticle forces. The flotation efficiency of algae and PAC was very low without coagulant dosage. However, with the increase in coagulation dosage, the zeta potential value increased and the flotation efficiency was also enhanced. Based on the experimental and theoretical results obtained, it was evident that the hybrid system consisting of adsorption and DAF can be effectively applied for the simultaneous removal of dissolved organic pollutants and suspended solids in water.

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