The Study on the Particle Separation and Disinfection using Plasma Air Flotation System

S. Ryu, E. Hong, J. Park, S. Yoo, and T. Lho
Plasma Technology Research Center, National Fusion Research Institute, Korea

Abstract—Dissolved air flotation process (DAF) is a flotation process that can be used to remove particles in conventional type plants. But, DAF has no anti-biotic ability. Plasma air flotation process (PAF), which can separate flocs by bubbles generated in underwater plasma, has developed. Plasma can generate OH radical, oxidants and micro bubbles in water. The average bubble diameter is 70 μm and it can float flocs. These bubbles and oxidants enhance degradation, separation and inactivation of organic matters and microorganisms in salt water. In this study, humic acid removal efficiency was compared between plasma air flotation process and sedimentation process based on UV254 absorbance. Separation velocity of humic acid by plasma air flotation is faster than sedimentation process. To reach 80% removal of humic acid, PAF requires 19 min and sedimentation requires 30 min and the intermittent PAF 9 min in 8 L treatment. During the 30 min PAF process 99% of disinfection of E. coli was achieved and there were no re-growth of E. coli. With these results, continuous flow reactor was developed. Flow rate of 100 ppm humic acid is 1 l/m with simultaneous 1% alum dose of 10 cc/m. The removal efficiency of humic acid is approximately 90% and 99.9% disinfection was achieved.

Keywords—Plasma, flotation, disinfection, bubbles

I. INTRODUCTION

A. Backgrounds

The major two processes of water treatment are separation and disinfection. The traditional separation and disinfection processes are sedimentation and chlorination [1-3]. Recently, Dissolved air flotation process (DAF) can be considered as an alternative of separation process [4]. Chlorination and ozonation can be selected as disinfection processes. This work is focused on a plasma aided hybrid system for separation and disinfection.

The charged particles, especially the electrons, provide several processes such as ionization, dissociation and attachment phenomena which take place in the plasma and these can form activated species which are named radicals [5, 6].

High-voltage electrical discharges directly in water have been demonstrated to produce hydrogen peroxide, molecular oxygen and hydrogen and hydroxyl, hydroperoxyl, hydrogen, oxygen, ozone and micro bubbles at the high voltage electrode [7-12].

Plasma Air Flotation (PAF) can utilize disinfectants and micro bubbles generated by plasma [13].

B. Research Objectives

Fig. 1 is a concept of plasma air flotation to replace conventional sedimentation and disinfection. DAF has shorter processing time and needs much less site than sedimentation process. But DAF has no anti-biotic ability.

PAF, which can separate flocs by bubbles generated in underwater and can inactivate microorganisms as well.

Plasma produced in water is able to generate OH radical, oxidants and micro bubble. These bubbles and oxidants enhance degradation, separation and inactivation of suspended solids and microorganisms in water.

Fig. 1. Comparison between Sedimentation and PAF. The diagram is a concept of plasma air flotation to replace conventional sedimentation and disinfection. PAF has shorter processing time than sedimentation. Moreover it has a disinfection power.

Corresponding author: Tailhyeon Lho
e-mail address: tlho@nfri.re.kr

Presented at the 8th International Symposium on Non-Thermal/Thermal Plasma Pollution Control Technology & Sustainable Energy, in June 2012
II. METHODOLOGY

A. Reactor Design and Induced Power

A.1. Batch Type Reactor and its Power

If water contains high electrical conductivity, it is very hard to produce electrical discharge or requires considerable high voltage. But specially designed electrode can generate plasma discharge to saline water. Ryu et al. suggested double layered electrode (tungsten electrode covered with ceramic insulator) to generate electrical discharge easily [13].

Electrode panel containing 10 double layered electrodes was installed at the bottom of the batch type reactor (W*D*H = 90*180*1000 mm) and the water was mixed with mechanical agitator (motor speed is 30~200 rpm). Applied pulsed power conditions are 1 kV, frequency 5 kHz, pulse width 3 micro second (Fig. 2). Output power is about 3 kW (EESYS Pulsed Power supply, Korea).

A.2. Continuous Flow Reactor and its Power

Fig. 3 shows continuous flow PAF system. 4 electrode panels containing 12 electrodes respectively were installed at the bottom of the continuous flow type reactor (total volume 16 L, W*D*H = 800*100*200 mm). 16 L reactor is divided to 4 regions by 4 walls. 1st region was rapidly mixed for coagulation. 2nd to 4th regions were slowly mixed for flocculation and flotation continuously. Electric power was 2.5 kW to 1 electrode panel and overall power was 10 kW.

B. Experimental and Analytical Methods

B.1. Experimental Methods

The humic substance of Aldrich, Inc. was selected as the representative of contaminants. The artificial sea water containing 3.5% concentration of NaCl was used for testing separation efficiency of humic acid. The selected concentration of humic acid is 100 mg/L and UV 254 nm absorbance is 2.3~2.6 cm$^{-1}$. Aluminum sulfate concentration for flocculation is about 100 mg/L. Operating method for sedimentation is coagulation for 1 min with 200 rpm mixing, flocculation for 20 min with 30 rpm mixing and 1 hr sedimentation without mixing. Another method for PAF is 1 min coagulation and electrical discharge with 200 rpm mixing, flocculation for 20 min with 30 rpm mixing and 1 hr flotation without mixing. Three sampling port were installed to compare sedimentation with plasma flotation. The sampling position of sedimentation is surface of the treated water and that of PAF is bottom of the water.

The method for intermittent PAF is 1 min coagulation and electrical discharge with 200 rpm mixing, flocculation for 4 min with 30 rpm mixing and 3 repetitions of coagulation, discharge and flocculation. After the repetitions of the intermittent PAF, it was remained without mixing for 11 min. Table I shows the operating conditions of the batch type processes. With the optimum operating conditions of batch reactor, the continuous flow reactor was designed and its operating conditions are written in Table II.

B.2. Analytical Methods

Absorption at 254 nm was selected as the index for evaluating separation efficiency of the humic acid. HS-3300 (HUMAS, Korea) spectrophotometer was used to
measure UV 254 absorbance. All samples were measured over than 3 times.

E. coli was selected as a microorganism to check disinfection. It was inoculated with the colonies of E. coli in 2% of nutrient agar, and incubated for 1 day at 37°C. The targeted humic water mixed with cultivated E. coli was used for testing inactivation by PAF. The number of colonies of sampled E. coli was counted after cultured in solid medium for one day at 37°C. Experimental conditions and method are followed standard methods.

III. RESULTS

A. Plasma Generation and Bubble Formation

Electrical conductivity of seawater containing 3.5% salt is approximately 53 mS. This is very hard condition to produce plasma discharge or require considerable high voltage. But specially designed electrode can generate plasma discharge to salty water [13]. Plasma discharge in water can generate bubbles. The optimum bubble size to float flocs in DAF system is 40–80 μm [14]. 1 min plasma generation in thin layer reactor with 5 electrodes by different power (0.5, 0.9, 1.2 kW) can produce micro bubbles. The average diameters of micro bubbles produced from different power is 96.9, 70.1 and 93.6 μm. The 900 watt power to 5 electrodes produced smallest bubbles and it helps flotation. Therefore, about 200 watt to 1 electrode is best suitable power condition to generate micro bubbles and it can be applied to float flocs like DAF.

B. Humic Acid Removal and Disinfection Efficiency by Batch Type PAF

Removal efficiencies of humic acid by rapid mixing and electrical discharge for 1 min in 3 and 8 L are 47 and 43%, but these by only rapid mixing in 3 and 8 L are 40 and 18%. After rapid mixing, PAF process removes humic acid faster than sedimentation process. In slow mixing region, PAF can separate organic matter but sedimentation cannot. Removal efficiencies of humic acid by flocculation for 1 min. in 3 and 8 L PAF system are 85 and 67%, but these by only rapid mixing in 3 and 8 L are 41 and 28%. (Figs. 5 (a), (b)).

In Fig. 5, the widths of error bar between the beginning and ending time are different. At the flocculating time (-20 min to 0 min) the humic acid floccs mixed in the reactors. Therefore, sometimes the sample can have a big flocs and sometimes not. That is the reason of big error formation. But in the separation time (0 min to 60 min), flocs removed gradually and the sample doesn’t have flocs. So, the error bar is not big in the ending time.
It is worthy to watch the curve of 8 L PAF process. The trend of humic acid separation in 8 L PAF test is not fit to exponential curve. Especially the curve fluctuated in slow mixing region. It is due to the flocs mobility.

The flocs may grow in slow mixing. A few times later, the force of gravity can become greater than that of buoyancy and starting to settle down.

It has been tested what is optimum flocculation time using different volume of contaminated water. (Fig. 5(c)) If the volume of water exceeds 5 L, (the height of 5 L is 310 mm) settling started and removal efficiencies of humic acid have decreased. It is related to bubble retention time. The velocity of bubble flotation can be calculated by Stokes’s law for laminar flow.

$$V_b = \frac{g(\rho_w - \rho_b)d_b^2}{18\mu} \quad (1)$$

($V_b$: velocity of bubble, $g$: gravitational constant, $\rho_w$: water density, $\rho_b$: air bubble density, $d_b$: bubble diameter, $\mu$: water dynamic viscosity)

The velocity of 70 μm bubble is 0.148 m/min. The height of 5 L water volume is 0.31 meter in this research and flotation time of bubble can be 2.1 min. The survival time of 70 μm bubbles in 5 L is about 2 min. So, Flotation time in 5 L must be in 2 min. If the height of water reservoir is over than 0.31 meter, there are fewer bubbles and flocs can begin settling down. Fig. 5(c) shows nonlinear line of 6 to 8L test.

Fig. 6 shows the disinfection of E. coli by PAF process in 3 and 8 L batch reactors. 1min discharge, 2 min slow mixing and 30 min separation process was applied and measured every 10 minute. Additionally, 1 day and 5 days stored sample were counted. During the 30 min PAF process 99% of disinfection of E. coli was achieved at 3 and 8 L respectively. And there were no re-growth of E. coli. But rather the disinfection rate was enhanced due to the residual disinfectants like chlorine.

C. Humic Acid Removal Efficiency by Intermittent PAF

To prevent sedimentation phenomenon in 8 L PAF process, intermittent discharge process was applied. The method for intermittent PAF is 1 min coagulation and electrical discharge with 200 rpm mixing, flocculation for 4 min with 30 rpm mixing and 3 repetitions of coagulation, discharge and flocculation.
After the repetitions of the intermittent PAF, it was remained without mixing for 11 min. Fig. 7 shows the results of humic acid removal by the intermittent PAF process. In all regions, humic acid flocs didn’t settle down and removal velocity of humic acid is faster than PAF and sedimentation. The time for 90% removal of humic acid is 18min rather than 36 min by PAF or sedimentation.

D. Humic Acid Removal Efficiency in Continuous Flow Type PAF System

Flocculation time is important factor in batch type PAF reactor and intermittent plasma discharge is efficient to float flocs. 3 times discharge in every 5 min can remove humic acid to 90%. The continuous flow PAF reactor was designed on the basis of the intermittent PAF results. The volume of 16 L was divided to 4 L by acryl wall. Every region has electrode panel containing 12 electrodes. 1 lpm humic acid with simultaneous 1% alum dose of 10 cc/m can experience 4 times discharge. The discharging time is 10, 20, 30, 40, 50 and 60 second in every 5 min. 1st stage reactor was rapidly mixed for coagulation. 2nd to 4th stage reactor was slowly mixed for flocculation and flotation continuously. Fig. 8 shows the effluent humic acid concentration. Discharging time is not important. Even 10 second discharge can make enough bubbles to separate flocs.

E. coli disinfection rate has been examined. (Fig. 9) The number of E. coli colonies of influent was 1.2×10⁶ and that of effluent was 1.2×10³. Averagely 99.9% disinfection rate to E. coli has been achieved.

IV. CONCLUSION

Plasma air flotation system can produce 70 μm diameter micro bubbles and it can float flocs. PAF process removes humic acid faster than sedimentation process. To reach 80% removal of humic acid, PAF requires 19 min and sedimentation requires 30min and the intermittent PAF 9 min in 8 L treatment. The continuous flow PAF system of 1 L/m has 90% removal efficiency of humic acid and 99.9% disinfection rate to E. coli.

REFERENCES


