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Flocculation options in DAF for water quality

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ABSTRACT

The focus of this study was on exploring flocculation and the removal efficiency of particles in the DAF process using high hydraulic energy in the contact zone. First, a batch test was performed to compare the turbidity removal efficiency with and without flocculation. Results showed that flocculation could be omitted under specific conditions using hydraulic energy in the DAF process. Next, the turbidity removal efficiency, according to the hydraulic loading rate, was compared for the following cases: without flocculation, installation of baffles in the contact zone without flocculation, inclusion of a flocculator in the contact zone without flocculation, and inclusion of a flocculator with flocculation. The results showed that application of conventional flocculation, operation of a flocculator in the contact zone, installation of baffles in the contact zone, and elimination of flocculation are highly efficient. In particular, when the hydraulic loading rate was as low as 6, the efficiency of the process was >90%. When the hydraulic loading rate was 10, as in current water treatment plants, installation of either a flocculator or baffles in the contact zone resulted in over 90% efficiency. The hydraulic energy is high due to the injection of pressurized water into the contact zone, and appropriate installations in the contact zone lead to a decrease in the load of flocculation in DAF.

Keywords: DAF; Flocculation; Contact zone; Hydraulic energy; Hydraulic mixing

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1. Introduction

The treatment process in an existing water treatment plant was changed from a conventional sedimentation process to a flotation process in order to expand the treatment capacity. A disadvantage of the flotation process however is that high levels of energy are required to generate bubbles [1]. In the DAF process, chemical addition and flocculation are applied to increase the size of the floc particles before flotation. Although the recommended retention time during the flocculation process in DAF is shorter than that for sedimentation, flocculation still requires much energy. Because the standards of coagulation and flocculation parameters in DAF processes are not determined clearly, these processes are usually operated excessively.

Edzwald et al. (1992) reported that pin-point floc, which has a size range of 10–30 μm, is the optimum size for flocculation in DAF plants to achieve maximum removal efficiency [2]. Han et al. [3] deduced from their modeling results that the highest efficiency is obtained when the size of the floc is close to the size of the bubble [3]. Considering that the bubble size is generally in the range of 30–50 mm [4], the best floc size is similar. Even though the range of optimum size is different across literature, a shorter flocculation time is required because the optimum floc size in the range of 10–50 mm is created after a shorter retention time. Therefore, flocculation could be replaced by high turbulent energy, generated by high pressure and a nozzle for microbubble generation, at the contact zone in the DAF process.

This study was focused on exploring flocculation and estimating the removal efficiency of particles in the DAF

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process using high hydraulic energy at the contact zone; flocculation was omitted in one case study.

The specific objectives are as follows:

1. Determine, in a batch test, the removal efficiency of flocs formed as a result of high hydraulic energy without flocculation.
2. Determine, in a pilot plant, how to increase the efficiency of the process by only changing the contact zone, without flocculation. This was achieved in two ways: (a) by installing a flocculator and then determining changes in removal efficiency according to the mixing strength to enhance the probability of particle–particle and particle–bubble collisions in the contact zone, and (b) by installing baffles to change the hydraulic mixing and then determining changes in removal efficiency.
3. Using the above results, determine the most appropriate mixing conditions, with respect to various hydraulic loading rates, in the DAF contact zone.

2. Experimental methods

2.1. Batch test

A batch test was carried out to determine whether the flocs can be formed with only the hydraulic energy of the return flow without flocculation and whether particles can be removed.

All suspensions were mixed with distilled water at 15°C and kaolin. Turbidity was adjusted to 30 NTU, and pH and alkalinity of the suspensions were adjusted to 60 and 50 ppm (as $CaCO_3$), respectively, using solutions of H_2SO_4 and $NaHCO_3$. Aluminum sulfate ($Al_2(SO_4)_3 \cdot 18H_3O$) was used, in a 1% (w/v) solution, as flocculant.

In the case of mixing condition, *G*-value was maintained as 115 s^{-1}. The operating conditions in the DAF process were: recovery rate of 10% at 5 atm, and separation time of 10 min. The experiment was set up as Fig. 1.

2.2. Pilot plant

An experiment was performed to determine whether flocculation can be omitted in the DAF process. First, a suitable pilot plant was designed. A square reactor made of transparent acrylic was used in the experiment, and its dimensions are as follows: volume of 27.5 l, length of 0.55 m, height of 0.5 m, and width of 0.1 m. A schematic illustration of the reactor is shown in Fig. 2. The flotation basin comprised a contact zone and a separation zone. Pressurized water was held in a pressure tank.

Two methods were applied to facilitate flocculation in the contact zone. First, a flocculator was installed in the contact zone to enhance particle–particle and particle–bubble mixing. A hydraulic loading rate of 10 $m^3\ m^{-2} \cdot h^{-1}$ was used to analyze the removal efficiency, by changing the mixing as follows: 10, 40, 55, 75, and 82 s^{-1}. Because the possibility of coalescence between bubbles is low, as a result of bubble size [5] and coagulant injection [6], the effect of coalescence is ignored. Second, a baffle was installed in the contact zone and the hydraulic mixing was guided. The hydraulic loading rate was adjusted to 10 $m^3\ m^{-2} \cdot h^{-1}$ in order to determine the efficiency when the number of baffles was changed (1, 3, 5, 7, and 9). The flocculator and baffle were installed as shown in Fig. 3. The hydraulic loading rate was determined according to the operating conditions in an actual plant [7,8].

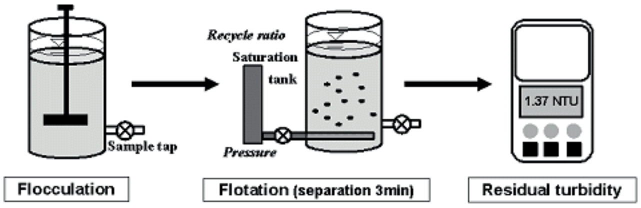

Fig. 1. Schematic illustration of the DAF experimental setup.

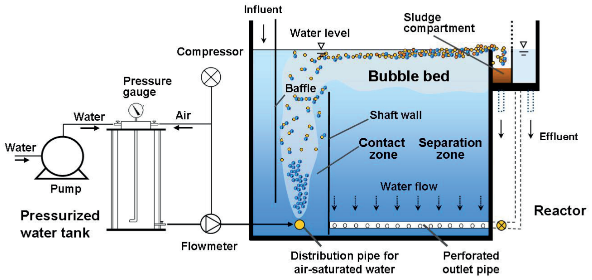

Fig. 2. Schematic illustration of a continuous flotation system.

2.3. Selection of appropriate mixing, considering hydraulic flow in the DAF contact zone

The appropriate mixing was selected considering hydraulic flow in the DAF contact zone. The applied setup was able to simulate the four flocculation conditions shown in Fig. 3: (a) conventional flocculation, (b) without flocculation, (c) flocculation in the contact zone, and (d) a baffled hydraulic flocculator in the contact zone. The pressure was kept at 5 atm and the recycle ratio was kept constant at 10%. A kaolin suspension (30 NTU) was used for the experiment. The removal efficiency was measured on the basis of residual turbidity.

3. Results and discussion

3.1. Batch test

The removal efficiency of injected flocculants was analyzed through a batch test (Fig. 1) in order to compare a system without flocculation with a system having a conventional flocculation process. The results are shown in Fig 4.

From the results of flocculation, the highest removal efficiencies of turbidity are as follows: 98% at 30 ppm and >80% at 15–60 ppm. The efficiency did, however, decrease rapidly at <15 ppm and >60 ppm. In contrast, rapid mixing after flocculant injection without flocculation resulted in a removal efficiency of more than 80% at 20–40 ppm. Compared to the result obtained with flocculation, this result was considered low; the highest efficiency was 92% at 30 ppm.

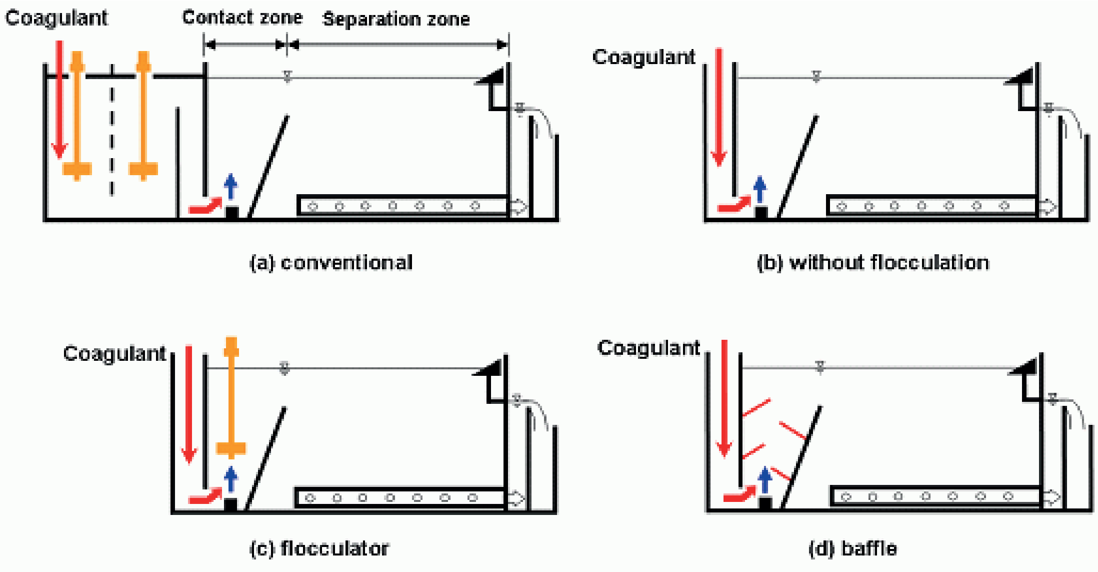

Fig. 3. Schematic diagram of laboratory-scale DAF experiments; (a) conventional, (b) without flocculation, (c) flocculator, (d) baffle.

This experiment showed that only proper injection of flocculants without flocculation resulted in more than 90% efficiency. The reason is probably that the generation of hydraulic mixing by pressurized water injected at 5 atm led to particle–particle and bubble–bubble mixing. Furthermore, flotation in compression, such as settling in compression, with bubble rising, led to bubble–particle collisions, and a high turbidity removal efficiency was obtained.

3.2. Continuous flotation system (pilot plant)

In the above batch test, a removal efficiency of >90% could only be achieved with hydraulic energy at specific conditions in the flotation process. Here, pilot plant assays were conducted for determining efficiency according to various mixing strengths. A flocculator was installed at the contact zone in order to increase the hydraulic mixing energy in a continuous flotation system without flocculation. Changes in efficiency according to various baffle numbers were also investigated by installing baffles in the contact zone.

3.2.1. Flocculator

Fig. 5 shows that the *G*-value, achieved by changing the mixing rate, affects removal efficiency when a flocculator is installed in the contact zone. Here, a hydraulic loading rate of 10 was used.

An analysis of the effect of the flocculator in the contact zone showed that a *G*-value of 40 resulted in the highest removal efficiency, and when the $G < 40$ the efficiency decreased.

Efficiency is decreased when the mixing strength exceeds a certain point possibly because of the destruction of particle–bubble combinations due to high *G*-values, despite better coagulation of bubbles following an increased mixing strength. Therefore, when the flocculator is installed in the contact zone, it should be operated with increased coagulation so that the particle–bubble combinations cannot be destroyed [9]. Thus, adequate hydraulic flow is required for providing sufficient collision opportunity between bubbles and particles, as suggested by Kichener and Gochin [10]. However, the *G*-value should not be too high and cause the destruction of particle–bubble combinations.

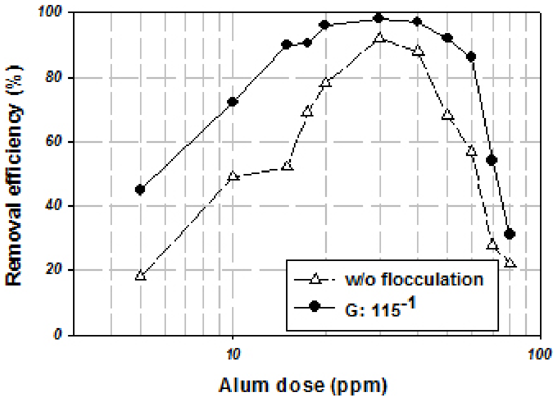

Fig. 4. Relationship between alum dose and removal efficiency in conventional DAF compared to DAF without flocculation.

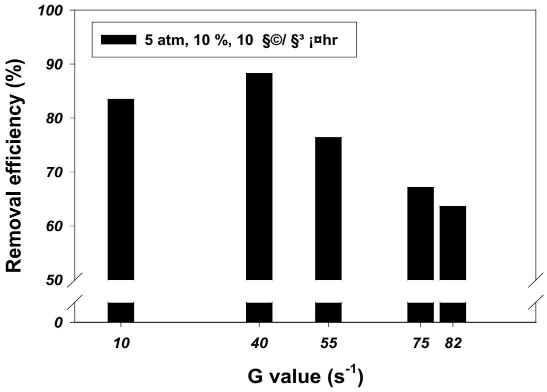

Fig. 5. Removal efficiency at various *G*-values, with a flocculator in the contact zone.

3.2.2. Baffles

Fig. 6 shows how the number of baffles installed in the contact zone impacts the removal efficiency. In this experiment, the hydraulic loading rate was 10.

After installing baffles in the DAF contact zone for hydraulic mixing, it was found that more baffles, up to seven, led to greater efficiency. The use of more than these seven baffles is expected to result in extremely rapid hydraulic flow because of the narrow space of the baffle and the larger dimensions of the dead zone. Moreover, a quicker flow could lead to destruction of the particle–bubble combination.

Therefore, when baffles are installed in the contact zone, the selection of the most favorable number of baffles is important. It was found that baffles positioned at an angle of 5°–10° gave the highest removal efficiency. This is probably because the dead zone inside was increased as the angle of the baffle was increased or decreased. When the baffle angle was 0°, more bubbles were attached to the surface of the baffle, and when it was 5°–10° the number of bubbles that gathered on the surface was decreased, and the dead zone could be minimized.

3.3. Selection of the appropriate mixing considering the hydraulic flow in the DAF contact zone

A significant advantage of the DAF process is the high hydraulic loading rate, and so an experiment was carried out to determine a method for optimum mixing under various hydraulic loading rates in the DAF contact zone. The following cases were studied and compared: without flocculation, installing a flocculator with a *G*-value of 40 s^{-1} in the contact zone, and installing five baffles. The results, including that of a control experiment, are shown in Fig. 7.

In the case with only rapid mixing without flocculation, analysis of removal efficiency under various hydraulic loading rates indicated that efficiency decreased more rapidly under higher loading factor. At a low hydraulic loading rate of 5 $m^3\ m^{-2}\cdot h^{-1}$, the efficiency was more than 95%, whereas it was 81% at 10 $m^3\ m^{-2}\cdot h^{-1}$, which is the operating condition in an actual plant. This is probably due to insufficient flocculation as a result of the shorter time, following a higher hydraulic loading rate, as suggested by Vrablik [11].

When installing a flocculator in the contact zone, an efficiency close to 90% was achieved at 10 $m^3\ m^{-2}\cdot h^{-1}$, while it was 50% at 20 $m^3\ m^{-2}\cdot h^{-1}$. When the loading factor was low, similar values to those achieved by the flocculation process were achieved, while at higher loading factors, values were similar to values achieved before installing the flocculator. This is probably because the role of the flocculator is relatively small in particle–particle and particle–bubble collisions, when the hydraulic loading rate is greater in the contact zone and the residence time is shorter.

When baffles were installed in the contact zone, a removal efficiency of 90% was achieved under a loading rate of 7.5 $m^3\ m^{-2}\cdot h^{-1}$, while it decreased to as low as 50% at 20 $m^3\ m^{-2}\cdot h^{-1}$. In the case of a small loading factor, with baffles installed, the efficiency was greater than before installation due to a longer time in the contact zone, while there was little effect when the hydraulic loading rate was greater, due to a shorter time.

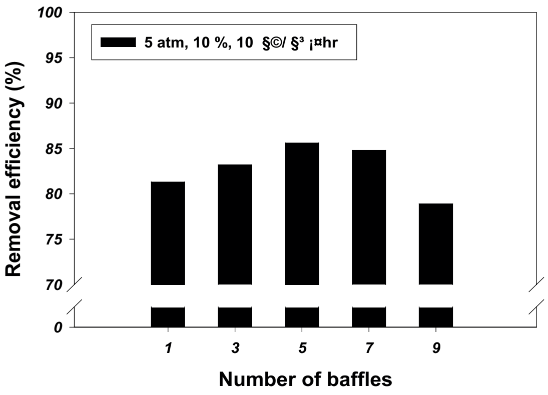

Fig. 6. Effect of the number of baffles in the flocculator in the contact zone on removal efficiency.

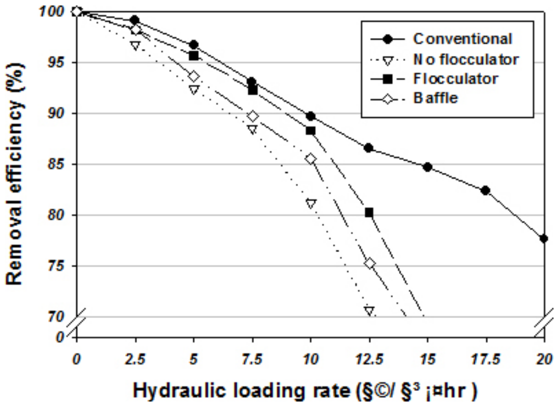

Fig. 7. Available range of four options to obtain removal efficiency of 90% and 80% as hydraulic loading rate.

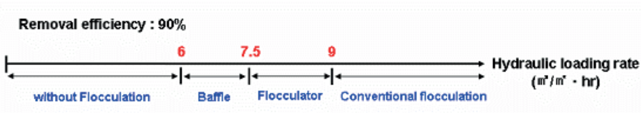

Fig. 8. Removal efficiency, with a goal of 90%.

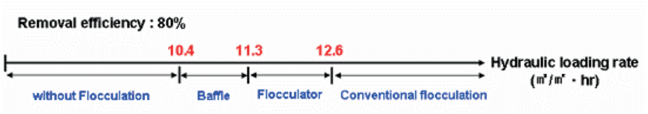

Fig. 9. Removal efficiency, with a goal of 80%.

Fig. 8 indicates how to determine the best method of operation according to the hydraulic loading rate when the goal of removal efficiency is 90%. A loading rate of up to 6 $m^3\ m^{-2}\cdot h^{-1}$ can result in achieving the desired water quality without inclusion of additional flocculation; only rapid mixing is required. When the hydraulic loading rate is 6–7.5 $m^3\ m^{-2}\cdot h^{-1}$ the target water quality can be achieved by installing baffles in the contact zone, and when it is 7.5–9 $m^3\ m^{-2}\cdot h^{-1}$ the goal can be achieved by using a flocculator in the contact zone. It was however found that when the loading rate is greater than 9 $m^3\ m^{-2}\cdot h^{-1}$, a removal efficiency of more than 90% can be achieved only by introducing the existing flocculation process. In the same way, the best method of operating according to the hydraulic loading rate could be determined by Fig. 9 when the goal of removal efficiency is 80%. In the light of a loading rate of 10 $m^3\ m^{-2}\cdot h^{-1}$ in an operating DAF plan, the installation of either a flocculator or also baffles can lead to higher efficiency.

4. Conclusions

It was found that high hydraulic energy exists in the contact zone in the DAF process, which implies that flocculation in DAF is unnecessary [12]. Therefore, operating with reference only to the hydraulic loading rate but without flocculation can lead to high efficiency in particle–particle and particle–bubble collisions. It can however be expected that the energy spent in coagulation and the cost thereof will be greater, considering the current trend towards an increased loading factor in the DAF process. This study proves that using only hydraulic flow in the contact zone, and without the inclusion of the existing coagulation process, is adequate. It was also found that installation of a flocculator or baffle can enhance process efficiency. This could contribute to savings in cost and energy spent in the DAF process.

To date, sedimentation and/or flotation after coagulation have been recognized as merely pretreatment to filtration in water treatment plants. It could, however, impose excessive burden on the filter basin. From the perspective of making use of several processes in water treatment, to remove pollutants, it is now concluded that flotation can assume a greater role (greater than 90%) when the hydraulic loading rate is less than 10 $m^3\ m^{-2}\cdot h^{-1}$, applying only hydraulic flow in the contact zone without the currently used coagulation process. With good understanding of the respective roles of flocculation, sedimentation, flotation, and filtration, and their interactions, we should be able to achieve higher efficiency, with a lower energy requirement at lower cost.

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