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# Intelligent judgement of coagulation performance based on settling velocities calculated by floc images

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**Abstract:** As a method to determine the coagulant dose quickly and without human intervention, this study develops a method to obtain the size and density of each floc particle from the floc group photographed by the underwater camera, and to obtain the precipitation rate of them. Coagulated flocs immediately after slow mixing were continuously recorded with an underwater video camera for 1 year under various coagulation conditions using a pilot scale plant. Images of individual floc particles were successfully extracted automatically by binarization, object detection and cropping from the images of the photographed floc group. Fractal dimensions and diameters were calculated from the extracted floc particle images, and the precipitation rates of individuals were determined using Stokes' equation. Using this technique, it became possible to set the flocculation condition based on the precipitation rate, and the possibility of suppressing excessive coagulant dose and the sludge produced was shown. Also, the system would detect the coagulation abnormality at an early stage compared to the coagulation control using the conventional turbidimeter.

**Keywords**: coagulation; computer image analysis; automation

## Introduction and Objective

In Japan, it becomes difficult to quickly optimize the coagulation condition since a rapid turbidity increase associated with extreme heavy rain events. Additionally, with the recent reduction in the number of employees and the retirement of highly skilled staff, a non-manual and intelligent approach for coagulation optimization is required.

The coagulation condition can be determined autonomously so that the precipitation rate is appropriate. Vahedi & Gorczyca (2011) have succeeded in calculating the fractal dimension by the box count method. However, generally, when a floc image in water is captured by a camera, many flocs are recognized in one image, and an operation of extracting individual flocs is separately required (Figure 1.1). In recent years, with the development of image processing technology utilizing the artificial intelligence algorism, a technology for recognizing an individual object in an image with high accuracy is being established.

This study aims to establish an image processing algorithm for extracting individual floc particles from floc images taken by underwater video cameras, and to calculate the precipitation velocity. A pilot-scale coagulation and sedimentation tank were installed in a water purification plant, and various floc images were taken while changing the coagulation conditions. The effectiveness of the coagulant dose control method proposed in this study was verified by comparing the precipitation rate distribution with the turbidity after flocculation sedimentation.

## Materials and Method

Continuous coagulation and sedimentation experiments were conducted from October 2021 to September 2022 at a water treatment plant (Saitama, Japan). The schematic of the plant is shown in Figure 2.1. The coagulant used was poly-aluminium chloride (PAC250, basicity: 47 ~ 57 wt%). The retention times of the mixing tank, flocculation tank, intermediate tank and sedimentation tank were set at 3, 15, 7.5 and 60 min, respectively. To capture a variety shape of flocs, continuous operation was carried out by sequentially switching the coagulant injection rate to 4 levels of 0.5, 1.0, 2.0 and 3.0 mg-Al/L every 12 hours.

Floc images were obtained by clipping the video at 0.1 fps from captured by the underwater camera (UC-IP150, Mikami co., ltd., Japan) installed at the position of the water depth of 10 cm of the intermediate tank. Individual flocs were extracted by binarization, object detection and cropping. Otsu method (1979) was applied for binarization (Figure 2.2) and cv2.findcontourus from the OpenCV library was used to detect the contour of individual particles.

$$v_s = \frac{g\,a}{18\mu} d^{D-1} \ldots (Eq.1)$$

The sedimentation rate of individual floc $v_s$[mm/s] was calculated by Eq.1, based on Stokes' equation and the floc density function (Tambo et al., 1979). The fractal dimension $D$ [-] was obtained by the box counting method and the equivalent circle diameter, calculated as 0.0177 mm/pixel, was used for the floc diameter $d$[mm]. $\mu$ is the viscosity of water [kg/(mm·s)], $a$ is a constant derived from Tambo et al. (1979) and $g$ is the gravitational acceleration [mm/s$^2$]

**Results and Conclusion**

Floc-particle images extracted from Figure 1.1 using the floc extraction algorithm are shown in Figure 3.1. As a result of comparing the number of visible floc particles with the number of extracted floc particle images for 10 randomly selected camera images, 98% of the particles were recognized. From these results, it was confirmed that our proposed algorithm can automatically extract individual floc particles from the photographed floc group.

Fractal dimensions and floc diameters calculated from the floc-particle images extracted in Figure 3.2, 3.3 are shown. Figure 3.2 show that the fractal dimension D is distributed between 1.20 and 1.97. Since the two-dimensional fractal dimension is less than two, the fractal dimension D calculated by this study is a reasonable value. The floc diameter d of Figure 3.3 was distributed over 0.50 ~ 4.74 mm, which agree with the results of Tambo et al. (1979).

Figure 3.4 shows the floc precipitation rate, determined using parameters obtained from individual floc-particle images. The observed floc precipitation rates were minimal 0.11 mm/s, maximal 7.7 mm/s, and median 0.89 mm/s. Comparison of the sedimentation rate profiles of floc particles between high turbidity and normal conditions revealed that the precipitation rate was 60% faster at high turbidity (Figure 3.7). These results agree with the phenomenon that flocs with better sedimentation properties are likely to be formed at high turbidity than at low turbidity, as has been pointed out in the past, and support the validity of the method developed in this research. In water purification plants, an operation is adopted in which ALT ratio is kept above a certain level by adjusting the coagulant dose to avoid the failure of coagulation, but it brings an increase in the sludge amount and in the chemical substitution are caused. If the precipitation rate of floc particles can be quantified, the flocculation can be efficiently through control at low ALT ratio.

In general, the coagulation condition is determined based on the turbidity at the effluent of settling basin. As in this study, if the precipitation rate of individual floc particles is clarified, the effect accompanied by the change of the coagulation condition can be immediately known from the floc image, so that it becomes possible to control the coagulation more quickly and with higher accuracy than before, and the possibility of constructing the autonomous control which can optimize the coagulation operation without the human resource was shown.

**REFERENCES**

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Vahedi, A. & Gorczyca, B. 2011. Application of fractal dimensions to study the structure of flocs formed in lime softening process. *Water research,* **45***,* 545-559.

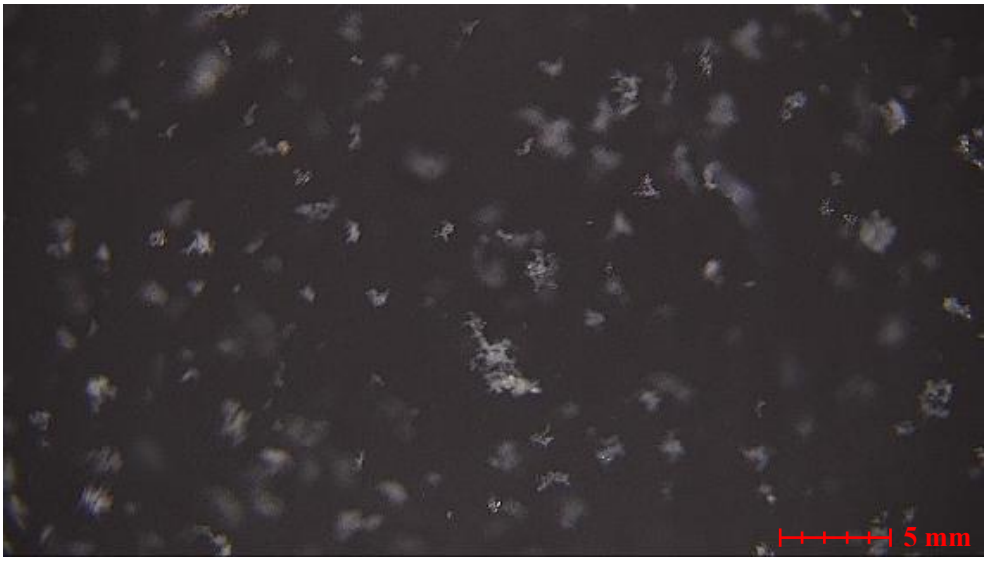


**Figure 1.1** Captured floc image by underwater video camera.

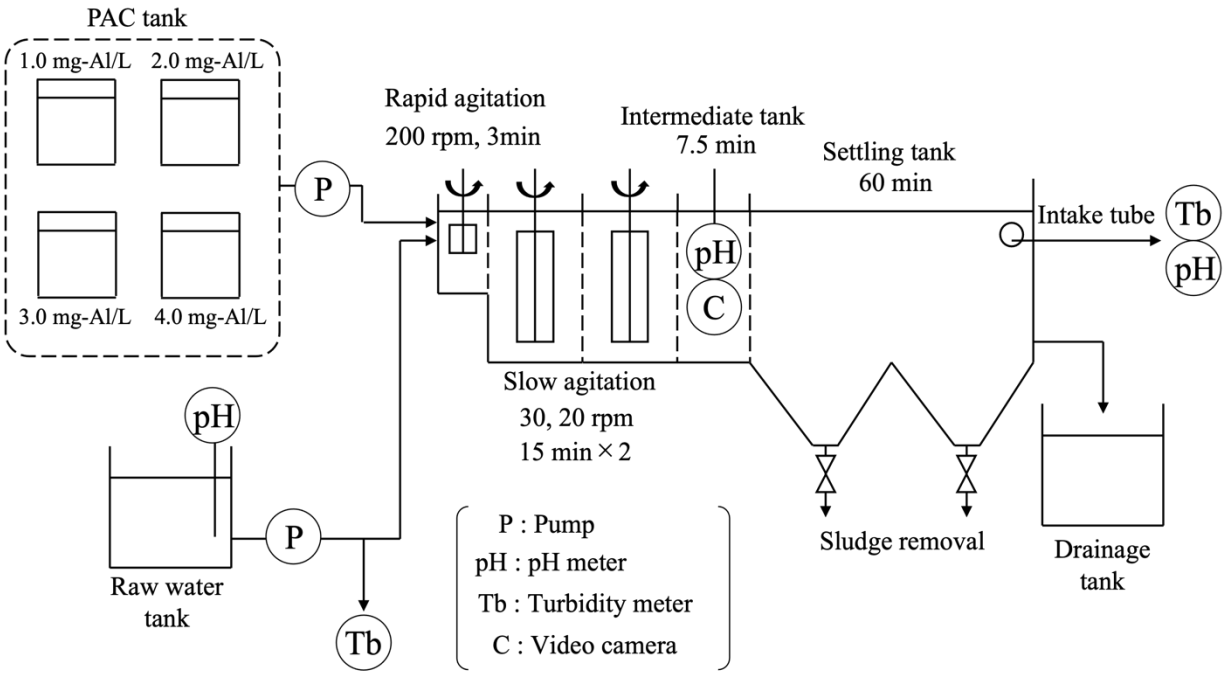


**Figure 2.1** Schematic image of the pilot-scale coagulation-sedimentation plant.
Water is supplied from left to right. Flow rate is set at 10.4 L/min.

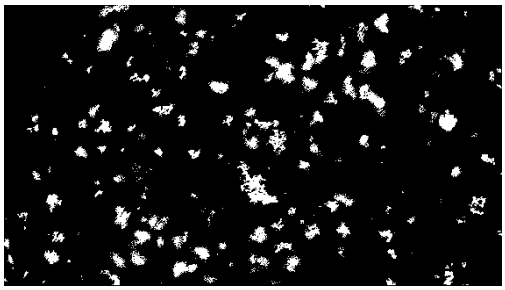

**Figure 2.2** Binary image of captured floc.

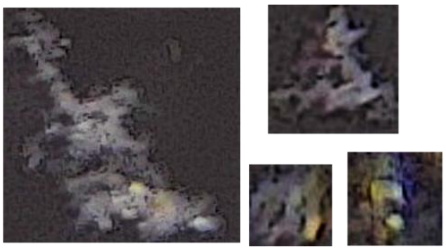

**Figure 3.1** Extracted flocs from captured floc images.

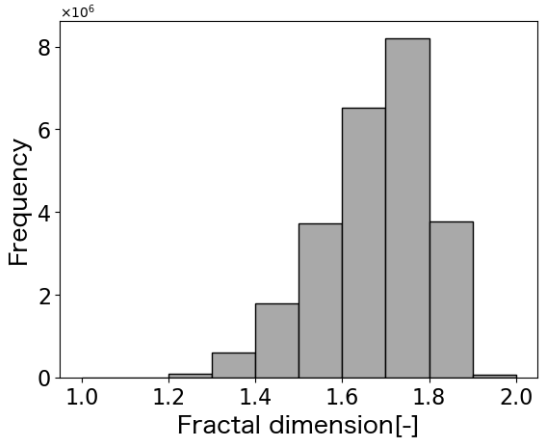


**Figure 3.2** Distribution of fractal dimension of all flocs (N = 24,810,528)

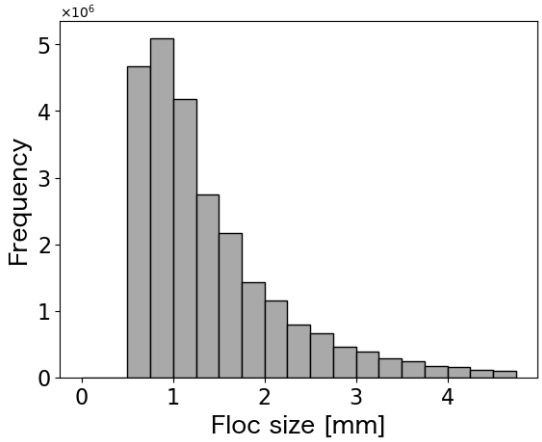


**Figure 3.3** Distribution of floc size (N = 24,810,528)

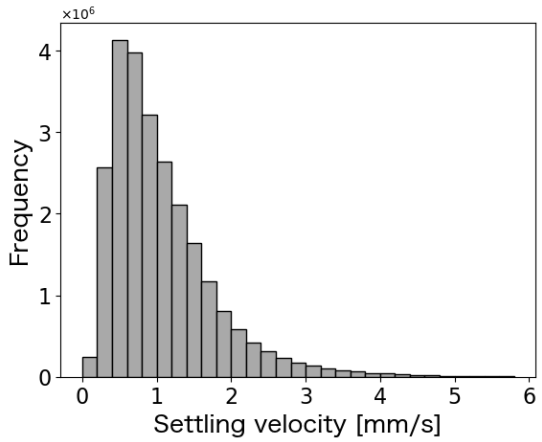


**Figure 3.4** Distribution of floc settling velocity (N = 24,810,528)

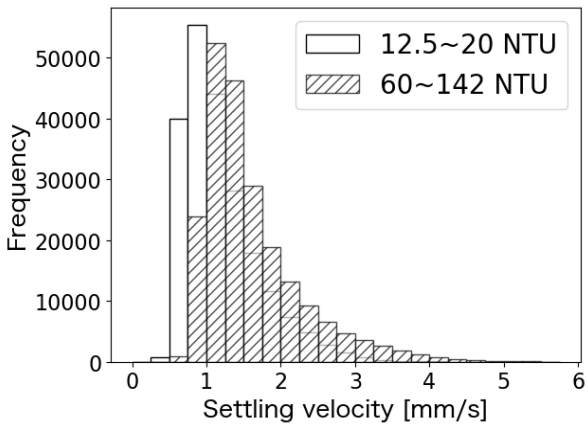


**Figure 3.5** Difference of settling velocity between usual (12.5~20 NTU) and high turbidity (60~142 NTU) conditions