Removal of suspended substances by coagulation and foam separation from municipal wastewater

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Abstract A new method for solid–liquid separation for wastewater incorporating simple operation and shortened treatment time is necessary for improvement of sewage systems. In this study, removal of suspended solids from municipal wastewater by coagulation and foam separation using coagulant and milk casein was examined. By adding casein before the foam separation process, the removal of suspended substances was dramatically improved. The optimum condition for treating sewage was 20 mg-Fe/L of $FeCl_3$, 3 mg/L of casein, and pH 5.5, which resulted in a removal rates of over 98% for turbidity and SS. A removal of 96–98% was also possible for phosphate and anionic surfactant. When PAC was used, the floc was also efficiently recovered in foam by the addition of casein. It became clear that coagulation and foam separation using casein as the collector is an effective method for removing suspended solids in municipal wastewater in a short time (within 10 min).

Keywords Coagulation and foam separation; collector; dispersed air flotation; milk casein; removal of suspended solids; wastewater treatment

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Introduction

Generally, a municipal wastewater processing system consists of primary physical treatment process such as settling and sedimentation, and secondary biological treatment process such as activated sludge or oxidation ditch method, etc. The treatment of suspended organic substances and dissolved organic matter in the effluent from the preliminary sedimentation basin depends entirely on the biological treatment. The load for the biological treatment process is large and the fluctuating range of the load is also wide. At present, the management of the biological treatment process is the most important consideration in many treatment facilities. For maintaining the water quality of treated water, it is desirable that the amount of the load on the biological treatment process be reduced. If the suspended substance contained in the effluent of a preliminary sedimentation basin can be removed, the load can be reduced. In addition, the management of water quality is facilitated because biological treatment is easy for dissolved organic matter. A shortened processing time can also be expected. Therefore, development of a treatment process that can remove suspended substances in municipal wastewater in a short time would be a huge improvement for sewage treatment systems.

Flotation using bubbles is one of the fastest methods of solid–liquid separation. Flotation is classified as dissolved air flotation or dispersed air flotation, depending on the type of bubble supply system. Dissolved air flotation appears to be a suitable method for recovering scum, whereas dispersed air flotation is more suitable for recovering foam. At present, dissolved air flotation is the most popular flotation method and has been widely adopted for water treatment (Hyde *et al.*, 1977; Valade *et al.*, 1996). On the other hand, dispersed air flotation has the advantages of rapid separation and easy maintenance. This method is used in the mineral processing industries. For water treatment, however, in the past, though the dispersion air flotation method has utilized various surfactants, large amounts of surfactant were required, and conditions varied greatly depending on the type of suspended particle used (Crandall and Grieves, 1968). Previous studies have indicated that when the ionic strength is high in drainage, the function of chemicals such as sodium dodecyl sulfate and other surfactants is inactivated, and the treatment capability becomes bad (Peng and Di, 1994; Beheir and Aziz, 1996). For large number of samples of municipal wastewater, wastewater processing by the foam separation method (without coagulant and other reagents) was examined in detail by Rubin *et al*. (1963). However, though this method was very effective in the removal of detergent such as alkylbenzene sulfonic acid, it was ineffective in the removal of suspended solids. To date, the foam separation method has not been successful in removing suspended solids from wastewater. However, foam separation by dispersed air flotation has the potential to be a rapid processing method for the removal of suspended solids, if it is possible to change the hydrophilic interface of solids or flocs in waste to a hydrophobic interface by an effective collector agent.

When the water in which fish are reared is aerated, stable foam with various concentrated pollutants such as suspended organic matter, colloids, and bacteria generates on the water surface (Maruyama *et al*., 1991, 1996, 1998; Chen *et al*., 1993; Suzuki *et al*., 2000). Fish mucus, a protein, acts as both collector and frother (Suzuki and Maruyama, 2000a). We considered that the principle of suspended matters concentrated in foam could apply to the solid–liquid separation method in water treatment engineering, and we developed a coagulation and foam separation method using milk casein as the active chemical (Maruyama *et al*., 1998). Casein functions as an excellent collector that makes the floc interface hydrophobic (Suzuki and Maruyama, 2000b). “Coagulation and foam separation”, which is described in this study, is different from dissolved air flotation in terms of bubbling, adsorbed pattern of suspended substances on the bubble surface, and the method of recovering floating substances. Coagulation and foam separation is generally classified as dispersed air flotation. In this study, removal of suspended solids by coagulation and foam separation from municipal wastewater was examined.

Materials and methods

Sampling and reagents

Samples of municipal wastewater were collected from the effluent of the primary settling tank in a wastewater treatment plant. The tested coagulants were ferric chloride ($FeCl_3$, Reagent grade, Wako Chemical Co.) and polyaluminium chloride (Taki Chemical Co.). The stock solution of ferric chloride ($FeCl_3$) as a coagulant was dissolved in 0.01 M hydrochloric acid (HCl) solution in a concentration of 10,000 mg-Fe/L. The stock solution of milk casein (Reagent grade, Wako Chemical Co.) was dissolved in 0.01 M NaOH in a concentration of 10,000 mg/L.

Jar test procedure

Experiments on 500 ml samples were performed using a jar test apparatus (MJ-8, Miyamoto Co.). The standard jar test procedure consisted of rapid mixing at 150 rpm for 3 min after the addition of chemicals, followed by slow mixing at 40 rpm for 15 min. The floc was then allowed to settle for 15 min. After settling, the supernatant liquid was taken out, and turbidity and pH were measured.

Coagulation and foam separation

A sample (500 ml) was dosed with the coagulant and rapidly mixed (150 rpm) for 3 min. The pH was adjusted by addition of NaOH or HCl. After coagulation, casein was then added to the sample and mixed for 1 min. By transferring this suspension to the cylindric column (height, 100 cm; diameter, 3.0 cm) of the batch flotation equipment (Figure 1), foam separation was carried out. Dispersed air was supplied from the bottom of the column with a glass ball-filter (Kinoshita Rika Co., pore size 5–10 μm). Foam generated on the water surface was drawn into a trap bottle by a vacuum pump. The recovered foam is called "foam separated water". The processing time for foam separation was 5 min. The air supply flow rate was 0.3 L-air/min. The treated water was sampled from the drain. The turbidity of raw water and treated water was measured to determine the removal rate.The total processing time was only 10 min.

Water analysis

Turbidity was measured by a turbidimeter (Mitsubishi Kasei Co., SEP-PT-706D). The concentration of total organic carbon (TOC), and dissolved organic carbon (DOC, below 0.45 μm) were determined by a total carbon analyzer (Shmazu Co., TC-5000). Ammonium and phosphate were analyzed by DR-2000 analyzer (HACH Co.). The Co-PADAP method was used to determine the anionic surfactants in wastewater. LAS was used as a standard compound for the calibration curve. The other major parameters such as pH, conductivity, BOD, and total coliform were determined according to *Standard Methods* (1992).

Results and discussion

Optimum condition for coagulation

The relationship between pH and turbidity removal of municipal wastewater by coagulation and sedimentation with $FeCl_3$ is shown in Figure 2. The turbidity removal rate was low, when $FeCl_3$ dosage was 2 mg-Fe/L. In 6 mg-Fe/L, there was precipitation in the low pH region near pH 3. At a range of 10~30 mg-Fe/L, the optimum pH region was spread on the base of pH 5.0~5.5 with the increase in $FeCl_3$ dosage. Therefore, the optimum coagulation condition of municipal wastewater was 20 mg-Fe/L of $FeCl_3$ dosage at a pH range of 5~6.

Coagulation and foam separation using $FeCl_3$ and casein

The effect of casein dosage on turbidity removal rate and foam separated water is shown in Figure 3. The $FeCl_3$ dosage was 20 mg-Fe/L, and the pH was adjusted in the 5.2~5.8 range. In the casein-free case, foam was generated because surfactants such as the detergent were contained in the wastewater, but floc solids were not accumulated in the foam, and the processing was very bad. The interface of the floc was not made hydrophobic without casein,

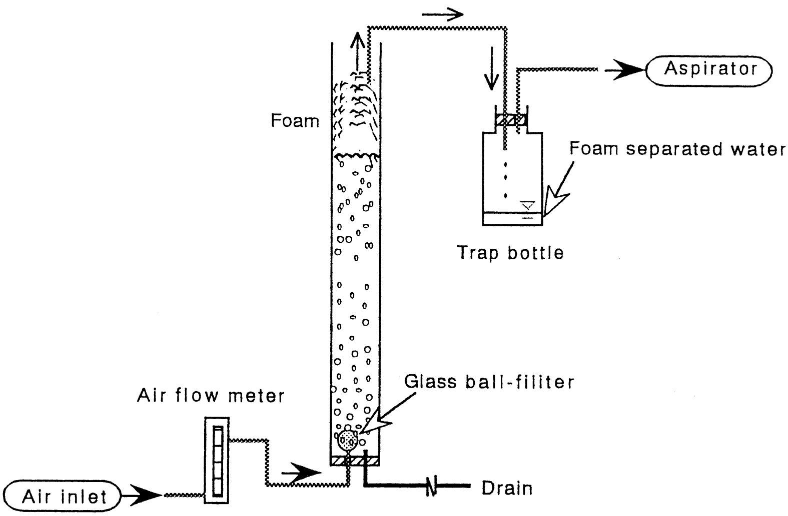

Figure 1 Schematic diagram of batch foam separating system (not to scale)

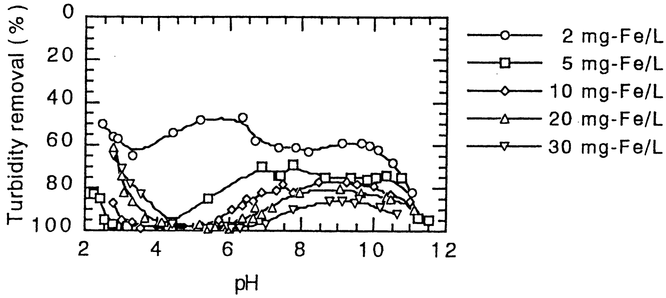

Figure 2 Turbidity removal by coagulation sedimentation method with $FeCl_3$ as a function of pH
Condition: rapid mixing (150 rpm), 3 min; slow mixing (40 rpm), 15 min; sedimentation time, 10 min

so that hydroholic floc could not adsorb on a bubble. It was clear that the surfactant contained in sewage did not make the floc interface hydrophobic. However, the treatment was remarkably improved by adding a small amount of casein. In casein dosages above 3 mg/L, the turbidity of treated water was 2 turbidity units (TU) or less, and the removal rate was over 98%. The floc interface was changed to hydrophobic with casein adsorption, and the flocs were able to be adsorbed on the bubbles. The optimum dosage of casein in foam separation processing of the municipal wastewater was judged to be 3 mg/L. That is to say, the hydrophobicity of the interface is the critical factor that controls the flotation of flocs. Casein has a high ability to make hydrophobic flocs. The relationship between pH and turbidity removal rate is shown in Figure 4. The dosage of casein was fixed at 3 mg/L, and $FeCl_3$ was changed from 10 to 30 mg-Fe/L. The pH region treated well was enlarged as the flocculant dosage increased. The best condition for treating sewage was 20 mg-Fe/L of $FeCl_3$, 3 mg/L of casein, and pH 5~6, which resulted in a removal rate of over 95%. The appropriate pH region of the municipal wastewater treatment depended on the coagulation region. It is clear that suspended substance removal by coagulation and foam separation is

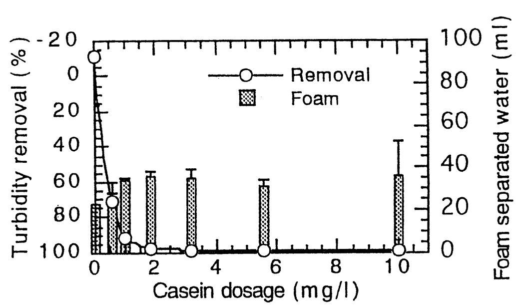

Figure 3 Turbidity removal and the amount of foam separated water as a function of casein dosage in coagulation and foam separation ($FeCl_3$, 20 mg-Fe/L; pH, 5.2(5.8)

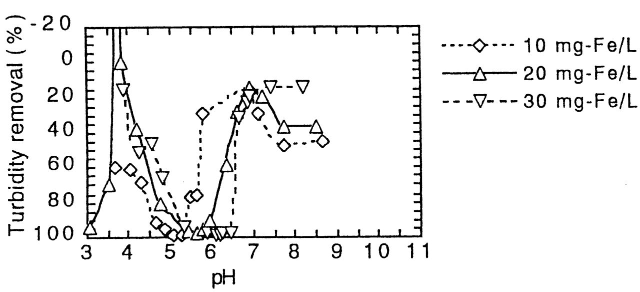

Figure 4 Turbidity removal as a function of pH in coagulation and foam separation ($FeCl_3$, 20 mg-Fe/L; casein, 3 mg/L)

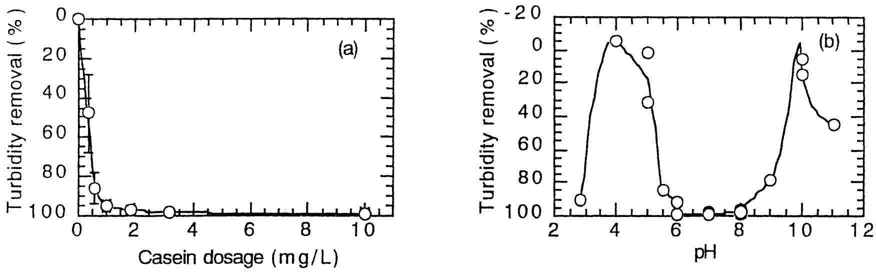

Figure 5 Turbidity removal by coagulation and foam separation using PAC and casein (a) as a function of casein dosage: (PAC, 20 mg-Al/L; pH, near 7), (b) as a function of pH (PAC, 20 mg-Al/L; casein, 3 mg/L)

difficult in the pH region where flocs are not formed. The coagulation process is important for controlling the treatment.

Coagulation and foam separation using PAC and casein

The coagulation condition for PAC was decided by the jar test as well as $FeCl_3$. When using PAC in 20 mg-Al/L, the pH was placed in the appropriate coagulation region (pH 7), even if the pH moderator, such as HCl or NaOH, was not used. The effect of casein dosage on turbidity and removal rate is shown in Figure 5(a). The PAC dosage was fixed at 20 mg-Al/L and pH was not adjusted. Though foam was generated, the treatment was inadequate without casein. However, the turbidity removal rate rose remarkably with an increase in the casein dosage. The turbidity removal rate reached 95% in 1 mg/L of casein. When PAC was used, the floc was also efficiently recovered in foam by the addition of casein, as well as $FeCl_3$ used. The relationship between pH and the turbidity removal rate is shown in Figure 5(b). The optimum pH range by PAC was 6~8, and it widened further than in the case in which $FeCl_3$ was used. It is proven that the control of pH is facilitated by using PAC.

Water quality of municipal wastewater and treated water

The experiments on municipal wastewater treatment were repeated 10 times to confirm the reliability of this method using $FeCl_3$ and casein under the optimum conditions described above. The samples for the experiment were collected on different days. The quality of raw water and treated water for each sample is summarized in Table 1. The removal of suspended solids was not influenced by varying the raw water quality, and the removal rates of turbidity and TSS were maintained at an average of 98%. Total coliform was removed with the solids component, and the removal rate reached 99%. Phosphate was removed by coprecipitation with iron and adsorption to iron hydroxide, and it showed the high removal rate of

Table 1 Treatment of municipal wastewater by coagulation and foam separation

$FeCl_3$ (mg-Fe/L)	pH	Casein (mg/L)	Parameter*	Raw water (mean ± SD)	Treat water (mean ± SD)	Removal (%, mean)	Repricate (number)
			Turbidity, TU	73.5 ± 14.1	1.3 ± 0.6	98.2	15
			TSS, mg/L	69.8 ± 18.3	1.6 ± 0.9	98.1	5
			TOC, mg-C/L	61.9 ± 10.8	25.1 ± 7.2	56.3	15
			DOC, mg-C/L	29.8 ± 3.1	22.3 ± 3.8	25.1	10
20	5.5	3	BOD, mg/L	99.9 ± 8.7	36.2 ± 6.8	60.1	5
			Coli., cfu/mL	$(2.0 \pm 0.2) \times 10^5$	$(7.7 \pm 6.3) \times 10^2$	99.6	3
			PO_4-P, mg-P/L	6.91 ± 2.30	0.13 ± 0.11	98.1	5
			T-P, mg-P/L	9.18 ± 0.32	0.49 ± 0.21	94.7	5
			NH_4-N, mg-N/L	29.8 ± 3.3	27.1 ± 4.4	9.1	5
			Surfactants, mg/L	5.9 ± 0.9	0.2 ± 0.3	96.5	5

* TSS = total suspended solids; TOC = total organic carbon; DOC = dissolved organic carbon; Coli. = total coliform; T-P = total phosphorus; Surfactants = anionic surfactants

over 98%. In addition, surfactants contained in raw water acted as frother for removing flocs, and 96% of anionic surfactants were removed. For coagulation and foam separation, the detergent, which is one of the processing object substances in the wastewater, is utilized as a foaming agent and is removed with foam. On the other hand, since the removal of DOC was low, the rate of TOC became 56%. BOD in treated water was the residual dissolved organic matter. By this method, therefore, the removal of dissolved organic matters of nonsurface activity could not be expected. Ammonia was not removed by this method either.

Conclusions

For treatment of municipal wastewater, the applicability of the foam separation method using metal salt coagulant and casein was examined. By adding casein before the foam separation process, the removal of suspended substances was dramatically improved. The optimum pH region of the foam separation process was controlled in the pH region of the coagulation. A high removal rate of suspended substances was obtained in optimum coagulation pH, when either $FeCl_3$ or PAC was used. Optimum processing conditions in using $FeCl_3$ are as follows: $FeCl_3$ dosage, 20 mg-Fe/L; casein dosage, 3 mg/L; pH 5~6. The conditions for PAC are as follows: PAC dosage, 20 mg-Al/L; casein dosage, 3 mg/L; pH 6~8. The removal rate of the suspended solid was very high, and the removal rates of turbidity and SS were over 98%. A removal rate of 96~98% is also possible for phosphate and anionic surfactants. In contrast, the removal rate of dissolved organic matters was low, so that BOD removal remained at about 60%.

It became clear that the coagulation and foam separation using casein as the collector was an effective method for removing suspended solids in municipal wastewater in a short time (within 10 min). We believe this method can be adopted as a pretreatment process before the biological treatment process of the sewage treatment system.

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