CHARACTERS OF SEDIMENTATION OF SUSPENSION FLOCCULATED OR COAGULATED[①]

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ABSTRACT The properties of flocs were analysed by microphotography and auto image analysis technique, and the sedimentation of flocculated or coagulated suspension and water osmosis in sediment were studied. It was found that, the flocs size is related to the average diameter of fine solid particles, the locus of the compressive points of the sedimentation curves of flocculated suspensions is a straight line approximately, the water permeating of sediment is unsteady and water osmosis rate reduces with extension of sedimentation time, the sediment resistance to fluid flow is the main factor that affects the average sedimental concentration.

Key words flocculation coagulation floc sedimentation of suspension

1 INTRODUCTION

Since flocculants and coagulants are introduced in solid-liquid separation, flocculation and coagulation techniques have developed extensively. The exploitation of new flocculants and coagulants enlarges their active range, which even may be able to solve some "exotic" separation problems, such as suspensions with extreme pH values, temperatures, electrolytes content and pulps with special organic impurity from biotechnological processes.

The most important results of using polymers are the sharp reduction of time of the solid particles settling, and the increase of clarification effect for finest and colloidal particles in the suspension. Therefore, the settling tanks may be strongly reduced in needed volume. In addition, the negative effects of broad variations in concentration and size distribution of the solids in the suspension will be equalized by polyenic flocculation. So it is important to research the characters of sedimentation of suspension flocculated or coagulated for improving settling tank and thickener's function, calculating and governing clarification and thickening.

2 MATERIALS AND METHODS

2.1 Materials

The material was magnetite tailings. Its chemical composition was as follows: 8.27% Fe_2O_3, 71.36% SiO_2, 3.89% CaO, 3.48% Al_2O_3, 1.93% MgO, 9.27% Others.

The −200 mesh content of the material was about 80%. Its density was 2.61×10^3 kg/m^3, measured in distilled water using a pycnometer. The electrokinetic potential was −24.88 mV, measured by a single tube electrophoretic apparatus.

2.2 Measurement of flocs properties

The suspension with a given concentration was poured into a 2000 mL beaker and mixed well-distributedly. According to every experimental condition, put flocculants into the suspension and stirred up it at 300 r/min for 30 s, and then at 200 r/min for 90 s. Flocs samples of the flocculated suspension moved on the glass covered with a film of water. Laid the glass on the carrier of the microscope camera and took photograph of flocs. Then calculated the equivalent circle diameter of flocs with a auto image-analyzing computer.

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The density and porosity of the flocs are measured by Torcachiev B A[1] method. That is to say, weigh 1.00 g sample exactly and make it flocculate in a 5 mL graduate under a given condition. Then measure volume of flocs while all flocs settled down at the bottom of graduate and calculate the flocs density and porosity according to Eqns(1) and (2), respectively.

$$\rho_f = \rho_l + \frac{M}{V_f}(1 - \frac{1}{\rho_s}) \quad (1)$$

$$\varepsilon_f = \frac{V_f - \frac{M}{\rho_s}}{V_f} \times 100\% \quad (2)$$

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Flocs properties

Table 1 shows the relationship between flocs properties and flocculant's variety, molecular mass and dosage. When suspension is added into cationic polyacrylamide(CPAM) average equivalent circle diameter of flocs is small, its density is heavy and the porosity is low. Therefore, settling velocity of flocs is high. However, anionic polyacrylamide(APAM) links fine particles by "bridging action" mainly, and the density of flocs is the smallest though its size is larger and porosity is higher. The settling velocity of this type of flocs is lower.

The higher PAM's (non-ionic polyacrylamide) molecular mass is, the larger the equivalent circle diameter of the flocs is. It is non-linear between the two parameters. When PAM's molecular mass is more than 600 × 10^5, flocs' size increases slowly.

In a certain extent, the more dosage of the flocculant is, the larger flocs size will be, and the looser its structure is. Flocs density reduces with increasing flocculant dosage. When PAM dosage exceeds 30 g/t, the settling velocity of flocs increases almost linearly. The result implies the bridging action of PAM is developed fully only when flocculant concentration in suspension is appropriate.

Table 2 shows flocs size, density and porosity at various pH values, PAM molecules partly hydrolyze and produce — COO^-, and the molecule chains stretch because of its identical charge. At high pH values, PAM molecular chains become more straight, and this moment, negative charge of particles surface increases, so flocculants are absorbed on the particles surface by hydrogen bond. The more straight PAM molecular chain is, the larger flocs size is, and flocs density reduces[2].

Table 3 shows the effect of solid particles size on average flocs diameter d_f. The data implies that there is no relationship between d_f and particles size of solid material. But by further analysis it is found that d_f corresponds with average diameter of − 55 μm particle size fraction in the material, d_{-55}. The result shows polymers have distinctive function to fine solid particles.

3.2 Initial interface settling velocity

Fig. 1 shows the relation between initial interface settling velocity u and initial concentration C_0. The regressive equations concerning u with C_0 are listed in Table 4.

Table 1 Relation between flocs properties and flocculants*

	Flocculant			PAM Molecular mass(× 10^6)				PAM Dosages/ g·t^{-1}					
	CPAM	PAM	APAM	360	600	900	1 290	5.0	10.0	20.0	30.0	40.0	50.0
d_f / μm	120	132	130	158.1	195.3	220.4	228.2	91.1	91.8	96.5	148.8	197.0	221.0
ρ_f / kg·m^{-3}	1216	1 193	1 187	1 194	1 184	1 172	1 165	1 247	1 240	1 185	1 176	1 173	1 165
ε_f / %	86.6	88.0	88.4	87.9	88.6	89.3	89.7	84.7	85.1	88.5	89.1	89.3	89.6
u^{**} / m·h^{-1}	7.11	6.60	6.24	5.30	6.81	7.32	7.45	6.20	7.00	7.70	8.80	11.50	13.00

* Initial volume concentration of suspension is 6.29%;
* * interface settling velocity of flocculated suspension

Table 2 Properties of flocs at various pH values

pH values	4.2* 4.0**	5.7* 5.9**	6.8* 7.0**	8.2* 8.2**	9.1* 9.4**	10.8* 11.0**	12.6* 12.2**
ρ_f/ kg·m^{-3}	1 132	1 124	1 119	1 116	1 112	1 107	1 106
ε_f / %	86.8	87.6	88.1	88.4	88.8	89.3	89.4

* pH for measuring flocs diameter;
** pH for measuring flocs density and porosity

Table 3 Effect of particles size on flocs

No.	Mass Fraction of -400 mesh/ %	d_{-75} / μm	d_{-55} / μm	d / μm	d_f / μm	$d_{f,max}$ / μm	$d_{f,min}$ / μm
A_1	38.22	28.60	17.85	46.88	161.0	219.0	130.0
A_2	48.14	30.70	21.58	43.80	192.0	207.0	166.0
A_3	61.80	30.20	22.51	38.80	208.0	242.0	169.0
A_4	82.86	28.80	22.28	34.90	202.0	220.0	164.0
A_5	92.14	24.50	21.40	29.50	173.0	215.0	135.0

Table 4 Regressive equations concerning u and C_0 for various suspensions

General form	$u = u_0(1 - C_0)^n$	Valid Range of C_0 / %
Flocculated suspension	$u = 9.39(1 - C_0)^{9.59}$	1.95~ 14.1
Coagulated suspension	$u = 3.12(1 - C_0)^{11.8}$	1.95~ 14.1

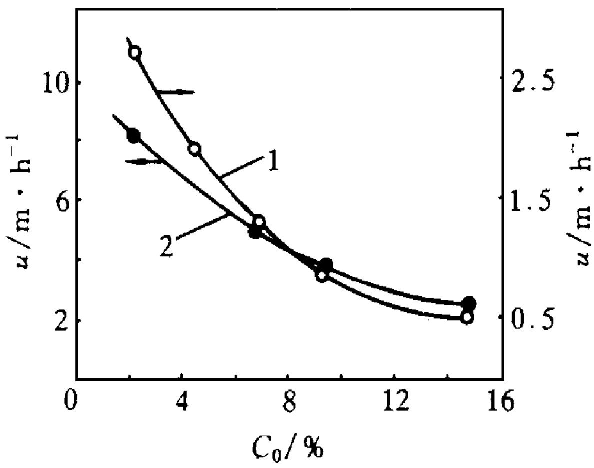

Fig. 1 u **vs** C_0 **plot for suspension with chemicals**
1 —coagulated suspension;
2 —flocculated suspension

3.3 Sediment concentration

Average concentration of sediment C_s is solid particles mass in unit volume(kg/ m^3) of sediment as sedimentation lasted for 12h. In Fig. 2, average sediment concentration for flocculated suspension is smaller and it rises with increasing of C_0. When sediment is thin, flocs is not feasible to be broken. Water packaged in flocs also is difficult to be drained off. When sediment height rises with increasing of C_0, pressure acting on flocs in sediment rises. Once anti-crushing and anti-shearing abilities of flocs are not enough to counteract pressure from the above sediment, most of flocses are crashed, water in sediment is drained through capillary holes in flocs and average sediment concentration increases. There is a similar result for coagulated suspension.

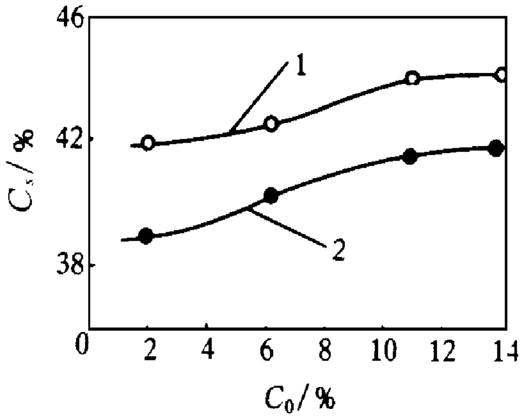

Fig. 2 Relation between average sediment concentration and initial concentration
1 —flocculated suspension;
2 —coagulated suspension

Fig. 3 shows the relation between average sediment concentration and particles size. For flocculated suspension, the sediment concentration change matches average flocs diameters. Analyzing Fig. 3 and Table 3, we find that the flocs settling velocity and its sediment concentration increase with growing of flocs size. It is deduced that the sedimentation of coagulated suspension and flocculated suspension is similar according to Fig. 3.

Fig. 4 and 5 show sedimentation curves of various conditional suspensions. We may find the compressive points of sedimentation curves of flocculated suspensions with various initial concentrations are on a straight line approximately. Their loci equations are listed in Table 5.

Fitch[5] and Font R[6] ever pionted out that

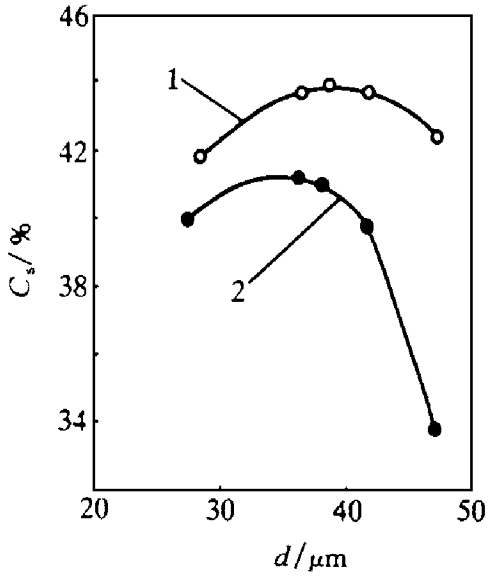

Fig. 3 Sediment concentration vs solid particles sizes plot

1 —flocculated suspension;
2 —coagulated suspension

a compressive pionts locus is the sediment curve. According to their view, we deduced there is less effect of initial concentrations and initial settling heights on sediment forming, which seems to be contradictory with sediment curves in Figs. 4 and 5. In fact, we may see the interface height is L_2 in Fig. 6(b). Gaudin[7] ever investigated density distribution of suspension for batch sedimentation by X-rays (Fig. 6(a)). Values of L_2-L_1 is changeable for different concentration suspensions, once sedimentation is over, it approachs zero.

4 WATER OSMOSIS IN SEDIMENT

Water content in sediment directly affects the underflow concentration in a continuous thickener. That water in sediment permeates in a short time is important to raise a thickener's capacity and underflow concentration.

Water osmosis rate in sediment is calculated as follows:

$$v = \frac{Q}{At_2} = \frac{L_1 - L_2}{t_2} \tag{3}$$

Since value of v is very small, water head of liquid flow is not considered, average pressure of water osmosis in sediments is:

$$J = \frac{P_2 - P_0}{L_2} \tag{4}$$

According to Darcy's law, we acquire:

$$v = kJ \tag{5}$$

Combining Eqns. (3), (4) and (5), we may work out permeation coefficient k, which affects permeating character of water in the sediment.

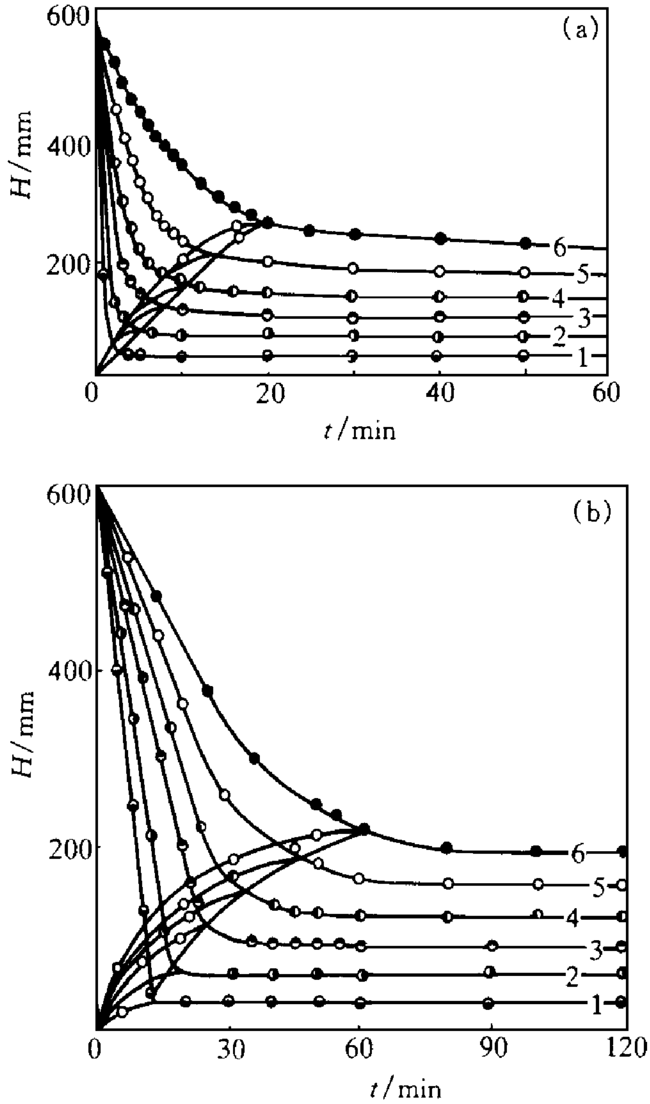

Fig. 4 H vs t polt for different initial concentration suspension

(a) —flocculated suspension;
(b) —coagulated suspension;
1 —C_0= 1.95%; 2 —C_0= 4.08%; 3 —C_0= 6.29%;
4 —C_0= 8.70%; 5 —C_0= 11.2%; 6 —C_0= 14.1%

Fig. 7(a) is water osmosis rate vs relative time plots and Fig. 7(b) is water permeating coefficient vs relative time plots for flocculated suspensions. Origin of abscissa is relative time zero when the compressive point appears. Fig. 7 shows water osmosis rate in sediment decreases with increasing of time non-linearly. During a given time, character of water osmosis in sediment is unsteady. If initial concentration of

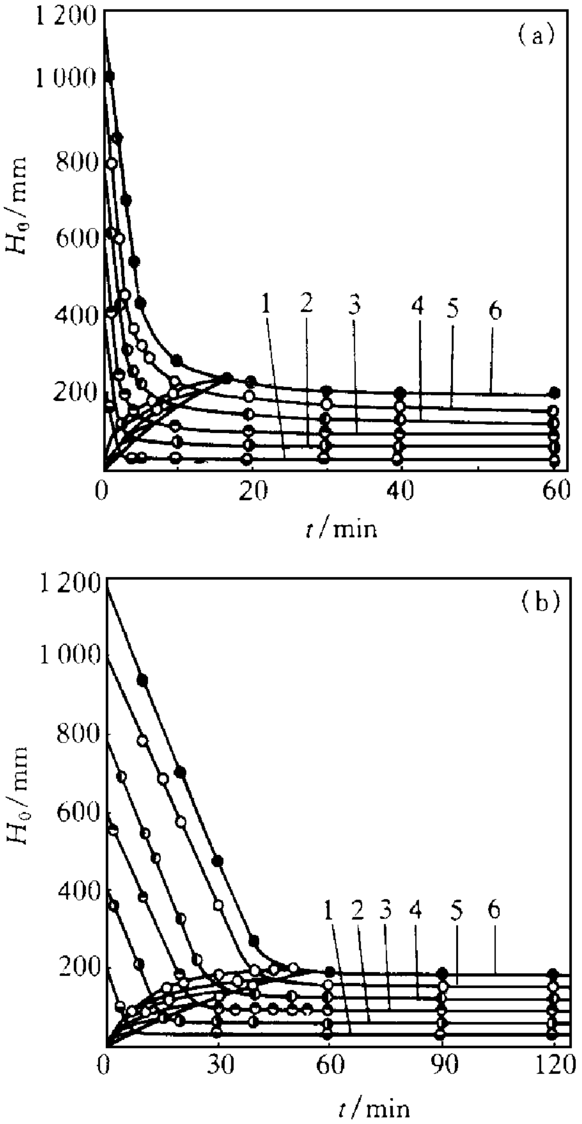

Fig. 5 H vs t plot for different initial settling heights of suspension (C_0= 6.29%)

(a) —flocculated suspension;
(b) —coagulated suspension

Table 5 Loci equation for compressive points of sedimentation curves for various suspension

	Different initial concentration		Different initial height	
	$L = a + bt$	r	$L = a + bt$	r
Flocculated	$L = 6.69 + 1.23t$	0.995	$L = 5.48 + 1.435t$	0.980
Coagulated	not linear	0	not linear	0

flocculated suspension is low, water osmosis rate in sediment decreases fastly.

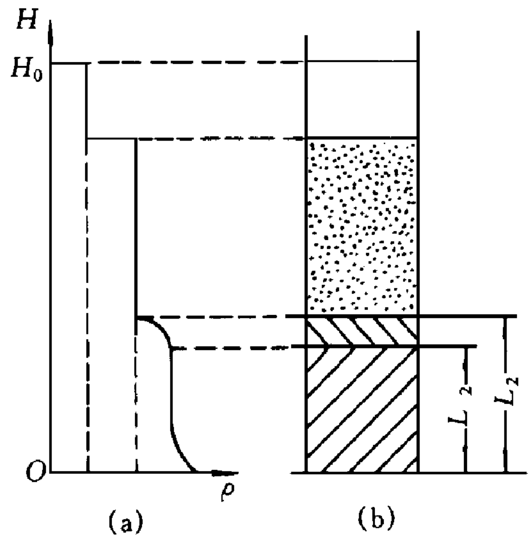

Fig. 6 Suspension density distribution in cylinder

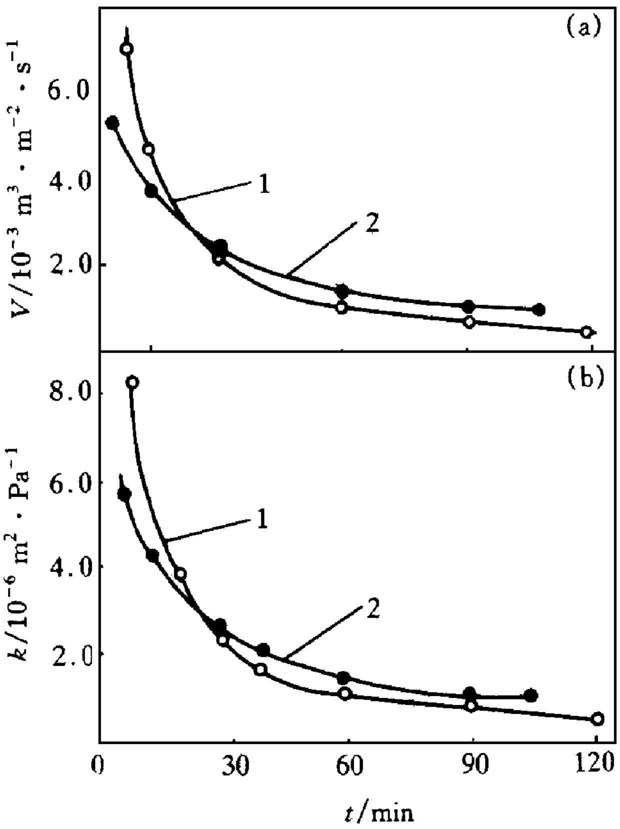

Fig. 7 Water osmosis character in sediment for flocculated suspension

(a) —Water osmosis rate vs. relative time plot;
(b) —Permeating coefficient vs. relative time plot;
1 —C_0= 6.29%; 2 —C_0= 14.1%

5 CONCLUSIONS

(1) It is advantageous for the experimental material to flocculate small and dense flocs acted

by the cationic polyacrylamide (CPAM), and large, loose flocs by the anionic polyacrylamide (APAM). The proper molecular mass and dosage of the flocculants is important to bring its "bridging action" into full play.

(2) The flocs size is related to the average diamter of fine solid particles. Average flocs diameter increases with the rising of the average diameter of − 55 μm part of the material.

(3) The relationship between u and C_0 for flocculated or coagulated suspensions is $u = u_0(1 - C_0)^n$. That is to say, the u reduces with increasing of C_0 for the two kinds of suspensions.

(4) The initial concentration of flocculated or coagulated suspensions affects the sediment concentration. At the different initial concentrations and intital settling height, the loci of the compressive points of the sedimentation curves of flocculated suspensions are straight lines approximately. Their functional expression is $L = a + bt$.

(5) Water permeating of the sediment is unsteady and water osmosis rate reduces with extension of sedimentation time. The flow resistance in sediment is the main factor that affects the average sedimental concentration.

6 NOTATION

M —solid particles mass, kg; V_f —volume of solid particles mass M, m^3; d_f —average flocs diameter, μm; d_{-55}, d_{-75} —average diameter of − 55 μm and − 75 μm parts of solid particles, respectively, μm; u —initial suspension interface settling velocity, m/h; u_0 —free settling velocity of solid particles, flocs or coagulum, m/h; C_0 —initial volume fraction of solid particles in suspension, %; C_f —average volume fraction of solid particles in sediment, %; L —sediment height, mm; t —sedimentation time, s; L_1, L_2 —sediment height at time t_1 and t_2, respectively, mm; a —the intersect in $L = a + bt$, mm; b —the slope in $L = a + bt$, mm/s; r —linear correletion coefficient, dimensionless; v —water osmosis rate, m^3/(m^2 · s); Q —water volume permeated out of the sediment during time t_2, m^3; A —cross section area of settling cylinder, m^2; J —average hydrogradient of water osmosis in sediment, Pa/m; p_0, p_2 —sediment pressure at $L = 0$, L_2, respectively, Pa; k —water permeability coefficient of sediment, m^2/Pa; ρ_f —average flocs density, kg/m^3; ρ_2, ρ_1 —solid particles and liquid media density, respectively, kg/m^3; ε_f —flocs porosity, %; ε —porosity of suspension, %

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