Research Article

Preparation and Coagulation Behavior of a Novel Multiple Flocculant Based on Cationic Polymer, Hydroxy Aluminum, and Clay Minerals

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Received 12 July 2014; Revised 22 August 2014; Accepted 22 August 2014

Academic Editor: Zhaohui Li

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Cationic polymer, hydroxy aluminum, and clay minerals are three flocculants with different action mechanisms and a more cost-efficient multiple flocculant can be prepared by compositing them through appropriate technology. All of attapulgite (ATP), clay minerals containing magnesium, aluminum, and silicate, are porous environmental mineral material with good absorbability and have found wide applications in industrial sewage treatment. With polyaluminum chloride (PAC), poly(dimethyl diallyl ammonium chloride) (PDMDAAC), and attapulgite (ATP) clay being the main raw materials, multiple flocculant CMHa (liquid) with good storage stability was prepared and its optimized blending mass percent was PDMDAAC of 2%–3%, ATP of 4%–6%, and PAC of 20%–30%. The liquid poly(dimethyl diallyl ammonium chloride) (PDMDAAC) was firstly loaded on solid material in kneader and then mixed in certain proportion with PAC and ATP to prepare solid CMHa convenient for storage and transportation. The optimized mass ratio is PAC : ATP : PDMDAAC = 80 : 10 : 2.4. When this multiple flocculant was used to treat domestic sewage, coal washing sewage, dyeing wastewater, and papermaking wastewater, its equivalent dosage was just 50% of PAC, while overall production cost has been reduced to about 40%, viewing showing broad application prospect.

1. Introduction

Flocculants have found wide application due to their good coagulation and purification behavior, low price, and convenience and have been the most widely used water treatment agent with the largest consumption [1, 2].

Micromolecular inorganic salt flocculants, for example, aluminium chloride ($\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$), ferrous sulfate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$), and ferric chloride ($\text{FeCl}_3 \cdot \text{H}_2\text{O}$), have advantage in low cost but their alum grains are small and are strongly corrosive, so they are generally replaced by inorganic polymer flocculants. Polyaluminum chloride (PAC), polyferric sulfate (PFS), polyferric chloride (PFC), and polyaluminium ferric chloride (PAFC) are popular inorganic polymer flocculants. Relatively speaking, inorganic polymer flocculants have better flocculation performance

and cheaper than organic flocculants; however their storage stability is poor and will produce plenty of sludge; thus it is difficult for subsequent treatment [1, 3].

Organic flocculants have advantage in low dosage, fast flocculation velocity, being affected little by coexisting salts, pH of medium, and environment temperature, small amount of sludge, and good decolorization performance, but they are costly and their hydrolyzed or degraded products are toxic. Organic polymer flocculant is classified as natural and multiple [3, 4].

Multiple flocculants can be classified as inorganic-organic multiple, organic-organic multiple, inorganic-inorganic multiple, multinuclear inorganic polymer flocculant, and so forth. Among them, multiple of polymeric aluminum, polymeric iron, and polyacrylamide is the most popular, which integrates the merits of inorganic and organic flocculants

and makes good use of electrical neutralization, adsorption, bridging, and furl mechanism, thus improving flocculation performance, reducing costs, decreasing flocculant dosage and the amount of sludge, promoting the stability of multiple flocculant, and broadening its application. Consequently, it has been the research focus in developing new flocculant [5–13].

Mineral flocculants remove organics and metal ions in water through adsorption and thus no secondary contamination exists, particularly suitable for the treatment of seriously polluted domestic and industrial sewage [7, 10, 11, 13, 14]. However, mineral flocculants also have some disadvantages in practical application. At first, the dosage is large. When treating the same water sample, dosage of mineral flocculants is far larger than that of conventional flocculants (e.g., PAC). In addition, the large dosage makes larger amount of alum grain sediments after treatment than that produced by conventional flocculants. Thirdly, its treatment efficiency is low. Conventional flocculants can flocculate rapidly, while mineral flocculants remove organics and metal ions in water through adsorption and adsorption often takes some time, thus making the treatment efficiency of mineral flocculants lower.

By combining structural features and flocculation performance of organic cationic polymer (C), inorganic hydroxy aluminium (Ha), and clay mineral (M), this paper aims at developing a multiple flocculant CMHa with good performance and low cost.

2. Materials and Methods

2.1. Instruments. SGE-2 Digital Turbidity Meter (Shanghai Yuefeng Instruments Co., Ltd.), TDL-5A High-Speed Centrifuge (Shanghai Fulgor Analysis Instruments Co., Ltd.), and NH-1 Kneader (Shandong Laizhou Longhe Chemical Industrial Equipment Co., Ltd.) are used.

2.2. Materials. Attapulgit (ATP) (Mingguang, Anhui); bentonite (Ningcheng, Inner Mongolia); polyaluminum chloride (PAC) (liquid sample PAC; solid sample SPAC) (Gongyi, Henan); kaolinite (Karamay, Xinjiang); poly(dimethyl diallyl ammonium chloride) (PDMDAAC) (Kemira, Jiangsu); cationic polyacrylamide (CPAM) (Xitao, Beijing); poly(dimethyl diallyl ammonium chloride-acrylamide) (PDA) (Kemira, Jiangsu); diatomite (Linjiang, Jilin); cellulose graft starch (PPS) (Pinggu, Beijing); puffing modified starch (EPPS) (Pinggu, Beijing); and silane graft starch membrane-forming agent (SIM) (Pinggu, Beijing) are used. All of the samples are industrial products obtained from China chemical market.

2.3. Methods

2.3.1. Hydration of Mineral Material. Prepare suspension of clay minerals with various concentrations and then the prepared suspension was stirred for 20 min in high speed stirrer (10000 rpm) followed by hydrating for 16 h.

2.3.2. Preparation of Liquid CMHa. Blend PAC, cationic polymer, and hydrated mineral suspension in various proportions at first and then the mixture was stirred at certain temperature to form uniform solution, that is, liquid CMHa sample.

2.3.3. Load and Solidification of PDMDAAC. Add some support materials into kneader and then add liquid PDMDAAC sample slowly. Keep heating and kneading until water in PDMDAAC evaporates almost completely; then take out the sample for crushing, that is, solidified PDMDAAC sample, recorded as PDMDAAC-S.

2.3.4. Preparation of Solid CMHa. Mix dry solid PAC, PDMDAAC-S, and clay mineral uniformly, that is, solid CMHa sample CMHa-S.

2.4. Evaluations

2.4.1. Evaluation on Flocculant Stability. Leave it stand and observe its stability. And then evaluate its stability by mechanical centrifugation. Take some prepared samples and centrifuge them for 5 min at rotation speed of 2000 rpm, 3000 rpm, 4000 rpm, and 5000 rpm, respectively. The rotation speed at which sample begins separating out water or layering is selected as stability evaluation indicator. The faster rotation speed indicates better stability.

2.4.2. Evaluation on Flocculation Performances. Diatomite suspension with turbidity of 1000 NTU was prepared to simulate water sample (600 g water mixed with 1.1 g diatomite). Then add certain amount of flocculant sample into 100 mL simulated water sample and stir rapidly for 2 min at first and then stir slowly for another 2 min. After that, add certain amount of polyacrylamide and stir slowly for 2 min. Observe and record the size and settling time of alum grain. After 30 min, measure the turbidity of supernatant.

3. Results and Discussion

3.1. Influence Factors on Stability and Coagulation Behavior of CMHa

3.1.1. Mineral Materials Types. It can be known through investigating the stability of CMHa prepared by different mineral materials (shown in Table 1) that the presence of bentonite in ternary system makes the system layer and yellow liquid separate out in upper layer; precipitates can be observed in the system in the presence of kaolinite as kaolinite tends not to suspend; ATP makes the ternary system very stable, so it is selected as mineral material used in following tests.

3.1.2. Cationic Polymers. The presence of PDA makes CMHa ternary system layer, while adding PDMDAAC will not affect the system's stability. However, if content of PDMDAAC exceeds 3%, viscosity of the system will increase and thus it cannot flow easily after standing, while low content will

TABLE 1: The stability of different kinds of minerals in the CMHa.

PAC	PDMDAAC	CMHa (%)		ATP	Sample appearance after standing
		Bentonite	Kaolinite		
15	1		15		Settling
15	2		10		Settling
20	1	4.0			Obvious separated layer
20	1	5.0			Obvious separated layer
25	1	5.0			Obvious separated layer
15	1	5.0	5.0		Separated layer
15	1	3.0	3.0	3.0	Separated layer
15	1			5.0	Stable
15	1		6.0	4.0	Settling
15	1	3.5	1.5		Separated layer

TABLE 2: The influence of different kinds of cationic polymers on the stability of CMHa.

PAC	PDMDAAC	CMHa (%)		ATP	Sample appearance after standing
		PDA			
20	1			5	Relatively stable
20	2			5	Relatively stable
20	3			5	Thick and viscous
20		1		5	Obvious separated layer
20		2		5	Obvious separated layer
20		3		5	Obvious separated layer

TABLE 3: The influence of attapulgite on the stability of CMHa.

PAC	CMHa (%)		Sample appearance after standing
	PDMDAAC	ATP	
25	2	3.7	A little water separated in the upper part
25	2	4.2	Uniform
25	2	4.8	Uniform
25	2	5.2	Uniform
25	2	5.5	Uniform
25	2	6.0	Difficult to flow
25	2	7.0	Difficult to flow

degrade the flocculation performance of products. Consequently, the suitable dosage of PDMDAAC is 2%-3%, as shown in Table 2.

3.1.3. Mineral Material Content. When content of ATP was lower than 4%, viscosity of product is low and water tends to separate out in upper layer, and thus layering is observed; while content of ATP is greater than 6%, viscosity of product is too high and its flow ability becomes poor after standing. Consequently, appropriate content of ATP ranges from 4% to 6%, as seen in Table 3.

3.1.4. Reaction Temperature. Influence of reaction temperature on stability, viscosity, and flocculation behavior can be seen in Tables 4 and 5. Increasing temperature promotes

stability, increases viscosity of system, and enhances flocculation performance. However, solidification will be observed after standing some time due to high viscosity and poor flow ability. Therefore, optimal temperature should be 40°C~60°C.

3.1.5. Polyaluminum Chloride (PAC). PAC exerts great influence on the stability and flocculation behavior of CMHa. Results in Table 6 show that PAC content of 35% makes the flow ability of product poor. Content of PAC affects the performance of multiple flocculant directly and it should be as high as possible if stability allows for it. Therefore, the optimal content of PAC should be 25%~30%.

3.2. Effects of Treating Water with Different Turbidities Used Liquid CMHa. Compare the flocculation performance of solid PAC (SPAC) with that of liquid CMHa sample prepared at 60°C in the selected optimal blending ratio with good stability (25% PAC + 2% PDMDAAC + 5% ATP) according to results in Table 6. Results in Table 7 show that, when compounding with CPAM, turbidity removal performance of liquid CMHa with two times of dosage was better than that of solid PAC and settling velocity also accelerates. When singly used, turbidity removal performance of liquid CMHa with two times of dosage was improved significantly and settling velocity also accelerated considerably.

3.3. Solidification of CMHa

3.3.1. Selecting Carrier for PDMDAAC. To address the inconvenient storage and transportation of liquid CMHa, porous

TABLE 4: The influence of reaction temperature on the stability and the coagulation behavior for the produced samples (1000 NTU diatomite suspension).

PAC	CMHa (%) PDMDAAC	ATP	Reaction temperature (°C)	Centrifugal stability (rpm)	Residual turbidity (NTU)
25	2	5	25	3000	1.1
25	2	5	40	3000	0.80
25	2	5	60	4000	0.63
25	2	5	80	5000	0.42

TABLE 5: The influence of reaction temperature on the appearance viscosity of produced samples.

PAC	CMHa (%) PDMDAAC	ATP	Reaction temperature (°C)	Sample appearance
20	3	6	40	Thin liquid
20	3	6	60	Thick liquid
20	3	6	80	Difficult to flow
25	2	6	40	Thin liquid
25	2	6	60	Viscous liquid
25	2	6	80	Difficult to flow

TABLE 6: The influence of PAC in CMHa on the stability of produced flocculants.

PAC	CMHa (%) PDMDAAC	ATP	Reaction temperature (°C)	Centrifugal stability (rpm)
15	2	5	60	3000
20	2	5	60	3000
25	2	5	60	4000
30	2	5	60	4000
35	2	5	60	Difficult to flow

solid materials are used to carry PDMDAAC solution with active ingredient content of 40% at first. Then compounding with solid PAC and solid CPAM, solid CMHa can be prepared, that is, CMHa-S. Solid carriers used in tests as shown in Table 8 were selected from natural mineral materials (Attapulgate, Diatomite, Kaolinite, Bentonite) and natural polymeric materials (PPS, EPPS, and SIM). Flocculation performance of SPAC and CMHa-S sample with optimal blending ratio was compared, as seen in Table 9. By comparing the capacity of carriers, status being loaded by PDMDAAC, flocculation performance, and costs, SIM was finally selected as the carrier for liquid PDMDAAC. CMHa-S sample prepared by SIM being as carrier is the best option.

3.3.2. Comparing Flocculent Performance of CMHa with Different PDMDAAC Contents. CMHa samples with different PDMDAAC contents were prepared as seen in Table 10. These samples were used to treat diatomite suspension of 1000 NTU to compare their flocculation performance and results shown in Table 11. Results show that higher PDMDAAC content meant better flocculation performance of CMHa in the presence/absence of CPAM. Coagulation behavior of CMHa-S-PDMDAAC24 sample in the absence of CPAM was similar to that of SPAC with three times higher dosage than it and

the settling velocity accelerates considerably, while its flocculation performance in the presence of CPAM was similar to that of SPAC with two times higher dosage than it. It is suggest that SPAC mixed mineral material and cationic polymer with an enhanced coagulation performance. However, increasing PDMDAAC content in samples made kneading difficult, so CMHa-S-PDMDAAC24 was an optimized formula considering both cost efficiency and technology.

3.3.3. Economic Efficiency of CMHa-S. Taking CMHa-S-PDMDAAC24 as an example and according to current price of raw materials, it can be known that total cost of raw materials is 2100 yuan/ton, comprehensive processing charge is 300 yuan/ton, total production cost is 2400 yuan/ton, and selling price is 3000 yuan/ton. As the equivalent dosage of SPAC is 2~3 times higher than that of CMHa-S and the price of good SPAC is about 2500 yuan/ton, the price of CMHa-S is only 40% lower than that of PAC. And therefore CMHa-S is more cost-efficient.

3.4. Results of CMHa Treating Industrial Sewage. The industrial solid CMHa-S-PDMDAAC24 sample was diluted by water to 32% and then the solution was used to treat domestic sewage, coal washing sewage, and dyeing wastewater. Then

TABLE 7: The coagulation behaviors of CMHa versus PAC (100–1000 NTU diatomite suspension).

Turbidity of diatomite suspension (NTU)	Flocculants (mg/L)	CPAM (mg/L)	Settling time (s)	Residual turbidity (NTU)	Coagulation behaviors
1000	SPAC (30)	3	50	5.7	Larger alum floc
1000	CMHa (60)	3	40	4.5	Larger alum floc
1000	SPAC (60)	—	130	7.6	Larger alum floc
1000	CMHa (120)	—	90	5.9	Larger alum floc
500	SPAC (20)	2	60	2.7	Larger alum floc
500	CMHa (40)	2	50	2.3	Larger alum floc
500	SPAC (40)	—	150	4.5	Smaller alum floc
500	CMHa (80)	—	100	3.1	Larger alum floc
100	SPAC (15)	2	80	1.8	Larger alum floc
100	CMHa (30)	2	70	1.6	Larger alum floc
100	SPAC (30)	—	180	2.5	Smaller alum floc
100	CMHa (60)	—	120	1.9	Larger alum floc

TABLE 8: The carried dosage of different carrier materials for PDMDAAC.

Carrier materials (g)	PDMDAAC (g)	Content of PDMDAAC in solidified samples (%)	Characteristics of solidified samples
Attapulgate (100)	100	28.6	High viscosity and difficulty to kneading reaction
Bentonite (100)	100	28.6	High viscosity and difficulty to kneading reaction
Diatomite (100)	200	44.4	Low viscosity and easiness to kneading reaction
EPPS (100)	80	24.0	High viscosity and difficulty to kneading reaction
PPS (100)	80	24.0	Low viscosity and easiness to kneading reaction
SIM (100)	80	24.0	Low viscosity and easiness to kneading reaction

TABLE 9: The influence of different carrier materials on the coagulation behaviors of CMHa-S (1000 NTU diatomite suspension).

Flocculants (mg/L)	CPAM (mg/L)	Settling time (s)	Residual turbidity (NTU)
SPAC (30)	2	20	0.9
SPAC (45)	2	20	0.6
CMHa-S-SIM (15)	2	20	0.8
CMHa-S-diatomite (15)	2	30	1.5
CMHa-S-PPS (15)	2	25	1.3
SPAC (100)		150	5.5
SPAC (150)		90	2.5
CMHa-S-SIM (50)		90	2.4
CMHa-S- diatomite (50)		100	2.6
CMHa-S-PPS (50)		110	3.7

evaluate its flocculation performance and compare with that of SPAC.

3.4.1. Treating Domestic Sewage. Results in Table 12 show that when CMHa was used to treat the domestic sewage of a sewage treatment plant in Changzhou the residual turbidity of treated water is lower than that treated by PAC, and alum

TABLE 10: CMHa-S with different carried dosage of PDMDAAC.

Samples number	CMHa (%)			
	SPAC	ATP	SIM	PDMDAAC
CMHa-S-PDMDAAC8	80	10	9.2	0.8
CMHa-S-PDMDAAC16	80	10	8.4	1.6
CMHa-S-PDMDAAC24	80	10	7.6	2.4

grain produced by CMHa is larger and its settling velocity is faster.

3.4.2. Treating Dyeing Wastewater. Flocculation behaviors of CMHa versus PAC for treating dyeing wastewater of a textile dyeing and printing plant in Shandong were shown in Table 13. The original wastewater with turbidity of 52 NTU is neutral pH and looks light yellow. Turbidity removal performance of CMHa with only half dosage of PAC can approach that of PAC, while settling velocity of CMHa is faster than that of PAC and its floccules were larger.

3.4.3. Treating Papermaking Wastewater. Flocculation behaviors of CMHa versus PAC for treating papermaking wastewater of a paper mill in Zhejiang were shown in Table 14. Being used singly, the turbidity removal performance and settling velocity of CMHa and PAC are close to each other. However,

TABLE 11: The coagulation behaviors of CMHa-S carried different dosage of PDMDAAC (1000 NTU diatomite suspension).

Dosage of flocculants (mg/L)	CPAM (mg/L)	Settling time (s)	Residual turbidity (NTU)	Characteristics of alum floc during coagulation reaction
SPAC (100)		150	5.5	Alum floc slow and minor
SPAC (150)		100	2.2	Alum floc quick and larger
CMHa-S-PDMDAAC8 (50)		100	4.5	Alum floc quick and larger
CMHa-S-PDMDAAC16 (50)		90	3.1	Alum floc quick and larger
CMHa-S-PDMDAAC24 (50)		80	2.1	Alum floc quick and larger
SPAC (30)	2	20	1.4	Alum floc quick and larger
CMHa-S-PDMDAAC8 (15)	2	20	1.2	Alum floc quick and larger
CMHa-S-PDMDAAC16 (15)	2	25	1.1	Alum floc quick and larger
CMHa-S-PDMDAAC24 (15)	2	20	0.8	Alum floc quick and larger

TABLE 12: Coagulation behaviors of CMHa versus PAC for domestic-sewage treatment (original wastewater 50 NTU).

Dosage of flocculants (mg/L)	CPAM (mg/L)	Settling time (s)	Residual turbidity (NTU)	Coagulation behaviors
SPAC (20)	5	80	2.7	Smaller alum floc
CMHa (10)	5	70	2.3	Larger alum floc
SPAC (30)	5	70	1.4	Larger alum floc
CMHa (15)	5	70	1.1	Larger alum floc
SPAC (20)		300	5.8	Smaller alum floc
CMHa (10)		200	5.6	Smaller alum floc
CMHa (20)		180	4.6	Larger alum floc

TABLE 13: Coagulation behaviors of CMHa versus PAC for dyeing-wastewater treatment (original wastewater 52 NTU).

Dosage of flocculants (mg/L)	CPAM (mg/L)	Settling time (s)	Residual turbidity (NTU)	Coagulation behaviors
SPAC (200)	10	120	20.2	Smaller alum floc
CMHa (100)	10	100	20.5	Smaller alum floc
SPAC (400)	10	100	10.3	Smaller alum floc
CMHa (200)	10	80	10.8	Larger alum floc
Solid PFS (400)	10	—	—	Without effect
Solid FeSO ₄ (400)	10	—	—	Without effect

TABLE 14: Coagulation behaviors of CMHa versus PAC for paper-making wastewater treatment (original wastewater 850 NTU).

Dosage of flocculants (mg/L)	CPAM (mg/L)	Settling time (s)	Residual turbidity (NTU)	Coagulation behaviors
SPAC (100)	3	50	50	Smaller alum floc
SPAC (120)	3	40	42	Larger alum floc
CMHa (50)	3	50	65	Larger alum floc
CMHa (100)	3	40	52	Larger alum floc
SPAC (200)		70	43	Smaller alum floc
SPAC (250)		60	40	Larger alum floc
CMHa (100)		60	45	Larger alum floc
CMHa (150)		60	42	Larger alum floc

when compounding with CPAM, the settling velocity of CMHa is faster than that of PAC and its floccules were larger.

Turbidity removal performance of CMHa with only half dosage of PAC is far better than that of PAC.

3.4.4. Treating Coal Washing Sewage. Flocculation behaviors of CMHa versus PAC for treating coal washing sewage of a coal washing plant in Shanxi were shown in Table 15.

3.5. Action Mechanism of Multiple Flocculant. The three components of CMHa work differently. CMHa makes full use of the comprehensive characteristics of inorganic and

TABLE 15: Coagulation behaviors of CMHa versus PAC for coal-washing wastewater treatment (original wastewater 1200 NTU).

Dosage of flocculants (mg/L)	CPAM (mg/L)	Settling time (s)	Residual turbidity (NTU)	Coagulation behaviors
SPAC (50)	5	20	19	Larger alum floc
CMHa (30)	5	15	9.4	Larger alum floc
CMHa (20)	5	15	17	Larger alum floc
SPAC (80)		150	40	Smaller alum floc
CMHa (50)		60	14	Larger alum floc
CMHa (40)		80	22	Larger alum floc

organic polymer flocculants and adsorption, bridging, and flocculation aid capacity of natural porous mineral materials, which is not simple arithmetical addition of flocculation performance of single component. Combining the previous research and results of this paper, action mechanism of multiple flocculant includes the following three aspects.

3.5.1. Role of Mineral Material in CMHa. Being as flocculant, mineral material contains exchangeable inorganic cations in its interlayer and some oxygen atoms exposed on its crystal surface. This special molecular structure and irregular crystal defect of mineral material enable it to adsorb contaminants in water well. Clay mineral is characterized as being porous, having large specific surface area, and having strong polarity and its price is often lower than that of conventional flocculants. Some unwieldy contaminants in water (e.g., organics and metal ions) can be removed through adsorption of minerals and secondary pollution can be avoided [10, 11].

3.5.2. Role of Hydroxyl Aluminum in CMHa. Polyaluminum chloride is an intermediate from hydrolyzation and its flocculation performance is related to its degree of alkalization. It is often expressed by the formula $Al_2(OH)_nCl_{(6-n)}$ and n means degree of alkalization. Hydroxyl aluminum contains polyhydroxy complex-ions and these ions will form multinuclear complex-ions using OH^- as bridge. So it can adsorb colloidal particles strongly and then promote the agglomeration of colloid through adsorption, bridging, and cross-linking. Meanwhile, physicochemical changes will occur and then charges on the surface of colloidal particles and suspended solids can be neutralized and Zeta potential is reduced, which makes the repulsive colloid particles become attractive, destroys the stability of micelles, and promotes the collision of colloidal particles, and therefore flocculant coagulative precipitation is produced and its surface area can be as large as $(200-1000) m^2/g$, having adsorption capacity [12, 15-18]. In short, polyaluminum chloride plays various roles including adsorption, destabilization, adhesion, bridging, and furl flocculation.

3.5.3. Role of Polymer in CMHa. The molecular mass, molecular structure, shape, and groups of polymer can affect the activity of flocculant. In addition, organic flocculant carried charge and thus can play electrical neutralization. Due to its large molecular mass, polymer can be regarded as a bridge helping produce flocs with structure of "colloidal particle-polymer-colloidal particle" and the flocs will settle. It can be

interpreted as that two colloidal particles with like charges are connected together by a colloidal particle with unlike charges to form precipitate. Polymer flocculant with linear structure can be absorbed on the surface of colloidal particles and can enlarge the volume of alum grains and accelerate settling through furl mechanism [19, 20].

4. Conclusions

Cationic polymer, hydroxy aluminum, and clay minerals are three flocculants with different action mechanisms and a more cost-efficient multiple flocculant can be prepared by compositing them through appropriate technology.

With polyaluminum chloride (PAC), poly(dimethyl diallyl ammonium chloride) (PDMDAAC), and attapulgite (ATP) clay being the main raw materials, multiple flocculant CMHa (liquid) with good storage stability was prepared and its optimized blending mass percent was PDMDAAC of 2%-3%, ATP of 4%-6%, and PAC of 20%-30%.

The liquid poly(dimethyl diallyl ammonium chloride) (PDMDAAC) was firstly loaded on solid material in kneader and then mixed in certain proportion with PAC and ATP to prepare solid CMHa convenient for storage and transportation. The optimized mass ratio is PAC:ATP:SIM: PDMDAAC = 80 : 10 : 7.6 : 2.4. When this multiple flocculant was used to treat domestic sewage, coal washing sewage, dyeing wastewater, and papermaking wastewater, its equivalent dosage was just 50% of PAC, while overall production cost has been reduced about 40%. Consequently, multiple flocculant CMHa shows broad application prospect.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgment

This research was supported by National High Technology Research and Development Program of China (863 Program 2012AA06A109).

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