Evaluation of Al_{30} polynuclear species in polyaluminum solutions as coagulant for water treatment

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Abstract

Polyaluminum coagulant with a content of 76.8% of Al_{30} ($\text{PAC}_{\text{Al}_{30}}$) was prepared. Its coagulation behaviors were compared with high Al_{13} content polyaluminum coagulant ($\text{PAC}_{\text{Al}_{13}}$) and AlCl_3 . The species stability was studied using Al-Ferron method and ^{27}Al NMR. The coagulation performances were investigated by studying the rate of flocs development, the turbidity removal efficiency and charge neutralization capacity under fixed pH conditions and uncontrolled pH conditions. The effect of pH on coagulation was also studied. The results show that $\text{PAC}_{\text{Al}_{30}}$ are stable for using as coagulant. $\text{PAC}_{\text{Al}_{30}}$ causes less pH depression than $\text{PAC}_{\text{Al}_{13}}$. The charge neutralization capacity of $\text{PAC}_{\text{Al}_{30}}$ is slightly lower than that of $\text{PAC}_{\text{Al}_{13}}$ at $\text{pH} \geq 6.8$ and higher at $\text{pH} \leq 6.5$. $\text{PAC}_{\text{Al}_{30}}$ achieves the most effective turbidity removal in these three coagulants. And it acts effectively within a much broader dosage range and a wider pH range when compared with $\text{PAC}_{\text{Al}_{13}}$. $\text{PAC}_{\text{Al}_{30}}$ achieves the highest turbidity removal due to its strong flocs formation capacity. The results verify that Al_{30} is another highly active coagulation/flocculation species for turbidity removal.
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Keywords: Al_{13} species; Al_{30} species; Charge neutralization; Coagulation; Polyaluminum chloride; Turbidity removal

1. Introduction

Coagulation/flocculation is a common process in water and wastewater treatment, which destabilizes the suspended and dissolved materials, followed by aggregation into large flocs that are easily separated from the water by subsequent sedimentation/flotation and filtration processes. Coagulant plays a key role during the process of coagulation. The pre-hydrolyzed polyaluminum coagulants are the most widely used coagulants and receive extensive research (Duan and Gregory, 2003). Compared with the conventional Al salts such as AlCl_3 and alum, polyaluminum coagulants have the advantage of being more effective

within a broader pH range and more rapid aggregation velocity (Gao et al., 2002). Additionally, the high charge neutralization capacity of polyaluminum species often results in a decrease in dosage and the associated waste sediment production. Polyaluminum coagulants can achieve higher turbidity removal efficiency than traditional Al salts because the hydrolysis degree of polyaluminum can be controlled during manufacturing, and the hydrolytic Al species in polyaluminum coagulant can be tailor made. The polynuclear Al species in polyaluminum coagulant remains relatively stable for a long-term after dosing. However, the traditional Al salts hydrolyze and precipitate rapidly after dosing into water (Luan, 1997). The formation of Al species during this process is uncontrollable, and varies with the change of raw water nature.

Various meta-stable or transient state species such as monomers, oligomers, Al_{13} ($[\text{AlO}_4\text{Al}_{12}(\text{OH})_{24}(\text{H}_2\text{O})_{12}]^{7+}$) polymer, other high polymers and Al sols coexist in

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polyaluminum coagulant (Tang, 1998). It is generally believed that Al_{13} species is the optimal species for coagulation in polyaluminum coagulant due to its high charge neutralization capability, strong structure stability and nanometer molecular diameter (1.0 nm). Thus, the high content of Al_{13} is one of the goals in the production of polyaluminum coagulants. However, the commercial polyaluminum coagulant only contains small amount of Al_{13} due to the aggregation of Al_{13} (Wang and Hsu, 1994), which is an insurmountable problem in the production of polyaluminum coagulant.

Al_{30} ($[\text{Al}_{30}\text{O}_8(\text{OH})_{56}(\text{H}_2\text{O})_{24}]^{18+}$) polymer is another polycation with Keggin structure in hydrolytic polyaluminum solutions, which was characterized by ^{27}Al nuclear magnetic resonance (NMR) and single-crystal X-ray diffraction. Al_{30} species is composed of two $\delta\text{-Al}_{13}$ connected by four Al monomers. The two tetrahedral coordinated Al in Al_{30} species produce a broad ^{27}Al NMR signal at $\delta = 70$ ppm (Allouche et al., 2000; Rowsell and Nazar, 2000). Al_{30} is more temperature resistant and less sensitive to pH variations than $\varepsilon\text{-Al}_{13}$ (Allouche et al., 2000). Al_{30} possesses eighteen positive charges and unique nanometer molecule dimension (2.0 nm in length) (Allouche et al., 2000). It may be another promising active species in polyaluminum coagulant responsible for coagulation/flocculation besides Al_{13} species. But there is still no report on the coagulation/flocculation performance of Al_{30} species.

Our previous research investigated the formation conditions of Al_{30} species, and the results show that Al_{30} species can become the dominant species in polyaluminum solution when the freshly prepared polyaluminum solution is heated for 12 h at 95 °C. And the formation of Al_{30} is accelerated by the increase of total Al concentration (Chen et al., 2005). The formation conditions of Al_{30} coincide with the production conditions of commercial polyaluminum coagulant, in which polyaluminum coagulant has a high total Al concentration and is prepared at high temperature for a long time.

In the present research, polyaluminum coagulant with 76.8% Al_{30} content ($\text{PAC}_{\text{Al}_{30}}$) was prepared. Its stability, flocs formation rate and coagulation performance were evaluated by comparison with Al_{13} species and AlCl_3 .

2. Materials and methods

2.1. Materials

The reagents used in the current research are all of analytical grade. All solutions were prepared by deionised water. The coagulant that contains high content of Al_{13} (abr. $\text{PAC}_{\text{Al}_{13}}$) was prepared by slowly neutralizing 1.0 M AlCl_3 aqueous solution with 0.6 M NaOH solution at 80 °C under vigorous stirring until the Al hydrolysis ratio ($B = [\text{OH}]/[\text{Al}]$) reached 2.4. The final Al concentration (Al_T) was 0.2 M. The coagulant that contains high content of Al_{30} (abr. $\text{PAC}_{\text{Al}_{30}}$) was prepared by heating $\text{PAC}_{\text{Al}_{13}}$ at 95 °C for 12 h under stirring and refluxing. Both samples

were rested at room temperature for 5 d before analysis, characterization and coagulation experiments. Al_T was measured by inductively coupled plasma-atomic emission spectroscopy (Vista-MPX ICP-AES, Varian). B value was measured by chemical analysis according to the Chinese standard method (GB 15892-1995). The pH values were measured on a pH meter (Orion 710A).

The Al species distribution in these two coagulants as well as 0.2 M AlCl_3 aqueous solution (abr. AlCl_3) were measured by the time-developed Al-Ferron complex colorimetry on UV-Vis spectrophotometer (DR/4000U, Hach) and by high-field ^{27}Al NMR method on Fast Fourier Transformation spectrometer (JNM-ECA600, JOEL). Based on the difference of the dissociation and complex reaction kinetic rate between Ferron and hydrolyzed Al species, Al species in coagulants were divided into three types: monomeric species (Al_a) (reacting with Ferron within 1 min), planar oligomeric and medium polymeric species (Al_b) (reacting with Ferron from one to 120 min), and three-dimensional species or sol-gels (Al_c) (reacting with Ferron after 120 min and non-reacting with Ferron). Al_c was obtained by Al_T minus Al_a and Al_b (Parker and Bertsch, 1992). In ^{27}Al NMR analysis, the aluminum at 0 ppm was assigned to Al monomer (Al_m). The concentration for 62.5 ppm and 70 ppm signals were multiplied by 13 and 15, respectively, to obtain the concentration of Al_{13} and Al_{30} , respectively. The concentration of Al species that cannot be clearly measured (Al_u) was calculated by Al_T minus Al_m , Al_{13} and Al_{30} (Chen et al., 2006). The detailed specifications of these coagulants are listed in Table 1. All coagulants were used directly, without prior dilution to avoid the change of Al species arose from dilution.

A stock suspension of kaolin clay was prepared by dispersing a measured amount of reagent-grade kaolin in deionised water by high shear mixing. The suspension was settled overnight, and the upper half of solution was collected and diluted to a concentration of 20 g l⁻¹. The particle size distribution of the kaolin suspension was measured on laser particle size analyzer (Mastersizer 2000, Malvern). The mean particulate size was 1.5 μm , and with 87.4% of particle size was below 2.0 μm . The working solution was prepared by diluting a calculated amount of stock suspension with deionised water. The concentration of alkalinity and electrolyte of working solutions were adjusted using 0.5 M NaHCO_3 and 0.5 M NaNO_3 , respectively.

2.2. Methods

The development of flocs size during coagulation period was measured on a modified Laser Particle Size Analyzer (Mastersizer 2000, Malvern). The input and output tubes of the particle size analyzer were connected to a jar test flocculator with a single-paddle stirrer. The suspension in the beaker of flocculator was sucked into the particle size analyzer by a peristaltic pump continuously for online measurement of particle size during coagulation. The

Table 1
The Al species distribution and pH values of freshly prepared and aged samples

Samples	Coagulants aging time	Al _T (M)	B	Al species distribution (%)							pH
				Al _a	Al _b	Al _c	Al _m	Al ₁₃	Al ₃₀	Al _u	
AlCl ₃	5 d	0.2	0	97.3	2.7	0.0	100.0	0.0	0.0	0.0	2.86
PAC _{Al13}	5 d	0.2	2.4	4.7	78.8	16.5	4.7	81.5	0.0	13.8	4.26
	30 d	0.2	2.4	4.8	77.1	18.1	5.0	77.7	3.7	13.6	4.19
	60 d	0.2	2.4	5.4	73.7	20.9	4.0	72.2	5.8	18.0	4.16
PAC _{Al30}	5 d	0.2	2.4	2.7	23.0	74.3	3.7	16.5	76.8	3.1	4.20
	30 d	0.2	2.4	2.6	22.8	74.7	3.2	14.6	73.1	9.2	4.20
	60 d	0.2	2.4	2.5	21.6	76.0	2.9	10.5	72.5	14.1	4.19

turbidity, pH, and NaHCO₃ and NaNO₃ concentration of working solution were 80 NTU, 7.5, 5.0 mM, and 5.0 mM, respectively. The 1000 ml working solution was added into the beaker. A measured amount of coagulant was pipetted into the working solution to give a dosage of 50 µM as Al under rapid stirring. The solution was stirred rapidly at 200 rpm for 2 min after coagulant dosing, and followed by slow stirring at 30 rpm for 15 min. The mean diameter of flocs was measured once every 60 s after the addition of coagulant.

Coagulation experiments were carried out at 25 °C using jar test on a six-paddle gang stirrer. The pH of the working solutions was adjusted to certain values with 0.1 M HCl solution or 0.1 M NaOH solution before the addition of coagulants. The pH value of working solution was depressed by the acidity and hydrolysis of coagulants after dosing. The coagulation experiments under fixed pH conditions and uncontrolled pH conditions were carried out. Experiments under fixed pH conditions were conducted by compensating the pH decrease with 0.1 M NaOH solution using an automatic titrator. Experiments under uncontrolled pH conditions were carried out without alkalinity compensation. A measured amount of coagulant was pipetted into the working solution to give a certain Al concentration under rapid stirring. The solution was stirred rapidly at 200 rpm for 2 min after coagulant dosing, followed by slow stirring at 30 rpm for 15 min, and then settled for 30 min. A supernatant sample was withdrawn for residual turbidity (RT) measurement (2100N Turbidimeter, Hach) after sedimentation. A sample was taken using a syringe immediately after the 1 min rapid mix period for the measurement of Zeta potential (Zetasizer 2000, Malvern). All experiments were repeated at least three times to assure the reproducibility of experimental results.

3. Results and discussion

3.1. Stability of PAC_{Al30} and PAC_{Al13}

In water treatment practices, it is not practical to prepare fresh coagulant. For a commercial coagulant, stability is needed for storage purposes. After aging for 60 d at room temperature, PAC_{Al13} and PAC_{Al30} solutions are both transparent, and there exists no visible deposition.

The Al species distribution of samples aged at room temperature for 30 and 60 d are listed in Table 1. The Al species distribution in PAC_{Al13} and PAC_{Al30} change slightly after aged for 60 d. Al_b content decreases, Al_c content increases. Al species in PAC_{Al13} and PAC_{Al30} tend to further polymerize and aggregate slowly upon aging. Al₁₃ content in PAC_{Al13} and Al₃₀ content in PAC_{Al30} decrease slightly. In general, the two coagulants have adequate stability for acting as a coagulant.

3.2. Study of flocs development

The development of flocs mean size after the coagulant addition is shown in Fig. 1. It can be seen that PAC_{Al30} exhibit the strongest aggregation and flocs formation capacity. After coagulating for 17 min, PAC_{Al30} achieves larger flocs than PAC_{Al13} and AlCl₃. The average diameters of flocs formed by PAC_{Al30}, PAC_{Al13} and AlCl₃ are about 549 µm, 482 µm, and 413 µm, respectively. Within 60 s after coagulant addition, PAC_{Al13} displays more quick aggregation rate than PAC_{Al30} and AlCl₃ due to its strong charge neutralization capacity. But the sizes of flocs for all coagulants are small at this time. The flocs mean sizes increase rapidly after a short lag time (1–3 min), and reach

Fig. 1. Mean flocs diameter versus flocculation time after the addition of different coagulants. (Dosage 50 µM as Al, raw water pH 7.5, and raw water turbidity 80 NTU.)

a plateau. The rapid increase in flocs size is caused by the hydrolysis of coagulants and the formation of amorphous hydroxide precipitation (Wang et al., 2002). When the precipitated hydroxide precipitation reaches a certain size and number, rapid aggregation of particles achieves due to the surface interaction between the impure particles and the hydroxide precipitation with high specific surfaces. AlCl_3 displays the shortest lag time (60 s) due to its rapid hydrolysis and precipitation after dosing into water. However, PAC_{Al13} displays the longest lag time (200 s). The stability of colloidal particles is possibly enhanced by the formation of highly charged Al oxyhydroxide sol-gels when Al_{13} hydrolyzes on surfaces of the colloidal particles (Waite et al., 2001). The rapid increase in flocs size can only be reached after further hydrolysis of these sol-gels.

3.3. Coagulation under pH uncontrolled

It is well known that the results of coagulation are related to raw water conditions (e.g. pH, alkalinity, ionic strength, co-existing anion, and particles concentration, distribution and charge density), coagulant and coagulation assistant employed, dosage, and coagulation parameters (temperature and mixing conditions). In order to compare the coagulation performance of different coagulants, the same raw water conditions and coagulation parameters were adopted during jar test. And the pH value of working solution was depressed without pH adjustment after the addition of coagulant. The turbidity, pH value, and NaHCO_3 and NaNO_3 concentration of raw water are 80 NTU, 7.5, 5.0 mM, and 5.0 mM, respectively. The RT and Zeta potential as well as the final pH of treated water as a function of dosage are shown in Fig. 2. As can be seen from Fig. 2b, with the increase of dosage, the Zeta potential of particles increase rapidly firstly and reverse for PAC_{Al13} and PAC_{Al30} , then increase slowly and monotonically. The particulate Zeta potential for coagulating with AlCl_3 is much lower than that for coagulating with PAC_{Al13} and PAC_{Al30} within low dosage range. However, the particulate Zeta potential for AlCl_3 presents a second rapid increase within high dosage range, and it exceeds the particulate Zeta potential for PAC_{Al13} and PAC_{Al30} , because AlCl_3 causes much more pH decrease than PAC_{Al13} and PAC_{Al30} at a high dosage range. The dosages required to reach zero point of Zeta potential for PAC_{Al30} , PAC_{Al13} and AlCl_3 are 6.25 μM , 3.55 μM , and 154 μM , respectively. This indicates that the charge neutralization capacity of PAC_{Al13} is slightly higher than that of PAC_{Al30} , and that of AlCl_3 is markedly lower than that of polymeric coagulants (PAC_{Al13} and PAC_{Al30}).

As can be seen from Fig. 2a, the RT curves decrease sharply within low dosage range for all three coagulants with the increase of dosage, and maintain a very low turbidity level within a certain dosage range, then increase rapidly to a high turbidity and level off when the dosage increases further. PAC_{Al30} is more effective than PAC_{Al13} and AlCl_3 for turbidity removal. The minimum dosages

Fig. 2. Effect of coagulant dosage on (a) residual turbidity, (b) zeta potential and (c) pH value of treated water with different coagulants. (Raw water pH 7.5, and coagulation at pH uncontrolled.)

needed to achieve effective turbidity removal ($\text{RT} \leq 2$ NTU) for PAC_{Al30} , PAC_{Al13} and AlCl_3 are 94 μM , 153 μM , and 122 μM , respectively. The discrepancy between turbidity removal efficiency and charge neutralization capacity indicates that there exist other coagulation mechanisms that may affect the turbidity removal besides the charge neutralization mechanism. PAC_{Al30} achieves effective turbidity removal within a much wider dosage range than PAC_{Al13} and AlCl_3 . AlCl_3 can only give effective turbidity removal within a very narrow dosage range. The broad dosage range for PAC_{Al30} to achieve effective turbidity removal is benefit to avoid the fluctuation of treated water quality in practical water treatment plant, especially for coagulation of raw water with its nature changing frequently.

As can be seen from Fig. 2a and c, the pH of solutions treated by PAC_{Al30} is only slightly higher than that treated by PAC_{Al13} , but PAC_{Al30} achieves effective turbidity removal within a much broader dosage range. The broad dosage range for PAC_{Al30} is not only related to the less pH depression of PAC_{Al30} than that of PAC_{Al13} and AlCl_3 , but also related to the difference of Al speciation in coagulants. Restabilization occurrence under uncontrolled pH condition is due to the pH decrease caused by Lewis acidity

of coagulants, and the restabilization happens at high dosage regions. With the increase of dosage, as the pH value of PAC_{Al30} treated water decrease below 6.5–6.6, restabilization (RT ≥ 10 NTU) occurs due to particle charge reverse, at the same time, the depression of pH prevents the hydrolysis of coagulant and the formation of Al hydroxide precipitation that needed for sweeping coagulation. The threshold pH values of restabilization for PAC_{Al13} and AlCl_3 are 6.7–6.8 and 5.7–5.8, respectively. The different Al species distribution in these coagulants result in Al hydroxide precipitation form at different minimum pH value after dosing, and which lead to restabilization occur at different pH value.

3.4. Coagulation under fixed pH condition

Fig. 3 shows the RT and Zeta potential as a function of dosage when coagulating at fixed pH 7.5. The raw water employed is the same as that during coagulation under uncontrolled pH condition above. PAC_{Al30} achieves the lowest residual turbidity than PAC_{Al13} at the same dosage though the charge neutralization ability of PAC_{Al30} is slightly lower than that of PAC_{Al13} . Corresponding with the rapid increase of Zeta potential, the significant turbidity removal can be observed for three coagulants with the

increase in dosage. And the RT reaches a low value and levels off. There exists no restabilization at high dosage region because the addition of NaOH supplied the alkalinity required for the hydrolysis of Al species. The conventional restabilization under fixed pH condition takes place at a low dosage region, and it is mainly related to particle charge reverse (Duan and Gregory, 2003). The hydrolysis of Al species results in the formation of amorphous $\text{Al}(\text{OH})_3$ precipitations, which assures the function of flocs patch, adsorption, bridging, enmeshment and sweeping (Duan and Gregory, 2003). Although PAC_{Al13} has the strongest charge neutralization ability at all dosage range, it does not achieve the optimal turbidity removal. The optimum dosages for turbidity removal for both PAC_{Al30} and PAC_{Al13} do not coincide with the zero points of Zeta potential. Due to the high positive charge of Al_{13} and Al_{30} species, the dosage needed to neutralize the negative charge of colloidal particles is very low, and the aggregate rate of the destabilised colloidal particles is very slow within this low dosage range. So it is difficult to form large particles for turbidity removal during the subsequent settlement. The effective turbidity removal occurs at a higher dosage, and the particulate Zeta potential reach positive values within this dosage range. These results further indicate that besides charge neutralization, there exist other flocculation mechanisms such as flocs patch, sweeping, bridging, enmeshment and adsorption, which may governs or jointly governs the turbidity removal (Wang et al., 2002). Additionally, the amount of NaOH needed to neutralize the pH depression caused by AlCl_3 addition is much more than that needed for coagulation with PAC_{Al13} and PAC_{Al30} . PAC_{Al30} causes the least NaOH consumption to maintain constant pH of working solution.

3.5. Effect of pH

The effect of pH on the coagulation efficiency and charge neutralization capacity of coagulants are shown in Fig. 4. The turbidity of raw water is 80 NTU. The respective concentration of NaHCO_3 and NaNO_3 in raw water are 5 mM. The dosage is 100 μM as Al, and the coagulation was conducted at fixed pH condition. It can be seen that the pH has an important effect on the coagulation behavior of coagulants. The Zeta potential of colloids decreases monotonically with the increase of pH value. As can be seen from Fig. 4b, PAC_{Al13} and PAC_{Al30} display much higher charge neutralization capacity than AlCl_3 . The isoelectric pH for PAC_{Al30} , PAC_{Al13} and AlCl_3 are about 8.9, 9.1, and 7.2, respectively. The charge neutralization capacity of coagulants is not only related to Al speciation in coagulants, but also related to the hydrolysis rate of Al species after dosing into water. Al^{3+} in AlCl_3 undergoes rapid hydrolysis, polymerization and precipitation after dosing, and ultimately forms low charged amorphous $\text{Al}(\text{OH})_3$ sols and precipitations (Dental, 1988). However, the pre-polymerized Al_{13} and Al_{30} in PAC_{Al13} and PAC_{Al30} are rather stable and have a better opportunity to adsorb

Fig. 3. Effect of coagulant dosage on (a) residual turbidity and (b) zeta potential with different coagulants. (Raw water pH 7.5, and coagulation at fixed pH 7.5.)

Fig. 4. Effect of pH on coagulation by different coagulants at dosage 100 μM as Al: (a) residual turbidity, (b) zeta potential. (Coagulation at fixed pH condition.)

on negative colloidal particles and to neutralize the negative charges (Luan, 1997). The higher the pH of working solution is, the faster the coagulants hydrolyze. At the same time, the increase in particulate negative charges caused by the increase of pH also results in the decrease of the apparent charge neutralization capacity of coagulants. At higher pH region ($\text{pH} \geq 6.8$), PAC_{Al13} behaves slightly higher charge neutralization capacity than PAC_{Al30} . But PAC_{Al30} exhibits slightly higher charge neutralization capacity than PAC_{Al13} at lower pH region ($\text{pH} \leq 6.5$). This is because Al_{30} is more labile to hydrolysis and polymerisation than Al_{13} in medium and high pH solutions due to the relative high acidity of the four connected Al atoms in Al_{30} (Rustad, 2005). This may be why PAC_{Al30} exhibits a stronger flocs formation capacity than PAC_{Al13} .

As can be seen from Fig. 4a, PAC_{Al13} and PAC_{Al30} achieve effective turbidity removal at a much broader pH range than AlCl_3 . The optimal pH range for AlCl_3 is 6.5–7.5, and it is more adjacent to the low pH side than that of PAC_{Al13} and PAC_{Al30} , which is broadly consistent with the data of Zeta potential of AlCl_3 (Fig. 4b). PAC_{Al30} is more effective than PAC_{Al13} at weak acid side (e.g. pH 6.8–7.0) because it is easier to produce flocs than PAC_{Al13} . Outside the optimum coagulation pH range, the turbidity removal is rather poor. At the high acid side, flocs are

difficult to form due to the increase in equilibrium solubility of amorphous $\text{Al}(\text{OH})_3$ precipitation. At the high alkaline side, due to the increase of particulate negative charges and the formation of $\text{Al}(\text{OH})_4^-$ and low charged non-settling Al colloids (Pernitsky and Edzwald, 2003), the particulate negative charges are insufficiently neutralized. The optimal pH value for turbidity removal of AlCl_3 is lower than that of PAC_{Al30} and PAC_{Al13} , which is consistent with the minimum solubility of Al salts and polyaluminum coagulants. Coagulation at the optimal pH value for different coagulants should be effectively minimize dissolved residual Al in treated water (Pernitsky and Edzwald, 2003). The detail about residual Al is subjected to further investigation.

4. Conclusions

The experimental results indicate that the coagulation performance of polyaluminum coagulants is improved by transforming Al_{13} species into Al_{30} species. Although the charge neutralization capacity of Al_{30} species is slightly lower than that of Al_{13} species under medium and high pH conditions, Al_{30} achieves better turbidity removal than Al_{13} due to its higher flocs formation capacity. Compared with Al_{13} species, Al_{30} species causes less pH depression, and it achieves more effective turbidity removal within a broader dosage range and within a wider pH range. These advantages of Al_{30} are benefit to practical application, especially for coagulation of raw water with water nature changing frequently. The results verified that Al_{30} species is a high active species for coagulation. The research results will shed new light on the development and investigation of highly effective polyaluminum coagulants.

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