Research Article

An Effective Flocculation Method to the Kaolin Wastewater Treatment by a Cationic Polyacrylamide (CPAM): Preparation, Characterization, and Flocculation Performance

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P(AM-DMC) (PAD) was synthesized by ultraviolet- (UV-) initiated copolymerization with methacryloxyethyl trimethyl ammonium chloride (DMC) and acrylamide (AM) as the monomers and initiator 2,2-azobis [2-(2-imidazolin-2-yl) propane] dihydrochloride (VA-044) as the photoinitiator. Parameters that affect the molecular weight were reviewed by using the single-factor approach. The results showed that the molecular weight (MW) of PAD could come to $7.88 \times 10^6$ Da with the optimum polymerization conditions as follows: monomer concentration of 30%, monomer mass ratio m(AM):m(DMC) of 3:1, initiator concentration of 0.6‰, illumination time of 80 min, solution pH value of 4.5, and incident light intensity of 1000 $\mu W m^{-2}$. The PAD was represented by several instruments. The results of FTIR and $^1H$ NMR showed that PAD was indeed polymerized by AM and DMC. The results of TGA showed that PAD was very stable at room temperature while the result of SEM revealed that PAD had a porous structure and rough surface. For PAD used as floculant in kaolin wastewater treatment, the results confirmed that, at optimal conditions, the turbidity and the floc size $d_{50}$ could reach to 5.9 NTU and 565.936 $\mu m$, respectively, at the optimal conditions (pH = 7.0 and dosage = 2 mg l$^{-1}$). Kaolin wastewater flocculation test outcome reveals that the PAD with high cationic degree and intrinsic viscosity could boost the charge neutralization and bridging capability. Consequently, the result is an excellent flocculation performance of treating kaolin wastewater.

1. Introduction

Water is a key element for life to exist. The importance of water is underscored by the fact that organisms cannot survive without it [1]. Water is considered as the most basic and indispensable resource in the world. There is no gainsaying the fact that neither social/economic development nor environmental diversity could be preserved without water [2]. This makes steady supply of clean and unpolluted water to ever be in high demand. The kaolin wastewater from the paint, rubber, paper filler, coating pigment, and chemical production industries contain large quantities of kaolin clay, which reduces water quality. Kaolin wastewater bring with them multiple negatives including environmental pollution, soil and air contamination, air with attendant consequences for human health, and associated risks. Other implications are damage to vegetation, wildlife, and other biota [3]. This makes it imperative to dispose of kaolin wastewater before it is discharged into the environment. Recently, many investigations such as membrane [4], electrochemical oxidation
[5], and flocculation [6] have been explored for the purpose of reducing the quantity of kaolin produced by wastewater and improve the quality of the treated effluents. Among them is flocculation which has become one of the alternative treatment technologies for kaolin wastewater. It was found to be very effective to use flocculation method for kaolin wastewater treatment [7]. By adding flocculants, the finely dispersed coal particles are first and foremost totally neutralized to lose their stability by charge neutralization.

Nowadays, the simplest and most widely used polymerization method for preparing CPAM is solution polymerization. Solution polymerization can be initiated by heat, rays, microwave radiation, and ultraviolet (UV) light [8–12]. UV-initiated polymerization has a lower reaction temperature, less initiator, shorter polymerization time, and higher reaction rate and has an environment-friendly way [13]. Zheng et al. reported that a novel anion polyacrylamide was obtained under high-pressure ultraviolet initiation after 60 min; the copolymer is effective in dioctyl phthalate removal from water [14]. Zang et al. have successfully synthesized a fluorine-containing polyacrylate emulsion through UV-initiated method, and this method was demonstrated to be efficient. The results showed that the porous structure of the copolymer is conducive for adsorbing and bridging between the copolymer molecules and the sludge particles [15]. In addition, UV-initiated polymerization is not just easy to operate but it is also environmentally friendly [16]. As a new polymerization technique used to synthesize the CPAM, UV-initiated polymerization can be engaged to prepare the copolymer. Acrylamide (AM) and methacryloxyethyltrimethyl ammonium chloride (DMC) were regarded as the less toxic and the most frequently used monomers to synthesize the CPAM [17]; therefore, it was more important to prepare a cationic flocculants (PAD) using DMC and AM as monomers through UV-initiated copolymerization for kaolin wastewater separation and removal.

Taking into consideration all of the factors that were mentioned above, this study attempts to (1) synthesize the template copolymer (PAD) through UV-initiated polymerization using AM and DMC as monomers and VA-044 as photoinitiator; (2) characterize the chemical structure of polymers using Fourier transform infrared spectroscopy (FTIR), $^1$H nuclear magnetic resonance spectroscopy ($^1$H NMR), scanning electron microscope (SEM), and thermogravimetric analysis (TGA); (3) explore the influence of the pH and dosage on the flocculation performance and calculate the flocculation performance in terms of turbidity removal and floc size; and (4) explore the possible flocculation mechanism involved in the flocculation progress.

2. Materials and Methods

2.1. Materials. We purchased monomer AM and DMC from Chongqing Lanjie Tap Water Company (Chongqing, China) and collected initiator 2,2-azobis [2-(2-imidazolin-2-yl) propane] dihydrochloride (VA-044) from Apotheker Chemical Reagent Co. Ltd. (Chengdu, China). Similarly, we bought ethyl alcohol (99.9 wt%) from Jinan Chimical Co. Ltd. (Jinan, China). Suffice it to say that the reagents mentioned above were all of analytical grade except for AM and ethyl alcohol which were of technical grade. Commercial flocculants CCPAM (copolymerization of AM and acryloyloxyethyltrimethyl ammonium chloride (DAC)) and polyacrylamide (PAM) were made in the laboratory and were used for analyzing in flocculation test.

2.2. Preparation of Copolymers. By using AM and DMC, PAD was synthesized by ultraviolet light (wavelength: 365 nm and power: 200 W) [18]. The preparation scheme of UV-initiated template copolymerization is shown in Figure 1. A predetermined mass of AM and DMC was added into a 150 ml glass vessel with a sealed cover. A specific amount of distilled water was added into glass vessel, and the glass vessel was swayed until a dissolved mixture was produced. The glass vessel was bubbled with pure N$_2$ (99.99%) for 20 minutes. This was meant to completely remove oxygen at an ambient temperature. Subsequently, the glass vessel was sealed immediately after being added with photoinitiator VA-044. The glass vessel was transferred into an ultraviolet system with a certain time of irradiation. Then, the polymer was cut into particles and washed three times with acetone and alcohol for purification. Finally, the product PAD was dried in a vacuum drying oven at 95°C and grounded into powder.

2.3. Characteristics of Copolymers. The intrinsic viscosities of polymers (η) related to the molecular weight were used to assess the absorption and bridging ability. This was conducted on an Ubbelohde viscosity meter (Shanghai Shenyi Glass Instrumental Co. Ltd., China) in a 2 mol·L$^{-1}$ NaCl aqueous solution at 30°C. The molecular weight of the polymer was calculated by the equation displayed as follows [19, 20],

$$M_n = 802 \cdot [\eta]^{1.25},$$  \hspace{1cm} (1)

where $M_n$ and $[\eta]$ are the molecular weight and the intrinsic viscosity of the polymer, respectively. The Fourier transform infrared spectroscopy (FTIR) was performed.
on a 550 Series II infrared spectrometer (Mettler Toledo Instruments Co. Ltd., Switzerland) to record the polymer function groups. The \(^1\)H nuclear magnetic resonance spectroscopy (\(^1\)H NMR) of the products was recorded using an Avance 500 nuclear magnetic resonance spectrometer (Bruker Company, Ettlingen, Germany) in deuterium oxide (D\(_2\)O). Scanning electron microscope (SEM) analysis was performed on MIRA 3 LMU SEM system (TES-CAN Company, Czech Republic). This procedure carried out to observe the morphologies of the copolymers. Besides, thermogravimetric analysis (TGA) of the polymers was conducted on a DTG-60H synchronal thermal analyzer (Shimadzu, Kyoto, Japan) at a heating rate of 10\(^{\circ}\)C min\(^{-1}\) under argon atmosphere from 20 to 600\(^{\circ}\)C.

### Table 1: The details of flocculants used in the characterization and flocculation tests.

| Flocculants\(^a\) | Cationic monomer molar content (%) | Molecular weight \((10^6\) Da\) | Synthetic method |
|------------------|---------------------------------|-----------------------------|-----------------|
| PAD-1            | 30.0                            | 7.0                         | UV              |
| PAD-2            | 30.0                            | 5.0                         | UV              |
| CCPAM            | 30.0                            | 5.0                         | —               |
| PAM              | —                               | 5.0                         | UV              |

\(^a\)g/mol or Dalton or 1g/mol = 1 Da.

2.4. Flocculation Test. The flocculation efficiency of the copolymers PAD was investigated by treating simulated kaolin wastewater. Meantime, commercial flocculants (CCPAM) and PAM were used to make a comparison with PAD. The simulated kaolin water was prepared as follows: 1.0 g kaolin powder was added to 1000 ml glass beaker with 1000 ml deionized water and stirred at 300 rpm for 20 min, followed with a setting time of 30 min. The initial turbidity of the kaolin solution for each of flocculation tests was the same at 117.6 NTU. The initial zeta potential value of the colloids in initial kaolin solution was \(-24.8\) mV. The flocculants used in this flocculation test are described in Table 1. The flocculation tests were performed on a program-controlled jar test apparatus (ZR4-6, Zhongrun Water Industry Technology Development Co. Ltd., China) at ambient temperature. The pH of these simulated kaolin wastewater (1000 ml) was adjusted to the given value by HCl (0.5 mol l\(^{-1}\)) and NaOH (0.5 mol l\(^{-1}\)) after adding them into a 1000 ml glass beaker. The flocculation tests involved the following three procedures: a rapid stirring at 200 rpm for 1 min, a slow stirring at 40 rpm for 15 min, and a setting period of 15 min without any interruption. After these procedures, the turbidity was detected with a 2100P turbidity meter (Hach, Loveland, CO) and the zeta potential of supernatant collected from 2 cm below the water surface was recorded on a Zetasizer Nano ZS90 (Malvern Instruments Ltd., Malvern, UK). Floc size was investigated by a laser diffraction instrument (Mastersizer 2000, Malvern, UK). Each result was an average of three repeated tests, and the standard interval was controlled at below 5%.

### 3. Results and Discussion

3.1. Single-Factor Approach of Ultraviolet-Assisted Aqueous Solution Polymerization

3.1.1. Effect of Monomer Concentration on Copolymerization. Figure 2 shows the effect of monomer concentration on the molecular weight of copolymers. The experiment was conducted with \(m(AM) : m(DMC) = 3 : 1\), 0.60 wt\% initiator concentration, 80.0 min of illumination time, pH = 4.5, and 1000 \(\mu\)W cm\(^{-2}\) incident light intensity. The molecular weight first showed an increasing and later a decreasing trend with the increased monomer concentration from 15% to 45%. At 30.0% monomer concentration, the molecular weight reached the maximum of \(7.88 \times 10^6\) Da. PAD was synthesized using UV initiation method. This indicates a process of copolymer synthesis, which was based on free radical mechanism using chemical free radical initiator (VA-044) to generate free radical sites on the acrylamide backbone [21]. Less collision occurred between monomers and free radicals at low monomer concentrations. This occurrence resulted in a cage effect which interfered with the growth of molecular chains and led to a reduction of the molecular weight. However, further increase in monomer concentration accelerated the rate of chain transfer and chain termination. This gradually stopped the reaction when the rate of chain termination was faster than that of chain propagation leading to a reduction in molecular weight [22]. In addition, the intermolecular cross-link and gel effect resulted in lower polymer solubility in water, along with lower reduction of the molecular weight. Therefore, the optimum monomer concentration used in this part was 30.0%.

3.1.2. Effect of Monomer Mass Ratio on Copolymerization. The molecular weight of copolymers was studied under different \(m(AM) : m(DMC)\). The experiment was conducted with a monomer concentration of 30%, 0.60 wt\% initiator
concentration, 80.0 min of illumination time, pH = 4.5, and 1000 μW cm\(^{-2}\) incident light intensity. The results are shown in Figure 3. Initially, the molecular weight of copolymers increased along with the increasing of m(AM) : m(DMC), but when it reached its peak, it significantly decreased with a further increase of m(AM) : m(DMC). At a low content of AM, due to the lower reactivity of DMC, the activity of free radicals initiated by the initiator and ultraviolet decreased in the polymerization system. Therefore, the monomers were difficult to be initiated to polymerize and the molecular weight decreased subsequently [16]. At a high content of AM, the copolymer with a high molecular weight could be quickly prepared. This is because of a higher reactivity of AM when compared with DMC. However, a very high content of AM could lead to implosion, which shortened the molecular chain and resulted in a significantly lower molecular weight [23]. This phenomenon is consistent with the general rule of copolymerization. Therefore, the optimal m(AM) : m(DMC) was 3 : 1.

3.1.3. Effect of Initiator Concentration on Copolymerization. Figure 4 shows the variations of the molecular weight as a function of initiator concentration with other parameters remaining the same. The polymer molecular weight quickly increased with the increased VA-044 concentration at the earlier stage of reaction but significantly decreased with further increasing VA-044 concentration. Therefore, an optimum VA-044 concentration was required for the molecular weight. The results showed that the maximum molecular weight of 7.88 × 10\(^6\) Da was achieved at a VA-044 concentration of 0.60 wt%. However, the molecular weight showed a decrease in the process of increasing the initiator dosage. This is because more generated free radicals accelerated the copolymerization reaction. This led to further increase in primary radical termination and chain transfer. As a result, the molecular weight declined [24]. Furthermore, the optimum photoinitiator dosage in this study was deemed to be 0.60 wt%.

3.1.4. Effect of Illumination Time on Copolymerization. Figure 5 demonstrates the effect of illumination time on the molecular weight of copolymers, where the other parameters remained consistent. The initiator can generally be decomposed by UV absorption and generate free radicals. The results shows that the illumination time markedly affected the molecular weight. As shown in Figure 4, the molecular weight gradually increased with the increase in illumination time below 80 min. When illumination time extended to 80 min, the molecular weight copolymer reached its maximum. The molecular weight of copolymers almost remained constant even after further increase in illumination time. At the very start of the reaction, UV irradiation lowered the activation energy, accelerated the molecular bond breakage, and increased graft sites, which resulted in the rapid growth of the molecular chain and the molecular weight [25]. However, when illumination time exceeded 80 min, the initiator and...
the monomer were used up. So, we chose 80 min illumination time as the optimal illumination time in this study.

3.1.5. Effect of pH on Copolymerization. Figure 6 shows the effect of pH on the molecular weight of copolymers, and the other parameters remain consistent. Results show that the molecular weight heavily increased with an increase of pH, but a distinct drop in the molecular weight occurred with further increase of pH. At strong acid condition (pH: 1.5–3.0), acrylamide was prone to imidization reaction between molecules, a cross-linking between the AM occurred, which seriously interfered the free collision between AM and DMC. Consequently, the reaction efficiency has grown, and a lower molecular weight of copolymers was observed [26]. In neutral and alkalescent environments, hydroxyl methylation was likely to occur, which reduced the intrinsic viscosity and conversion of polymer polymerized by UV initiation. At strong acid alkaline condition (pH: 9.0–10.5), it would speed up the hydrolysis of the quaternary ammonium group of DMC monomer and hinder chain growth to form a high molecular weight. The weak acid environment (pH: 4.5–6.0) alleviates the hydrogen-bonding interaction among carboxylate and quaternary ammonium groups, and it was more favorable for the free collision between AM and DMC and the molecular weight increase. Accordingly, the optimum pH (4.5) was chosen in this study.

3.1.6. Effect of Incident Light Intensity on Copolymerization. Figure 7 shows the effect of the incident light intensity on the molecular weight of copolymers, as other parameters remained constant. The results showed that the molecular weight increased with increase in incident light intensity. UV-initiated polymerization had a higher polymerization rate and conversion than conventional polymerization methods. The initiation rate with VA-044 was directly proportional to the incident light intensity [27]. After adding photoinitiator, UV light accelerated the decomposition of photoinitiator which generated free radicals. With increased incident light intensity by UV light irradiation, more free radicals were generated and the polymerization rate improved, and a high molecular weight was observed. However, when the light intensity exceeded 1000 $\mu W \cdot cm^{-2}$, there was an increase in molecular weight. Therefore, in this study, the light intensity at 1000 $\mu W \cdot cm^{-2}$ was the optimal illumination time.

3.2. Characterization of Flocculants

3.2.1. FTIR Spectrum Analysis. The FTIR spectra of PAM and PAD are shown in Figure 8, and the flocculants had several related adsorption peaks as follows: the strong stretching vibration of $-NH_2$ and C=O adsorption peaks was observed at 3443 cm$^{-1}$ and 1665 cm$^{-1}$, respectively [28]. The stretching vibration at 2940 cm$^{-1}$ was caused by $-CH_3$ [29]. The peak, at 1454 cm$^{-1}$, resulted from the deformation stretching vibration of methylene group. Compared with PAM, the characteristic absorption peak of PAD was shown at 956 cm$^{-1}$, which resulted from quaternary ammonium in the monomer.
DMC [30], thereby showing that the PAD was successfully copolymerized by AM and DMC.

3.2.2. TGA Analysis. The TGA analyses of the PAD where PAD shows three stages of the thermal decomposition are shown in Figure 9. Because of the evaporation of the adsorbed moisture in the polymer, the first stage was observed in the range of 30–195°C with a weight loss of 6.6 wt% was for PAD [31], while the second stage occurred in the range of 195–340°C, and a 27.7 wt% of weight loss was assigned to PAD. A previous research attributed this stage weight loss to imine thermal decomposition in the amide group [32]. The third stage was within the range of 340–500°C, and the weight loss was 42.2 wt% for PAD, which was attributed to the carbonization of the copolymer chain [33]. Based on the above TGA analytical results, it is clear that PAD showed an inferior thermal stability.

3.2.3. ¹H NMR Spectrum Analysis. In Figure 10, the ¹H NMR spectra of the PAM and PAD were explored in order to further understand their microstructure. As shown in Figure 10(b), the absorption peaks at δ = 1.67 ppm and δ = 2.22 ppm were derived from the −CH₃ (a) and −CH− (b) groups of AM monomer, respectively [34]. Compared with PAM, PAD showed the following characteristic peaks: peak of protons in methyl group −CH₃ (c)
was at $\delta = 1.156$ ppm in DMC, peak of protons in the group of $\text{-O-CH}_2\text{-}$ (d) was at $\delta = 4.48$ ppm, peak of protons in the methylene group of $\text{(-CH}_3\text{-N}^+\text{)}$ (e) was at $\delta = 3.78$ ppm in DMC, the sharp peak of protons in the three equivalent methyl groups of $\text{-N}^+\text{(CH}_3\text{)}_3\text{)}$ (f) was at $\delta = 3.210$ ppm in DMC, and the sharp peak of protons in solvent $\text{D}_2\text{O}$ was at $\delta = 4.79$ ppm [35]. After the copolymerization of AM and DMC, the adsorption peaks of AM and DMC all emerged in the PAD, an indication that the PAD was successfully copolymerized by AM and DMC.

3.2.4. SEM of Polymers. The SEM images of the polymers (PAM and PAD) are shown in Figure 11 as we investigated their amorphous morphology. It was clearer that this kind of polymers demonstrated different surface morphology. As a homopolymer of AM, PAM showed a polished and dense surface morphology without any holes [36]. But, with the grafting of DMC on AM, a thorough morphological change occurred. A rough surface morphology with a laminar structure was reviewed for PAD. Compared with AM, the cationic DMC was demonstrated by multiple functional chemical groups such as $\text{-O-CH}_2\text{-}$, $\text{-CH}_2\text{-N}^+$, and $\text{-N}^+\text{(CH}_3\text{)}_3\text{)}$, thereby exhibiting a significant discrepancy in the aspect of the physicochemical property. Therefore, after successful grafting monomer DMC, the surface morphologies of PAD were more irregular and rough rather than dense and smooth.

4. Flocculation Performance

4.1. Effect of Flocculant Dosage. Because of the strong charge repulsion generated by innumerable positive charged hematite particles in the water solution, the kaolin wastewater system became more stable which made solid-liquid separation difficult. So, adequate dose flocculants with an opposite charge were needed to break the stability of the hematite colloid particles. In Figure 12, the impact of flocculant dosage on the turbidity and zeta potential was investigated. The turbidity first decreased and then increased, whereas zeta potential increased in the full dosage range (1.0 to $5.0$ mg l$^{-1}$). At the relatively low dosage range ($<2.0$ mg l$^{-1}$), the flocculant showed an increasing efficiency in neutralizing and capturing the positively charged hematite particles with increase in dosage. Contrarily, the disproportionate dosage led to a sort of cake effect and electrostatic repulsion which stopped the floc growth and reduced the flocculation efficiency. Therefore, a deterioration of the flocculation performance was manifested [37]. Compared with PAM, PAD-2 and CCPAM had lower turbidity in the full range of dosage. The PAD-2 and CCPAM had a 30% cationic degree; hence, the charge neutralization ability of PAD-2 and CCPAM was stronger than PAM (without any positive charge). Consequently, more and more positive charged hematite particles were neutralized and destabilized completely by the PAD-2 and CCPAM and then formed large flocs under the effect of bridging. Meanwhile, the PAD-1 demonstrated ability to perform the best in the kaolin wastewater removal among the flocculants, which indicated that the flocculant, with the highest molecular weight, was favorable for the kaolin colloidal particle removal. In this condition, the destabilized kaolin colloidal particles were captured and aggregated together to form large flocs through bridging effect [38].

4.2. Effect of pH. In addition to flocculant dosage, the effects of pH on turbidity and zeta potential were explored at the optimal dosage of $2.0$ mg l$^{-1}$. The results are shown in Figure 13. It indicates that these four flocculants displayed a
similar flocculation variation tendency under various pH values (pH: 1.0–11.0). A sharp and rapid increase in turbidity was shown at the pH range of 1–7, which indicated that the flocculation performance was extremely affected by the acid condition. The acid led to a strong charge repulsion between the hematite particles and a protonation of the amino group (-NH₃⁺), resulting in a worse flocculation phenomenon [39]. When the pH condition was alkali, progressively more positive charged hydroxyl (OH⁻) would be attracted by the positively charged hematite particles. These adsorbed OH⁻ ions tightly wrapped around kaolin particles to form a protective layer which decreased the combination chance between the flocculant and kaolin particles; thus, a deteriorative flocculation performance occurred. Moreover, PAD-1 displayed the lowest turbidity in the full range of pH, whereas the zeta potential was the maximum among the four flocculants because PAD had the highest molecular weight and cationic degree, which was more capable of the enhancement of charge neutralization and bridging. It showed a prominent flocculation performance even under the strong acid and alkali conditions. Lastly, the acceptable flocculation occurrence for PAD-1 and PAD-2 was in a wider pH range (pH: 5–9), which showed that TPAD could be generally applied in the practical solid-liquid separation.

4.3. Floc Size. Comparison in floc size distribution of the polymers was recorded at 2.0 mg l⁻¹ and pH = 7.0. As shown in Figure 14, the kaolin floc size of PAD-1 was evidently larger than others. For example, the floc size characterized with the median equivalent volumetric diameter (d₅₀) was 565.936 μm, 468.437 μm, 361.348 μm, and 312.795 μm for PAD-1, PAD-2, CCPAM, and PAM, respectively. The large floc size was attributed to the effect of the high molecular weight and cationic degree of PAD-1. The flocculation was mainly dominated by charge neutralization, then bridging, and which accounts for why the floc size of PAD-1 was the largest among the flocculants. From one perspective, the high molecular weight of PAD-1 would result in an adequate polymer chain, branches, and adsorption sites to enhance its bridging ability. From another perspective, the PAD-1 with a high cationic degree and more negatively charged particles would be totally neutralized and lose their stability. And under the bridging effect of PAD-1, the destabilized particles were tightly absorbed on the PAD-1 polymer chain to form large and compact flocs [40]. Meanwhile, the kaolin wastewater conditioned by the PAD-1 will form a more condensed structure which benefits the separation of the kaolin particles from the water. The possible flocculation mechanism of the PAD could be summarized as follows: (1) the high cationic...
Figure 14: Continued.
The degree of the PAD greatly enhanced the charge neutralization and thereby the positive charge particles were neutralized completely, (2) the high molecular weight of the PAD was more effective for enhancing bridging ability of the polymer to capture and adsorb the kaolin particles, and (3) under the combination of charge neutralization and bridging, the large and compact kaolin flocs were formed and were efficiently removed.
5. Conclusions

In this study, a cationic polyacrylamide (PAD) was synthesized by UV-initiated copolymerization. The help of ultraviolet favored the copolymerization process of PAD, in addition to a shorter reaction time, a lower initiator dosage, and a higher molecular weight. When the monomer concentration is 30%, monomer mass ratio m(AM):m(DMC) 3:1, initiator concentration 0.6‰, illumination time 80 min, solution pH value of 4.5, and incident light intensity 1000 μW cm⁻², a high molecular weight (MW) of 7.88 × 10⁶ Da could be obtained. FTIR, ¹H NMR, TGA, and SEM techniques were used to characterize the structures of copolymers. The result showed that copolymers were successfully synthesized. Furthermore, the TGA and SEM analysis showed an inferior thermal stability and a rough surface morphology of PAD, respectively. The optimal flocculation conditions were set at a dosage of 2.0 mg l⁻¹ and a pH of 7.0. In the kaolin wastewater flocculation tests, the supernatant residual turbidity and the floc size were used to review the kaolin flocculation performance by adding the synthesized PAD. The kaolin wastewater flocculation results show that a high molecular weight and cationic degree of PAD-1 are what produced the strong charge neutralization and bridging abilities resulting in an excellent kaolin wastewater flocculation performance (residual turbidity = 5.9 NTU and floc size d₅₀ = 565.936 μm).

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

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

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