Physicochem. Probl. Miner. Process., 61(2), 2025, 204126

http://www.journalssystem.com/ppmp

Physicochemical Problems of Mineral Processing

ISSN 1643-1049

Effect of ion type and molecular weight of polyacrylamide on dewatering performance of flotation clean coal

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Abstract: Polyacrylamide (PAM) is a commonly used flocculant that can significantly enhance dewatering performance by adjusting its ionic type and molecular weight. However, the specific mechanisms by which different PAM types and molecular weights impact the solid-liquid separation process still require in-depth investigation. This study examined the effects of high molecular weight polymers with varying ionic types and molecular weights on the solid-liquid separation performance of flotation clean coal, focusing on the mechanism by which PAM improves flocculation dewatering. By experimentally comparing cationic (CPAM) and anionic (APAM) types, as well as various molecular weight PAMs, on clean coal dewatering, the results revealed that when the dosage of CPAM1200 is 60 g/Mg, the water content of flotation clean coal filter cake reduced from 21.57% to 18.97%, and when the dosage of CPAM 1200 could lower the filtration time to just 16 s, the filtration time can be shortened from 98 s to only 16 s. The ionic type and molecular weight of PAM significantly impact the cake resistance, filtrate viscosity, and floc structure. High molecular weight CPAM demonstrated optimal performance in reducing cake resistance and improving dewatering efficiency, while APAM primarily enhanced cake compressibility by promoting bridging between particles. Low molecular weight PAMs, in some conditions, struggled to form effective flocs, thereby reducing dewatering efficiency. Selecting the appropriate PAM ionic type and molecular weight can markedly improve the solid-liquid separation performance of flotation clean coal, providing valuable guidance for industrial dewatering processes.

Keywords: polyacrylamide, flotation clean coal, dewatering, specific resistance

1. Introduction

In the coal washing and processing stages, both primary and secondary fine coal generate slurry water. The presence of water in fine coal lowers its calorific value, reduces the efficiency of coal resource utilization, raises transportation costs, and contributes to environmental problems. Therefore, dewatering fine coal is a crucial step in coal processing. With the advancement of coal mining and washing technologies, the particle size of fine coal has become increasingly finer, which enlarges the surface area and enhances its surface charge. This creates a highly stable suspension system, severely impacting solid-liquid separation efficiency (Zhang et al., 2025). Traditional mechanical dewatering methods struggle to address this challenge, leading to persistently high moisture content in coal fine filter cakes. This not only increases the costs of transportation and drying but also limits the industrial applicability of coal fines. Consequently, the use of efficient chemical filtration aids, especially high-molecular-weight flocculants, has become essential in improving coal fine dewatering efficiency (Li et al., 2022).

Polyacrylamide (PAM), a commonly used high-molecular-weight flocculant, is widely applied in the dewatering of fine coal due to its excellent flocculation performance and adjustable molecular structure (Guo et al., 2023). Different types of PAM influence the flocculation and dewatering performance of fine coal through various mechanisms. Cationic polyacrylamide (CPAM) utilizes electrostatic adsorption to

DOI: 10.37190/ppmp/204126

interact with the negative charges on coal fine particles, reducing electrostatic repulsion between particles. This encourages the formation of larger flocs, thereby enhancing solid-liquid separation efficiency. In contrast, anionic polyacrylamide (APAM) relies on its long-chain structure to physically adsorb onto particle surfaces, forming looser flocs through bridging effects (Zhang et al., 2024). The molecular weight of PAM also significantly impacts its flocculation effectiveness. High-molecular-weight PAM tends to have stronger bridging capabilities, which promotes the formation of larger and denser flocs. Low-molecular-weight PAM, due to weaker bridging effects, generally exhibits comparatively poorer flocculation performance (Costine et al., 2018; Dwari et al., 2018). Factors such as polymer type, dosage, temperature, pH, and slurry concentration also considerably affect the dewatering of fine coal (Tao et al., 2003).

Studies have shown that the adsorption-bridging action of polyacrylamide (PAM) alters the particle size distribution in dewatered slurries, forming well-structured flocs with high permeability that significantly improve filtration and dewatering efficiency of fine-grained materials (Chang et al., 2019). Both cationic and anionic flocculants enhance filtration speed, with anionic flocculants particularly effective at reducing filter cake moisture content. This suggests that the primary dewatering mechanism of polymer flocculants is adsorption bridging, rather than being significantly impacted by added metal ions (Groppo and Parekh, 1996). High-molecular-weight flocculants offer enhanced bridging efficiency due to their longer-chained form, which can extend from one particle surface to another, promoting the formation of stable bridges (Razali et al., 2011).

During this process, the flocculants attach to particle surfaces through hydrogen or chemical bonding, with their hydrocarbon chains stretching to increase particle attachment possibilities (Ofori et al., 2011; Reuter and Hartan, 1986). Selecting the optimal flocculant dosage is essential for maximum efficiency. Excessive polymer can destabilize the suspension by preventing bridge formation, as no available surface sites remain for bridging with other particles (Ciftci and Isık, 2017). Anionic flocculants tend to form large, compact flocs with low porosity, thereby increasing filtration speed. In contrast, cationic flocculants form smaller and denser flocs, which can reduce filtration rates due to the poorer permeability of the filter cake (Khazaie et al., 2022). However, some researchers argue that high-molecular-weight flocculants may increase final moisture content in fine coal cakes due to the presence of hydrophilic functional groups, which can encapsulate water within the floc structure, leading to higher water retention within larger flocs (Ren, 2018).

While prior research has delved into the mechanisms of polyacrylamide (PAM) in dewatering flotation clean coal, a systemic analysis of the synergistic impact of its ionic type and molecular weight is still lacking. Particularly, the effects of different ionic PAMs on floc structure, filter cake resistance, and micro-particle aggregation behavior remain inadequately clarified. This study comprehensively examines the influence of various PAM types (cationic, anionic) and molecular weights on the dewatering performance of flotation clean coal. By analyzing particle flocculation characteristics, filter cake structure evolution, and moisture migration mechanisms, it offers a theoretical foundation for optimizing PAM selection and application. The findings not only fill existing literature gaps but also provide scientific grounds for the precise control of coal slime water treatment in industrial settings, advancing the development of efficient, low-energy coal slime dewatering technologies.

2. Materials and methods

2.1. Materials

The coal sample used in this study was the flotation clean coal of gas fat coal in a coking coal washing plant in Shanxi Province, which was collected from the overflow pipeline of flotation cells. The brand of polyacrylamide with different ion types and molecular weights is Macklin. CPAM1200 and CPAM800-1000 are cationic polyacrylamides with molecular weights of 12 million and 8–10 million Daltons, respectively. They have a solid content of ≥88% and a degree of ionization of 30%–35%. APAM500, APAM700, APAM800-1000, and APAM1000-1200 are anionic polyacrylamide (APAM) with molecular weights of 5 million, 7 million, 8–10 million, and 10–12 million Daltons, respectively. They have a solid content of 90%–100%, a degree of hydrolysis of 10%–45%, and a residual monomer content of <0.05%.

2.2. Methods

2.2.1. Filtering aid experiments

15 g of flotation clean coal sample was placed in a beaker and prepared into pulp with a mass concentration of 200 g/dm^3. The pulp was stirred at 400 rpm using a stirrer, and surfactant was added after 5 min of stirring. Following the mixing of the pulp, it was poured into the Buchner funnel, and filtration was started at 0.1 MPa. After the filtration process, the filter cake was taken out, the filtration time was recorded, it was dried at 105^{o}C, and the moisture content of the filter cake was calculated. The moisture content of the filter cake (M_{ad}) was calculated using Eq. 1:

$$M_{ad} = \frac{m_1 - m_2}{m_1} \times 100\% \quad (1)$$

where M_{ad} is the moisture content of air-dried basis (%), m_1 is the mass of the sample before drying (g), and m_2 is the mass of the sample after drying (g).

2.2.2. Fourier transform infrared spectroscopy (FTIR) analysis

The FTIR analysis was carried out on the Nicolet summit infrared spectrometer (Thermo Fisher Scientific Shier Technology (China) Co., Ltd.). The flotation clean coal samples were treated with various reagents. After the treatment, the solution was filtered using a vacuum filtration device to achieve solid-liquid separation. The filtered solid powder was then dried in a vacuum drying oven set at 40°C. The dried mineral particles were mixed with potassium bromide (Pure Spectrum, Shanghai Yixiang Instrument Co., Ltd.), with the mineral sample comprising 2% of the total weight. Finally, a small amount of the mixture was pressed into transparent pellets for infrared spectroscopy scanning.

2.2.3. Zeta potential measurements

Zeta potential was measured on a NanoBrook Zeta potentiometer produced by Brookhaven Company. A coal slurry with a mass concentration of 20% was allowed to settle in a beaker for 5 min. The supernatant was then drawn with a pipette and added to the sample cell, which was fitted with electrodes. The zeta potential measurements were conducted at 25°C.

2.2.4. Floc size analysis

Particle Track G400, a focused beam reflectance measurement (FBRM) produced by Mettler Toledo Company, was used to measure and analyze the influence of filter aid on the number of flocs in coal slurry. The FBRM instrument employed a precision laser probe to emit a focused beam that scanned the particles in the slurry. The chord length of the particles was calculated by multiplying the scanning speed by the time taken for the laser beam to traverse the ends of the particles. The chord length represented the particle size within the slurry.

2.2.5. Average mass-specific resistance of filter cake

In constant pressure filtration, the relationship between cumulative filtration volume (v) and time (t) can be expressed by the basic equation of Ruth filtration theory (Eq. 2):

$$\frac{V}{t} = \frac{\Delta P}{\mu(R_m + \alpha \cdot C \cdot V)} \quad (2)$$

In Eq. 2, V is the cumulative filtrate volume (m^3), t is the filtration time (s), ΔP is the constant pressure differential during filtration (Pa), μ is the filtrate viscosity (Pa·s), R_m is the resistance of the filter medium (m^{-1}), a is the specific cake resistance coefficient (m/kg), and C is the concentration of solid particles in the suspension (kg/m^3).

Pure water (Preparation of NW-UV water purifier of Lixin Instrument (Shanghai) Co., Ltd.) was used to test the dielectric resistance (R_m) of the filter media (Buchner funnel and filter paper). The vacuum filter was opened, and water was continuously added to the Buchner funnel to ensure the liquid level completely covered the funnel's bottom, maintaining a stable pressure difference (the pressure difference at this time was recorded). Water was then added to reach liquid levels of 50 cm^3, 75 cm^3, 100

cm^3, 125 cm^3, and 150 cm^3 in the Buchner funnel, and the time required for filtering each different volume of water was recorded respectively. R_m was calculated using Eq. 3:

$$\frac{V}{t} = \frac{\Delta P}{\mu R_m} \tag{3}$$

Table 1. Dielectric resistance of Buchner funnel and filter paper

V/t (m^3/s)	ΔP (Pa)	μ (Pa s)	R_m (m^{-1})
$1.4205.10^{-5}$			$4.3393.10^{12}$
$1.5000.10^{-5}$			$4.1092.10^{12}$
$1.4948.10^{-5}$	70000	$1.1357.10^{-3}$	$4.1236.10^{12}$
$1.4468.10^{-5}$			$4.2604.10^{12}$
$1.4259.10^{-5}$			$4.3229.10^{12}$

The dielectric resistances calculated by 50 cm^3, 75 cm^3, 100 cm^3, 125 cm^3, and 150 cm^3 of water passing through the Buchner funnel and filter paper are presented in Table 1. The average dielectric resistances represented those of the Buchner funnel and filter paper, with a value of $4.2311.10^{12}$ m^{-1}.

3. Results and discussion

3.1. Screening analysis of flotation clean coal samples

The screening results of flotation clean coal are shown in Table 2, respectively. The ash content of flotation clean coal was 9.09% In the flotation clean coal, fine particles were predominant, with those below -0.074 mm accounting for 76.34%. These fine particles tended to adsorb more water and reagents, thus increasing the water-holding capacity of the filter cake. During the filtration, they could fill the pores of the filter cake, reducing permeability and hindering water drainage. The ash content of the -0.045 mm particles, at 10.04%, was higher than that of other particle size fractions. This suggested a higher content of hydrophilic minerals in the -0.045 mm size fraction, leading to a tight bond between water and particles and making dewatering challenging. Hydrophilic particles easily form stable hydration films that increase the resistance to solid-liquid separation.

Table 2. Test results of flotation clean coal screening

Particle Size (mm)	Yield (%)	Ash (%)	Cumulative Oversize		Cumulative Undersize	
			Yield (%)	Ash (%)	Yield (%)	Ash (%)
+0.500	0.45	8.45	0.45	8.45	100.00	9.09
-0.500+0.250	3.30	5.73	3.75	6.05	99.55	9.09
-0.250+0.125	7.20	6.29	10.95	6.21	96.25	9.20
-0.125+0.074	12.71	7.29	23.66	6.79	89.05	9.44
-0.074+0.045	11.27	8.41	34.93	7.31	76.34	9.80
-0.045	65.07	10.04	100.00	9.09	65.07	10.04
Total	100.00	9.09				

3.2. Influence of ion type and molecular weight of polymer on filtration performance of flotation clean coal

The effects of different polymer ion types and molecular weights on the moisture content of flotation clean coal filter cakes are shown in Fig. 1. APAM700 increased the moisture in flotation clean coal filter cakes from 21.57% to 54.97% with a sharp rise even at lower dosages. Within the experimental dosage range, APAM500 and APAM800-1000 also increased the moisture but to a lesser extent compared to APAM700. APAM1000-1200, CPAM800-1000, and CPAM1200 first decreased and then increased with the increase of reagent dosage. When the dosage of CPAM1200 is 60 g/Mg, the moisture content of flotation clean coal filter cake decreases from 21.57% to 18.97%. CPAM1200 showed the best effect in reducing the moisture content of filter cake compared with polyacrylamide with other ionic types and molecular weights.

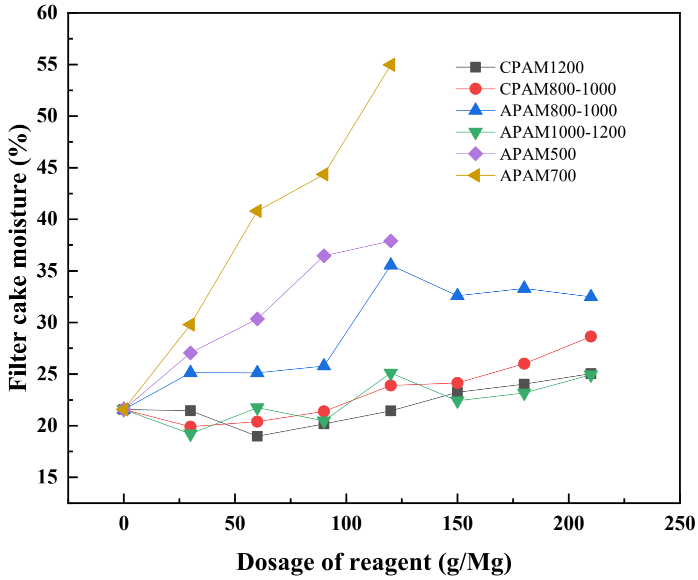

Fig. 1. Effect of ion type and molecular weight of polymer on the moisture content of flotation clean coal filter cake

The influence of different polymer ion types and molecular weights on the filtration time of flotation clean coal is shown in Fig. 2. APAM700 and APAM800-1000 increased the filtration time of flotation clean coal from 98 s to 1483 s and 1008 s, respectively. APAM500 first reduced the filtration time to 24 s at a reagent dosage of 30 g/Mg, and as the dosage increased, the filtration time increased to 352 s. CPAM1200, CPAM800-100, and APAM1000-1200 first decreased and then increased the filtration time. Among them, CPAM1200 could lower the filtration time to just 16 s. The filtration rate correlates with the molecular weight of high-molecular-weight polymers, and high-molecular-weight polymers are better than low-molecular-weight ones in reducing the filtration time of flotation clean coal. CPAM1200 was the most effective in reducing the moisture content and filtration time of the filter cake of flotation clean coal. However, the reagent dosages required for the lowest moisture content and the shortest filtration time differ. APAM500 can achieve a low filtration time with a smaller reagent dosage. APAM1000-1200 can achieve low filter cake moisture with a lower reagent dosage.

Considering factors such as reagent dosage, filter cake moisture, and filtration time, different ionic types and molecular weights of polyacrylamide are needed to meet various requirements. CPAM1200 achieved the best dewatering performance at 60 g/Mg with low filter cake moisture and a high filtration rate. This suggests that high-molecular-weight CPAM enhances particle aggregation and filter cake structure via electrostatic adsorption and bridging, improving dewatering efficiency. The filtration rate is closely related to the molecular weight of the polymer. High-molecular-weight polymers are more effective in reducing filtration time, while cationic polyacrylamide, such as CPAM1200, outperforms other types in lowering filter cake moisture.

3.3. Analysis of surface functional groups of flotation clean coal before and after the action of ion type and molecular weight of polymer

The FTIR spectra of flotation clean coal filter cakes before and after the addition of reagents are shown in Fig. 3. No significant changes were observed in the FTIR spectra of flotation clean coal after the addition of polyacrylamides with different ionic types and molecular weights. No new peaks were generated, indicating that polyacrylamides and their hydrolysis products did not form new functional groups on the surface of the flotation clean coal, and the interaction between polyacrylamide and coal surface was mainly physical adsorption rather than chemical bonding. This physical adsorption may involve van der Waals forces or electrostatic interactions, which did not alter the existing functional groups on the coal surface. Consequently, the FTIR spectra remained largely unchanged, reflecting the absence of chemical modifications or new functional group formations. This suggested that polyacrylamides primarily function through physical adsorption to bridge particles, facilitating the flocculation of flotation clean coal and tailings particles.

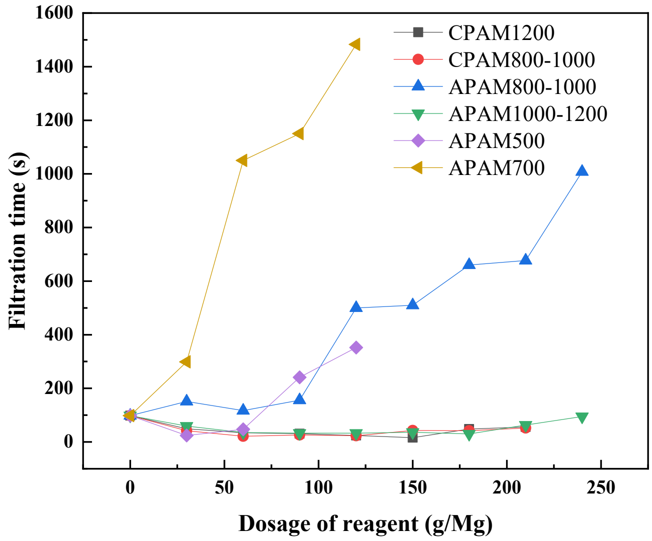

Fig. 2. Effect of ion type and molecular weight of polymer on filtration time of flotation clean coal

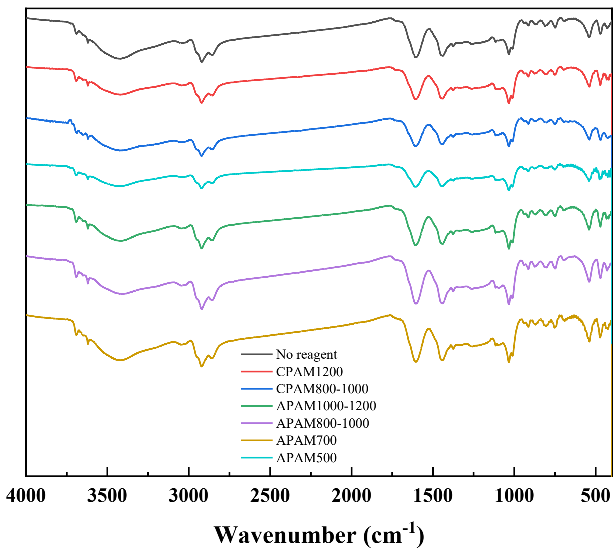

Fig. 3. The impact of polyacrylamide types and molecular weight on the surface functional group flotation clean coal filter cake

3.4. Influence of ion type and molecular weight of polymer on surface electrical properties of flotation clean coal

In the study of flotation clean coal dewatering, the ionic type and molecular weight of polyacrylamide (PAM) were critical for regulating the surface charge of mineral particles. Zeta potential, a key indicator of surface charge distribution, provided insights into the mechanisms by which filtration aids affect particle interactions. Fig. 4 shows the effect of polyacrylamide with different ionic types and molecular weights on the zeta potential of float coal concentrate. When no reagent was added and the pH was neutral, the zeta potential of flotation clean-coal particles was -30.26 eV. CPAM and APAM caused a positive shift in the zeta potential. Under neutral pH conditions, APAM500 led to the highest decrease in the absolute zeta potential value, reaching -20.24 eV. The order of reduction is APAM500, APAM1000-1200, CPAM1200, APAM700, and CPAM800-1000. Notably, under CPAM1200, APAM1000-1200, and APAM700 conditions, the zeta potential values of float coal concentrate are very close.

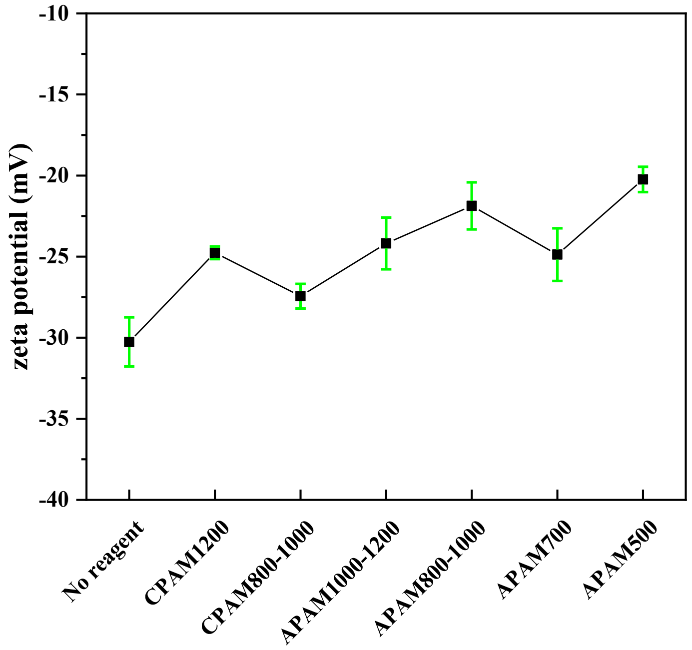

Fig. 4. The impact of polyacrylamide types and molecular weight on the zeta potential of flotation clean coal

According to Fig. 4, PAMs of various ionic types and molecular weights consistently reduced the absolute zeta potential of flotation clean coal, demonstrating their significant role in surface charge modulation. CPAM, carrying a positive charge, neutralized the negative charge on the surface of flotation clean coal particles through electrostatic adsorption, thereby reducing the absolute zeta potential. APAM, with its negative charge (Wu et al., 2008), indirectly influences the surface charge distribution through its bridging and adsorption capabilities in solution. Among the tested additives, APAM500 exhibited the greatest reduction in the absolute zeta potential. This might be attributed to its moderate molecular weight and good dispersion, which enhanced its interaction with particle surfaces and enabled effective surface charge regulation. In contrast, APAM1000-1200, despite its higher molecular weight, demonstrated slightly less effective charge neutralization. This might result from the longer molecular chains forming complex coiled structures upon adsorption, hindering its ability to regulate charges efficiently. APAM700 displayed moderate charge regulation capacity, with its balanced molecular weight and structure providing adequate charge neutralization. Notably, the zeta potential reduction effect of APAM700 was comparable to that of CPAM1200 and APAM1000-1200, suggesting that under specific conditions of molecular weight and charge density, different types of PAM may exhibit similar mechanisms for modulating zeta potential.

3.5. Influence of ion type and molecular weight of polymer on the chord length of flotation clean coal floc

In the dewatering process of flotation clean coal, the ionic type and molecular weight of polyacrylamide significantly affect the flocculation behavior of particles in pulp, which has an important impact on the chord length of particles (that is, the average distance between particles). Under the action of polyacrylamide with different ion types and molecular weights, the chord length of flotation clean coal particles is shown in Fig. 5. CPAM1200, CPAM800-1000, and APAM1000-1200 showed a great influence on the chord length of particles in flotation clean coal slurry, while APAM800-1000, APAM700, and APAM500 had a little influence on the chord length of particles in flotation clean coal slurry. Polyacrylamide with a small molecular weight has a poor flocculation effect on flotation clean coal, and it is difficult to form a large floc structure.

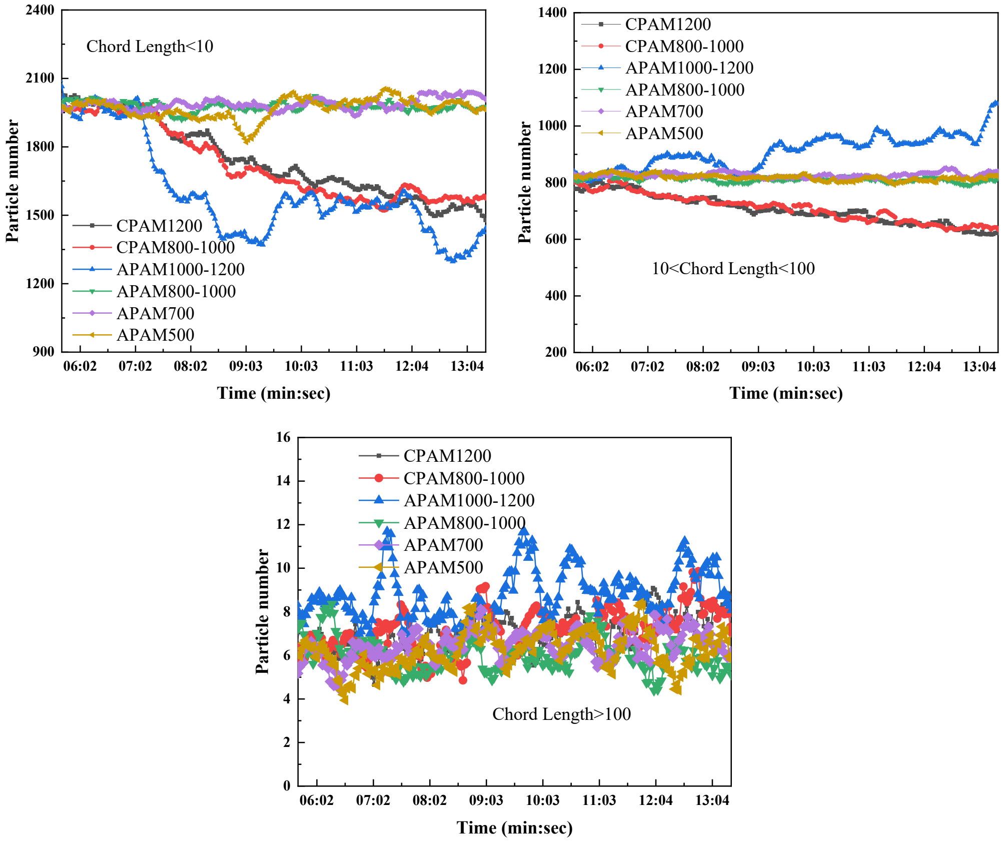

Fig. 5. Effect of polyacrylamide with different ion types and molecular weight on flocculation chord length of flocculation clean coal

CPAM1200 and CPAM800-1000 have longer molecular chains, which enables them to bridge flotation clean coal particles more effectively, increase the mutual attraction between particles, and then form a larger floc structure. This bridging effect reduces the gap between particles, resulting in a significant increase in chord length. The positive charge of cationic polyacrylamide is helpful to neutralize the negative charge on the surface of clean coal particles and further enhance the flocculation effect between particles. Although APAM1000-1200 is an anionic polyacrylamide, its large molecular weight can still form enough bridging effect between flotation clean coal particles, prompting the particles to gather into larger flocs, thus increasing the chord length. This shows that high molecular weight anionic polyacrylamide can also achieve a good flocculation effect through physical adsorption and particle interaction under certain conditions. Low molecular weight polyacrylamide, with its short molecular chain and relatively low molecular weight, cannot effectively form bridges between particles. It disperses easily in solution, but its short molecular chain limits its ability to aggregate particles, resulting in weak particle interactions, a small floc structure, and minimal changes in chord length.

CPAM neutralizes surface charges by electrostatic adsorption with negatively charged particles, which reduces electrostatic repulsion between particles and enhances the possibility of particle aggregation. This charge neutralization effect helps the particles to aggregate into larger flocs, which significantly increases the chord length of the particles. APAM mainly depends on physical adsorption and molecular chain bridging, and its flocculation effect is weaker than CPAM due to the repulsion of negative charges on the particle surface. However, APAM with high molecular weight can still achieve particle aggregation through a long-chain structure.

3.6. Effect of ion type and molecular weight of polymer on viscosity of flotation clean coal filtrate

Under different reagent conditions, the viscosity of flotation clean coal filtrates is listed in Table 3. When no reagent was added, the filtrate viscosity of flotation clean coal was 1.12624 cP. CPAM1200, CPAM800-1000, and APAM1000-1200 increased the filtrate viscosity, while APAM800-1000, APAM700, and APAM500 decreased it. The increased viscosity of the filtrate under high molecular weight polyacrylamides can be attributed to their long-chain structures. The amide groups ($-CONH_2$) and other functional groups on the polymer chains interact with flotation clean coal molecules and other polymer chains, forming complex network structures. The entanglement and cross-linking of polymer chains in solution increase flow resistance, thereby elevating viscosity. High molecular weight polyacrylamide solutions exhibit viscoelastic behavior, combining both viscous and elastic properties during flow and deformation. As long-chain polymers stretch and entangle during flow, they enhance the internal friction of the solution, resulting in higher viscosity.

Table 3. The viscosity of filtrate of flotation clean coal under different reagent conditions

Reagent type	Filtrate viscosity (cP)
No reagent	1.12624
CPAM1200	1.29431
CPAM800-1000	1.28138
APAM1000-1200	1.20985
APAM800-1000	1.07618
APAM700	1.08424
APAM500	1.09050

Although CPAM800-1000 and APAM800-1000 have similar molecular weights, CPAM800-1000 increased filtrate viscosity, while APAM800-1000 decreased it. This difference arises primarily from the cationic groups on the CPAM chains, which strongly attract negatively charged flotation clean coal particles via electrostatic interactions. This attraction promotes the formation of a robust network structure between CPAM molecules and particles, thereby increasing filtrate viscosity. Conversely, the anionic groups on APAM chains repel the negatively charged flotation clean coal particles, leading to particle dispersion in the solution. This repulsion reduces particle-particle and particle-polymer chain interactions, thereby lowering filtrate viscosity.

Low-molecular-weight APAMs, with their shorter polymer chains, form less stable and loosely organized network structures in solution, which are less capable of significantly increasing viscosity compared to high-molecular-weight APAMs. Additionally, the anionic groups on low-molecular-weight APAM chains repel negatively charged particles, further dispersing them in the solution. This dispersion reduces interactions and aggregation among particles, thereby decreasing filtrate viscosity.

3.7. Effect of ion type and molecular weight of polymer on average mass specific resistance of flotation clean coal filter cake

The average mass-specific resistance of flotation clean coal under different ion types and molecular weights is listed in Table 4. When no reagent was added, the specific resistance of the filter cake of flotation clean coal was $3.32.10^{15}$. CPAM reduced the specific resistance to the lowest at 4.20^{14}, while APAM700 increased it to the highest at $3.83.10^{16}$. CPAM800-1000, APAM1000-1200, APAM800-1000, and APAM500 all decreased the specific resistance of the flotation clean coal filter cake. CPAM800-1000, APAM1000-1200, APAM800-1000, and APAM500 all decreased the specific resistance of flotation clean coal filter cake.

CPAM1200 significantly reduced the specific resistance of filter cake of flotation clean coal, mainly because of its high molecular weight and cationic property. Cationic polyacrylamide can generate electrostatic attraction with the surface of negatively charged clean coal particles, forming a more compact flocculation structure, reducing the gaps between particles, making the structure of filter cake more compact, thus reducing the retention of water and reducing the specific resistance of filter cake. Although CPAM800-1000 also effectively reduced the specific resistance, its effect was slightly inferior to CPAM1200. The possible reason was that its molecular weight was small and its long chain structure was short, which led to the flocculation effect is not as strong as CPAM1200, and the density of the filter cake structure being slightly lower. Anionic polyacrylamide (APAM) forms bridging flocculation with the cationic part in coal slime or the adsorbed cationic bridge, which makes the particles physically cross-linked, thus enhancing the flocculation effect. APAM1000-1200 with larger molecular weight can form large-size flocs because of its longer molecular chain, which reduces the gap between particles, makes water easier to discharge, and thus reduces the specific resistance of filter cake. APAM800-1000 had little influence on specific resistance, its molecular weight is in the middle level, its flocculation effect was not as remarkable as that of higher molecular weight APAM1000-1200, and its influence on filter cake structure is also small.

Table 4. The average mass-specific resistance of flotation clean coal under different reagent conditions

Reagent type	*V/t*	μ (Pa.s)	*a*
No reagent	$1.40.10^{-6}$	$1.13.10^{-3}$	$3.32.10^{15}$
CPAM1200	$6.67.10^{-6}$	$1.29.10^{-3}$	$4.20.10^{14}$
CPAM800-1000	$5.00.10^{-6}$	$1.28.10^{-3}$	$6.88.10^{14}$
APAM1000-1200	$4.29.10^{-6}$	$1.21.10^{-3}$	$9.33.10^{14}$
APAM800-1000	$3.82.10^{-6}$	$1.08.10^{-3}$	$1.17.10^{15}$
APAM700	$1.56.10^{-7}$	$1.08.10^{-3}$	$3.83.10^{16}$
APAM500	$4.33.10^{-6}$	$1.09.10^{-3}$	$9.77.10^{14}$

Although the chain length of APAM500 with a small molecular weight was short, its low molecular weight enables it to maintain good solubility and dispersibility. This helps to form a proper amount of flocculating substances, especially at low particle concentration or ionic strength, APAM500 has a moderate molecular chain length, which can effectively bridge dispersed particles and form small and stable flocs, thus showing a certain flocculation ability. Although the molecular weight of APAM700 was slightly higher than that of APAM500, the increase in molecular weight may lead to the deterioration of its solubility or dispersibility, and the molecular chain may become more rigid and curly, which affects its ability to spread in water and effectively adsorb particles. Because the molecular chain cannot be fully expanded, APAM700 cannot effectively bridge particles or form stable large flocs, resulting in insufficient flocculation ability. Compared with APAM800-1000 and APAM1000-1200, APAM700 cannot form large flocs, and the dispersibility of APAM700 was worse than that of APAM500.

In summary, the experimental results demonstrated that the type and molecular weight of polyacrylamide significantly influence the specific resistance of flotation clean coal filter cakes. CPAM, particularly CPAM1200, showed the most effective reduction in specific resistance due to its high molecular weight and strong electrostatic attraction with negatively charged coal particles, forming compact flocs that minimized water retention. APAM also reduced specific resistance, with higher molecular weight APAM1000-1200 performing better than lower molecular weight. However, APAM700 increased specific resistance, likely due to its lower molecular weight and reduced solubility, which hindered effective flocculation.

4. Conclusions

In the experimental studies, high-molecular-weight polymers were found to be more effective in reducing the moisture content and filtration resistance of flotation clean coal compared to low-molecular-weight polymers. It was observed that cationic and anionic polyacrylamides, along with their hydrolysis products, did not form new functional groups on the surface of flotation clean coal. Their primary mechanism involved physical adsorption, which facilitated bridging interactions to aggregate flotation clean coal and tailings particles into flocs. CPAM achieved flocculation by adsorbing onto negatively charged particle surfaces through electrostatic attraction. This process neutralized surface charges, reduced electrostatic repulsion among particles, and enhanced the likelihood of particle aggregation. The resulting charge neutralization promoted the formation of larger flocs and significantly increased the chord length between particles. In contrast, APAM relied predominantly on physical adsorption and molecular chain bridging to achieve flocculation. However, due to the electrostatic repulsion between the negatively charged APAM molecules and particle surfaces, its flocculation efficiency was lower than that of CPAM. Nevertheless, high-molecular-weight APAM, with its extended chain structure, could still effectively aggregate particles through bridging interactions.

The superior dewatering performance of high-molecular-weight CPAM was attributed to its strong electrostatic attraction and excellent flocculation capabilities, which significantly reduced the specific resistance of the flotation clean coal filter cake and enhanced water removal efficiency. While high-molecular-weight APAM also demonstrated favorable flocculation properties, its effectiveness was less pronounced compared to CPAM. In contrast, low-molecular-weight APAM, particularly APAM700, exhibited insufficient flocculation capacity due to its shorter molecular chains. This inadequacy might even result in increased specific resistance, thereby compromising dewatering performance.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (Project No. 52174264).

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