The application of an efficient modified decolorizer in coagulation treatment of high color reclaimed water

Mengqi Wang, Yimei Tian, Xin Zhao and Xiang Li

ABSTRACT

High color concentrations in inflows at reclaimed water treatment plants are typically considered as emergency situations, which must be solved using an appropriate decolorizing process. Using the decoloration mechanism of a modified dicyandiamide-formaldehyde polymer (DFP), a urea-formaldehyde polymer and a melamine-formaldehyde polymer (MFP) were prepared with ammonium chloride and ammonium sulfate as the modifiers. An orthogonal experiment indicated that a modified urea-formaldehyde polymer had no effect on decolorization; however, the MFP modified by ammonium chloride in number 16 (MMFP-C16), the DFP modified by ammonium chloride in number 9 (MDFP-C9) and modified by ammonium sulfate in number 6 (MDFP-S6) were successful. The removal rates were above 50% in acidic and reactive dye reclaimed water. Fourier transform infrared spectroscopy was used to microscopically analyze the differences in decolorization effect among the polymers. The effect of pH on decolorization was analyzed. Compared to the MDFP-C9 and MDFP-S6, the MMFP-C16 was not sensitive to changes in conditions. The pilot plant test proved that the three optimal decolorizers also had a good decolorizing effect, and MMFP-C16 was better both at decolorizing and floc sedimentation. Thus, the latter can be considered as an efficient modified decolorizer for rapid treatment of high color reclaimed water.

Key words | decoloration, Fourier transform infrared spectroscopy, modified melamine-formaldehyde polymer, reclaimed water

INTRODUCTION

Reclaimed water is generally referred to as treated sewage that conforms to specific water quality standards, satisfies certain usage requirements, and will not be harmful to humans or the environment. It has become an essential alternative water resource to address the ever-increasing demand for water worldwide (Tortajada & Ong 2016). In particular, reclaimed water contains various chromophoric groups such as dyes, which have a high degree of visibility despite being often present in small quantities (Elahmadi et al. 2009). The color of reclaimed water has attracted growing concern from users (Hurlimann & Mckay 2006), giving rise to increasingly strict restrictions on color in recycling standards. The color of reclaimed water used for circulating cooling water in boilers, farm irrigation, and toilet flushing is required to be less than 30 degrees (SL 368-2006, China). When the color of inflow is very high, the number of chromophoric groups and organics increase, leading to an increase in the ozone dose required to treat it and the severity of microfiltration membrane fouling (Shkavro et al. 2009). Worse still, even a treatment process running at full capacity may not be able to make the color of the effluent reach the standard. Therefore, common problems with reclaimed water treatment plants include unpleasant smell or color in the treated water, which consequently restricts its ability to be recycled (Zahrin et al. 2011).

Many methods for decolorizing water have been proposed, including chemical oxidation (Cai et al. 2016), biodecolorization (Guadie et al. 2017), and adsorption (Foguel et al. 2017). These methods, however, are commonly associated with an ineffective decolorization rate, high equipment and operational cost, and simultaneous generation of byproducts which are potentially more hazardous (Liang et al. 2009). To date, coagulation is regarded as one of the cheapest and easiest approaches (Vijayaraghavan et al. 2017). A range of conventional inorganic and organic coagulants have been tested to remove color from reclaimed...
water. Aluminum-based salts and iron-based salts are the most commonly used inorganic coagulants because they are cheap (Liang et al. 2009). However, the water-soluble and low molecular dyes were observed to have a poorer floc settling ability (Wang et al. 2012). To improve these limitations, organic polymer coagulants were studied. They can bind with colloidal particles with strong absorbing actions, and are also widely used due to their many practical applications and remarkable performance. Research started early on using dicyandiamide-formaldehyde polymer (DFP), one of the many organic polymer coagulants, to prepare a flocculating decolorizer (Shiba et al. 2006).

Two steps were involved in the preparation of the DFP. Firstly, a methylol dicyandiamide was formed by the addition reaction of dicyandiamide with formaldehyde. And then, a dimer bonded by an ether group or methylene group was created by the polycondensation reaction in a weak acid medium. With further heated and cross-linking reaction, polymer was formed eventually. DFP, which is highly cationic, neutralizes the anions on the surface of dyes; thus, the dye particles lose their original stability and settle (Lee et al. 2014). However, the flocs formed in the process using DFP were relatively small. It was found that using this polymer alone could not produce an excellent decolorization effect (Li & Wang 2006). Many studies suggested that the effect of decolorizer with ammonium performed both decolorizing ability and floc sedimentation better (Qian & Li 2008), but the cost of dicyandiamide makes the decolorizer uneconomical. The reaction between dicyandiamide and formaldehyde occurs via -NH2 and -NH-. Urea is an amide and melamine is an amine; they can react with formaldehyde via -NH2. There are two steps involving in the preparation of the urea-formaldehyde polymer (UFP). Firstly, a methylolurea can be obtained by the addition reaction of urea with formaldehyde. Secondly, in a weak acid medium, an oligomer bonded by a methylene group or methylene ether group was synthesized by condensation reaction of methylolurea. For the melamine-formaldehyde polymer (MFP), it can be also synthesized by two steps. The first step was hydroxymethylation. A methylol melamine was formed by the addition reaction of melamine with formaldehyde. And then, the high reactive methylol took the reaction of etherification and polycondensation in a weak acid medium. The price of urea and melamine is about one-fifth and one-half, respectively, of the same weight of dicyandiamide. However, whether a UFP and a MFP have an effect on the decolorization of reclaimed water was still unknown.

Therefore, according to the DFP decolorization mechanism, UFP and MFP were prepared with ammonium chloride as well as ammonium sulfate as the modifier. There are two targets of using ammonium as the modifier: (1) it can provide a weak acid reaction conditions for polycondensation and increase the molecular weight of floc, which is beneficial to sedimentation; (2) it can modify the decolorizer to contain more amino groups. Accordingly, the amino groups can be protonated further, which can make the polymers positively charged and make better effect on decolorization. The dyes used were acid blue 47, acid orange 10 and reactive red 13. This study selected optimal decolorizers through the orthogonal test. To further explain the differences of decolorization effects of different polymers, this study used Fourier transform infrared (FTIR) spectroscopy to provide information on the main chemical constituents and different polymer components. The effect of pH on the decolorization of optimal modified decolorizers was analyzed. After evaluating the effect of decolorization of selected optimal decolorizers in a pilot plant test, this study provided useful guidance to operators working in actual production conditions.

**MATERIALS AND METHODS**

**Laboratory-scale study**

**Materials**

Urea, melamine, dicyandiamide, ammonium chloride, and polymeric aluminum chloride (PAC) were all obtained from Tianjin Guangfu Fine Chemical Institute; formaldehyde (37% w/w) was obtained from Tianjin Fengchuan Chemistry Reagent Company; and solid NaOH was obtained from Tianjin Jiangtian Chemical Reagents Company. All chemicals used were analytical grade without any further purification. Distilled water was used throughout this experiment.

**Preparation of polymers by orthogonal experiment**

Each component in the polymers was determined. Formaldehyde and amines are the main parts of the polymer, so the ratio of the two plays a very important role in the decolorization effect. When the molar ratio of formaldehyde to urea was less than 3:1, solubility was poor (Lin et al. 1990). So the molar ratio of formaldehyde to urea in the experiment was 3:1, 4:1, 5:1 and 6:1, respectively. When the molar ratio of formaldehyde to melamine was less than 10:1, the reaction product was insoluble in water (Chang 1992). During the
pre-testing stage, it was found that the molar ratio of formaldehyde to melamine was less than 15:1, and the polymer turned from clear liquid to solid white. As a result, the molar ratio of formaldehyde to melamine in the experiment was 15:1, 17.5:1, 20:1 and 22.5:1, respectively. It was indicated that the best decolorization effect could be achieved when the molar ratio of formaldehyde to dicyandiamide was 2:1–3:1 (Qian & Li 2008). Accordingly, the molar ratio of formaldehyde to dicyandiamide was 2:1, 2.5:1, 2.9:1, respectively. NaOH and distilled water are used to control the pH, to meet alkaline reaction condition requirements. Flocculation is poor for the six polymers when the reaction temperature is below 50 °C or above 80 °C (Zhu et al. 1997). The modifier dosages, reaction temperature, and reaction time were determined during the pre-testing stage.

The laboratory-scale study was divided into two groups for each polymer. The factors and details pertaining to the orthogonal experiment are shown in Supplementary Tables S1–S3 (available with the online version of this paper). A one-step process was used. According to Supplementary Tables S1–S3, reactants were added to the reactor in order first, and then the mixture was stirred until it was combined. On the basis of reaction temperature and time, full heating was required. After cooling down to room temperature, the polymer was prepared successfully.

Coagulation experiment

After considering the actual operating parameters of a water recycling plant, this study proceeded as follows. The main component of the polymer and varying amounts of other chemicals were mixed to prepare each polymer. Ten milligrams of each dye was dissolved in 2 L of reclaimed water to simulate highly colored water. As per the platinum cobalt colorimetric method, the maximum color of the inflow water quality was approximately 120 degrees, which was the same as the concentration of the dye, namely, 5 mg/L. Ten milligrams per liter PAC was added to the water. Using the Jar Tester (ZR4-6, Zhongrun, China), the solution was rapidly mixed at 150 rpm for 2 min, then at a reduced speed of 40 rpm for 3 min, before being mixed finally at 20 rpm for 3 min. After starting the Jar Tester, the polymer was added first and the PAC 20 s afterwards. The particles settled for 30 min. After settling, samples were taken for analysis.

Analytical methods

The concentrations of acid blue 47, acid orange 10, and reactive red 13 in water were determined by their absorbance at 638 nm, 485 nm, and 540 nm, using a UV-Vis spectrometer (Alpha-1860, Puyuan, China). A pH meter (HACH-HQ11D, HACH, USA) and a turbidity meter (HACH-2100Q, HACH, USA) were used to detect the pH and turbidity, respectively, of the effluents. The viscosity of the decolorizer was monitored with a digital rotational viscometer (NRJ-5S, Jingtian, China). A spectrophotograph (FTS3000, Bio-Rad, USA), with a wavenumber from 370 cm\(^{-1}\) to 7,500 cm\(^{-1}\) and resolution from 0.9 cm\(^{-1}\) to 1.0 cm\(^{-1}\), was used to discriminate between the different polymer components.

Pilot plant test

The test was carried out continuously at the plant, which had the same process flows as the reclaimed water treatment plant including mechanical mixing tank, four-stage mechanical flocculating tank, tube settler, immersed micro filter basin, ozonation column and clean water pond. The treatment scale of the pilot plant test was 72 m\(^3\)/d. In order to simulate a high color inflow, acid blue 47, acid orange 10 and reactive red 13 were added separately to the inflow water. The concentration of each dye was 5 mg/L. Inflow was mixed with 0.10 ml/L decolorizer and 10 mg/L PAC at 110 rpm for 2 min. Then the water entered the four-stage flocculation tank. The mixing speeds were 15.2 rpm, 13.4 rpm, 8.7 rpm, and 6.2 rpm, and each stage lasted for 3.75 min. After 30 min of settling in the tube settler, as the decolorization effect stabilized, samples were taken from sedimentation tank for analysis. To reduce errors, three parallel tests were conducted.

RESULTS AND DISCUSSION

The absorbency and turbidity of the water treated by the DFP, UFP, and MFP without modifier was tested to make sure they had no effect on decolorization (Supplementary Table S4, available with the online version of this paper). In order to eliminate the interference of PAC, a blank experiment with PAC alone was also carried out.

Treatment effect with modified polymers

Effects of treatment with MUFP

The effects of decolorization with UF-modified by ammonium chloride as well as ammonium sulfate were
relatively poor, almost the same as PAC alone (Figures 1 and 2). Therefore, it was reasonable to assume that the decolorization of water was mainly because of PAC, while modified urea-formaldehyde polymer (MUFP) had no effect. This meant that although it had a better effect on turbidity removal, MUFP should be excluded. Accordingly, there was no sense in using urea instead of dicyandiamide despite the fact that urea was much cheaper.

Figure 1  | Effect of UFP, modified by ammonium chloride, on the removal of three kinds of dyes: (a) acid blue 47, (b) acid orange 10, and (c) reactive red 13. Dye initial concentration: 5 mg/L; the dosage of decolorizer: 0.1 mL/L; the dosage of PAC: 10 mg/L; measured wavelengths: \(\lambda_{\text{blue}} = 636 \text{ nm}, \lambda_{\text{orange}} = 485 \text{ nm}, \lambda_{\text{red}} = 540 \text{ nm}\).
When only part of the dicyandiamide was replaced with urea, an excellent deodorization effect and low cost was found. Zhou (2006) added urea in condensation reaction of formaldehyde with dicyandiamide to treat wastewater from dyeing and printing. The removal rate of the color was 89.40%.

Figure 2  Effect of UFP, modified by ammonium sulfate, on the removal of three kinds of dyes: (a) acid blue 47, (b) acid orange 10, and (c) reactive red 13. Dye initial concentration: 5 mg/L; the dosage of decolorizer: 0.1 mL/L; the dosage of PAC: 10 mg/L; measured wavelengths: \( \lambda_{\text{blue}} = 638 \text{ nm}, \lambda_{\text{orange}} = 485 \text{ nm}, \lambda_{\text{red}} = 540 \text{ nm}. \)
The color removal rates were 0 with numbers 1, 2, 3, and 4, in particular, as shown in Figure 1. That was because the viscosities of the polymers increased constantly in the process of cooling to room temperature and eventually lost liquidity. Thus, they formed globules very easily and lost their decolorizing ability.

Effects of treatment with MMFP

This study examined the effect of decolorization with MFP modified by ammonium chloride as well as ammonium sulfate. As shown in Figure 3, the color removal rates were 0 with numbers 1, 2, 3, 4, 5, and 6 because of the high viscosity of the polymers. The other polymers removed acid blue 47 and reactive red 13 at rates above 50%, and the removal rates of acid orange 10 were close to 50%. The turbidity of the water was also affected by the decolorizer. For example, the turbidity removal efficiencies of decolorizer number 9 and 12 were negative, indicating that those were not beneficial in removing turbidity. Peoples’ views on water quality depend on intuition; this includes not only the color of the water, but also the degree of turbidity (Hsieh et al. 2015). Therefore, it is also an important index to use turbidity to evaluate the quality of the treated water. Although the adoption of a membrane filtration process can remove turbidity, the heavy particle load would cause serious fouling and reduce the working life of the membrane (Choi & Dempsey 2004). Therefore, numbers 7, 9, 12, 14, and 15 should be excluded because of their negative turbidity.

As shown in Figure 4, the effect of decolorization with MFP modified by ammonium sulfate was relatively poor, that is, almost the same as PAC alone. A white precipitate formed easily when the molar ratio of ammonium sulfate to melamine was more than 1:80 in our pre-test. Accordingly, smaller amounts of ammonium sulfate played less of a role as a modifier. Worse still, the turbidity of the acid orange 10 and reactive red 13 samples were negative. Above all, ammonium sulfate was not a good modifier for MFP.

Effects of treatments with MDFP

The effects of decolorization with MDFP were studied (Figures 5 and 6). The experiment showed that the DFP modified by ammonium chloride as well as ammonium sulfate were successful in removing color. DFP modified by ammonium chloride had a removal rate above 60%; therefore, it was widely used to treat wastewater, among others from printing and dyeing, textiles, and papermaking (Geng et al. 2016). However, most of the results showed that the turbidity of the treated water increased to even more than twice that of the raw water.

The result of DFP modified by ammonium chloride under 65 °C is noteworthy. At the coagulation stage, there was no floc in numbers 8 and 11, and there were some flocs in number 2 smaller than those in number 13. Number 8 and number 11 had the highest level of ammonium chloride, followed by number 2, and number 13 had the lowest. Perhaps too much cationic ammonium chloride made the flocs change size and re-stabilize. Furthermore, too much ammonium chloride had a dilution effect (Geng et al. 2016). Therefore, it would be better to add a modifier in moderation.

Selecting the optimal decolorizers

An orthogonal experiment indicated that MUFP as well as MFP modified by ammonium sulfate had no effect on decolorization. Based on the example of the DFP modified by ammonium sulfate, this paper gives a brief description of how to select the optimal decolorizer.

First, list the decolorizer numbers which achieved the top 30 percent of the removal rates for each dye. These were the numbers 3, 5, 6, 8, 10 and 16 for acid blue 47, numbers 6, 8, 10, 11, 12, 15 and 16 for acid orange 10 and numbers 2, 3, 4, 5, 6, 7 and 10 for acid reactive red 13. Second, focus on the turbidity. Numbers 3, 5, 10 and 16 for acid blue 47, numbers 8, 10, 11, 12 and 16 for acid orange 10 and numbers 2, 3, 5, 7 and 10 for acid reactive red 13 should be excluded because of their negative turbidity. Finally, select the intersection of the rest of the decolorizer. It was indicated that DFP modified by ammonium sulfate in number 6 had a good effect on decolorization and turbidity removal for three kinds of dyes.

According to their color and turbidity removal efficiencies, the best decolorizers were MFP modified by ammonium chloride in number 16, DFP modified by ammonium chloride in number 9, and DFP modified by ammonium sulfate in number 6. For convenience, they were called MMFP-C16, MDFP-C9, and MDFP-S6, respectively. The three optimal decolorizers were prepared as follows. MMFP-C16 was made at 70 °C for 3 h with an optimum molar ratio of 1:22.5:2:0.1 of melamine: formaldehyde: ammonium chloride: NaOH. MDFP-C9 was made at 75 °C for 3 h with an optimum molar ratio of 1:2.6:0.75:1.8 of dicyandiamide: formaldehyde: ammonium chloride: water. MDFP-S6 was made at 75 °C for 3.5 h with an optimum molar ratio of
Figure 3 | Effect of MFP, modified by ammonium chloride, on the removal of three kinds of dyes: (a) acid blue 47, (b) acid orange 10, and (c) reactive red 13. Dye initial concentration: 5 mg/L; the dosage of decolorizer: 0.1 mL/L; the dosage of PAC: 10 mg/L; measured wavelengths: $\lambda_{\text{blue}} = 638$ nm, $\lambda_{\text{orange}} = 485$ nm, $\lambda_{\text{red}} = 540$ nm.
Figure 4   Effect of MFP, modified by ammonium sulfate, on the removal of three kinds of dyes: (a) acid blue 47, (b) acid orange 10, and (c) reactive red 13. Dye initial concentration: 5 mg/L; the dosage of decolorizer: 0.1 mL/L; the dosage of PAC: 10 mg/L; measured wavelengths: $\lambda_{\text{blue}} = 638 \text{ nm}$, $\lambda_{\text{orange}} = 485 \text{ nm}$, $\lambda_{\text{red}} = 540 \text{ nm}$.
Figure 5 | Effect of DFP, modified by ammonium chloride, on the removal of three kinds of dyes: (a) acid blue 47, (b) acid orange 10, and (c) reactive red 13. Dye initial concentration: 5 mg/L; the dosage of decolorizer: 0.1 mL/L; the dosage of PAC: 10 mg/L; measured wavelengths: $\lambda_{\text{blue}} = 638$ nm, $\lambda_{\text{orange}} = 485$ nm, $\lambda_{\text{red}} = 540$ nm.
Figure 6 | Effect of DFP, modified by ammonium sulfate, on the removal of three kinds of dyes. (a) acid blue 47, (b) acid orange 10, and (c) reactive red 13. Dye initial concentration: 5 mg/L; the dosage of decolorizer: 0.1 mL/L; the dosage of PAC: 10 mg/L; measured wavelengths: $\lambda_{\text{blue}} = 638$ nm, $\lambda_{\text{orange}} = 485$ nm, $\lambda_{\text{red}} = 540$ nm.
1:1.7:0.1:1.08 of dicyandiamide: formaldehyde: ammonium sulfate: water.

Determining polymer structure with FTIR spectroscopy

Seven polymers were investigated using FTIR spectroscopy to determine their microstructures. The polymers included the three optimal polymers mentioned above, UFP modified by ammonium chloride in number 8 (best decolorization effect with MUFP), and the three polymers without added modifiers. The absorption peak of water was very strong and may have affected analysis of the results. Accordingly, it was necessary to dry each polymer. As shown in Figure 7, the absorption peak around 1,640 cm\(^{-1}\) was caused by carbonyl of unreacted formaldehyde and the absorption peak around 1,017 cm\(^{-1}\) was caused by hydroxymethyl. The absorption peak around 3,400 cm\(^{-1}\) and 1,550 cm\(^{-1}\) were caused by \(-\text{NH}\) and \(-\text{NH}_2\), respectively. According to the reaction principle of polymers, modifiers can provide a weak acid reaction conditions for hydroxymethyl intermediate product promoting polycondensation reaction. Modifiers can also modify the decolorizer to contain more amino groups. Accordingly, the amino groups can be protonated further, which can make the polymers positively charged and make better effect on decolorization. After adding acid salts (ammonium chloride or ammonium sulfate), the absorption peak of the hydroxymethyl and carbonyl became weaker while the absorption peak of \(-\text{NH}\)- and \(-\text{NH}_2\) became stronger, confirming that the reactions became much more effective.

From this further analysis of the four modified polymers, the amount of \(-\text{NH}\) and \(-\text{NH}_2\) were almost the same for MMFP and MDFP, and both were much larger than that for MUFP. Accordingly, the FTIR spectroscopy results were consistent with the orthogonal experimental results; MUFP had no effect on decolorization. However, MMFP-C16, MDFP-C9, and MDFP-S6 were successful in removing color.

Effect of common factors on decolorization

This study analyzed the effect of water temperature, pH, decolorizer and PAC dosage, and order of decolorizer and PAC addition on decolorization by the optimal modified decolorizers. For the coagulation experiment, the form distribution of decolorizers and dyestuffs are greatly influenced by pH (Li 2005). Accordingly, it will be discussed in detail. This study analyzed the effect of pH on the decolorization under the actual operating conditions of a water recycling plant. The dosages of decolorizer and PAC were 0.1 mL/L and 10 mg/L, respectively. The pH levels were 6.8, 7.0, 7.2, 7.4, 7.6, and 7.8 which were consistent with the pH of inflow at a reclaimed water plant. The color removal ratios of the optimal modified decolorizers did not change significantly with pH (Supplementary Figure S1, available with the online version of this paper). The best color removal was for reactive red 13, the second best for acid blue 47, and worst for acid orange 10, which had a ratio of 40%. The decolorizers also had good results on turbidity removal, with ratios above 60%. In short, the three decolorizers had a great effect on both decolorization and sedimentation of flocs in that pH range, with MMFP-C16 performing the best. This is very important because the water recycling plant inflow was neutral or slightly alkaline. In such cases, no further adjustment of the pH is required. Owing to space constraints, the results of other factors were briefly introduced. The results showed that the modified decolorizers could perform well under the actual temperature of reclaimed water treatment plant inflow (13 °C–23 °C). MMFP-C16 had a higher turbidity removal ratio with the same decolorization rate and a smaller PAC dosage. The result suggested that it was very important to control the dosage of decolorizer in moderation. The color removal rate kept increasing, and the turbidity removal rate increased and then declined with increases in decolorizer dose. In addition, adding decolorizer first and then adding the PAC could lead to an effective treatment.

Pilot plant test

This study evaluated the effect of decolorization with selected optimal decolorizers in a pilot plant test and tried to provide useful guidance to operators working in actual production conditions. As shown in Table 1, MMFP-C16 and MDFP-S6 removed acid blue 47 by almost 50%, better than the removal rate of MDFP-C9. MDFPs removed acid orange 10 at a rate above 40%, higher than MMFP-C16. For reactive red 13, the removal rates of all three decolorizers were around 50%. Experimental data indicated that MMFP-C16 performed the best in turbidity removal. There are subsequent processes, such as microfiltration and ozonation, which can further remove color in the water so that the effluent would easily meet the standard needed for reusing reclaimed water. With the decrease in color, many chromophoric groups which may have caused membrane fouling were removed. Moreover, the ozone oxidation process requires a lot of expensive electricity to
produce ozone (Ulson et al. 2010; Adeleye et al. 2016). Decreasing chromophoric groups can somewhat decrease the ozone dose needed. In other words, after using a decolorizer, the life of a filtration membrane can be extended and the operational cost of a reclaimed water treatment plant drastically reduced.
Compared with the laboratory-scale results, the color removal rate was lower while the turbidity removal rate was higher in the pilot plant. The inclined tube sedimentation tank, which has great surface load, was adopted in this test. It had a better effect on removing turbidity than laboratory-scale gravitational settling did. While there was still little impact on the treatment scale, larger water quantities and other uncertain factors may reduce the color removal rate slightly.

The water to be treated in the coagulating basin possesses the highest color in the reclaimed water treatment plant. Adding decolorizer to this existing coagulation stage will not influence any current treatment processes, creating no need to modify them. For the regular water treated at the plant, there is no need to add decolorizer to meet the effluent water standards, and operating under the current processes is appropriate. However, when the inflow of a reclaimed water treatment plant has a high level of color and the effluent cannot meet the standards using the current treatment technologies, the addition of a decolorizer allows rapid decolorization and provides an economical means to deal with such an emergency situation. Therefore, the results obtained in the pilot plant test can act as a guide for reclaimed water treatment plant operations.

This study also examined the differences in the components among the seven polymers using FTIR spectroscopy. After the modifiers were added, the absorption peak of the hydroxymethyl and carbonyl became weaker while the absorption peak of -NH and -NH₂ became stronger. Further analysis of the four modified polymers showed that the levels of -NH and -NH₂ were almost the same in MMFP-C16, MDFP-C9, and MDFP-S6, which had them in much higher amounts than MUF did. Thus, the results of the FTIR spectroscopy validated the orthogonal experimental results.

The three optimal decolorizers also performed well in the pilot plant test. MMFP-C16 performed better at both decolorization and floc sedimentation. The maximum color removal rate reached almost 50%. These results indicate that the use of MMFP-C16 should be encouraged because of its low cost and good performance.

**ACKNOWLEDGEMENTS**

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**REFERENCES**


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**Table 1 | The removal efficiency of different decolorizers used in a pilot plant test**

<table>
<thead>
<tr>
<th>Types of decolorizer</th>
<th>Acid blue 47</th>
<th>Acid orange 10</th>
<th>Reactive red 13</th>
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<tr>
<td></td>
<td>Average decolorization rate (%)</td>
<td>Average removal rate of turbidity (%)</td>
<td>Average decolorization rate (%)</td>
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<tr>
<td>MFP modified by ammonium chloride</td>
<td>49.22 ± 2.20</td>
<td>66.09 ± 2.87</td>
<td>34.64 ± 1.56</td>
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<td>DFP modified by ammonium chloride</td>
<td>37.92 ± 2.40</td>
<td>41.92 ± 1.86</td>
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<td>DFP modified by ammonium sulfate</td>
<td>49.27 ± 2.08</td>
<td>45.88 ± 2.22</td>
<td>42.22 ± 1.61</td>
</tr>
</tbody>
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Note: The data are mean ± standard deviation.

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**CONCLUSIONS**

This study evaluated the effect of UFP, MFP, and DFP modified by ammonium chloride and ammonium sulfate on decolorization. The orthogonal experiment indicated that MUF had no effect on decolorization. However, MMFP-C16, MDFP-C9, and MDFP-S6 were successful in removing color. The color removal rates of these three optimal decolorizers were above 50% for acid and reactive dye reclaimed water. Moreover, MMFP-C16 had a good effect on the sedimentation of flocs.


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