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Efficiencies and mechanism of enhanced coagulation pre-treatment on domestic sewage with PAC-HCA compound

Zichun Yan[a,b], Li Shen[b,*], Zhibing Pei[b], Mingxia Yang[b] and Wei Zhang[b]

[a] Key Laboratory of Yellow River Water Environment of Gansu Province, Lanzhou 730070, China
[b] School of Environmental and Municipal Engineering, Lanzhou Jiaotong University, Lanzhou 730070, China
*Corresponding author. E-mail: 296320739@qq.com

LS, 0000-0001-9865-1888

ABSTRACT

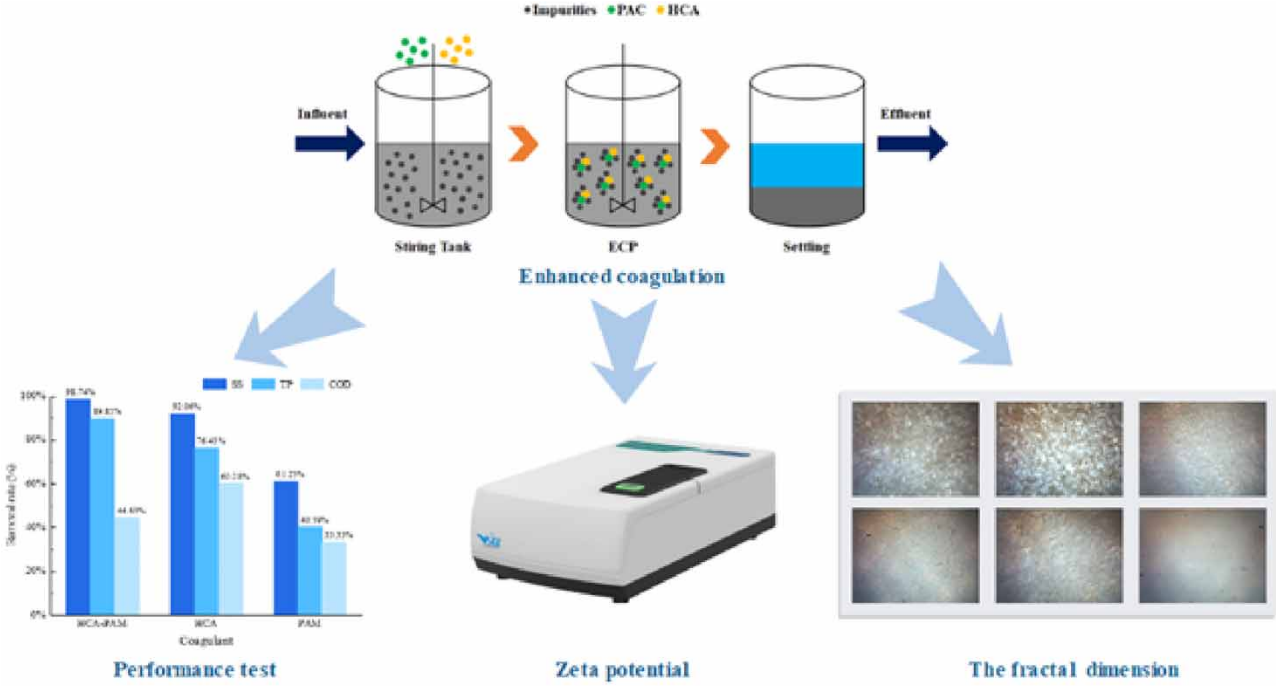
Poly dimethyl diallyl propyl ammonium chloride (HCA) and poly aluminum chloride (PAC) were used to prepare complex coagulants for the enhanced coagulation (EC) pretreatment of domestic sewage. The influences of hydraulic conditions, the dosage ratio of PAC-HCA complex coagulants, initial pH value, and dosage on the removal efficiency of SS, COD, and TP in domestic sewage were investigated. The fractal dimension and Zeta potential were used to verify and characterize the experimental results. The results showed that the optimum coagulant conditions were as follows: $G_1 = 200.0–265.0\ s^{-1}$, $T_1 = 1.5$ min, $G_2 = 40.0\ s^{-1}$, $T_2 = 5$ min, PAC: HCA = 25:1, dosage = 15 mL/L, pH = 8. At the mentioned point, the removal rates of SS, COD, and TP are 98.74%, 44.63%, and 89.85%, respectively. In addition, through comparative tests, PAC-HCA compound coagulants show better treatment efficiency than PAC and HCA used alone. When the HCA dosage was 15 mg/L, Zeta potential and flocs fractal dimension was 2.29 mv and 0.9844, respectively. This indicates that PAC-HCA has a good treatment effect on domestic sewage, and the mechanism of enhanced coagulation to remove nutrients is mainly electrical neutralization.

Key words: domestic sewage, enhanced coagulation, fractal dimension, PAC-HCA, zeta potential

HIGHLIGHTS

- The optimum adding conditions of PAC-HCA for treating domestic sewage were determined.
- The mechanism of enhanced coagulation was analyzed by the Zeta potential and fractal dimension method.
- Removal rates at optimum conditions: SS = 98.74%, TP = 89.85%, COD = 44.63%.
- The coagulation mechanism of PAC-HCA was mainly electrical neutralization.
- The application of PAC-HCA coagulant in actual water treatment is promising.

GRAPHICAL ABSTRACT



1. INTRODUCTION

The rapidly rising generation of wastewater is an inevitable consequence of human activities due to urbanization, industrialization, and population growth (Hanjra *et al.* 2012). In this context, the number and scale of urban domestic sewage treatment plants are expanding, and the treatment process is becoming more mature (Fan *et al.* 2020). Pretreatment is a step set up according to the water quality requirements of the subsequent treatment process before sewage enters the traditional biochemical treatment, and it plays an important role in the sewage treatment process. Nowadays, many scholars have studied the pretreatment methods of domestic sewage. Ma *et al.* found that reverse osmosis pretreatment could effectively enrich organic and inorganic substances in water samples to enable a more effective and sensitive toxicity evaluation (Ma *et al.* 2013). Ezra *et al.* investigated the effect of membrane filtration pretreatment of domestic sewage by chemical enhanced primary treatment and found that the effluent was lower in quality with regard to total organic content (TOC) (45 vs. 16 mg/L) and suspended solids (SS) (21 vs. 8 mg/L), but had a much lower phosphate concentration (0.1 vs. 4.2 mg/L) in comparison to biologically treated effluent from a sequential batch reactor (SBR). (Even-Ezra *et al.* 2011). Sawai *et al.* estimated that the capital cost and treatment fees of applicability of pretreatment using subcritical water liquefaction were cost-competitive compared to conventional treatments (Sawai *et al.* 2013).

Coagulation is an effective and low-cost pre-treatment technology to improve the removal rate of SS and organic matter in the first-grade treatment unit of domestic sewage (Bu *et al.* 2019; Pramanik *et al.* 2019). Coagulation occurs in an initially dispersed mixed colloidal system, where differences in the rates of coagulation of various species are of sufficient magnitude that one species may separate, leaving the other in suspension after a certain period (Zhao *et al.* 2021). EC technology is to strengthen the treatment by increasing the dosage of coagulant and controlling the pH value (Lin *et al.* 2020; Priyatharishini & Mokhtar 2021), hydraulic condition (Rong *et al.* 2013; Lin *et al.* 2019), temperature (Nadella *et al.* 2020), and other coagulation conditions applicable to coagulant. In recent years, the application of EC has been gradually transferred from the initial water supply to the treatment of sewage and has generally achieved a good effect. Smotraiev *et al.* compared the treatment effect of pre-polymerized zirconium and traditional aluminium prosthetic on domestic water and found that the maximum rates of total suspended solids (TSS), TU, and OP removal by the zirconium and aluminium coagulants were 92.5% and 91.0%, 97.1% and 96.4%, and 97.6 and 93%, respectively (Smotraiev *et al.* 2022). *Moringa oleifera* at the optimal dosage of 600 mg/L showed results statistically equal to the use of alum (200 mg/L), achieving bacterial load, turbidity, and apparent color removal higher than 99, 92, and 66%, respectively (Vega Andrade *et al.* 2021). As one of the most commonly used coagulants, polyaluminum chloride (PAC) has been widely used in coagulation because of its low price and strong adsorption electricity neutralization ability (Shen *et al.* 2017). However, PAC has the disadvantages of lower molecular weight and poor ability to realize bonding and bridging (Sudoh *et al.* 2015; Zhang *et al.* 2018). HCA is a kind of polymer organic coagulant and widely used in the field of drinking water purification with the characteristics of good water solubility, high positive charge density, easy to control molecular weight, high efficiency, and non-toxic (Bolto & Gregory 2007; Wang *et al.* 2008; Sun *et al.* 2011; Xu & Gao 2012). Based on the characteristics of Poly dimethyl diallyl propyl ammonium chloride (HCA) and PAC, HCA has been combined with PAC to improve natural organic matter removal and the size and settling ability of flocs due to its positive charge and adsorption and bridging abilities in previous studies. Shen *et al.* found that coagulation using PAC-HCA with a viscosity range from 0.99 dL/g to 1.86 dL/g can significantly reduce membrane fouling, leading to increasing water fluxes from 0.1170 to 0.4906 in.the ultrafiltration process (Shen *et al.* 2017). Yang *et al.* investigated the relationship between removal efficiency, floc operational parameters, and residual Al species when PAC-HCA was applied in coagulation of a reservoir water (Yang *et al.* 2013). These studies all showed that PAC-HCA had a good performance in coagulation treatment.

However, there are few reports on the application of PAC-HCA in the pretreatment of domestic sewage. To improve the pretreatment effect of domestic sewage, HCA and PAC are combined to achieve the purpose of efficient and economic treatment in this study. Furthermore, HCA and PAC coagulants are used to make compound coagulants according to the proportion of their net content, and the treatment efficiencies and mechanism of compound coagulants on domestic sewage are studied. These experiments will provide a reference value for the application of coagulants in the pretreatment of domestic sewage in practical engineering.

2. MATERIALS AND METHODS

2.1. Raw-water quality and measurement method

The influent of the reactor was domestic sewage from Lanzhou Jiaotong University, which was mixed sewage from flushing, canteen drainage, toilet, and bath. Due to intermittent discharge of sewage, water quality and quantity change greatly. A total of 12 groups of water samples were sampled at different time periods within 3 days, and the specific inlet water quality during the test is shown in Table 1.

Influent and effluent detection indexes include SS, TP, and COD. SS and TP concentrations were determined using normative methods and the COD concentration was determined using DRB200 COD digestion apparatus and HACH DR5000 (Zhang *et al.* 2021); ZR4-2 portable agitator (Coagulation); Nano-zs90 Zeta potentiometer (Zeta potential); Cfx-1001 digital microscope(Microscopic observation); HACH-2100p (SS); 721- spectrophotometer; PHS-25 acidity meter (pH).

2.2. Reactor configuration and operation

Compound coagulants with different dosage ratios were prepared by adding 2.5 g HCA and a certain amount PAC into 1 L flask. The two coagulants were fully mixed by repeated shaking and then transferred to a reagent bottle for storage. During the test, PAC-HCA compound coagulant and 1 L of water sample were placed in a beaker and stirred with a ZR4-2 portable agitator before the stirring. The schematic diagram of the enhanced coagulation reactor is shown in Figure 1.

2.3. Fractal dimension method

The flocs formed after coagulation were slowly moved to the glass surface dish, and the flocs formed were photographed continuously with a microscope (amplification ratio parameter: 0.25). After that, CFX-1001 was used to analyze the image, and the data were processed according to $lnA = DrlnP + lnK$ by measuring the circumference P and area A of the image based on

Table 1 | The domestic water characteristics

	Water temperature (°C)	pH	SS (mg/L)	TP (mg/L)	COD (mg/L)	BOD_5/COD
Value	17–22.3	7.5–8.5	40–152	4.45–7.77	237.2–452.5	>0.4
Mean Value	19.61	7.76	122.4	5.59	364.5	0.62
Media Value	19.7	7.7	118	5.48	342.1	0.63

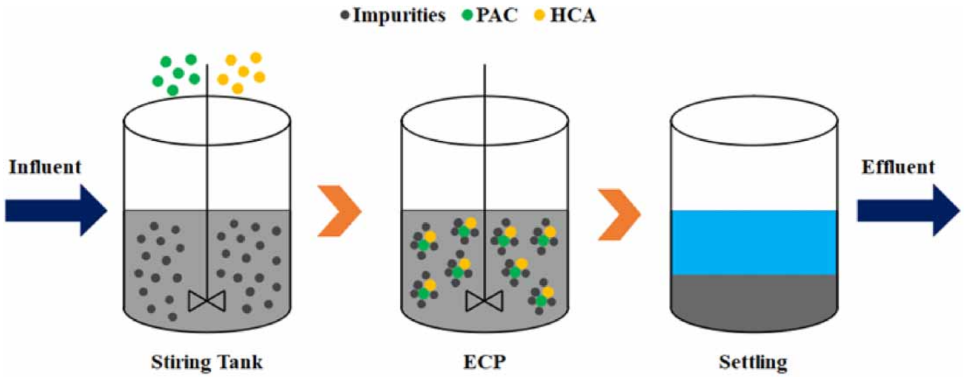


Figure 1 | Enhanced coagulation reactor.

the fractal theory and practical experience (Kostoglou & Konstandopoulos 2001). The obtained *lnA* and *lnK* were plotted as horizontal and vertical values respectively, and the slope of the obtained line was the fractal dimension *Dr* (*K* was a constant).

2.4. Zeta potential determination method

Zeta potential is an important indicator of the stability of a colloid or suspension. After the coagulant is added to the water, many positively charged hydrolyzed polymeric cations of aluminum or iron are formed, which reduce the zeta potential of the colloid or suspended particles, destroy the stability and settle down by neutralizing the adsorption and compressing the double electric layer. The determination of Zeta potential can provide some reference for the analysis of the coagulation mechanism (Henderson *et al.* 2008). Zeta potential was measured by Nano-ZS90 Zeta potentiometer. A small amount of the supernatant obtained from the coagulation experiment was transferred to the Special U-shaped tube of the Zeta potentiometer to measure the Zeta potential of the water sample. The above steps were repeated 3 times and the average value was taken (López-Maldonado *et al.* 2014; Meraz *et al.* 2016).

3. RESULTS AND ANALYSIS

3.1. Analysis of influence factors of coagulation test

3.1.1. Effect of hydraulic condition of aggregation stage on removal effect

Hydraulic condition is an important factor in the static coagulation test. The general hydraulic conditions of coagulation agitation include agitation intensity and agitation time. In this test, G (velocity gradient) and stirring time values were taken as the evaluation indexes. To investigate the effect of the G value of aggregation stage (G_1) on the removal effect at the aggregation stage, all coagulation conditions except G_1 were based on previous laboratory studies (stirring time of aggregation (T_1) = 1.5 min, stirring speed of flocculation (G_2) = 40 s^{-1}, stirring time of flocculation (T_2) = 5 min, PAC-HCA (PAC-HCA mixed coagulant) dosage: 10 mg/L, and initial pH value was not adjusted) (Figure 2(a)). The experimental results show that the removal rates of SS, TP, and COD increase gradually with the increase of G_1 from 5–70 s^{-1} to 200–265 s^{-1} and decreasing dramatically when G1 was over 265.0 s^{-1}. When G_1 was 200.0 ~ 265.0 s^{-1}, the removal efficiency of nutrients reached the best, and the removal rates of SS, TP, and COD reached 82.72%, 50.8%, and 61.3% respectively. To investigate the T_1 on removal effect at the aggregation stage, G_1 was controlled in the range of 200–265 s^{-1}, G_2 = 40 s^{-1}, T_2 = 5 min, initial pH value was not adjusted, and HCA dosage was 10 mg/L (Figure 2(b)). It is not difficult to find that with the change in stirring time, the changes in the three indicators are not obvious. When the T_1 was 1.5 min, the SS removal rate was slightly better, and after several experiments, the flocculant sedimentation rate is faster when T_1 was 1.5 min. PAC-HCA with short stirring time is not easy to disperse evenly in water samples due to the viscosity of HCA. However, long stirring time consumes more energy but does not significantly improve the removal rate. According to the actual engineering economic considerations, the optimal T_1 is finally determined as 1.5 min.

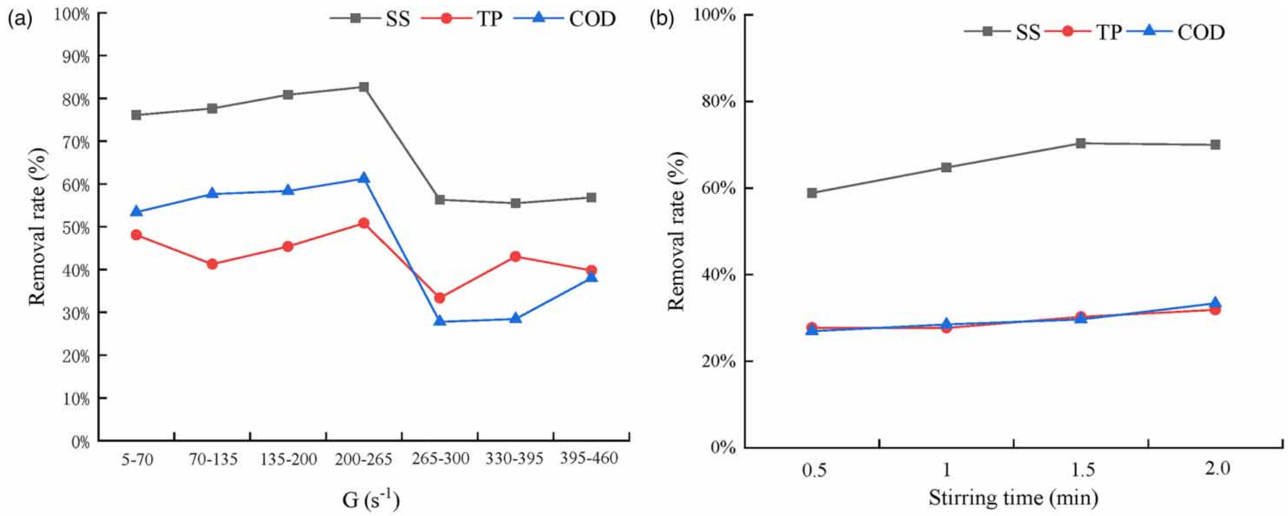


Figure 2 | Effect of hydraulic condition on removal effect at aggregation stage. (a) G^{-1}. (b) String time.

3.1.2. Effect of hydraulic condition of flocculation stage on removal effect

Figure 3(a) shows the influence of G_2 on wastewater treated by PAC-HCA. The G_1 was determined to be 264.5 s^{-1}, T_1 was 1.5 min, and T_2 was 5 min. According to the flocculation theory, the optimal G_2 should be 20–100 s^{-1}. However, according to the observation in the test process, when G_2 was greater than 50 s^{-1}, the flocs originally formed by mixing and agitation would be decomposed and broken in the process of flocculation agitation, and some small flocs particles would be suspended in water, which was not easy to settle, and ultimately affect the treatment effect. Therefore, G_2 in this test was determined to be between 10–50 s^{-1}. The experimental results show that the influence of G_2 on the three evaluation indexes was not obvious, and the effect was slightly better when the average G value was about 40.0 s^{-1}. To discuss the influence of T_2 on the PAC-HCA treatment effect, the G_1, T_1, and G_2 were selected to be 264.5 s^{-1}, 1.5 min, and 39.7 s^{-1} respectively. T_2 was set to 1, 2, 5, and 8 min respectively, the initial pH value was not adjusted, and the HCA dosage was 10 mg/L (Figure 3(b)). As can be seen from the figure, with the increase in stirring time, the removal rate of each evaluation index was improved, especially the SS removal rate. When T_2 was 5 min, the removal rate of TP and COD was the best, and the removal efficiency of SS was slightly lower than that of $T = 8$ min. However, the removal rates of TP and COD decreased when $T_2 = 8$ min. Overall, the optimal T_2 is determined to be 5 min.

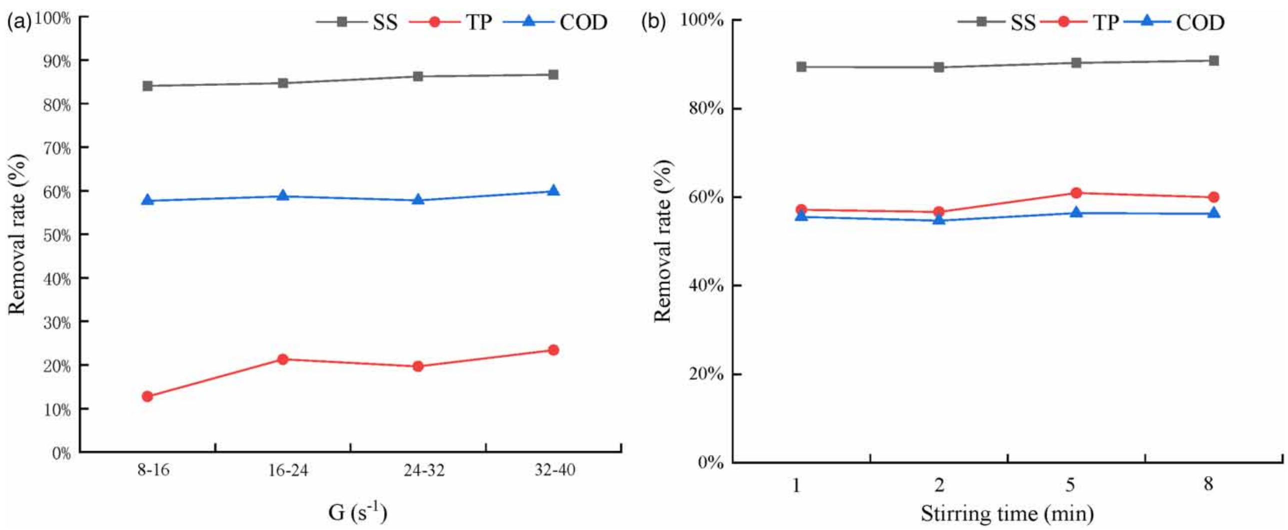


Figure 3 | Effect of hydraulic condition on removal effect at flocculation stage. (a) G^{-1}. (b) String time.

3.1.3. Effect of PAC-HCA ratio on removal of nutrients

Compound coagulants with PAC: HCA net content ratio of 1:5, 1:1, 5:1, 10:1, 15:1, 20:1 and 25:1 were prepared respectively. The initial pH value was not changed, and the dosage was all 10 mL/L for the experimental study. The effect of different PAC-HCA ratios on the removal of nutrients was shown in Figure 4.

As can be seen from Figure 4, with the gradual increase of the ratio of input, the removal rate of all indicators shows an overall upward trend. When the dosage ratio was 25:1, the removal rates reached the highest, and the removal rates of COD, TP, and SS reached 52.79%, 82.15%, and 99.37%, respectively. Theoretically, PAC plays role of coagulation, charge neutralization, but HCA with quaternary ammonium groups is responsible for flocculation to form big flocs, which further enhances its performance (Zhang *et al.* 2020). At a pH close to raw water (7.5–8.5), HCA dissociates the polymer chain with a positive charge, and PAC also generates hydrolytic products with a positive charge, such as a hydroxyl complex, in the hydrolysis process. The combination of the two can better play the role of electrical neutralization, which is conducive to strengthening the removal of nutrients by coagulation (Yang *et al.* 2011; Shen *et al.* 2017). It can also be found that when the dosage ratio was greater than 1:1, the removal rates of SS and COD did not change much, but the removal ability of phosphorus was enhanced, which increased from 40.88% at 1:1 to 82.15% at 25:1. Presumably, PAC in the compound coagulant can hydrolyze to produce polynuclear hydroxyl complexes such as $Al_2(OH)_2^{4+}$ and $Al_{13}(OH)_{13}^{7+}$, which can give full play to the functions of compressing double electric layer, electric neutralization, and so on, and can remove part of insoluble phosphorus by combining with negatively charged suspended particles and colloid (Campinas *et al.* 2021). Colloids such as alumina hydroxide can also be produced during PAC hydrolysis, which can remove orthophosphates by adsorption coprecipitation (Wu *et al.* 2011). In addition, HCA has been dissolved in water to form a polymer chain, which is easier to make the unstable colloidal particles adhere to form flocs settlement. The combination of the two coagulants has realized the efficient removal of phosphorus in the water.

3.1.4. Effect of initial pH on removal of nutrients

0.1 mol/L NaOH and 10% HCl solution were used to control the initial pH values of water samples to be 5.0, 6.0, 7.52 (pH value of raw water), 8.0, 9.0, and 10.0. PAC:HCA dosage ratio was 25:1 and dosage was all 10 mL/L. The influence of the initial pH value on nutrient removal was investigated, and the result is shown in Figure 5.

As shown in Figure 5, with the gradual increase of the initial pH value, the removal of SS and TP firstly increased and then decreased, and the COD removal rate showed an overall upward trend. If the initial pH value is too low or too high, the

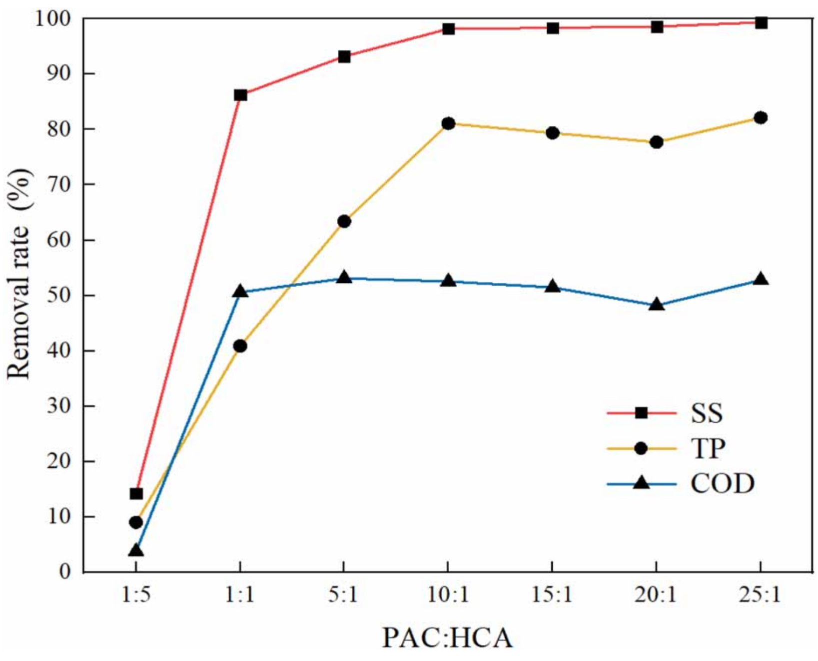


Figure 4 | Effect of PAC-HCA ratio on the removal of SS, COD, and TP.

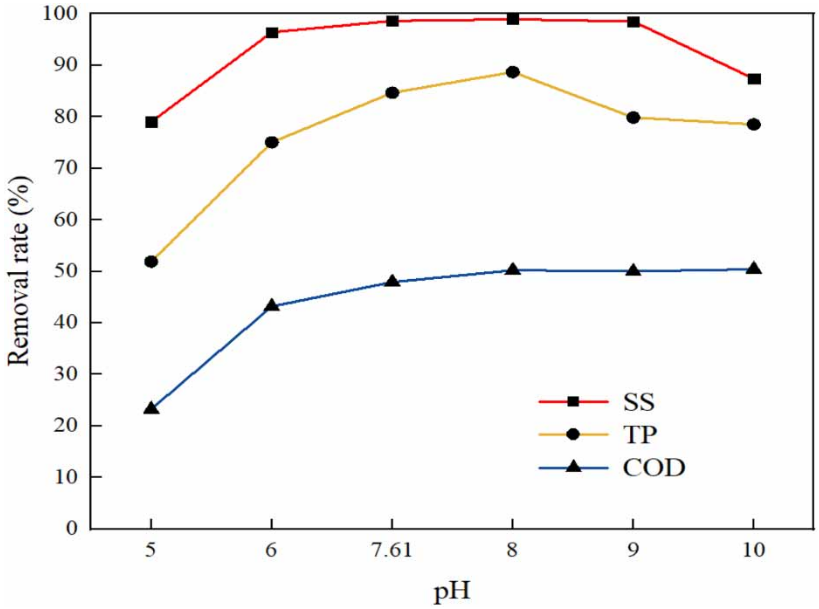


Figure 5 | Effect of initial pH on removal of SS, COD, and TP.

enhanced coagulation effect will be affected. When the pH value is 8.0, the treatment effect is better, and the removal rates of COD, TP, and SS are 50.23%, 88.67%, and 98.93% respectively. The reason for this result is that the hydrolytic products of PAC in an acidic environment are mainly low polymers such as $Al(OH)^{2+}$, $A1_2(OH)^{2+}$. With the increase in pH value, hydroxyl complex and $Al(OH)_3$ colloid become the main hydrolytic products of aluminum salt, and the low polymer form has good flocculation characteristics (Gao & Yue 2005). Moreover, HCA is easier to dissociate in an alkaline environment. The positively charged particles combine with negatively charged suspended solids and colloidal particles to form flocs after dissociation. Therefore, appropriately increasing the initial pH value is conducive to enhancing the removal effect of contaminants by the compound coagulant (Huang *et al.* 2015). When the initial pH value exceeds 8.0, the increase of OH^- concentration in the solution can further promote the dissociation of HCA, but the PAC hydrolysate changes to $[Al(OH)_4]^-$ and other forms, which repels each other with SS and colloidal particles in water and is difficult to form flocs settlement, and the removal rate of SS and TP is reduced (Yang *et al.* 2011; Toor & Kim 2019). COD removal rate did not change significantly.

3.1.5. Effect of coagulant dosage on removal of nutrients

The pH value of raw water was adjusted to about 8.0, and the dosage ratio of PAC-HCA compound coagulant was adjusted to 25: 1. Added 1 mL, 5 mL, 10 mL, 15 mL, 20 mL, and 25 mL complex coagulant to 1 L water sample for test, respectively, and investigated the influence of the dosage of PAC-HCA on the removal effect of each nutrient, as shown in Figure 6.

It can be seen from Figure 6 that the removal rates of COD, TP, and SS all showed a trend of first increasing and then decreasing with the increase of the dosage. When the dosage was 15 mL/L, the removal rates of each index reached the highest, corresponding to 44.63%, 89.85%, and 98.74%, respectively. HCA has a high positive charge density, which is superimposed with PAC surface positive charge to enhance the electric neutralization ability of the compound coagulant. The stronger the coagulation effect is, the higher the removal rate of SS, COD, and TP will be when increasing the dosage of PAC-HCA within a certain range. When the dosage exceeds 15 mL/L, the excess positive charge attaches to the colloidal surface with a negative charge, resulting in charge reversal, which leads to the phenomenon of restabilization of the destabilized colloidal and makes the coagulation effect worse.

3.1.6. Comparison of the effect of compound coagulant and single coagulant

The same domestic sewage was selected and the conditions were uniformly controlled as $G_1 = 200.0–265.0\ s^{-1}$, $T_1 = 1.5$ min, $G_2 = 40.0\ s^{-1}$, $T_2 = 5$ min, dosage = 15 mL/L, pH = 8. To compare the treatment effects of the three types of coagulants on

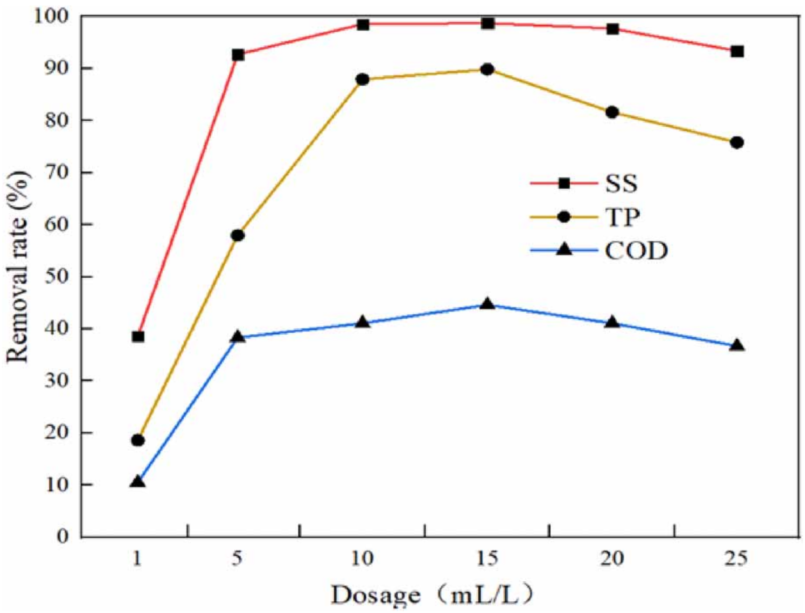


Figure 6 | Effect of coagulant dosage on removal of SS, COD, and TP.

domestic sewage, three kinds of coagulants were added in three same reactors with 15 mL/L respectively (PAC: HCA = 25: 1). As shown in Figure 7, it is clear that the combination of HCA-PAM is much better than the two coagulants alone. Compared with PAC alone, the removal rates of SS, TP, and COD by PAC-HCA increased by 37.51%, 40.46%, and 11.33%, respectively. Compared with HCA alone, the removal rates of SS and TP by HCA-PAM alone increased by 6.68% and 13.42% respectively, but the removal rates of COD decreased from 60.28% to 44.63%. However, coagulation is often used as a pretreatment for the

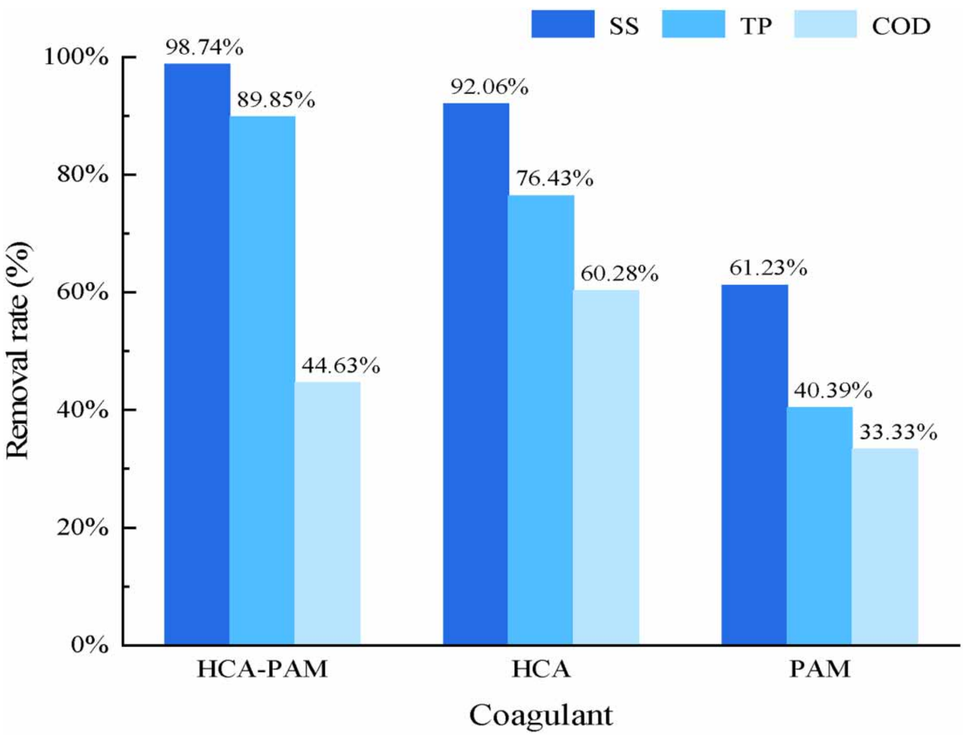


Figure 7 | Comparison of the effect of compound coagulant and single coagulant.

biological treatment of domestic sewage, which does not require a high COD removal rate, because the sufficient organic load in subsequent biochemical stage is often required.

3.2. Coagulation mechanism analysis of PAC-HCA compound coagulant

3.2.1. Zeta potential analysis

Zeta potential represents the potential difference of the diffusion double layer on the surface of colloidal particles and is an important indicator to characterize the stability of the colloidal dispersion system (Pandey *et al.* 2019). The level of Zeta potential is closely related to the treatment effect of coagulant: when the absolute value is low, the removal effect of nutrients is better, and the closer the absolute value is to 0 mV, the more obvious the coagulation effect is (Gerzhova *et al.* 2016). To further analyze the action mechanism of the compound coagulant, experiments on different PAC-HCA dosages were carried out. SS removal rate was taken as the evaluation index, and the Zeta potential of the water sample was measured. The results are shown in Table 2.

From Table 2, with the increase of PAC-HCA dosage, the Zeta potential of the water sample after coagulation increased from −18.07 mV to 9.68 mV, while the absolute value of Zeta potential decreased first and then increased. Since both HCA and PAC are coagulants with a positive charge, increasing the dosage of coagulants can effectively reduce the Zeta potential on the colloidal surface within a certain range, and the electrostatic repulsion between colloidal ions decreases, making it easier to destabilize and form alum deposition. If the addition amount is too large, the colloid surface with excessive positive charge reaches a stable state again, which is not conducive to colloid condensation, and the SS removal rate decreases. When the dosage was 15 mL/L, the absolute value of Zeta potential reached the minimum value of 2.29 mv, and the corresponding SS removal rate reached the highest 98.74%. It can be inferred that the mechanism of SS removal by PAC-HCA enhanced coagulation is mainly electrical neutralization.

3.2.2. Fractal dimension analysis of flocs

Figure 8 is the digital microscope image of 'coffee image' of flocs under different dosages of PAC-HCA (The type and dosages of coagulants corresponding to photos A ~ F are the same as those in Table 2). It can be seen from Table 2 that when the dosage of PAC-HCA was 15 mL/L, the time-division dimension fractal dimension was 0.9844, and the corresponding SS removal rate was 98.74%. It can be seen from the photo in Figure 8(d) that the floc is uniform and dense, and the Zeta potential is closer to 0 mV under this dosage. These results indicate that when the dosage of PAC-HCA compound coagulant increases within a certain range, the Zeta potential on the colloidal surface can be reduced and the flocs become denser, which further indicates that the compound coagulant can strengthen the coagulation treatment effect mainly through the electrical neutralization effect.

4. CONCLUSION

In summary, the results are summarized as follows:

(1) The effects of the hydraulic condition, PAC:HCA dosage ratio, initial pH value, and dosage on PAC-HCA treatment of domestic sewage were investigated by single factor tests. When the hydraulic condition was $G_1 = 200.0–265.0\ s^{-1}$, $T_1 = 1.5$ min, $G_2 = 40.0\ s^{-1}$, $T_2 = 5$ min, the ratio of HCA was 25:1, pH was adjusted to 8.0 and dosage was 15 mL/L,

Table 2 | Fractal dimensions and zeta potential changes of different compound coagulants

Number	Coagulant	Dosage (mL/L)	Removal rate of SS (%)	Fractal dimension	Zeta potential (mv) Before	After
a	PAC-HCA	1	38.58	0.9691	19.43	−18.07
b		5	92.71	0.9778		−15.80
c		10	98.54	0.9827		−3.45
d		15	98.74	0.9844		2.29
e		20	97.68	0.9825		5.73
f		25	93.38	0.9363		9.68

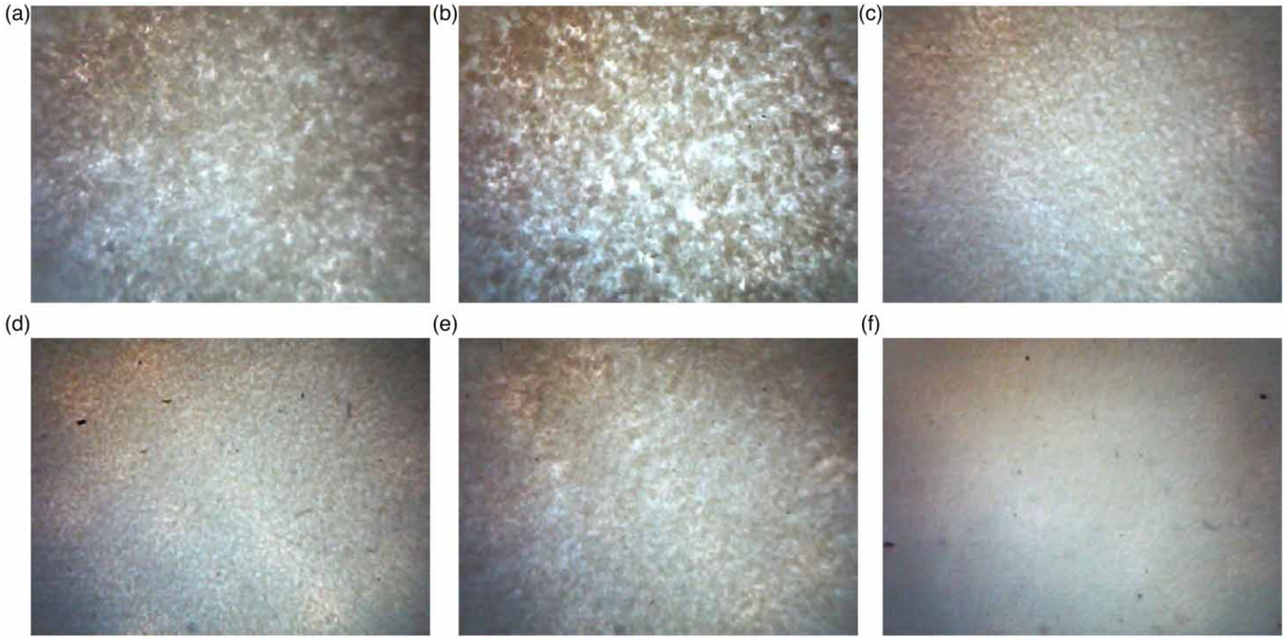


Figure 8 | The photo of the fractal dimension in different PAC-HCA compound coagulant doses.

the coagulation treatment effect was better, and the removal rates of SS, COD, and TP were 98.74%, 44.63%, and 89.85%, respectively.

(2) The fractal dimension and Zeta potential analysis showed that the combination of HCA and PAC was beneficial to reduce the absolute charge on the surface of the colloid and forming uniform and dense flocs. The analysis of the coagulation mechanism of PAC-HCA was mainly electrical neutralization.

(3) The dosage range of compound coagulant is wide, and it has a good removal effect on SS, COD, and TP in the range of 10–20 mL/L. The initial pH value has an obvious influence on the treatment effect of PAC-HCA, and the removal effect is better when the initial pH value is 8.0. The compound coagulant still has a good treatment effect when the pH value of raw water is not adjusted. The results have certain reference significance for the application of PAC-HCA coagulant in actual water treatment.

In this experiment, PAC-HCA has a high removal rate of SS and TP in domestic sewage under the optimal conditions, and a removal rate of nearly half of COD. If this method is applied to the pretreatment of biochemical treatment of domestic sewage, it can effectively reduce the load of subsequent biochemical treatment and reduce the cost of building construction. In addition, although the performance of PAC-HCA applying on domestic wastewater has been analyzed in this study, removal efficiency of nitrogen and the composition of the sludge were not systematically investigated. Subsequent studies can quantitatively analyze and investigate them.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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