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Relationship between the characteristics of cationic polyacrylamide and sewage sludge dewatering performance in a full-scale plant

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Abstract

To identify the key characteristics of cationic polyacrylamide (c-PAM) for evaluating sewage sludge dewatering performance, we examined the properties of 13 types of c-PAMs that come from different manufacturers via a laboratory assay. The sludge dewatering performance was determined through a full-scale test at a large wastewater treatment plant in Beijing. We checked the cationic degree, solution viscosity, dissolution time, and 1 mm sieve residue of c-PAM. The 1 mm sieve residue was found to affect the dissolution time, solution viscosity, and conductivity. The full-scale test indicated that the cationic degree is the most important factor that affects the dosage and treatment capacity of the belt filter press when the cationic degree ranges from 25% to 45%. However, the moisture content of sludge cake is mainly relevant to raw sludge organic content. The sludge dewatering performance of the 13 types of c-PAMs showed that the c-PAM should be selected based on cationic degree, solution viscosity, and 1 mm sieve residue. The dosage should then be adjusted at the appropriate time according to the status of the equipment and facilities during sludge dewatering.

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Keywords: c-PAM; sludge dewatering; cationic degree; belt filter press

1. Introduction

Cationic polyacrylamide (c-PAM) has been widely used in sludge dewatering in municipal sewage treatment plants because of its characteristics, which include low dosage, high efficiency, and pollution-

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free effects. However, PAM standards (GB 17514-1998) in China are applied only to non-ionic PAM and anionic PAM because of existing water treatment agents. Quality standards for c-PAM are not uniform; thus, the product quality in the market widely varies. The dewatering equipment and the nature of the sludge from each wastewater treatment plant (WWTP) are different. Therefore, c-PAM must be examined in full-scale plants to determine the appropriate model. The establishment of a set of test methods and evaluation system is necessary to provide a reference for c-PAM selection at WWTPs.

C-PAM products that were provided by 13 domestic and foreign manufacturers were tested through a sample assay and a full-scale test to analyze the results of the product application in a full-scale WWTP and to study further the factors involved in c-PAM application.

Nomenclature

c-PAM cationic polyacrylamide

WWTP wastewater treatment plant

2. C-PAM quality assessment

2.1 Detection result

Particles in sludge can be aggregated under the function of c-PAM flocculation. Therefore, c-PAM is applied as a sludge mechanical dewatering conditioner to help achieve sludge–water separation effects [1]. In most cases, molecular weight, cationic degree, and dissolution time considerably affect the quality of medical flocculation. To provide a reference for the relative evaluation item of similar product standards locally and internationally, this study proposes examination and evaluation standards for c-PAM quality. The testing method and results are provided in Tables 1 and 2, respectively.

Table 1 Detecting items and methods for c-PAM

Detecting items	Unit	Method
Screen tailings (1.00 mm screen)	%	Water treatment chemicals—PAM (GB17514-1998)
Screen tailings (0.18 mm screen)	%	Water treatment chemicals—PAM (GB17514-1998)
Solid content	%	Water treatment chemicals—PAM (GB17514-1998)
Dissolution time	min	Determination for dissolving velocity of powdered PAM (GB/T12005.8)
Solution viscosity (4‰ concentration, 25 °C)	cP	ANSI/AWWA B453-06—PAM
Cationic degree	%	Spectrophotometric titration by using polyvinyl sulfate potassium as a standard solution
Conductivity	μS/cm	Determination of the dissolving velocity of powdered PAM (GB/T12005.8)

Table 2 C-PAM sample test results

Sample	Screen tailings 1 mm (%)	Screen tailings 0.18 mm (%)	Solid content (%)	Dissolution time (min)	Solution viscosity (cP)	Cationic degree (%)	Conductivity (μ S/cm)
1	2.5	95.25	90.67	57	272.9	28.5	428.4
2	15.25	82	92.54	66	271.4	60.7	748.7
3	0.25	99.5	91.21	40	814.8	53.8	241.9
4	0.35	94.75	93.91	45	329.9	27.6	870.4
5	3	97	92.71	60	310.4	63.5	805.4
6	8.25	87.75	89.8	62	376.4	27.54	671.9
7	0.35	93.25	92.57	58	418.4	45.4	542.2
8	0.5	96.15	89.3	41	481.4	29.8	245
9	12.6	83.75	91.69	58	404.9	29.79	562.9
10	42.75	53.25	93.72	79	404.9	25	429.2
11	0.15	98.75	92.44	53	370.4	49	480
12	0.25	93.15	92.18	66	353.9	39.13	413.2
13	5	93	89.9	39	193.5	24.6	1148

2.2 Result analysis

These data clearly show the large differences in cationic degree, dissolution time, conductivity, solution viscosity, and 1 mm screen tailings among the samples. According to the results, the dissolution time correlates with the 1 mm and 0.18 mm screen tailings (shown in Fig. 1). The larger the amount of 1 mm screen tailings, the longer the dissolution time is, whereas the results of the 0.18 mm screen tailings indicate the contrary. During the c-PAM quality control test, solubility is mainly assessed based on the 1 mm screen tailing data, and the work environment caused by dust pollution is evaluated by referring to the 0.18 mm screen tailing data. The reason is that the large particles are characterized by the 1 mm screen tailing data, which can lead to a longer solution time. A particle size below 0.18 mm may cause dust pollution in a work environment. The possibility of pollution cannot be neglected although the product is easier to dissolve.

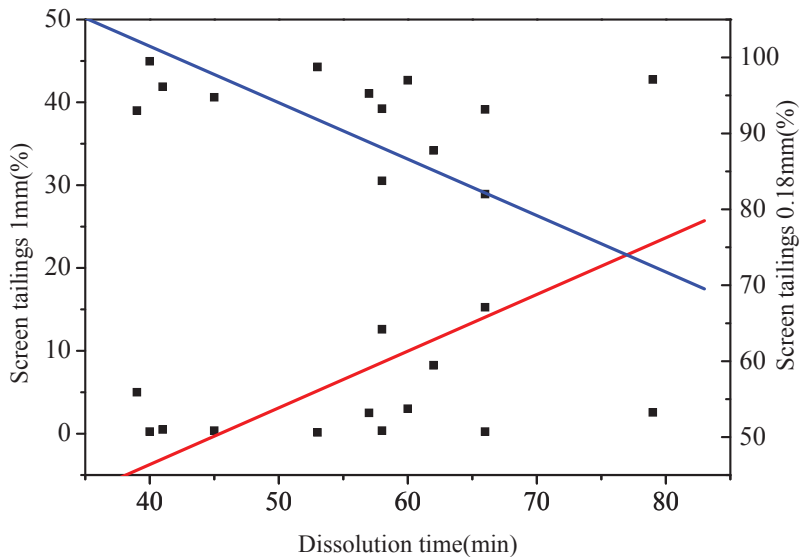


Fig. 1 Relationship between c-PAM dissolution time and screen tailings

A perfect correlation between the viscosity and the conductivity of the c-PAM solution exists (Fig. 2). The higher the viscosity of the solution, the lower its conductivity is; this finding is consistent with the study by Bonhöte^[2].

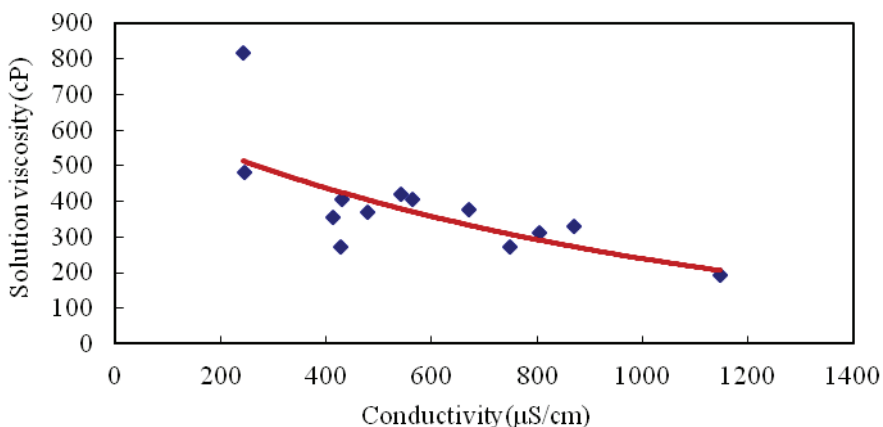


Fig. 2 Relationships between viscosity and conductivity of the c-PAM solution

C-PAM products in the market vary widely in terms of quality. Nevertheless, a certain correlation exists between specific indicators. In various WWTPs, the sludge nature and dewatering equipment considerably differ. The determination of product applicability through sample testing is difficult; hence, a full-scale test is necessary.

3. Full-scale test

3.1 Experimental condition

Full-scale tests are the most intuitive tests for determining whether the c-PAM product is suitable for WWTP operation. Likewise, the choice of reagent has a considerable influence on the effect of the dewatering treatment, particularly for belt filter presses. The study was conducted on a belt filter press equipment at a WWTP in Beijing for three months. In this full-scale experiment, primary sludge and excess sludge are mixed in a sludge thickener and are mechanically dewatered after undergoing gravity thickening. The test parameters are shown in Table 3.

Table 3 Experimental conditions

Experimental time	Sludge organics	Sludge moisture content	Dissolution time	Solute concentration	Design dry sludge load of dehydration	Dry sludge load
Day one sample	%	%	min	%	kg/h	kg/h
7	42 to 55	92 to 95	40	4	10	≥ 600

3.2 Correlation between cationic degree and treatment capacity

Cationic degree is the percentage of a cationic monomer that takes up a total monomer. The results of the tests indicate that the cationic degree has a crucial relevance to the sludge dewatering treatment capacity (Fig. 3); the higher the cationic degree, the higher the treatment capacity of the dewatering machine is. However, when the cationic degree continues to increase above 50%, the filter screen becomes blocked. The reason is that c-PAM flocculation mostly consists of charge neutralization and bridging effect^[4]. If the molecular weights of the organic polymer flocculants are similar, the bridging capability is almost the same, and charge neutralization increases as the cationic degree becomes higher, which leads to better results in sludge treatment. However, excessive cationic degrees are not conducive to sludge–water separation because these may directly result in the extreme positive charge in the sludge. Within normal dosage limits in a full-scale test, the c-PAM with a higher cationic degree can provide a more positive charge to complete sludge destabilization, which leads to a higher ability in controlling sludge. However, the c-PAM with a high cationic degree usually acquires a small molecule with a weak bridging capacity, and the formation of tiny loose flocs can lead to a decrease in treatment capacity. Floc viscosity is mainly affected by the molecular weight but also depends on the cationic molecular structure and morphology as well as the extension degree in the solvent. Therefore, when the cationic degree is over 50% in the test, the solution viscosity of the floc becomes extremely large and leads to filter-screen blocking.

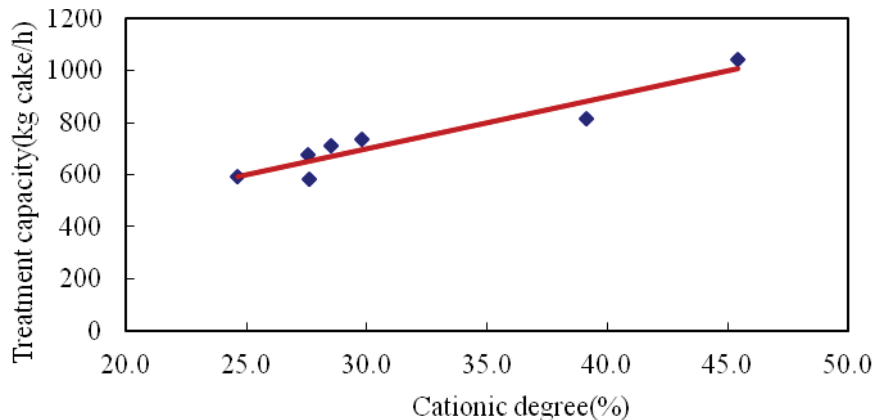


Fig. 3 Relationship between cationic degree of c-PAM and processing capacity

The c-PAM consumption plays a decisive role in the evaluation of the WWTP operation. The analysis and experimental results prove the relationship between the cationic degree and the dosage rate of the c-PAM (Fig. 4). When the cationic degree of the c-PAM is within the scope of 40% to 45%, the dosage is at the lower level. An extremely high or extremely low dosage is not conducive to sludge dewatering. The viscosity of the sludge will be increased with excessive c-PAM application because of the adsorption of excess polymer that gives a positive charge. Hence, sludge dewatering would become difficult, and processing costs would increase. Moreover, c-PAM's macromolecular structure can lead to wrapping around the sludge flocs and loose, rigid sludge flocs, which cause difficulty in removing the water contained in the floc when an excess dewatering agent is added. On the contrary, when the dosage is lacking, sludge–water separation and dewatering can be hindered by incomplete charge neutralization and weak adsorption.

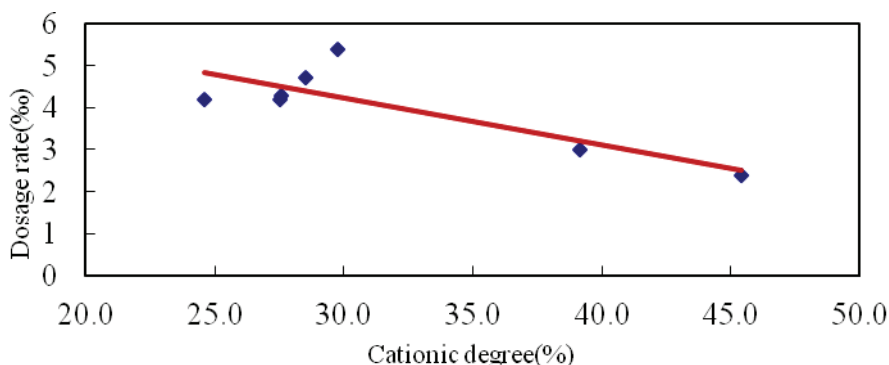


Fig. 4 Relationship between the cationic degree and the dosage of c-PAM

3.3 Correlation between sludge organic content and dewatering performance

During the three-month trial period, with the variation of water quality, the organic contents of the original sludge gradually ranged from 55% to 42%. The results of the WWTP experiments indicated a significant negative linear correlation between moisture content and organic content in sludge cake, although a variety of samples and process parameters were adopted (Fig. 5). According to the analysis, the high organic content of the raw sludge can increase the internal water content within the sludge particles or microbial cells, and this part of the water cannot be removed by mechanical dewatering. Thus, the sludge moisture content increases with the increasing sludge organic content. The organic content is therefore an important factor that influences the moisture in sludge cake.

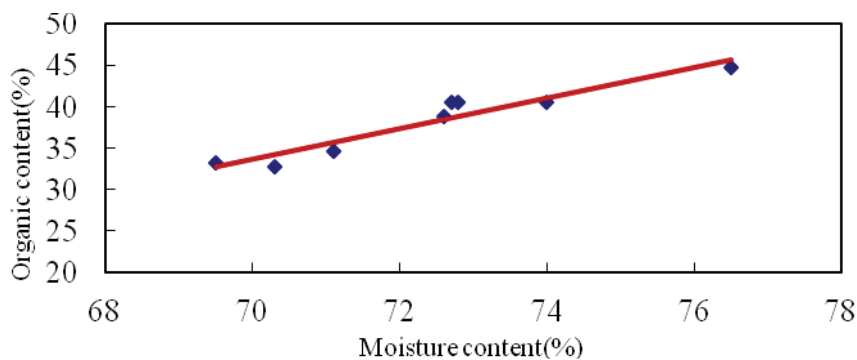


Fig. 5 Relationship between the organic content and the moisture content of the sludge

3.4 Sludge dewatering performance in the 13 samples

During the full-scale tests, each type of c-PAM sample was used for seven days. During the seven-day treatment, the capacity had to exceed the required load, and sludge leakage had to be avoided. The raw sludge and the sludge cake were tested and analyzed daily. The test data are presented in Table 4.

Table 4 Experimental data of c-PAM examination

Sample	Average dosage of c-PAM (%)	Dry sludge treatment amount (kg/h)	Sludge moisture content (%)
1	4.7	709	76.5
2	~	~	~
3	~	~	~
4	4.3	585	72.6
5	~	~	~
6	4.2	676	70.3
7	2.4	1044	74
8	~	~	~
9	5.4	734	72.7
10	3	1171	71.1
11	~	~	~
12	3	815	72.8
13	4.2	593	69.5

Supplement: ~ indicates that the product cannot meet the requirements.

The data suggest that eight products satisfied the production requirements, whereas five products did not. The reason for the failure was poor flocculation effect, which led to sludge leakage during the operation or treatment capacity, thus falling short of the required amount. For sample 2, the screen tailing of 1 mm is 15.25%, whereas the cationic degree is 60.7%. The parameter is extremely high, which leads to inadequate dissolution, high viscosity of the floc solution, and decrease in permeability of the dewatering belt. Thus, the failure of some products to meet the production requirements could be attributed to the high parameter. Likewise, samples 3, 5, and 11 exhibited the same circumstances, with cationic degrees of 53.8%, 63.5%, and 49%, respectively. The conductivity value of sample 8 is 245 $\mu\text{S}/\text{cm}$, which is significantly lower than the conductivity value of any other sample. Thus, the flocculation effect of this type of c-PAM is poor, and its dosage is high. In general, the c-PAM flocculation effect is closely associated with the screen tailings of 1 mm, the molecular structure, and the dosage [3].

4. Conclusions

- According to the results, the dissolution time is correlated with the 1 mm screen tailings. The larger the number of 1 mm screen tailings, the longer the dissolution process. If the screen tailings of 1 mm are more than 10%, the dissolution time is more than 1 hour. A significant negative linear correlation between viscosity and conductivity of c-PAM solution is indicated.
- The cationic degree of c-PAM has a direct effect on the dewatering machine treatment capacity and medical dosage when the value ranges from 25% to 45%. Moisture content depends primarily on the organic content of the sludge.

- The choice of c-PAM for sewage treatment plant is mainly based on solution viscosity, 1 mm screen tailings, and cationic degree. Another factor is the adjustment of the dosing rate, which should be according to the equipment and facility used in the operation.

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