

Study on the Effect of Coagulant Ratio on Dehydration Performance of Acrylic Sludge

ZHANG Cheng, ZHOU Cai-ling, ZHOU You-chao, SHEN Yue, WANG Yi-wei, GE Shi-fu*

Department of Energy and Environment, Southeast University, Nanjing 210096 China

E-mail: ZHANG Cheng 15062203880@163.com; *GE Shi-fu ge1962@126.com

Abstract. In this research, the coagulants mass ratio affecting the moisture content of acrylic sludge cake was studied. The effects of APAM, CPAM and PAC mass ratio on the moisture content of pressure filter cake and the specific resistance of sludge were studied by orthogonal experiment. The results showed that the specific resistance of sludge presented a highly positive correlation with the moisture content of the filter cake after the treatment of acrylic sludge with CPAM, APAM and PAC. The multivariate regression model for moisture content of the filter cake with coagulants mass ratio was established by response surface methodology. And the model was accurate and reliable in the experimental range which could predict the relationship between the moisture content of the filter cake and the coagulants. In addition, the order of coagulants influencing the moisture content of the filter cake was: CPAM> PAC> APAM. The optimal mass ratio of coagulants to sludge content were 1.5 ‰ (APAM), 1 ‰ (CPAM) and 1.9 ‰ (PAC); the moisture content of the filter cake was 46.45%; and the specific resistance of sludge was $9.65 \times 10^{-7} \text{ s}^2 / \text{cm}$. The study about the effects of coagulants addition order on dewatering performance indicated that the optimal order was PAC-CPAM-APAM. This work could provide a theoretical basis for the design and optimal control of acrylic sludge.

1. Introduction

Large amount of fine granular and high moisture content sludge was produced after the treatment of sewage, and the sludge had greater impact on the energy consumption in subsequent treatment [1]. The dehydration of sludge has become a vital part of the sludge treatment process [2]. While the type and proportion of coagulants are the main factors affecting the sludge dehydration effect. Using two or more categories of coagulants to reduce sludge specific resistance and to improve the sludge dehydration performance is feasible.

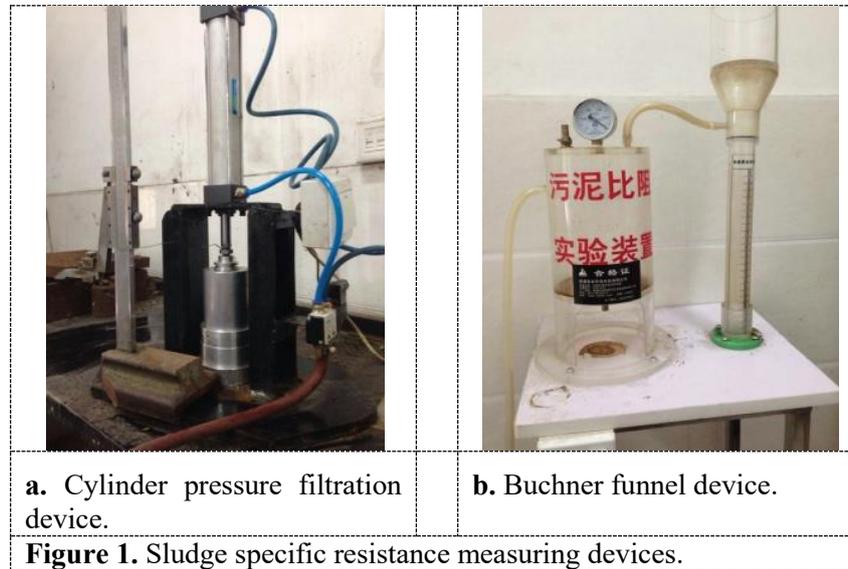
One petrochemical plant in Anqing is now stocking nearly tons of acrylic sludge. The moisture content of the sludge is nearly 90%. And it is characterized as hazardous waste, which has great environmental risks and is in urgent need of safe disposal. In this paper, orthogonal experiment and response surface optimization test were conducted to determine the optimal coagulants ratio in order to achieve the best performance of dehydration. And it ultimately provides a safe basis for reduction and disposal of acrylic fiber sludge.

2. Experimental materials and equipment



2.1. Experimental materials and methods

The acrylic sludge used in the experiment is from the petrochemical plant in Anqing. The initial moisture content and specific resistance of sludge are 90.62% and $8.49 \times 10^8 \text{ s}^2/\text{cm}$. Figure.1 presents two kinds of sludge specific resistance measuring devices.



2.1.1. Cylinder pressure filtration method. Mix the sludge and coagulants thoroughly, then put them into the equipment. Under 2Mpa air pressure, record the time interval t (s) and the piston decreasing displacement H (cm). According to the study[3], use the formula (1) to calculate the specific resistance.

$$\frac{t}{H} = \frac{\mu C_s R_c}{2 \Delta P} H + \frac{\mu R_m(\epsilon)}{\Delta P} \quad (1)$$

2.1.2. Buchner funnel method . Set the vacuum pressure P , then record the time t (s) and the filtrate volume V (ml), According to the study [4], use the formula (2) to calculate the specific resistance.

$$r = \frac{2PA^2}{\mu} \cdot \frac{b}{c} \quad (2)$$

In the formula, μ -dynamic viscosity of the filtrate, $\text{N} \cdot \text{s}/\text{m}^2$; P -filter pressure, N/m^2 , that's vacuum gauge numerical readings; A -filter area, m^2 , the diameter of the circle area is Buchner funnel inner diameter; b -the slope of Specific resistance formula, calculated by the coordinate value; c -filter cake dry weight per unit volume of filtrate, kg/m^3 , that's the filtered mud cake weight.

The Buchner funnel method and cylinder pressure filtration method are used to measure the specific resistance of sludge after conditioning; and measure pressure filter cake moisture content by the SFY-20A Halogen fast moisture analyzer.

2.2. Experimental materials and methods

Niu et al. [1] had studied the dosage of coagulants used in the remaining sludge from Beijing Beixiaohe Sewage Treatment Plant. The result shows: when the mass ratio of coagulants to dry sludge mass is 10%PAC + 0.5%PAM, the dehydration performance is optimal. Li et al. [5] had also studied the dosage of coagulants used in the sludge from Urban sewage treatment plant. The result shows: the optimal ratio of coagulant CPAM and dry sludge mass is $4.28 \sim 7.13 \text{ g} \cdot \text{kg}^{-1}$.

This article has investigated three similar and commonly used coagulants in Nanjing. One chemical plant pretreated sewage into sludge by APAM, while used CPAM and PAC in improving dehydration performance. The mass ratio of APAM to sewage is 3%; the mass ratio of CPAM to sludge is 1%;

and the PAC solution is mixed with the sludge at a volume of 1: 1. The moisture content of pressure-filtered sludge is about 80%.

Therefore, this paper studies three coagulants effect on the sludge dewatering performance. They are APAM solid, CPAM solid and PAC solution. For acrylic sludge, determine the mass ratio of three coagulants to sludge wet weight as 0.25×10^{-3} , 0.5×10^{-3} , 1×10^{-3} , 2×10^{-3} , 3×10^{-3} .

2.3. Response surface optimization experiment

In order to study the effect of three kinds of coagulants on the moisture content of filter press sludge cake and the specific resistance of the sludge, select filter cake moisture content as the response value. And use statistical analysis software Design-Expert 8.0.6.1 to establish three factors and three levels Box-Behnén model [6]. Determine optimal conditions of the filter press cake moisture content by response surface analysis. Experimental factors and levels are -1, 0, +1, the corresponding addition amounts are 1×10^{-3} , 2×10^{-3} and 3×10^{-3} .

2.4. Different coagulants addition sequence experiment

To study the effects of three coagulants addition sequences on sludge dehydration, the moisture content of filter press cake and sludge specific resistance were measured under different coagulants addition sequence. According to the results, get the optimal coagulant addition sequence make the moisture content and sludge specific resistance the lowest.

3. Results and Analysis

3.1. Orthogonal experiment analysis

Figure.2 presents the orthogonal experimental results of the moisture content of pressure filtration cake and the sludge specific resistance.

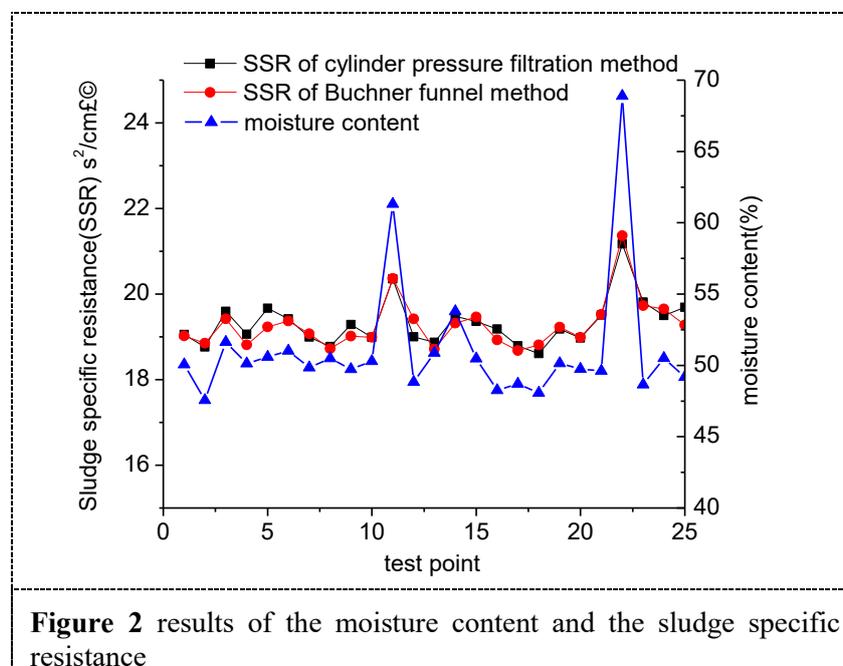


Figure.2 demonstrates that the specific resistance of sludge measured by pressure filtration and Buchner funnel method are basically the same and the average relative error is 13.4%. The sludge pressure filter cake moisture content and sludge specific resistance are positively correlated that the specific resistance increases with the increase of the moisture content of filter cake. Buchner or cylinder method to measure specific resistance can be both used in the acrylic sludge treatment project.

The mass ratio of three coagulants to sludge wet weight making press filter cake moisture content the lowest is 2‰, 1‰ and 2‰.

3.2. Response surface optimization experiment analysis

3.2.1. *Model establishment and significance test.* Response surface experimental design and test results are shown in Table 1. The software Design-Expert 8.0.6.1 was used for the second response surface regression analysis, and a multivariate quadratic regression model was obtained on the moisture content of filter press cake (Y):

$$Y=47.94+0.19A+2.42B-1.46C-1.55AB+0.28AC-2.17BC+1.81A^2+1.77B^2+1.67C^2 \quad (3)$$

Table 1. A slightly more complex table with a narrow caption

| Test No. | A | B | C | Y(MC) |
|----------|----|----|----|-------|
| 1 | 0 | 0 | 0 | 47.95 |
| 2 | -1 | 0 | 1 | 49.22 |
| 3 | 0 | 0 | 0 | 47.95 |
| 4 | 1 | 1 | 0 | 50.76 |
| 5 | 0 | -1 | 1 | 48.13 |
| 6 | 1 | 0 | -1 | 53.06 |
| 7 | 0 | 1 | 1 | 50.3 |
| 8 | 0 | 0 | 0 | 47.95 |
| 9 | -1 | 0 | -1 | 51.3 |
| 10 | -1 | 1 | 0 | 55.44 |
| 11 | -1 | -1 | 0 | 49.18 |
| 12 | 0 | 1 | -1 | 58.98 |
| 13 | 1 | -1 | 0 | 50.7 |
| 14 | 0 | -1 | -1 | 48.13 |
| 15 | 1 | 0 | 1 | 52.1 |
| 16 | 0 | 0 | 0 | 49.5 |
| 17 | 0 | 0 | 0 | 46.35 |

The result of variance analysis about formula (3) was shown in Table 2. The p value on the Table 2 is the significance level of the model[7]. The model $p=0.0255<0.05$ shows that the multivariate model is significant. Misjudgment item value is 0.0867 and greater than 0.05, which shows that the experimental results fit well with the mathematical model and means the results can be conjectured by formula (3). The interrelated coefficient of the regression equation is $R^2=0.8655$, which means that 86.55% of the data can be explained by this equation and the experimental deviation is small. The coefficient of variation (CV) reflects the confidence of the model, the lower the CV value, the higher the model confidence [8]. The CV value of this model is 3.21%, representing higher confidence and changes in response values can be analyzed by this model. While the value p of the CPAM(B) is Less than 0.01, indicating that CAPAM(B) has extremely significant impact on the response value. The value p of the BC is between 0.01 and 0.05, meaning that BC have significant impact on the response value. And the value p of the A, C, AB, AC, A^2 , B^2 and C^2 are greater than 0.05, indicating that their impact on the response value is not significant. According to the value F, the various influences of factors on the pressure filter cake moisture content are in this order: CPAM(B)>PAC(C)>APAM(A).

Table 2. Analysis of variance results.

| Sources of | ANOVA | DOF | MS | F | p | Significance |
|------------|-------|-----|----|---|---|--------------|
|------------|-------|-----|----|---|---|--------------|

| variance | | | | | | |
|--------------|--------|----|-------|-------|--------|----|
| model | 136.27 | 9 | 15.14 | 4.78 | 0.0255 | * |
| A | 0.27 | 1 | 0.27 | 0.09 | 0.7772 | |
| B | 46.75 | 1 | 46.75 | 14.77 | 0.0063 | ** |
| C | 17.17 | 1 | 17.17 | 5.43 | 0.0527 | |
| AB | 9.61 | 1 | 9.61 | 3.04 | 0.1249 | |
| AC | 0.31 | 1 | 0.31 | 0.10 | 0.7621 | |
| BC | 18.84 | 1 | 18.84 | 5.95 | 0.0448 | * |
| A2 | 13.76 | 1 | 13.76 | 4.35 | 0.0755 | |
| B2 | 13.23 | 1 | 13.23 | 4.18 | 0.0802 | |
| C2 | 11.78 | 1 | 11.78 | 3.72 | 0.0950 | |
| Residual | 22.15 | 7 | 3.16 | | | |
| Misjudgement | 17.19 | 3 | 5.73 | 4.62 | 0.0867 | |
| Pure error | 4.96 | 4 | 1.24 | | | |
| sum | 158.43 | 16 | | | | |

** , $P < 0.01$, extremely significant;

* , $0.01 < P < 0.05$, significant

3.2.2. Response surface interaction and optimization. Figure.3~5 show the response surface and contour line figures of the coagulants influences on the press filter cake moisture content. The effect of any two factors and their interactions can be analyzed and evaluated through these figures and the range of the optimal factor level can be also determined [7-9]. The more the contour line shape tends to the ellipse, the stronger the interaction is. The more rounded the contour line is, the weaker the interaction is [7]. According to Fig.3, the interaction of APAM(A) and CPAM(B) is not significant ($p > 0.05$), since the contour line tends to the round; According to Fig.4, the interaction of APAM(A) and PAC(C) is not significant ($p > 0.05$), since the contour line tends to the round; According to Fig.5, the interaction of CPAM(B) and PAC(C) is relatively significant ($p < 0.05$), since the contour line tends to the ellipse.

Figure.3~5 Show that the optimal point of interaction between different factors falls within the experimental range. And the optimal mass ratio of APAM,CPAM,PAC to the sludge to get the minimum moisture content of sludge is: 1.5‰, 1‰ and 1.9‰. The predictive value of moisture content is 46.83%. Under this optimized conditions, three parallel verification tests are carried out, and the moisture content of sludge is 46.455%. The verification results are in line with the theoretical predictions and the ratio is more accurate than orthogonal experiments.

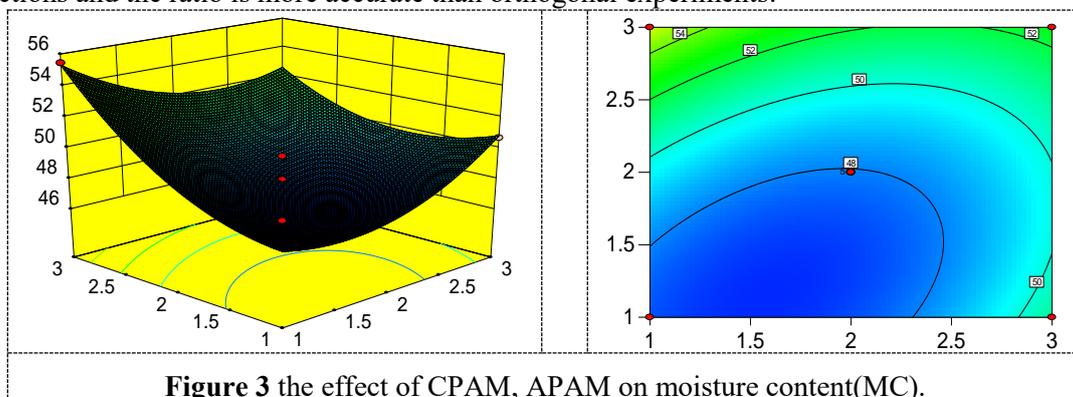
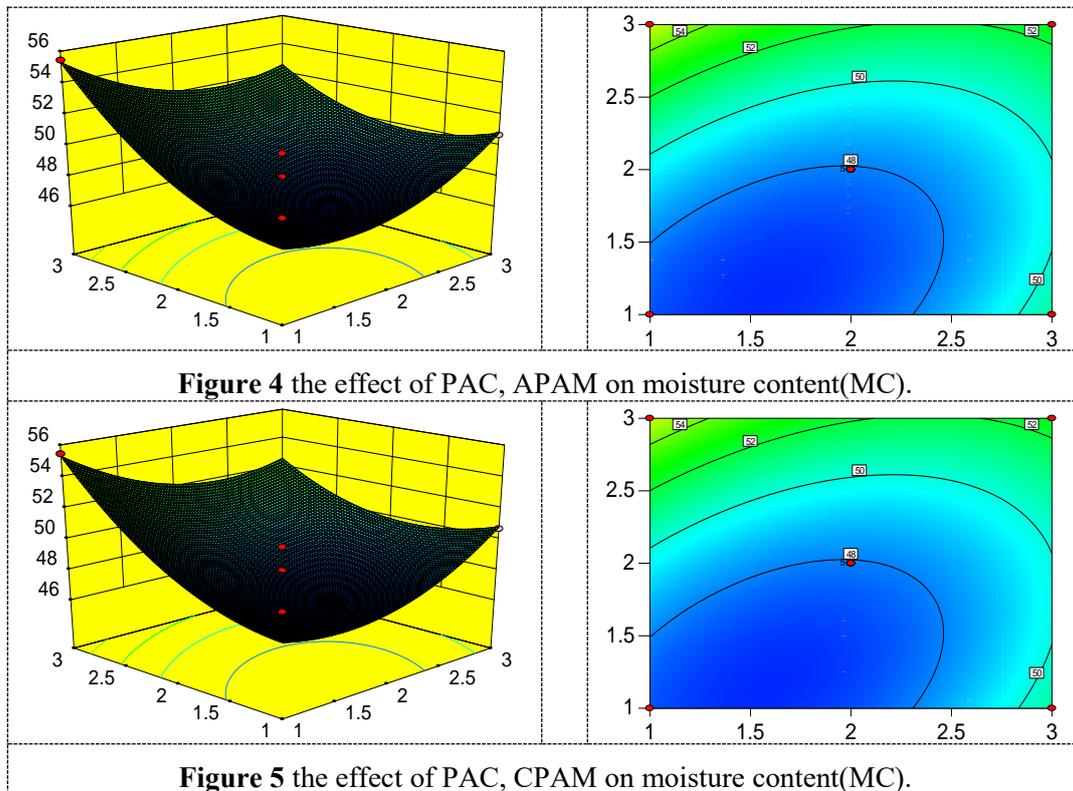


Figure 3 the effect of CPAM, APAM on moisture content(MC).



3.3. Effect of coagulants addition sequence on dehydration performance

According to the results of response surface and orthogonal experiment, the optimal mass ratio of three kinds of coagulants is applied. The mass ratio of APAM, CPAM and PAC to sludge mass is 1.5‰, 1‰ and 1.9‰. And under this ratio measure the moisture content of sludge cake in different coagulants addition sequence and the results are shown in Table 3.

Table 3. Effect of coagulants addition sequence on the moisture content and the specific resistance of sludge.

| Order | addition sequence | moisture content % | specific resistance ($\times 10^7$) s^2/cm |
|-------|-------------------|-----------------------|---|
| 1 | APAM-CPAM-PAC | 46.77 | 9.61 |
| 2 | APAM-PAC-CPAM | 46.82 | 9.76 |
| 3 | CPAM-APAM-PAC | 46.13 | 8.55 |
| 4 | CPAM-PAC-APAM | 46.28 | 8.63 |
| 5 | PAC-CPAM-APAM | 45.11 | 7.77 |
| 6 | PAC-APAM-CPAM | 45.79 | 7.84 |

The moisture content and specific resistance of sludge cake are the smallest when the addition order is PAC-CPAM-APAM. While the moisture content and specific resistance are 5.11% and $7.73 \times 10^7 s^2/cm$. The values are smaller when adding PAC first than CPAM, while adding APAM first is the biggest. Inorganic coagulant PAC forms various forms of water and complex in water and can adsorb negatively charged colloidal particles, destabilizing the colloid by compressing double layer,

electrical neutralization and bridging between hydroxyl groups. Then add polymer coagulant PAM, which has better adsorption bridging function. The long-chain molecular structure can adsorb, net catch and sweeping the sludge particles, to promote the formation of larger flocculation and its separation from the water, eventually achieving solid-liquid separation [10]. However, adding PAM firstly, the macromolecular structure of it makes sludge flocculation structure loose. Then adding PAC after that just neutralizes part of the electric charge, and weakens the function of compressed double layer, which results in worsened effect of sludge dehydration [11].

4. Conclusion

(1) After coagulants conditioning, the pressure filter cake moisture content of acrylic sludge is positively correlated with sludge specific resistance. The specific resistance increases with the increase of the moisture content of filter cake. The significant order of the effect on the pressure filter cake moisture content is: CPAM>PAC>APAM.

(2) The optimal mass ratio of three coagulants to sludge wet weight making press filter cake moisture content the lowest is: (APAM) 1.5‰, (CPAM) 1‰ and (PAC) 1.9‰. Under this condition, the press filter cake moisture content is 46.45% and the sludge specific resistance is $9.65 \times 10^{-7} \text{ s}^2/\text{cm}$.

(3) The optimal coagulants addition sequence is PAC-CPAM-APAM.

5. References

- [1] Niu M Q, Zhang W J, Wang D S. Study on effect of chemical conditioning using different coagulants on sludge dewatering performance[J]. *Acta Scientiae Circumstantiae*, 2012, 32(9): 2126-2133.
- [2] Zheng L Q, Cui H S, Huang R J, Wang X F. Synthesis of novel modified polyacrylamide and its effect on dewatering performance of sludge [J]. *Chinese Journal of Environmental Engineering*, 2011, 5 (5) : 1166-1170.
- [3] Zhao P T, Ge S F, Huang Y, Chen Z Q; Li X. Measurement of specific resistance to filtration of sludge by pressure filtration[J]. *Journal of Southeast University (Natural Science Edition)*, 2011, 41(1): 155-159.
- [4] Dong Y, Hang X G, Niu Y, Jiang X C, Zhuang Z K, Zhu S K, Lu Y S. Experiment on improving sludge dewatering ability using CPAM and CPAM coupled with inorganic coagulant [J]. *Environmental Protection and Technology*, 2015, (05): 24-28.
- [5] Li T, Wang Y L, Feng J, Xu Meng. Relationship Between Physical and Chemical Properties of Activated Sludge and Flocculation Conditioning Dosing [J]. *Acta Scientiae Circumstantiae*, 2012, (03): 889-895.
- [6] Guo R, Li J J, Guo L, Cheng G X. Optimization of the ultrasonic extraction process of glycyrrhizic acid by using response surface methodology [J]. *Jour. of Northwest Sci2Tech Univ. of Agri. and For. (Nat. Sci. Ed.)*, 2006, 34(9): 187-192.
- [7] GHORBEL B O, HAJJI S, YOUNES I, et al. Optimization of chitin extraction from shrimp waste with *Bacillus pumilus* A1 using response surface methodology[J]. *International Journal of Biological Macromolecules*, 2013, 61(10): 243-250.
- [8] WANG X, WU Q, WU Y, et al. Response surface optimized ultrasonic-assisted extraction of flavonoids from *Sparganii rhizoma* and evaluation of their in vitro antioxidant activities[J]. *Molecules*, 2012, 17(6): 6769-6783.
- [9] Zhong K, Wang Q. Optimization of hot water extraction of polysaccharide from dried longan pulp using Response Surface Methodology [J]. *Chemical Industry and Engineering Process*, 2010, 29(4): 739-744.
- [10] Tu Y. Influence of coagulant on sludge dewatering performance in sludge conditioning [D]. *Nanchang University*, 2008.
- [11] Yang X Y, Zhou L. Application and research progress of coagulation process for treatment of dyeing wastewater [J]. *Environmental Protection of Chemical Industry*, 2016, 36(01): 1-4. [2017-10-09].