Study on the Combined Conditioning Effect of High Efficiency Dehydration of River Sediment

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Abstract: It is the most difficult problem for treating river sediment through the work of the whole river regulation. How to solve the problem of low efficiency of river sediment dewatering has become an urgent problem. In this paper, the sediment from the river of Chencun town in Foshan was chosen as the research object. Different kinds of conditioners were selected for single factor experiment, compound conditioning experiment of inorganic coagulants and organic flocculants, and combined conditioning experiment of adding self-made conditioner. The sedimentation speed, the turbidity and the water content were measured for analysis of the change of dehydration performance. The results showed that the effect of CPAM conditioning was the best in case of single factor experiment with the speed of 1.76 cm∙min⁻¹, the turbidity of 0.82 mg∙L⁻¹ and the water content of 60.21%. The lowest water content was under 60% in case of compound conditioning. When self-made PSM was combined with inorganic and organic conditioning for the sediment, the water content became 43.15% where the speed and the turbidity were equal to 2.80 cm∙min⁻¹, 0.23 mg∙L⁻¹, respectively. Therefore, the combined conditioning scheme not only improved the dehydration rate of sediment, but also improved the degree of sediment dehydration, which achieved the goal of high efficiency dehydration and low cost.

1. Introduction

At present, about 90% of urban rivers in China have been seriously polluted, and many cities have begun to deal with the pollution of urban rivers. The pollution of desilting sediment is the most serious in the process of river treatment, so the sediment treatment becomes the most important work in the whole city. River sediment is not only the core part of regulating pollutant components of overlying water but also the central link of nutrient circulation. The polluted sediment will become the secondary pollution source of river water quality [1], which seriously affects the ecological environment, human health and river ecosystem [2]. Therefore, the treatment of river sediment is not only an important way of comprehensive treatment of urban river pollution [3], but also an important part of river ecological restoration.

However, the river sediment has high water content, high compressibility and low permeability, which brings great difficulties to the treatment of river. The water content of river sediment in China is generally above 95%, so the premise of river sediment treatment is how to quickly reduce its water content and its volume, which is conducive to saving subsequent transportation, landfill, incineration and other treatment costs. The water in sediment mainly consists of pore water, combined water, surface adsorbed water and internal water [4]. Pore water (i.e. free water) occupies about 70% of the total water, which can be removed directly through mechanical action. Binding water occupies about...
20% of the total water, which is difficult to remove. Surface adsorption water and internal water occupy about 10% of the total water, which can only be removed after changing its properties by physical, chemical and biological methods. The indexes of sediment dewatering performance are various. The dewatering efficiency of sediment depends not only on the dewatering rate, but also on the degree of dewatering. Generally, the dewatering rate is usually measured by SRF (i.e. specific resistance to filtration) [5] or CST (i.e. capillary suction time) [6], while the degree of dewatering is measured by water content. The research idea of looking for conditioning agents that can change the degree of dehydration comes into being [7]. This kind of conditioning agent can destroy the floc structure of sludge or change the surface properties of floc so that more water in sludge can be converted into free water which is easy to be removed. In this paper, the sediment of the river in Chencun town of Foshan city was selected as the research object. The exploration of how to improve the dewatering efficiency of sediment was made by researching the combined conditioning effect of high-efficiency dewatering of river sediment, which could improve the dewatering speed, but also effectively improve the degree of dewatering of sediment. The combination of conditioning dewatering agent with high dehydration efficiency and low cost was found out in order to provide an effective solution for the efficient dewatering treatment of urban river sediment.

2. Materials and methods

2.1. Materials
Taking the sediment from rivers in Chencun town of Foshan as the original sample, which was desilted by the cutter suction dredger. Its data of basic characteristics, such as the original water content, pH value, potential, suspended solids particle size, the turbidity and the limit value of water content, were measured by experiments and listed in Table 1. The muddy water of the sample was stratified after 24-hour sedimentation, and the lower layer sedimentation part is taken out. The water content of the sedimentation part was equal to 68.38% after mechanical extrusion and natural evaporation and drying for 48 hours, as shown in the last column of Table 1. According to the previous analysis, this value of 68.38% could be regarded as the water content limit of the dewatering degree of the without-conditioned sediment. After taking the turbidity of tap water in our laboratory as the calibration value, the turbidity of the above clarified liquid part was measured to obtain a value of 20.45 mg∙L⁻¹. The all original sediment sample was sealed in glass containers for further use. The effect of separation of mud and water was related to the physical and chemical characteristics of the sediment, such as the colloidal characteristics, particle size and structure of the components. The sediment particles were small and loose in structure with large specific surface area, and their surface was often charged, so they repelled each other, which made them often in suspension state and difficult to sink.

| Table 1. Basic characteristics of original sediment sample |
|---------------------------------|--------|-----|--------|-----|--------|
| Index | WCᵃ (%) | pH  | Potential (mV) | Particle (μm) | Size | Turbidity(mg∙L⁻¹) | WCᵇ (%) |
| Value | 96.54 | 6.79 | -8.56 | <74 | 20.45 | 68.38 |

ᵃNote: original water content of the sediment;  
bNote: water content after process.

The dewatering agents included three inorganic coagulants, namely, PSAF (i.e. poly aluminum ferric silicate), FC (i.e. ferric chloride) and PAC (i.e. poly aluminum chloride) and two organic flocculants, namely, APAM (i.e. anionic polyacrylamide) and CPAM (i.e. cationic polyacrylamide). In addition, the most important dewatering agent was the organic mixture with porous structure synthesized by our laboratory, which was represented by PSM (i.e. porous structure matter).

2.2. Experimental method
In order to study the effects of inorganic coagulants, organic flocculants and PSM on the dewatering
performance of sediment, we carried out conditioning experiments in three cases: single conditioner, inorganic and organic compound, and combination of inorganic and organic with PSM. After conditioning, we recorded the height of the clean and turbid interface after the same stratification time, and calculated the sedimentation speed of the first 5 minutes. After 30 minutes, the turbidity of the above clarified liquid part was measured, and the water content of the lower layer sedimentation part was measured by mechanical extrusion. We used these three physical quantities: sedimentation speed, turbidity and water content as the indexes to measure the effect of the conditioner on dewatering efficiency. Through the comparison, we found out the combined conditioning scheme which has the greatest influence on the dewatering speed and degree.

3. Results and discussion

3.1. Effect of single conditioner on dewatering performance

The above six kinds of conditioners were respectively added with water to prepare a certain different concentration of conditioner solution. Different amount of conditioner was added in the original sample of 500 ml, and was mixed well, and then let it naturally stratify and sink. The sedimentation speed of the first 5 minutes and the turbidity of clarified liquid part after sedimentation of 30 minutes were tested, in addition the water content of the sedimentation part after mechanical extrusion was measured. For each kind of conditioner, at least five groups of experiments with different added amount were measured. The relevant data to calculate the speed, the turbidity and the water content were recorded for each group of experiments, which were compared to find out the amount of conditioner corresponding to the optimal combination. The analyzed results were shown in Table 2. It should be noted that the mud cake was too loose to be extruded when adding self-made PSM alone, so the water content for PSM was not tested. It was found that when the amount of inorganic conditioner was lower than 50 mg L\(^{-1}\), the turbidity was between 5-11 mg L\(^{-1}\). When the amount increased, the turbidity value became smaller, but the sedimentary mud became more, which would increase the subsequent disposal cost. However, when the amount increased to a certain value, the clarified liquid became muddy. Therefore, appropriate amount should be determined. When the amount of organic conditioner was lower than 3 mg L\(^{-1}\), the turbidity was relatively higher, but the influence of the amount on the height of sedimentary mud and water content was not so obvious as that for inorganic conditioner. APAM mainly dealt with wastewater with positive charge and neutral or alkaline pH value. Table 2 showed that after APAM conditioning, the turbidity was one order of magnitude higher than that of CPAM conditioning, indicating that the sample tended to be acidic and negative potential, which was consistent with the data in Table 1.

Table 2. The optimal results of six kinds of different conditioners in single conditioning

| Conditioner | Amount (mg L\(^{-1}\)) | Speed (cm min\(^{-1}\)) | Turbidity (mg L\(^{-1}\)) | Water Content (%) |
|-------------|----------------------|-------------------------|--------------------------|-------------------|
| PSAF        | 150                  | 1.48                    | 2.48                     | 64.56             |
| FC          | 100                  | 1.56                    | 2.15                     | 63.47             |
| PCA         | 180                  | 1.34                    | 2.04                     | 65.43             |
| APAM        | 14                   | 1.75                    | 5.45                     | 62.05             |
| CPAM        | 12                   | 1.76                    | 0.82                     | 60.21             |
| PSM         | 200                  | 2.40                    | 8.79                     | -                 |

Table 2 showed that the sedimentation speed after PAM conditioning was higher than that corresponding to inorganic conditioner, because PAM may effectively reduce the repulsion between particles which makes it quickly absorb the suspended solid particles in water and significantly accelerate the sedimentation and the clarification effect of solution. Compared with inorganic coagulants, the flocculent aggregate formed by PAM was more compact and firm, which was more conducive to mechanical dewatering. So the water content of mud cake was lower than that for inorganic coagulants. The water content reduced to a certain extent in cases of no matter inorganic or organic conditioners, and the effect of CPAM was the most obvious. The water content was the value
of 60.21%, which was about eight percentage points lower than the limit value of 68.38% in case of without-conditioning. However, the reduction of less than 10% could not save the cost of the subsequent disposal. The amount of PSM was the highest and the turbidity was the biggest, but the sedimentation speed was the fastest. It had 79% faster than the slowest one for PCA and 36% faster than the fastest one for CPAM. Therefore, PSM could obviously accelerate the dewatering speed of river sediment, and whether PSM could improve the degree of dewatering needed further experiments.

3.2. Effect of inorganic and organic compound conditioning on dewatering performance

In the single factor experiments of inorganic conditioners, the PCA conditioned mud cake was more likely to run out than that in case of PSAF and FC while dehydrated by mechanical extrusion. Table 2 showed that PCA corresponded the highest water content, the slowest speed and the most amount although the turbidity was the smallest. Thus PCA was not suitable for the samples in this paper. In the single factor experiments of organic conditioners, CPAM had more advantages than APAM, and the corresponding mud cake was easier to squeeze. Therefore, PSAF, FC and CPAM were selected to do the compound experiments where the amount of inorganic coagulants were the values shown in Table 2, and the amount of CPAM was changed for four groups. In order to better compare their conditioning effects, the experiments of adding PSAF, FC and CPAM in different orders were carried out.

Table 3 was the results of the composite conditioning experiment by adding first inorganic conditioner and then CPAM. The sedimentation was faster than that of single conditioning of inorganic conditioners, where the speeds were greater than 1.7 cm·min⁻¹. The turbidity became lower with the values of less than 1 mg·L⁻¹. The values in the single conditioning were greater than 1 mg·L⁻¹ except that the value in CPAM conditioning. The clarified liquid was much clearer than that in single experiments. This showed that the combination of inorganic and organic conditioning was more conducive to solid-liquid separation, so that the vast majority of suspended solids and colloids sank. But the water content in most cases was higher than that for single CPAM conditioning whose value was 60.21%, which indicated that the proportion of non-free water from sedimentary particles to total water increased which made the water content higher but the turbidity became lower by composite conditioning. However, as long as the amount of CPAM was appropriate, this problem could be easily solved. The amount of CPAM was 16 mg·L⁻¹ when conditioning with PSAF, which got a lower water content of 58.91%. The amount of CPAM was 12 mg·L⁻¹ when treated together with FC, and the water content was 59.39%.

| Conditioner | CPAM Amount (mg·L⁻¹) | Speed (cm·min⁻¹) | Turbidity (mg·L⁻¹) | Water Content (%) |
|-------------|----------------------|------------------|--------------------|-------------------|
| PSAF        |                      |                  |                    |                   |
| 8           | 1.86                 | 0.36             | 72.28              |
| 12          | 1.82                 | 0.80             | 68.10              |
| 16          | 1.80                 | 0.42             | 58.91              |
| 20          | 1.72                 | 0.38             | 63.32              |
| FC          |                      |                  |                    |                   |
| 8           | 1.89                 | 0.34             | 63.27              |
| 12          | 1.87                 | 0.30             | 59.39              |
| 16          | 1.82                 | 0.44             | 60.23              |
| 20          | 1.78                 | 0.40             | 61.56              |

When the amount of CPAM was less than 8 mg·L⁻¹, the sedimentation speed increased with the increase of CPAM. When it exceeded 8 mg·L⁻¹, the speed showed a downward trend. It could be because when CPAM dosage continued to increase, there were different chain structures of floc alum formed by sediment particles, which made their adhesion occur in the sedimentation process, resulting in slow speed. Therefore, the proper amount of CPAM could promote the sedimentation and achieve the best flocculation effect.
Table 4 was the results of the composite conditioning experiment by adding first CPAM and then inorganic conditioners. As the same as that in Table 3, the sedimentation under composite conditioning was faster than that under single conditioning of inorganic coagulants. The values of speed were greater than 1.7 cm·min⁻¹ in both cases of two orders for composite conditioning experiments. However, when CPAM was added first, the sedimentation speed was smaller than that when CPAM was added later. The turbidity of Table 4 was greater than 1 mg·L⁻¹, obviously higher than that when CPAM was used alone (i.e. 0.82 mg·L⁻¹). This showed that although the sediment was clarified when CPAM was added, but the liquid became turbid when inorganic coagulants was added later, resulting in the final turbidity being between the values from single inorganic and from single CPAM conditioning experiments. In the order of first CPAM and then inorganic conditioners, the turbidity improvement was not obvious, but the water content was lower than that in Table 3. It proved that in this order experiment the substances containing more non-free water tended to stay in the above clarified liquid. This conclusion also explained the experimental results: under the compound conditioning of CPAM + PSAF, when the amount of CPAM was 20 mg·L⁻¹, the water content could be reduced to 51.06%, but the corresponding turbidity was the highest, which was equal to 1.70 mg·L⁻¹ as shown in Table 4. That was to say, when the turbidity was higher, the water content was lower, because the proportion of non-free to total water of sediment particles in the above clarified liquid was higher than that in the lower mud cake.

Table 4. The composite experiment results of adding first CPAM and then inorganic conditioner

| Conditioner | CPAM Amount (mg·L⁻¹) | Speed (cm·min⁻¹) | Turbidity (mg·L⁻¹) | Water Content (%) |
|-------------|----------------------|-----------------|-------------------|------------------|
| PSAF        | 8                    | 1.84            | 1.48              | 63.48            |
|             | 12                   | 1.72            | 1.30              | 63.75            |
|             | 16                   | 1.72            | 1.08              | 66.51            |
|             | 20                   | 1.72            | 1.70              | 51.06            |
| FC          | 8                    | 1.83            | 1.08              | 61.67            |
|             | 12                   | 1.81            | 1.00              | 60.26            |
|             | 16                   | 1.80            | 1.05              | 58.45            |
|             | 20                   | 1.76            | 1.20              | 62.16            |

Analysis of the data in Tables 3 and 4 proved that the composite conditioning improved the dewatering speed of the sediment. When the amount of CPAM was enough, it also improved the dewatering degree. However, too much organic flocculants will affect the composition of sludge, which was not conducive to later disposal. In addition the price of CPAM is not low. So we added self-made PSM together in the following experiments to find out an efficient and low-cost conditioning scheme.

3.3. Effect of inorganic and organic conditioners together with PSM combined conditioning on dewatering performance

The analysis in section 3.2 indicated that conditioning by adding first inorganic coagulant and then CPAM improved both the dewatering speed and the turbidity obviously. The colored iron ion of FC made the clarified liquid yellow. The ion was easy to corrode the treatment equipment. The mud cake produced after the conditioning of FC was easy to be slightly acidic, and maybe make the land easy to form plates. PSAF was selected and FC was eliminated for this experiment in order to avoid the trouble from increasing cost of sludge disposal. The biggest problem of PSM conditioning was that there was high turbidity as shown in Table 2. So that we added conditioners in this order: first PSM, then PSAF, and finally CPAM. Such a sequence not only improved turbidity, but also conformed to the actual engineering operation. It was found that the flocculation phenomenon was very prominent when CPAM was added in the last step, and the amount of CPAM needed was much less. Table 5 showed the best combination obtained by adjusting the amount of PSM, PSAF and CPAM.
Table 5. Experimental results of combined conditioning added in sequence of PMS + PSAF + CPAM

| Conditioner | Amount (mg·L⁻¹) | Speed (cm·min⁻¹) | Turbidity (mg·L⁻¹) | Water Content (%) |
|-------------|-----------------|------------------|-------------------|-------------------|
| PMS         | 180             |                  |                   |                   |
| PSAF        | 120             | 2.80             | 0.23              | 43.15             |
| CPAM        | 8               |                  |                   |                   |

The results showed that the sedimentation speed was 2.80 cm·min⁻¹, the turbidity of the clarified liquid was 0.23 mg·L⁻¹, and the water content of the mud cake was 43.15%, which were better than the results of single conditioning, inorganic and organic conditioners compound conditioning. Surprisingly, the water content of the mud cake was less than 50%. Compared with the data in Tables 2, 3 and 4, PSM not only improved the dewatering speed of sediment, but also improved the dewatering degree of sediment when it was combined with inorganic and organic conditioners. The turbidity decreased by 99% and water content decreased by 37% corresponding to the values before conditioning shown in Table 1.

The advantages of three kinds of conditioners with different properties resulted in the good results. From the appearance structure, the main component of PSM is very small granular smooth material with larger specific surface area and porosity. PSM has stronger adsorption, which can be adsorbed on the surface of particles in the sediment and destroy the colloidal stability. The particle size of PSM is smaller than that of the original sample, and it can enter the cavity of the sample to extrude the water in the pore. The raw materials for preparing PSM are very cheap. The active ingredients were extracted from the waste materials of power plant, and then were synthetized into PSM by special process. PSM owns certain particle size and porosity. PSAF has high positive charge density, good water solubility and flocculation performance. CPAM has the advantages of high removal ability for turbidity and good flocculation effect, which greatly increases the sedimentation speed and concentration multiple for the sample. Compared with the amount of CPAM corresponding to the lowest water content in Tables 3 and 4, the amount of CPAM required in the experiments after conditioning of PSM and PSAF was reduced by at least half. The amount of inorganic PSAF required in the combined conditioning experiment was also 20% less than that required in the other two kinds of experiment, which greatly reduced the cost of sediment treatment.

4. Summarization
The traditional inorganic coagulants have the advantages of low cost and good effect on colloidal flocculation, but the generated flocs are relatively small and have slow sedimentation. PAM has the advantages of less dosage, fast flocculation speed, less sludge generation, less influence by coexisting salts, pH value and temperature, etc. It has chain, ring and network structure, which lets pollutants easy to enter into flocs, causing good decolorization. CPAM has very strong flocculation and sedimentation efficiency for all kinds of suspended particles in aqueous solution, especially for those colloidal particles with negative charge.

In this paper, the sedimentation speed of the clean and turbid interface, the turbidity of the clarified liquid and the water content of the mud cake were taken as the indicators to measure the improvement of the dewatering performance through the observation of the sediment conditioning experiments. The results showed that the self-made PSM conditioner could effectively improve the dewatering speed and degree, which achieved the goal of efficient dehydration and low-cost treatment of sludge.

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Reference

[1] V., H.K.K. (2002) Briek production with dredged harbor sediments: An industrial-scale experiment. Waste Management, 22(5): 521-530.

[2] Wu L.L. (2007) Experimental study and engineering application for purification and remediation of black-color and odorous urban river. A master's thesis of East China Normal University. Shanghai.

[3] Yan Ch.Zh., Fan Ch.X., Yang J.H., Jin X.C., Zhao X.Zh. (2004) Prospect and progress of the study on environmental dredging technology of lake sediment. Environmental Pollution & Control, 03: 189-192+243.

[4] Lowe P. (1995) Developments in the thermal drying of sewage sludge. Water and Environment Journal, 10(9): 306-316.

[5] Ren B.Zh., Hou B.L., Yang Y.L. (2010) A study on the improvement in dewatering of sewage sludge by adding fly ash. Environmental Science & Technology, 33(12F): 184-187.

[6] Zhu R., Wu M., Yang J., Wei Ch.Y., Zhang B. (2010) Influences of extracellular polymeric substances (EPS) on dewaterability of thickened sludge. Acta Scientiarum Naturalium Universitatis Pekinensis, 46(3): 385-388.

[7] Li D., Li J., Liu W.Y., He J.W., Wen H.B., Li D.G. (2009) Experimental Research on Sludge Dewatering by Screw Press Dehydrator. Chinawater & Wastewater, 25(11):66-68.