Experimental Study on Dewatering Effect and Strength of Chaohu Sludge Treated by Soilags

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Abstract. The silt dredging project can effectively control the adverse effects of sediment accumulation at the bottom of the lake channel on the navigation channel, ensuring the full play of navigation benefits. The dehydration treatment of silt is a crucial part of the dredging project. Based on the channel dredging project in the Chaohu Lake area of the Yangtze River-Huaihe River Water Diversion Project, this paper utilizes the dehydration properties of soilbags to dehydrate the silt from Chaohu Lake. Through dehydration rate tests of soilbags, the study investigates the impact of flocculant types and flocculants with different molecular weights on the dehydration performance of Chaohu Lake silt, and selects the flocculant type and optimal molecular weight most suitable for treating the silt in the Chaohu Lake area. After the completion of the tests, the water content and strength of the silt inside the dehydrated soilbags were tested, and the compressive strength of the dehydrated soilbags was also tested. The results show that adding flocculants can effectively improve the dehydration performance of silt, reduce its water content, and give the silt a certain degree of strength. The flocculant dominated by anionic polyacrylamide has the best effect on treating the silt in the Chaohu Lake area, with an optimal molecular weight ranging from 10 to 12 million. When the molecular weight exceeds 12 million, the flocculation effect decreases instead, and the dehydrated soilbags exhibit good compressive strength. The dewatered soilbags exhibit good compressive strength, which is largely unrelated to the material inside the bags.

Keywords: Silt dredging; Soilbags; Dehydration Rate; Flocculant; Compressive Strength

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1 Introduction

The application range of soilbags is extensive, and they can be widely used in various projects such as dike construction, sludge treatment in chemical plants, cities, and wastewater treatment plants, as well as desilting projects in rivers, lakes, reservoirs, seaports, and docks. For general sludge, after filling the soilbags, the slow settlement speed and easy pore blockage of the sludge can ultimately affect the dehydration rate of the bags. In response to this issue, scholars at home and abroad have found through research that adding flocculants can be used for sludge dehydration and flocculation, effectively improving the settlement rate of sludge and enhancing its dehydration performance.

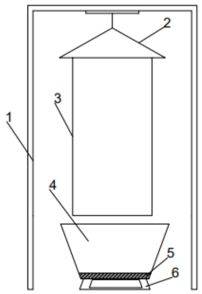
Moo-Young et al. [1] investigated the water permeability of geotextiles through pressure filtration tests and vacuum filtration tests, analyzing factors such as soil moisture content, fabric pore size, and particle composition on fabric permeability and soil retention. Huang et al. [2] studied the filtration characteristics of geotextiles for sludge through permeation tests. Koerner et al. [3] found that sling dehydration tests are relatively easy to implement indoors. Wu Yuelong et al. [4] compared the soil retention and dehydration efficiency of slings filled with mud of varying moisture contents. Pawar et al. [5] used a sling dehydration model to compare the dehydration rates between adding alum as a flocculant and natural dehydration. Zheng Hua et al. [6] conducted rapid dehydration tests to study the effects of different types and molecular weights of flocculants on the dehydration performance of dredged sediment from Wenzhou wetlands, screening out the optimal flocculation process for wetland sediment. Huang Tao et al. [7] addressed issues of land occupation and environmental pollution in the treatment of dredged sediment from Chaohu Lake by applying geotextile tubular bag technology for dehydration and solidification. Their research showed that adding a certain amount of solidifying agents and flocculants can rapidly dehydrate and reduce the volume of sediment without causing secondary pollution to the environment. Wu Haimin et al. [8] studied the influence of fabric pore size, clay content, and sand ratio of the filling soil on the soil retention and dehydration rate of tube through indoor sling dehydration model tests. Huang Jiayin et al. [9] conducted dehydration flocculation tests on sediment from Baiyangdian Lake and proposed a flocculation scheme suitable for its sediment. Wang Fei [10] studied the effects of three different flocculants on the dehydration characteristics of sediment from Wuhan's Guanqiao Lake, finding that a single flocculant can significantly improve the dehydration performance of sediment. Lawson [11] pointed out that the properties of sediment vary greatly in different regions. These studies demonstrate that the sling model test can well reflect the filtration performance of geotextiles, providing a theoretical basis for the dehydration flocculation process of geotextile tube. However, due to the complex composition of sediment, the properties of sediment in different regions differ significantly, resulting in varying effects of the same flocculant in treating sediment from different regions. Therefore, selecting the appropriate type and optimal molecular weight of flocculant for sediment with different properties is crucial for ensuring the dehydration efficiency of geotextile tube. Currently, the practical application of geotextile tube for the dehydration treatment of dredged sediment remains limited and has not been widely adopted.

This paper, based on the dredging project of the Zhaohekou Channel in Chaohu Lake, Anhui section, of the Yangtze River-Huaihe River Water Diversion Project, conducts dehydration rate tests on the sediment from this area using geotextile tube. The tests employ a sling dehydration model combined with the principle of rapid dehydration tests, using the dehydration rate of geotextile tube as the evaluation index to characterize the effects of flocculant types and different molecular weights on the dehydration performance of sediment. After the tests, the moisture content and density of the sediment are measured, and the dehydration effects of geotextile tube under different working conditions are summarized to select the optimal flocculation process for channel dredging projects.

2 Test Device and Test Materials

2.1 Test Device

The dehydration model test device used in this paper is shown in Fig. 1, which is mainly composed of a bracket, a geotextile tube, a tray, and an electronic mass scale. During the dehydration process, the geotextile tube is used to filter the sludge, the tray collects the filtrate, and the electronic mass scale monitors the real-time mass change of the filtrate. Among them, the width of the geotextile tube is 30cm, and the length is 70cm.



1-bracket; 2-hanger; 3-geotextile tube; 4-tray; 5-filtrate; 6-electronic mass scale

Fig. 1. Diagram of experiment device

2.2 Test Materials

Sludge. The silt used in the test was taken from the Zhaohekou channel in the Chaohu Lake area of the Anhui section of the Yangtze River to Huaihe River Diversion Project. The sampling location is shown in Figure 2.

Fig. 2. Collecting points

Bag Material. The raw material for the geotextile woven bags used in the test is domestic polypropylene with a weight of $90g/m^3$, as shown in Figure 3.

Flocculant. The test uses organic polyacrylamide (PAM) flocculants, including three types: anionic, cationic, and non-ionic. The specific information is shown in Table 1.

Table 1. Flocculant parameters

Types	Weight/g	Molecular Weight
non-ionic	960	12 million
anionic	960	6 million
	960	8 million
	960	12 million
	960	15 million
	960	20 million
cationic	960	12 million

2.3 Experimental Method

This experiment adopts a hanging bag dehydration model, combining the principle of rapid dehydration testing, utilizing geotextile tubes as the filtration medium. Specifically, the silt and flocculant solution are thoroughly mixed and poured into the geotextile tube, where dehydration is accomplished under the force of gravity. The filtrate is collected in a tray within the dehydration model, and an electronic scale monitors the change in the mass of the filtrate while recording the time. The ratio of the change in the mass of the filtrate to time is recorded as the dehydration rate, which characterizes the influence of different flocculants and molecular weights on the dehydration performance of the silt. Ultimately, the optimal flocculation scheme for the silt from the Zhaohekou channel in Chaohu Lake is selected.

To make the experimental results more consistent with engineering practice, the size ratio of the geotextile tube used in the laboratory test to that used on the construction site is 1:100. After retrieving the silt from the site, it is diluted by adding water and stirred to achieve a water content of approximately 90%. A flocculant solution with a concentration of 0.3% is prepared. A flocculant solution is added to a certain amount of diluted silt, and the mixture is stirred for 1-2 minutes. The stirred mixture is then poured into the geotextile tube, and dehydration is initiated with time recording.

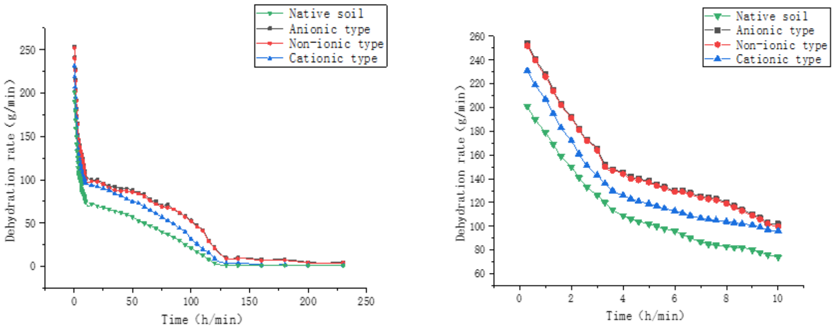
Following the above experimental steps, flocculant solutions with a concentration of 0.3% are prepared for anionic, cationic, and non-ionic flocculants, respectively. Dehydration tests are conducted after adding these flocculants to diluted silt. Upon completion of the tests, data are organized to obtain dehydration rate graphs for different types of flocculants. By comparing the dehydration rates, the optimal flocculant is selected.

Using the optimal flocculant (anionic flocculant) identified in the previous tests, the effects of flocculants with molecular weights of 6 million, 8 million, 12 million, 15 million, and 20 million on the dehydration performance of the silt are investigated. The hanging bag dehydration model is employed to study the dehydration rates, further determining the flocculation process suitable for the silt in Chaohu Lake.

2.4 Analysis of Experimental Results

Dehydration Rate Experiments with Three Types of Flocculants. Figure 3(a) illustrates the dehydration behavior of the silt under the influence of different flocculants. Overall, the dehydration rate is rapid within the first half-hour of the experiment. After this initial period, the rate decreases linearly, and after three hours of dehydration, it gradually levels off, following a trend that resembles an exponential function. To compare the dehydration effectiveness of the flocculants, the first 10 minutes of the dehydration process are enlarged in Figure 3(b). It can be observed that adding flocculants can significantly enhances the initial dehydration rate of the geotextile tube, markedly improving the initial dehydration performance of the silt. This is because after adding flocculants to the silt, mud-water separation occurs rapidly, and the silt flocculates to form precipitates. The supernatant liquid then overflows from the pores of the geotextile tube under the force of gravity. As the supernatant liquid gradually decreases, the dehydration rate of the geotextile tube also decreases, eventually approaching zero. Different flocculants have varying effects on the silt. Within the first 10 minutes, the dehydration effects of anionic flocculants and non-ionic flocculants are similar, with anionic flocculants slightly outperforming non-ionic flocculants, both of which are significantly faster than cationic flocculants.

Based on the comparative experiments conducted, it has been determined that anionic flocculants are the most suitable dehydration agent for treating the silt from Chaohu Lake. This conclusion is drawn from the observation that anionic flocculants demonstrated a higher initial dehydration rate and overall dehydration performance compared to non-ionic and cationic flocculants, particularly within the critical first 10 minutes of the dehydration process.



(a) Whole process curves (b) The first ten minutes curves

Fig. 3. Dehydration rate chart under the action of different flocculants

The selection of anionic flocculants as the optimal dehydration agent for Chaohu Lake silt is further supported by the fact that they were able to effectively facilitate mud-water separation and flocculation of the silt particles, leading to a more rapid and efficient removal of water content. This not only enhances the overall dehydration efficiency but also potentially reduces the time and resources required for silt treatment and disposal.

Therefore, for the specific conditions and characteristics of the silt from the Zhaohekou channel in Chaohu Lake, anionic flocculants are recommended as the preferred dehydration agent for future engineering applications.

Dehydration Rate Experiments with Different Molecular Weights of Anionic Flocculants. Having confirmed through previous experiments that anionic flocculants exhibit the best dehydration and flocculation effects on the silt from Chaohu Lake, further dehydration tests were conducted using anionic flocculants with varying molecular weights. The results, as depicted in Figure 4, reveal an interesting trend. Specifically, the dehydration rate of the geotextile tube does not increase proportionally with the increase in the molecular weight of the flocculant. Instead, the fastest dehydration rates are observed within a molecular weight range of 8 to 12 million. Beyond 12 million molecular weight, the dehydration rate declines, while below 8 million molecular weight, the dehydration rate remains relatively low, resulting in suboptimal treatment outcomes.

This observation can be explained by the underlying principles of the dehydration process. The dehydration rate serves as an indicator of the silt's dehydration performance, with faster rates signifying better enhancement of this performance. The optimal dehydration performance within the specified molecular weight range (8 to 12 million) suggests that this range allows for optimal flocculation and sedimentation of the silt particles, thereby facilitating more efficient removal of water content.

In conclusion, anionic flocculants with a molecular weight of 8 to 12 million are recommended as the most suitable for treating the silt from Chaohu Lake, as they demonstrate the best overall dehydration performance and effectiveness.

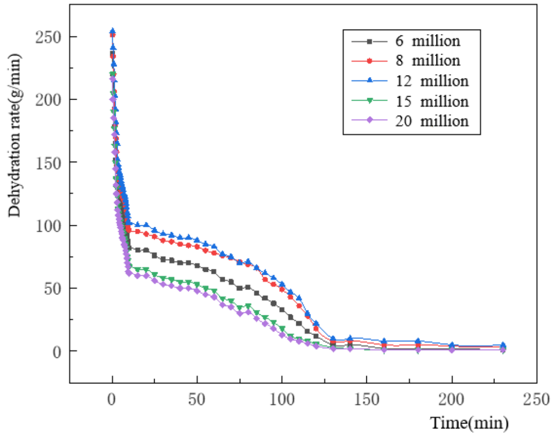


Fig. 4. Dehydration rate under the action of flocculants with different molecular weights

Based on the aforementioned experiments, it is evident that the dehydration rate varies significantly when treating silt with different types and molecular weights of flocculants. The addition of flocculants significantly enhances the dehydration efficiency, and the optimal flocculant addition scheme can be determined through graphical analysis.

3 Physical Characterization of Silt Before and After Dehydration

Having identified the optimal dehydration conditions for Chaohu Lake silt using flocculants, further tests were conducted to evaluate the physical properties of the silt before and after dehydration. Following the completion of the dehydration trials, samples were taken from the geotextile tubes, and their free moisture content and dry density were measured.

Table 2 presents the moisture content and dry density of the silt before and after dehydration under the influence of different flocculants. As evident from Table 2, the sole use of geotextile tubes for dewatering silt yields limited results. However, the addition of a certain amount of flocculant significantly improves the situation by reducing the excessively high moisture content of the silt. After dehydration, the silt can potentially be further treated with a stabilizer, facilitating its reuse in dredging channels. This approach not only protects the ecological environment but also satisfies engineering requirements.

In summary, the integration of flocculants and geotextile tubes for silt dehydration, followed by optional stabilization, offers a comprehensive solution for the treatment and reuse of dredged silt, thereby promoting sustainability and reducing waste.

Table 2. Moisture Content Change Table

Type	Moisture content	
	Before dehydration	After dehydration
Native soil	95.23	80.31
Anionic soil	94.55	52.11
Non-ionic soil	94.26	50.06
Cationic soil	93.29	60.12

Figure 5 is a bar chart showing the changes in density of the geotextile bag contents before and after dehydration under the action of different flocculants. It can be observed that the density of the sludge increases significantly after dehydration. This is because the addition of flocculants causes the sludge to flocculate and settle, with the supernatant being filtered out by the geotextile bag. The remaining flocculated solids have a higher density compared to the original sludge.

Under the action of different flocculants, the density of the flocculated solids formed from the sludge varies slightly, but all are greater than that of the original soil. Therefore, it can be concluded that adding flocculants can improve both the dehydration rate and the sludge density, achieving a better dehydration effect.

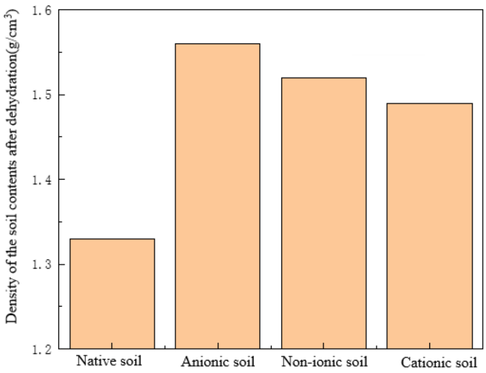
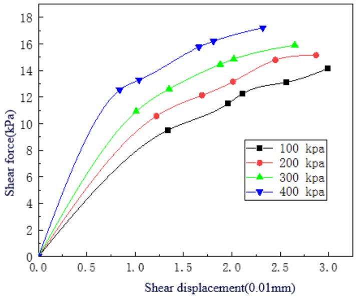


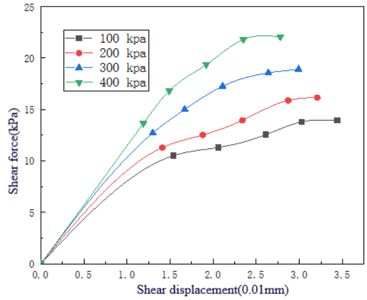
Fig. 5. Density of the soil contents after dehydration

Before dehydration, the sludge was in a fluid state, making it impossible to conduct shear strength tests. Therefore, shear strength tests were conducted on the four types of soil after dehydration and solidification. The shear displacement relationship is shown in Figure 6, the shear strength results are shown in Figure 7, and the shear strength indicators are summarized in Table 3. It can be observed that after dehydration with different flocculants and a period of natural solidification, the internal friction angle of the sludge remained basically unchanged, while the cohesion increased to varying degrees.

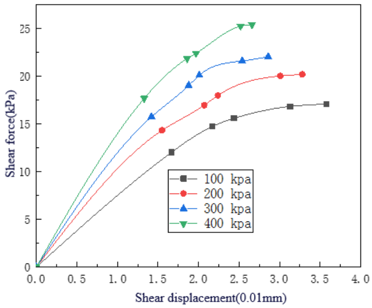
After sludge dehydration and solidification with anionic, non-ionic, and cationic flocculants, the anionic flocculant showed the greatest increase in internal friction angle, followed by the non-ionic flocculant, and the cationic flocculant performed the worst. This is because the anionic flocculant has the strongest flocculation effect, the fastest speed, and the largest amount of dewatering. After the same period of natural solidification, the water content was lower than that of the other two flocculants, resulting in the highest cohesion. However, overall, there was little difference in the improvement of shear strength of solidified sludge among the three flocculants. The shear displacement variation patterns under the three conditions were similar, with the displacement changing closely with the shear stress.



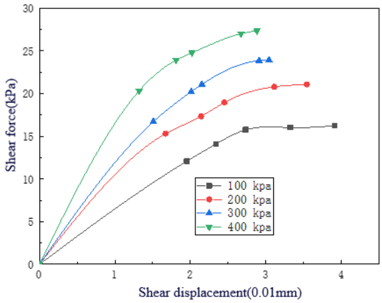
a) Native soil



b) Anionic soil



b) Non-ionic soil



d) Cationic soil

Fig. 6. Shear force~shear displacement

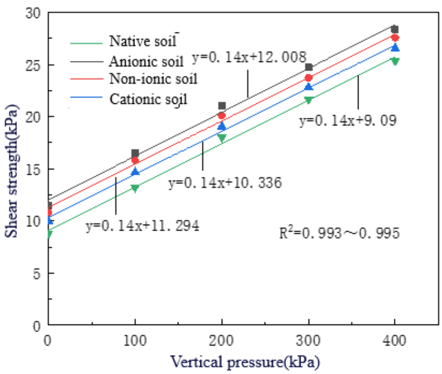


Fig. 7. Vertical pressure~shear stress

Table 3. Moisture Content Changes

Type of flocculant	Cohesive force	Friction angle
Native soil	9.09	7°
Anionic soil	12.08	8°
Non-ionic soil	11.29	8°
Cationic soil	10.34	8°

4 Geotextile Bag Strength Test

The geotextile bag strength test was conducted using the rock direct shear test system in the soil mechanics laboratory. This system mainly consists of a pressure-bearing platform, a hydraulic jack, a pressure gauge, a pressure rod, etc., as shown in Figure 8. To ensure uniform stress distribution on the geotextile tube bag during the loading process, a 30cm × 25cm (length × width) steel shim plate was horizontally placed between the hydraulic jack and the top-layer geotextile bag. A displacement meter was fixed on the shim plate to monitor the vertical deformation of the geotextile bag throughout the loading process.

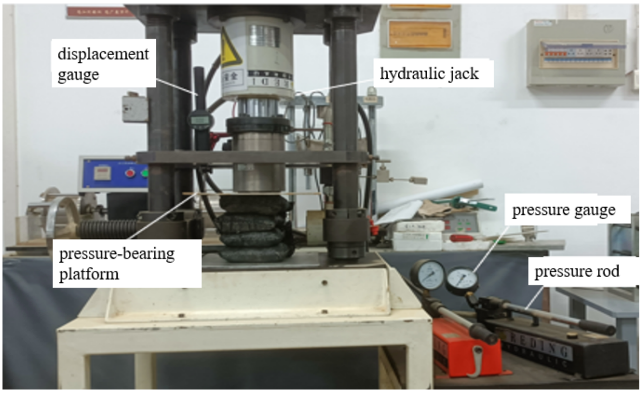


Fig. 8. Diagram of Experimental Setup

For the test, ordinary soilbags with dimensions of 20cm × 10cm (length × width) were selected. The raw material for the soilbags and the soil inside them were the same as those used in the previous tests. The soilbags were subjected to an unconfined compressive strength test. The completed soilbags were laid flat directly below the hydraulic jack of the direct shear system. To prevent constraint on the soilbags from the pressure-bearing platform, a shim plate was placed between the top-layer geotextile bag and the hydraulic jack after stacking the soilbags vertically in four layers. Before starting the test, the soilbags were pre-compressed. The displacement meter was zeroed after the surface of the top-layer geotextile bag was smooth and well-fitted with the shim plate. The hydraulic jack was then controlled by the pressure rod to apply a slow and uniform load to the underlying soilbags until the soilbags ruptured or could not sustain further loading.

After the test, the readings of the pressure gauge and displacement meter were recorded. The maximum unconfined compressive strength of the soilbags and the relationship between vertical pressure and vertical strain were analyzed. The stress-strain relationship curve is shown in Figure 9. It can be seen that for different materials inside the bags, the compressive strength of the soilbags is basically the same, indicating that the material inside the bags has little influence on the compressive strength of the soilbags.

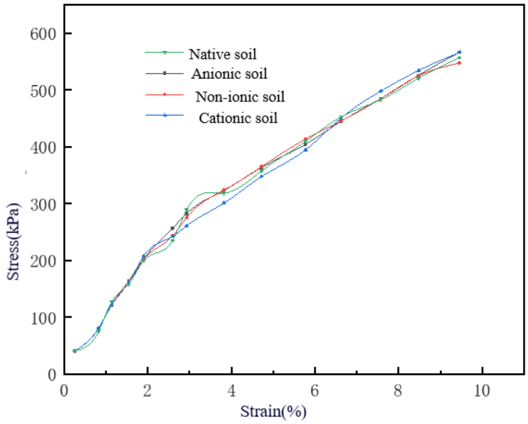


Fig. 9. Stress~strain of soil inside the bags

5 Conclusion

This paper conducted dehydration experiments on Chaohu Lake silt using a hanging bag dehydration model, combined with the principle of rapid dehydration, to select the optimal flocculation scheme for treating silt in the Chaohu Lake area. After the experiments, the density and moisture content of the silt were tested, and the physical property changes before and after dehydration were analyzed. The following conclusions can be drawn:

(1) The dehydration experiments explored the optimal flocculation process for treating Chaohu Lake silt. The results showed that the flocculation effects of the three flocculants were ranked as follows: anionic > non-ionic > cationic. Among them, the optimal molecular weight range for anionic flocculants was 10-12 million. Beyond 12 million, the flocculation effect was not satisfactory. Therefore, the flocculation scheme most suitable for treating silt in the Chaohu Lake area is anionic flocculants with a molecular weight of 10-12 million.

(2) The density and moisture content of untreated silt changed minimally after dehydration. However, the addition of a certain amount of flocculants significantly reduced the moisture content of the silt and increased its density more notably. This

indicates that flocculants effectively improve the dehydration performance of dredged silt.

(3) This paper defines the ratio of filtrate mass to time as the dehydration rate of the geotextile bag, which characterizes the dehydration effect of flocculants. The faster the rate, the better the dehydration effect. The dehydration rate graph shows that the dehydration rate of the silt gradually decreases from high to low and approaches zero, following a trend similar to an exponential function. This method can more accurately reflect the impact of different types of flocculants on the dehydration performance of silt, which is more reliable than observing the turbidity of the supernatant.

(4) Soilbags exhibit good compressive strength, and the material inside the bags has little influence on this strength.

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