Experimental study on sludge adhesion reduction using surface electro-osmotic pulse

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Abstract. The dewatering and drying of sludge are important to achieve volume reduction and resource utilization, while the sticky properties of sludge is one of the main problems in the dewatering and drying process. Therefore, reducing the viscosity of sludge and the amount of sludge adhesion is critical to improving the operating efficiency of drying equipment. In practice, the surface electro-osmosis has been used to reduce the adhesion of soil to a loading shovel, and electro-osmotic pulse is applied to a concrete structure to achieve humidity reduction. In this research, the effect of surface electro-osmosis pulse on reducing the adhesion of sludge is studied by using a periodically changing electric field combined with surface electroosmosis technology. The results showed that with surface electro-osmosis pulse, the sludge adhesion stress is reduced from 1514.7 to 820.5Pa at 45% water content within 10s, which indicates that surface electro-osmosis pulse has application value in dewatering and drying process.

1. Introduction

In recent years, China's sewage treatment industry has grown rapidly, and subsequently a large number of modern sewage treatment plants have been built. At the same time, sludge treatment and disposal problem has become a critical issue. The sludge contains extremely complex organic matter and a certain amount of heavy metal elements. It is usually in the form of a gelatinous liquid, which is perishable and odorous. Without proper treatment, the sludge will cause pollution to soil, water and the atmosphere, resulting harm to the environment [1]. According to [2], in 2015, the annual wet sludge production in China exceeded 40 million tons, and that number will continue to increase rapidly in the next few years.

Different measures have been taken to achieve more efficient volume reduction and resource utilization of sludge. Mechanical dewatering is the most commonly used dewatering method in sewage treatment plants due to its easy operation at low cost. However, after mechanical dewatering process the moisture content of the sludge is still as high as 75%-85%, so the sludge needs to be dried. After the drying process, the interstitial water, the surface adsorbed water and the internal combined water can be completely removed. Since the volume is greatly reduced, and the properties are also more stable, the negative impact of the sludge is weakened [3]. In landfill, incineration, and agricultural use, dewatering and drying of sludge are indispensable processes.

In the dewatering and drying process, the sticky phenomenon becomes one of the main problems. The sticky properties can be divided into two main types. One is adhesion that is the viscosity produced on the contact surface between sludge and another substance. And the second is cohesion,
which means the interior of the sludge has a tendency to integrate as a group. Sludge with sticky phenomenon has strong adhesive and cohesive stress. Many experiments and studies have shown that the physical and chemical properties of sludge are changing during the reduction of sludge moisture content [4,5,6]. When the water content decreases to 40%-60%, the adhesion and cohesion stress become the dominant part, and this phase is called sticky area [7,8].

The sticky properties of sludge will certainly have adverse effects on the dewatering process. The sludge adhering to the wall of the drying device sharply increases the heat transfer resistance, and the drying rate is significantly reduced. At the same time, the drying device needs to be cleaned more frequently, so the cleaning workload is greatly increased. On the other hand, the sludge adhered to the wall of the drying device is excessively dried due to prolonged heating, which is likely to cause safety problems. In addition, due to the viscosity of the sludge, the agitation and mixing effect of the device is deteriorated, which seriously affects the drying and dewatering process, and the drying efficiency is reduced. At the same time, the torque required for agitation is greatly increased, the energy consumption of the equipment is also increased.

Therefore, dealing with the sludge viscosity characteristics and reducing the amount of sludge adhesion is important to improving the operation efficiency of the drying device and achieving volume reduction and resource utilization of sludge.

In bionics, the bioelectrical test of earthworm has shown that the surface electroosmosis of the organism is completely different from the traditional separated electro-osmosis [9]. This surface electroosmosis causes the hydrated cations close to the body surface to flow toward the contact surface, improving the interface water lubrication, thereby increasing the thickness of the interfacial water film, and reducing the friction and adhesion of the soil.

Conventionally, the soil-contacting part has been taken as the negative pole and the soil as the positive pole. The negative and positive poles are thus on different surfaces. This conventional method is called separate electro-osmosis [10]. A high voltage is needed to give a significant effect by separate electro-osmosis since the distance between the two poles is large and the electric field for electro-osmosis is very low, which means the consumption of energy is high. Therefore, the separate electro-osmosis method is difficult and expensive to apply in engineering. But the electro-osmosis structure of an earthworm is different from that of the separate electro-osmosis technique. Its negative and positive poles are on the same surface, and this electro-osmosis method is called surface electro-osmosis.

In practice, the surface electro-osmosis was used in the operation of the loading shovel. The results showed that if the surface electro-osmosis scheme was adopted, the applied voltage value could be greatly reduced. The results also showed that the adhesion of soil to a shovel could be substantially reduced even the applied voltage value was at 12V [11]. In addition, Wang et al., 2011 and Yu et al., 2014 applied electro-osmotic pulse to the study of permeability and moisture resistance of concrete structures, and the results showed that the effect of dewatering and humidity reducing are remarkable when electro-osmotic pulse is applied in concrete structure [12,13]. Furthermore, Cong et al., 2000 analyzed the influence of water content of coal and the positive pressure on the tangential resistance between coal and working parts, and surface osmosis technology was applied to reduce the tangential resistance of coal [14]. The results showed that the surface electro-osmosis method could effectively reduce the tangential resistance of coal, and the electrode distribution might have a great influence on the electro-osmotic effect.

In this paper, inspired by the application of surface electro-osmosis and electro-osmosis pulse in mechanical and architectural fields, the effect of surface electro-osmosis on sludge viscosity characteristics is studied by using periodically changing electric field combined with surface electro-osmosis technology. The steel bars put in the grooves of the steel plate serve as the positive and negative electrodes. By comparing the adhesive stress of sludge on the contact surface over time, the effect of surface electro-osmosis adhesion reduction can be revealed.
2. Materials and methods
The sludge sample was taken from Shanghai Songjiang Wastewater Treatment Plant (water content is 82% wet basis) and sludge with water content of 35%, 45%, 60% and 70% were produced using electrothermal drying oven. The sludge samples were refrigerated at 4°C for later use, and the sludge was dried at 105°C for proximate and ultimate analysis. The results are shown in Table 1.

| Moisture (%) | Ash (%) | Volatile (%) | Fixed carbon (%) |
|--------------|---------|--------------|-----------------|
| 2.0          | 31.6    | 60.5         | 5.9             |

Table 1. Proximate analysis of dried sludge.

The test device for measuring the shear stress of sludge using plate method is shown in Figure 1 and Figure 2. The device is mainly composed of a stainless-steel plate, a hollow cylinder and a metal block. The value of adhesion stress can be determined by measuring the shearing stress of the sludge on the surface of the metal plate. The plate method is simple and reliable, and is not limited by water content. The size of the stainless-steel plate is 300mm×200mm. The bottom plate is engraved with several 5mm deep grooves. The steel bar in the size of 300mm×6mm×5mm is used as the positive and negative electrodes. The wire is connected to the waveform generator and the DC power supply to produce a periodically changing electric field. The area of the positive and negative electrodes can be flexibly arranged, and the ratio of the area of the positive and negative electrodes can vary from 1:1 to 1:14 by changing the number of positive and negative steel bars. The stainless-steel plate is covered with a plexiglass cover to eliminate safety issues.

![Figure 1. The schematic diagram of the test device using plate method.](image-url)
When the experiment began, about 50 grams of the sludge was placed in a hollow plastic cylinder, and then a metal block was placed over the sludge to squash it into a thin plate. A thin string was connected between the plastic cylinder and the tray through the fixed pulley. After the surface electro-osmotic pulse was applied for a period of time, some tiny steel balls were added to the tray until the plastic cylinder began to move, and the number of steel balls was recorded. The weight and the number of steel balls could lead to the maximum adhesive stress of the sludge. Compare this value with the one without surface electro-osmosis, and the effect of this method to reduce adhesive stress and sludge adhesion could be revealed.

3. Results and discussion
When the voltage is 12V, the area of the positive and negative electrodes is 1:1, and the duty ratio is 50%, the test data is showed in Figure 3. Before the surface electro-osmotic pulse is applied, the adhesive stress of the sludge with moisture content of 35%, 45%, 60% and 70% are 1155.0Pa, 1514.7Pa, 1486.3Pa and 1177.1Pa respectively. It is clear that when the surface electro-osmotic pulse was not applied, the initial adhesive stress of the sludge with moisture content of 35% and 70% is significantly less than that of the sludge with a water content of 45% and 60%, which complies with the characteristics of sludge when it is in the sticky area. After surface electro-osmotic pulse is applied, the adhesive stress of sludge with different water content all decreases, just as predicted. When the time reaches 10 seconds, the adhesive stress of the sludge with water content of 45% decreased from 1514.7Pa to 820.5Pa, which is the biggest drop. However, when the time exceeded 10 seconds, except for the slight decrease in sludge adhesion with a water content of 35%, the other three sludges increased to some extent. When the time reaches 20 seconds, the adhesive stress of sludge with a water content of 60% continues to rise, but the other three sludges are likely to remain stable. The possible reason is that when the water content decreases, there will be a dramatic increase in the adhesive stress of sludge, but the surface electro-osmotic pulse makes the concentration of water and hydrated cations higher. As a result, the thickness of the interfacial water film is enhanced, and adhesive stress of sludge on the contact surface is reduced. Since the water would seep through the gaps between the steel bars, the water content of sludge close to the contact surface would drop with time, and the adhesive stress may continue to rise.

The percentage of maximum adhesive stress reduction obtained by the ratio of the lowest adhesive stress value to the initial value is shown in Figure 4. The chart shows that the maximum adhesive stress reduction percentage is above 20% for the sludge with different water content. For the sludge with water content of 45%, the surface electro-osmotic pulse reaches its optimum effect, as the maximum adhesive stress reduction percentage reaches 45.80%. The results suggest that, by applying the surface-osmotic pulse, the adhesive stress of sludge is significantly reduced.
Figure 3. The change of adhesive stress over time.

Figure 4. The maximum adhesive stress reduction percentage under different water content.

4. Conclusions
The effect of surface electro-osmotic pulse on reducing sludge adhesion stress is studied under specific electro-osmotic voltage, certain ratio of positive and negative electrode area and constant duty ratio. The influence of voltage value and electrode distribution, and the relationship between surface electro-osmotic pulse and voltage are not included, so further studies are required.

The experimental results show that the surface electro-osmotic pulse can reduce the adhesion stress of the sludge to a certain extent in a short time. The adhesion stress will continue to rise after reaching the lowest point, but it is still lower than the initial stress value. The surface electro-osmotic pulse has significant effects in reducing sludge adhesion stress, and has application value in sludge dewatering and drying process.

Since the adhesion stress of the sludge during the experiment is determined by observing the number of steel balls placed in the tray when the plastic cylinder starts to move, there is still a certain error in the experimental measurement process.

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