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The Electro-Dewatering of Sludge Using Adsorptive Material

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Abstract. Electro-dewatering (EDW), enhancing conventional pressure filtration by applying an electric field, is an emerging technology with a potential to improve dewatering efficiency especially for sludge, but high power consumption limits its application in industries. In a traditional electro-dewatering process, the water removed by electro-osmosis is separated from the cathode or filter cloth by gravity. To solve this problem, in this paper a porous material, which is easy to regenerate by pressing, is proposed to separate the water from the cathode by adsorption instead of gravity separation. Consequently, much more water from the sludge can easily be separated and removed in combination of EDW and adsorption; meanwhile, the electric current through sludge is depressed, resulting in lower power consumption. Also a model is presented in which the sludge cake consists of two parts: a dewatered bed and a dewatering bed. The model describes the variation of water content with time and the electric power consumption as a function of water content in sludge cake. The result shows that the method is feasible.

Keywords: sludge, electro-dewatering, adsorptive material, power consumption

1. Introduction

Sewage sludge produced at wastewater treatment plants is generally called bio-solid sludge. Due to large amount and higher water content, the disposal and treatment of sludge become more expensive and the regulations are becoming even tighter. Its increasing volume makes also the transportation more difficult [1-3]. The processes to reduce sludge volume usually include concentrating, dewatering [4], drying [5-7], combustion [8], and so on. After a concentrating process, the sludge water content can be 95%-97% w/w. Through a dewatering process, the sludge water content can be decreased to 50%-80% w/w. Sludge dewatering can be accomplished by freeze-thaw, centrifuge force, mechanical press, electro-osmosis and so on. The freeze-thaw method is capable of decreasing the water content of sludge to 50%-60% w/w [9], but the consumption of energy limits its application. The centrifuge process and mechanical press, two common sludge dewatering methods being used in wastewater treatment plants in China, are necessary to reduce the water content of sludge to 65%-85% w/w, whereas the bound water may not be removed efficiently. For further removing of water from sludge, thermal drying – an energy intensive process should be applied.

Electro-osmosis, an interfacial electro-kinetic phenomenon, can be applied to enhance dewatering performance of a solid-liquid mixture such as a colloidal material. Electro- dewatering (EDW) is carried out in an external direct current (DC) electric field to the semisolid material, and the dewatering is caused by mass transfer in an electric double layer occurring on the interface between the surface of solid particles and liquid in the material [10].

Electro-dewatering has several advantages compared with mechanical dewatering used conventionally, and it is particularly effective for very fine particle sludge, gelatinous material and biological sludge, which are difficult to dewater by mechanical methods. Through an electro-dewatering process, much more free water between the sludge particles and surface water can be dewatered [11-13]. Barton removed the water of

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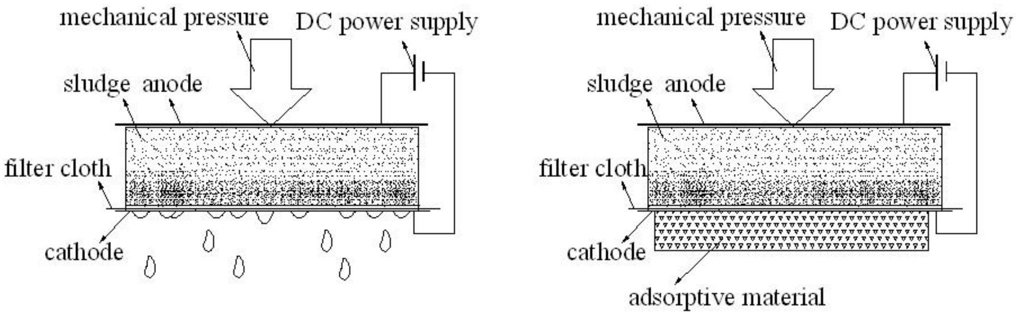
sludge to 54%-65% w/w through electro-dewatering process with mechanical press and polymer electrolytes [14].

Higher dewatering rate and lower water content of sludge show the potential application of electro-dewatering, but power consumption on the other hand restricts its application. Some studies have been made to improve dewatering rate and reduce power consumption, such as research on potential gradient and processing time [11], applying AC or pulse electric field [12,15], or dewatering in a horizontal electric field [13]. Ho and Chen [16] found significant enhancement of the electro-osmotic dewatering performance with a rotating anode and the dewatering cost is less than 20% of the latent heat of water evaporation. However, how to improve the water removal efficiency is still a challenge to EDW process.

The adsorptive material was used in this research to separate the water removed by electro-osmosis in DC electric field and accumulated on the cathode and in a filter cloth instead of gravity separation. The adsorptive material is soft and bibulous, and easy to regenerate by pressing. The effects of the electric potential on the processing time and power consumption were also analyzed.

2. BASIC PRINCIPLE OF THE ADSORPTIVE EDW

In a conventional EDW process, as shown in Fig. 1(a), the water inside sludge moves to the cathode by mechanical pressure and electro-osmosis, and then goes through the filter cloth and is finally separated by gravity. Due to much water contained both in the sludge layer near to the cathode and in the filter cloth, which is difficult to remove simply by gravity, the efficiency of EDW is decreased at the final stage of EDW. In order to overcome this problem, an adsorptive material was set below the cathode as shown in Fig. 1(b) to improve the water migration rate and increase the mass of removed water by making use of its intrinsic characteristics. The material is porous and bibulous, so it is easy to regenerate by gentle mechanical pressing.



(a) (b)

Fig. 1 The schematic of EDW using (a) gravity separation and (b) adsorption separation

3. MATERIALS AND METHODS

3.1. Sludge

The sludge cake combines the primary and secondary sludge as obtained from a local wastewater treatment plant. The sludge samples have 74%-77% w/w water content, the solids contained 55.4% w/w of organics, and pH was equal to 7.1 after concentrating and mechanical pressing.

3.2. Electro-dewatering experiments

Fig. 1 shows the schematic of experimental EDW apparatus. The electro-osmotic cell is 70mm in diameter. About 21g of the material as a layer 5mm thick was inserted into the cell in between of two stainless steel web electrodes (0.5 mm thick and 0.425 mm of aperture width). The filter cloth (0.2 mm or 0.4 mm thick) was placed on the cathode mainly to maintain the sludge cake as a whole but percolate the water through it. The continuous DC through the material was measured with a multimeter. The constant pressure of 6400 Pa, was applied by placing a weight during the electro-dewatering. The time of EDW was set to 3, 7 and 10 min. The adsorptive material was made of polyurethane with 80 kg/m3 of density and 10 mm thick. During EDW experiments, the mass of water separated from sludge sample was measured with balance. The measurement precision of voltage, current, and mass is 1V, 0.001A, and 0.01g, respectively. The reproducibility of experimental data can be controlled within 10%.

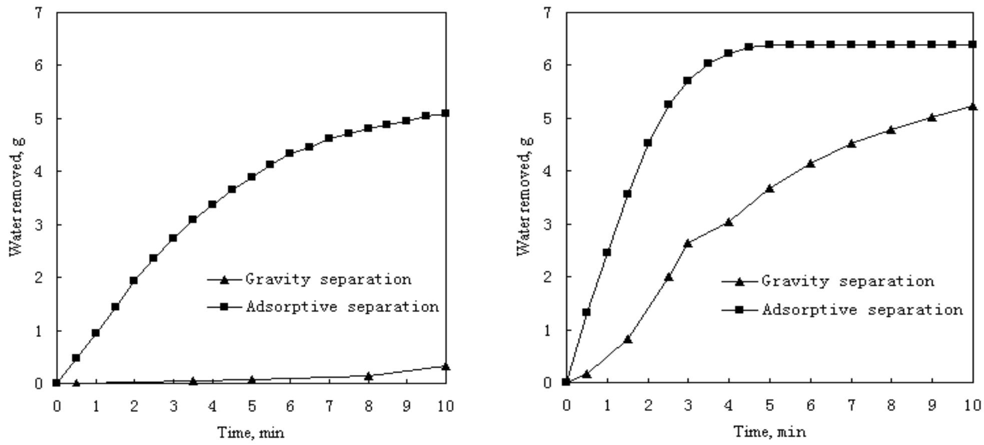
4. RESULTS AND DISCUSSIONS

4.1. Comparison of EDW with different separation methods

In order to compare the results of the two methods, the water mass separated and the current through the tested material were recorded and shown in Fig. 2 & 3 with applied voltages 10 V and 20 V.

4.1.1. Water mass separated

Fig. 2 shows that the EDW process with adsorptive separation can clearly improve the dewatering efficiency. When the voltage of 10 V is applied, the water separated from the sludge cake by gravity is insignificant. The mass of water separated was only 0.33 g and the sludge water content was just depressed to 73.6% w/w when the EDW experiment was finished. If the adsorptive material was applied, however, 5.09 g of water was separated, and the sludge water content reduced to 65.7% w/w. The same results were found for higher voltage (20 V). Finally, 5.23 g of water was separated by gravity giving final water content of 65.4% w/w. The respective numbers for adsorptive separation were 6.38 g of water and 62.7% w/w of water content. Clearly, applying high voltage can increase the water removal in the EDW process by gravity.

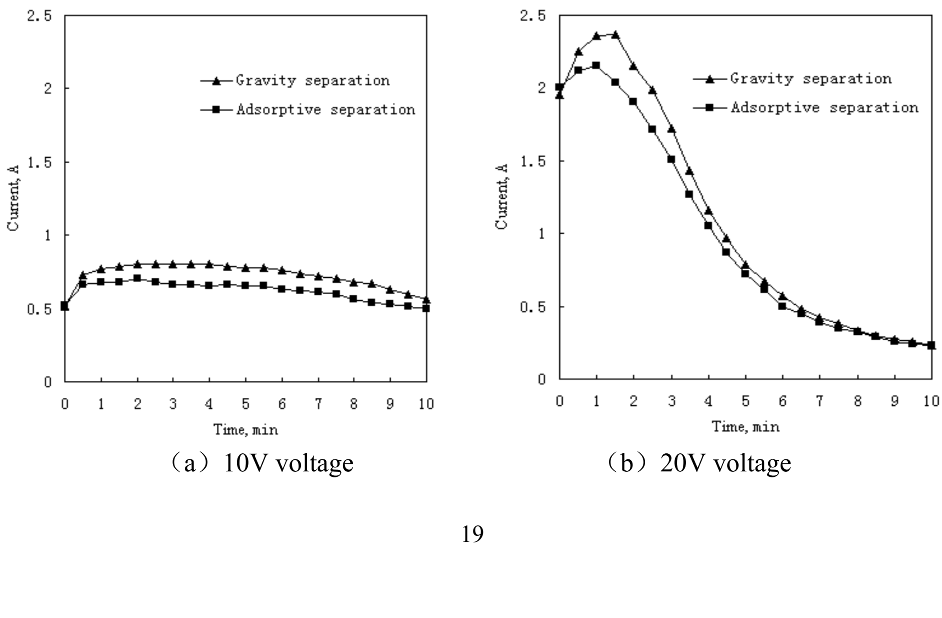


（a）10V voltage （b）20V voltage

Fig. 2 Variation of water removed in EDW process of sludge (Filter cloth 0.4mm thick)

4.1.2. Current through sludge sample

Fig. 3 shows the current variation in the sludge sample during the EDW processes. With adsorptive material applied, the current through the sludge sample is lower compared to that by gravity under the voltages of 10 V and 20 V. So the adsorptive separation can not only improve the water removal efficiency but also reduce the power consumption of EDW process due to low current.



（a）10V voltage （b）20V voltage

Fig. 3 Variation of current in EDW process of sludge (Filter cloth 0.4mm thick)

4.1.3. Final water content distribution

Under constant voltage of 30 V, the final distribution of water content in sludge cake is shown in Fig. 4. It can be seen with absorbent water materials, water content near the cathode decreases significantly, and water content near the anode decreases only slightly, with regard to the case without absorbent water materials.

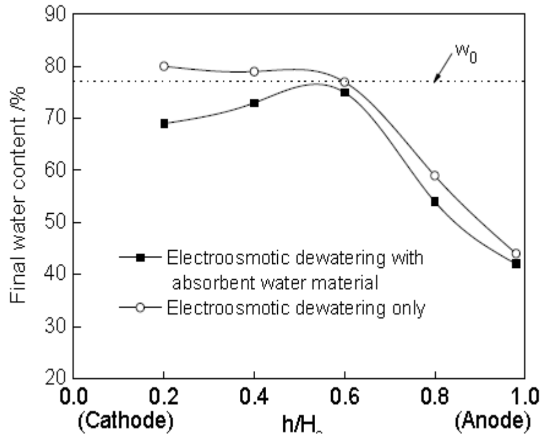


Fig. 4 Final water content distribution combined with absorbent water materials under constant voltage

4.1.4. Water content of sludge on the side of cloth

In order to test the effect of adsorptive material on water content in the filtrated sludge cake that trapped inside the cloth and in the cake above the cloth, about 2 mm-thick sludge layer above the cloth was scraped and its water content was measured, which is termed as the moisture content of cloth-side sludge. Moisture content based on the entire sludge cake is termed as whole average moisture content. The results are listed in Tab 1.

Tab 1 Variation of water content of sludge after EDW processing time of 10min

Cloth thick (mm)	Voltage (V)	Separation method	Water mass (g)	Average water content of sludge (%)	
				Cloth-side	Whole
0.2	10	Gravity separation	4.23	77.5	67.4
0.2	10	Adsorptive separation	6.11	75.6	63.3
0.2	20	Gravity separation	8.52	73.0	56.3
0.2	20	Adsorptive separation	8.95	70.4	54.7
0.4	10	Gravity separation	0.33	78.8	73.6
0.4	10	Adsorptive separation	5.09	76.9	65.7
0.4	20	Gravity separation	5.23	73.6	65.4
0.4	20	Adsorptive separation	6.38	71.2	62.7

It can be found from the results that with thinner filter cloth (0.2 mm) and at higher voltage, either the average water content of whole sludge cake or that of the cloth-side sludge layer near to the cloth was decreased to the most. Table 1 also shows that the adsorptive separation can easily reduce the water content of the sludge layer adjacent to the cloth and improve the water removal efficiency in EDW process rather than applying different clothes and voltages.

4.2. Effect of operating conditions in EDW using adsorptive material

The discussion above shows that adsorptive separation can improve water removal efficiency and reduce power consumption in EDW. It is a technically feasible and effective method to improve the performance of sludge dewatering, but its operating conditions and parameters should be tested by experiments in order to meet the need of application.

In the following experiments, the sludge sample of 77% w/w water content was used. The applied voltages were 6 V, 10 V, 20 V and 30 V and the processing time of EDW were 10 min, 7 min, 3 min and 3 min, respectively. The thickness of filter cloth applied was 0.4 mm. The results are shown in Fig. 5.

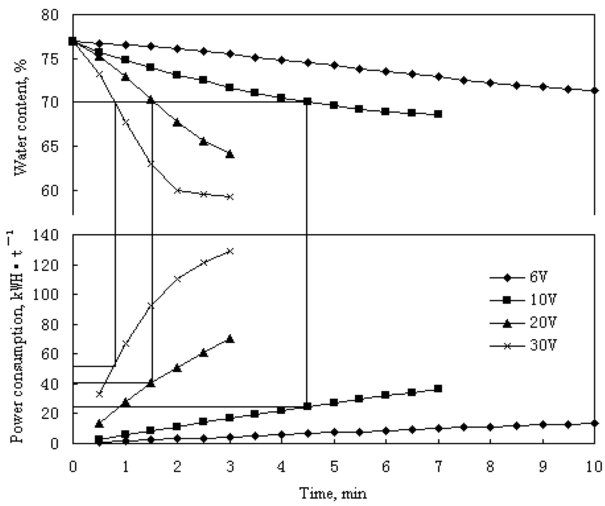


Fig. 5 Variations of water content and power consumption in adsorptive EDW

(Filter cloth 0.4mm thick)

4.2.1. Voltage and processing time

To reduce power consumption, the lower voltage is often used, but Fig. 4 shows that at lower voltage it is difficult to remove more water and also the processing time extends. When the test was performed under 6V voltage for 10 min, the water contents of the sludge cake reduced only to 71.4% w/w. It will take longer processing time to attain lower final water content. But when 10V voltage was applied for 7 min, the final water content decreased to 68.6% w/w. If 20 V and 30 V voltages were applied in EDW, the water contents could be decreased respectively to 64.1% w/w and 60% w/w under the processing time of 3 min and 2 min.

4.2.2. Power consumption

To evaluate the operation economy, the power consumption was calculated from the following Equation 1:

$$P = \int UId\tau \Big/ m_s \qquad (1)$$

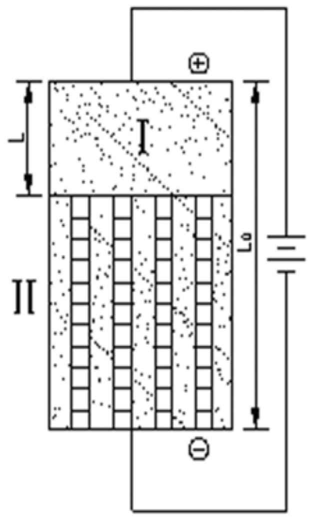
Where P is the power consumption per ton of wet sludge (kWh/t), U is the voltage (V), I is the current (A), m_s is the mass of wet sludge, and τ is the processing time (min).

As clearly shown in Fig. 4, higher voltage applied increases the power consumption. If the water content of sludge needs to be decreased to 70% w/w with adsorptive EDW, there are three levels of voltage which can be applied, that is, 10 V, 20 V and 30 V. Respectively, the power consumption is 25 kWh/t, 41 kWh/t and 53 kWh/t, and the processing times are 4.5 min, 1.5 min and 0.8 min.

5. MATHEMATICAL MODELS

The sludge cake being dewatered by electro-osmosis can be approximately represented by a simple model, as schematically shown in Fig. 6. During the electro-osmotic dewatering, the sludge cake in this model is divided into two parts: in one part dewatering is proceeding, and the other dewatering has finished. As shown in Fig. 6, the upper part Ⅰ is a dewatered sludge bed having a terminal water content corresponding to the applied electric field, from which all liquid flows out, and immovable water is only left in this part.

The lower part Ⅱ is a dewatering sludge bed having the same water content as an initial water content, and the liquid-filled pores have been idealized as cylindrical capillaries.



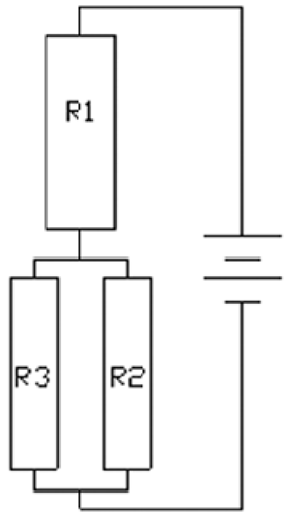


Fig. 6:Schematic diagram of electroosmotic dewatering model of sludge cake

Fig. 7:Chart of electrically conductive mode of sludge cake

In Fig. 7, $R1$ denotes the conductor Ⅰ of Fig. 6, $R2$ denotes the solid conduction (the unmovable water and sludge particles) of the conductor Ⅱ, and $R3$ denotes the conductor of movable water of the conductor Ⅱ.

A mathematic model, describing the relationships among the average water content in sludge cake, the initial electric field strength, the thickness of sludge cake and the dewatering time can be obtained as following equation 2:

$$x = \frac{-K_1 + \sqrt{K_1^2 - 2K_2\left(K_3\kappa(x_0 - x_c)^2 x_0 \cdot \frac{V_0}{L_0} \cdot \frac{t}{L_0} - \left(K_1 x_0 + \frac{1}{2}K_2 x_0^2\right)\right)}}{K_2} \quad (2)$$

Where κ is called the electro-osmotic dewatering coefficient, x_0 is the initial water content of sludge cake, x_c is the terminal water content of sludge cake, L_0 is the initial thickness of sludge cake, V_0 is the constant voltage applied to the sludge cake, t is the dewatering time.

$$K_1 = R_0 x_0 - \frac{R_0 R_0'}{R_0 + R_0'} \cdot x_c \quad (3)$$

$$K_2 = \frac{R_0 R_0'}{R_0 + R_0'} - R_0 \quad (4)$$

$$K_3 = \frac{R_0 R_0'}{R_0 + R_0'} \quad (5)$$

Where R_0 is the sum of electric resistance values of $R1$ and $R2$, $R_0'$is the initial value of electrical resistance for movable water in sludge cake before electro-osmotic dewatering, and they can be obtained directly from the experiment.

The energy consumption can be calculated by the following equation 6:

$$\mathrm{P} = \frac{(R_0 + R_0')(x_0 - x_c)^2 \cdot V_0^2 \cdot t}{L_0 A(x_0 - x)(R_0^2 x_0 + R_0 R_0'(x_0 - x_c) - R_0^2 x)} + C \quad (6)$$

Where *A* is is the cross sectional area of sludge cake, *C* is a corrected parameter, it reflects that the influence of thermal effect of sludge cake and electrolysis at electrodes in practice on the energy consumption during electro-osmotic dewatering, and it can be obtained from experiment.

6. CONCLUSIONS

Due to adsorptive material applied in EDW process, more water from sludge can be easily separated and removed compared to that by gravity, and the current through the sludge was depressed and meanwhile the power consumption decreased.

Higher voltage is still an essential factor in EDW with adsorptive separation. An optimal process should take into consideration not only the water removal efficiency and processing time but also the power consumption. The experiments show that, when voltages of 10 V, 20 V and 30 V were applied to decrease the water content of sludge from 77% to 70% w/w in EDW using adsorptive material, the power consumption was respectively 25 kWh/t, 41 kWh/t and 53 kWh/t, and the processing times were 4.5 min, 1.5 min and 0.8 min, respectively.

The electro-osmotic dewatering model under constant voltage has been developed from electrically conductive mode of sludge cake. The model describes the variation of water content in sludge cake with time and the energy consumption as a function of water content during electro-osmotic dewatering. Well we need to do much to inspect the accuracy of the model.

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