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Development and Performance Evaluation of Electrodewatering System for Sewage Sludge Recycling

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Abstract

A laboratory-scale electrodewatering system for enhancing conventional filter pressure dewatering by an electric field has been developed to decrease the water content of sludge generated in the wastewater treatment. It consists of a piston-typed filter press, a power supply and data acquisition system. The effect of electrodewatering is investigated as a function of applied pressure, applied voltage, sludge type and filtration time. Also the optimal conditions for maximizing the dewatering efficiency in the eletrodewatering system are investigated. Electric field strength and mechanical pressure are in the range of from 0 to 120 V/cm and from 98.1 to 392.4 kPa. The dewatering rates increased with increasing electric strength. These experiments produced a final sludge cake with water content of 60 wt% using electrodewatering technology, compared with a 80 wt% using pressure filtration alone. The conventional filtration system using the electrodewatering shows the potential to be effective method for improving dewatering Sludge.

Key words: Sludge Recycling, Electrodewatering (EDW), Electrophoresis, Electroosmosis, Electric Field Pressure, Water Content

Introduction

The dewaterability of sewage sludge is generally considered to be poor, with typical dewatered products containing about 80 wt% water content. Since the disposal and reuse of sludge cake produced from wastewater treatment plants is becoming more tightly regulated and expensive, there is an increasing demand for technology that substantially improves sludge dewaterability. This would lead to a substantial reduction in the downstream costs of transport and disposal. EDW occurs when a direct voltage is applied to a fine aqueous suspension of particles, and involves the transport of charged particles and associated counteractions towards electrodes of opposite polarity.

The principles of electro dewatering

The electrodewatering become the ideal method for the further removal of water trapped in the rather compacted swage sludge because its mechanism is based on the electrostatic effects operating in the electrochemical double-layers formed at the sludge particle-water interfaces obtaining in swage sludge.

Fig. 1. shows schematically the process of electroosmotic dewatering combined with pressure filtration. In the case of electroosmotic dewatering only, decrease of water content in the sludge starts from the upper part of the bed, but at the end of dewatering a lot of water still remains in the lower part. On the other hand, pressure filtration proceeds from the lower part of the bed, if the top surface of the bed is an impermeable face.

A long time is ordinarily needed in the pressure filtration. Finally, a uniform sludge bed with water content which corresponds to the applied mechanical pressure is formed at an equilibrium state [Yoshida,1993]. As described above, the electrodewatering process due to electroosmosis is fairly different from that of pressure filtration. Since electroosmotic dewatering and pressure filtration are complementary each other, a combination of these dewatering operations must be a useful means for improvement of electrodewatering. That is to say, this combined method proceeds from both the upper and lower parts of sludge bed, and it can be expected to improve the dewatering rate and the terminal water content in the sludge.

Electrodewatering occurs when a direct voltage is applied to a fine aqueous suspension of particles, and involves the transport of charged particles and the migration towards electrodes of opposite polarity. Thus, electrodewatering involves electrophoretic, electroosmotic phenomena, and coulombic heating effects, which all have a major influence on both the rate and extent of dewatering. Electrophoresis is the movement of the particles within the liquid sludge, which predominates during filtration. During the initial stages of dewatering, the particles are still free to move in the fluid suspension. Since the particles are usually negatively charged, they will tend to migrate towards the anode located at the top of the filtration cell, thus delaying the onset of cake formation on the lower filter medium and hence leading to enhanced water flow.

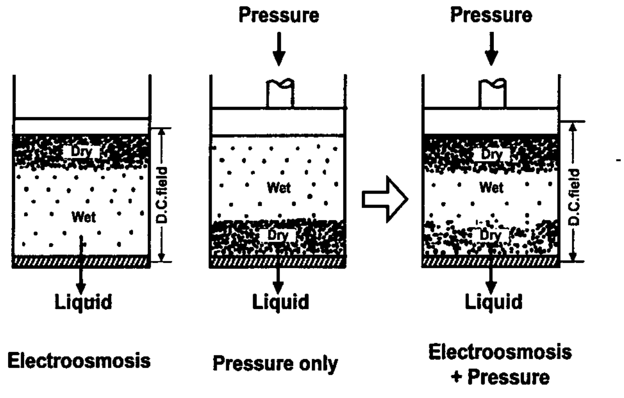
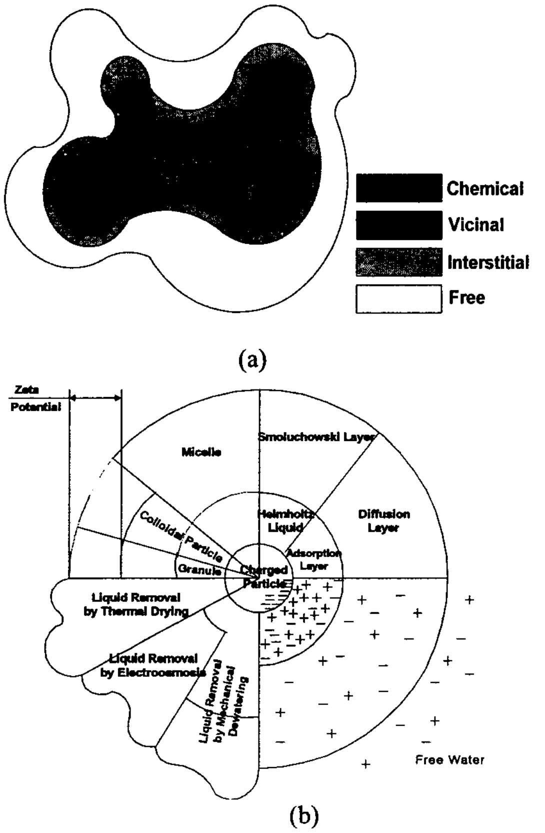


Fig. 1. Schematic diagram of combined dewatering process of electroosmosis and pressure [Vijh and Novak. 1997].



(a)

(b)

Fig. 2. The characteristics of sludge in the liquid, (a) water distribution in sludge-floc, (b) sludge-particle liquid in an electric double layer [Smollen and Kafaar, 1994]

Electroosmosis is the movement of the liquid phase through the pores of the filter cake, which predominates during filtration. In proportion to the negative potential of the particles, the surrounding liquid in the capillary gets the positive potential, which is known as the electric double layer in capillary tubes. Therefore, the liquid in the capillary is attracted to the cathode, and the water moves smoothly through the filter cloth on the cathode. Coulombic heating is due to the passage of a current though the sludge, leading to a reduction in the viscosity of the water and hence enhancement in dewatering kinetics. Coulombic heating becomes more significant as cake water content falls and the electrical resistance of the cake rises [Barton et al., 1999].

Fig. 2 shows the characteristics of sludge in the liquid. Sludge consist of a combination of solid phase with a certain quantity of liquid. Behaviour of this liquid is often wrongly assumed to be the same as that of ordinary water. There are different physical forms of water in sludge and these different forms play an important role in determining the ease or difficulty of phase separation. Fig. 2 (a) shows water distribution in sludge. The water is distributed into the following four parts in sewage sludges; free water did not associate with or influenced by suspended particles, interstitial water physically trapped within flocs or microbes that becomes free water if the flocs or microbes are destroyed, vicinal water involved water molecules held to the surface of hydrogen bound particles, and chemically bound hydration water removed thermally.

Fig. 2 (b) shows the particles and liquid of sludge in an electric double layer in relation to the water removal method. It is most important to investigate and interpret the physical and chemical phenomena that occur on the surface of sludge particle which is a part of a sludge. The prime characteristic of sludge particles is their large surface area. This provides not only a highly chemically active surface area but also allows for water to be held by absorption. Sludge particles are negatively charged. This charge is acquired by preferential absorption of ions from the solution. The combined system of the surface charge on the particle and the corresponding charge in solution is known as the electrical double layer. It consists of a strongly attracted layer known as Helmholtz liquid and diffused layer known as Smoluchowski liquid [Smolloen and Kafaar 1994].

Experimental

Materials

All sludge samples used in this study are taken from two of the sewage treatment plants located in Pusan, Korea. All sludges are placed in an ice cooled container immediately after sampling for transport back to the laboratory, where they were transferred immediately to a refrigerator and stored at 4 ℃ until required for experiment. No samples are kept for longer than 5 days. Total solid content and volitile solids are 3.0 % and 13.4 % by weight, respectively.

Table 1. shows that the properties of digested sludges used in this study. The particle size of digested sludges is 31 ㎛ in mass median diameter (MMD) using a particle counter [Malvern Instruments, Master sizer]. The

conductivity of sludges has a value of 670 μ mhos/cm using a conductivity meter [YSI Inc., YSI 3200].

Table 1. Properties of sludges used in the study

Parameters	Range	Average
Initial Water Content (wt %)	96.5~97.3	97.0
TS $^{a)}$ (%)	2.7~3.5	3.0
VS$^{b)}$/TS (%)	32.2~35.4	33.4
Particle Size (㎛)	23~40	31
PH	6.2~7.3	6.8
Conductivity(μ mhos/cm)	620~730	670

a) TS = Total Solids
b) VS = Volatile Solids

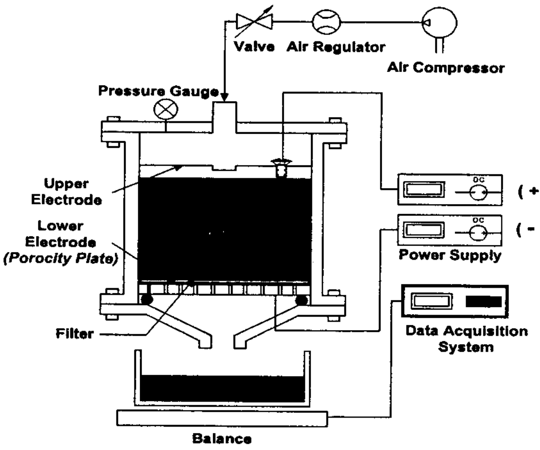


Fig. 3 Schematic diagram of Electrodewatering System

Experimental apparatus and test procedures

Fig. 3 shows an experimental apparatus of the electrodewatereing system. It consists of a cylinder cell fitted with two electrodes, a power supply [Korea Switching Inc. KSC-N300L5CD], balance [OHAUS, GT410], data acquisition systems, and an air compressor. The electroosmotic cylinder cell has dimensions of 70 mm in inner diameter and 500 mm in height as fabricated from 30 mm thick Teflon tube. The test material to be dewatered is inserted into the cell between two circular electrodes, the upper copper electrode piston as the anode (+Ve) and the lower electrode of perforated copper plate as the cathode (-Ve) having a multitude of 3 mm drain holes. Wires are fixed to both the electrodes using epoxy glue and connected to a D.C. power supply. Electricity is supplied to the electrodes in the constant voltage made. A filter cloth made of nylon with 5 ㎛ pore size is placed on top of the perforated plate to prevent the colloidal material from clogging the holes. A plate is placed underneath the lower electrode to collect the water drained from the sample. The sludges are put between two electrodes, and subsequently a D.C. electric field under constant voltage up to 120 V/cm is applied to it.

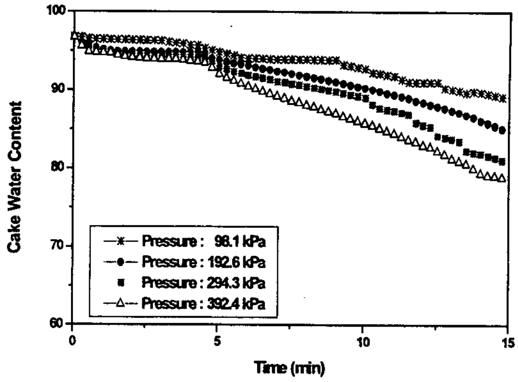


Fig. 4. Relationship between sludge cake water content and different pressure parameters

As the height of the sludge bed gradually decreased with dewatering, the upper electrode is always kept in contact with the top surface of the bed. The piston applies pressure to the sludge forcing water out of the sludge though the perforated plate at the bottom of the dewatering cell upon which the sludge rests. The time changes of dewatered volume, voltage applied between the electrodes, and electric current passing through the sludge bed are measured. The final water content of the sludge cake is determined by drying the cake in an oven at 105 ℃ for 24 hours.

Results and discussion

Fig. 4 shows the result of mechanical pressure dewatering as a function of applied pressure. The sludges of 100 g are placed in the cylinder cell and then applies the different pressure ranged from 98.1 to 392.4 kPa. From the applied pressure of 98.1, 192.6, 294.3 and 392.4 kPa, the water content of sludge cake in the range of 89, 84, 80 and 78 wt%, respectively. For the applied pressure of 98.1 kPa, water content of sludges is 89 wt% at the elapsed time of 15 min. Water content of sludges decrease with increasing applied pressure and elapsed time. Result shows that water content of sludge cakes are not decreased, though pressure strength increase from 294.3 to 392.4 kPa.

Fig. 5 shows the effect of electrodewatering by incorporating an electric field as an additional driving force to a conventional pressure dewatering as a function of electric field at the constant applied pressure of 392.4 kPa. For the electrical field of 0, 40, 80, and 120 V/cm, the final water contents of sludge cakes at the elapsed time of 15 min are 78, 71, 63, and 62 wt%, respectively. The final water content with electrodewatering has reached 62 wt% compared with only 78 wt% with pressure filtration alone. The optimal condition for maximizing the dewatering efficiency in the electrodewatering system is found to be the electrical field

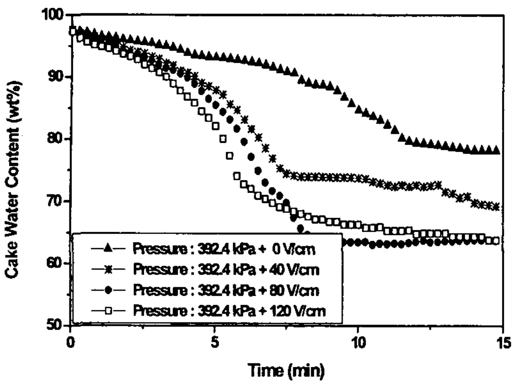


Fig. 5. Test results of the sludge water content in the electrodewatering system as a function of electric field strength.

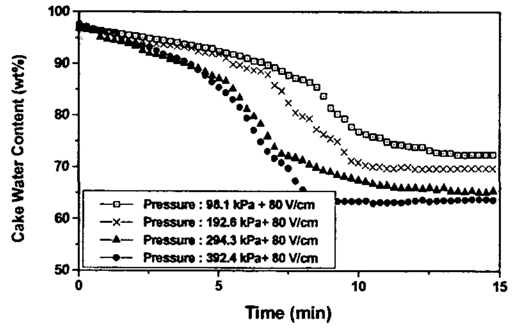
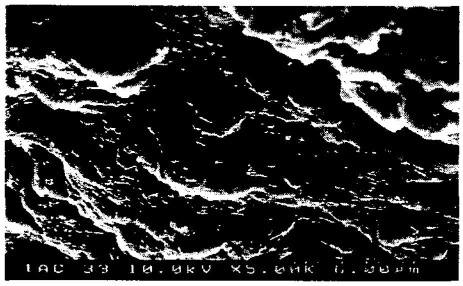
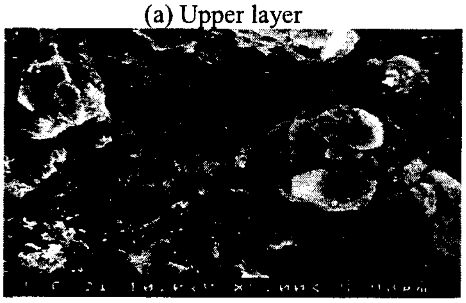


Fig. 6. Test results of the sludge water content in the electrodewatering system as a function of pressure.

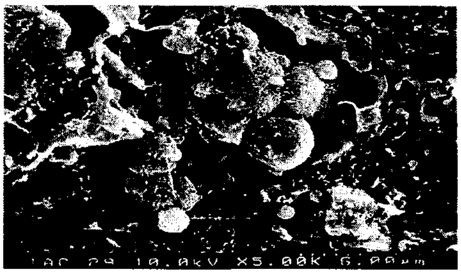


(a) Upper layer

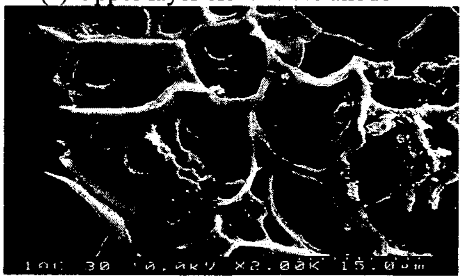


(b) Lower layer

Fig. 7. Scanning electron micrographs of the surfacelayer of dewatered sludge cakes by mechanical dewatering.



(a) Upper layer close to the anode



(b) Lower layer close to the cathode

Fig. 8. Scanning electron micrographs of the surfacelayer of dewatered sludge cakes by electrodewatering

strength of > 80 V/cm. The initial part of the electrodewatering profile, up to 2 minutes, is very similar to the pressure filtration profile, suggesting that the effect of electrophoresis on the rates of filtration and cake formation is not very significant. However, the latter part of the electroosmosis plays the important role in enhancing dewatering. There is no significant rise in filtrate temperature suggesting the absence of coulombic heating. At the final water content of 62 wt%, the power consumed is 1.47 kWh/kgDS. Further research is required to assess the economical aspects taking into account the cost of subsequent treatment processes and transporting wastes by reducing their volume and weight by the pilot scale system.

Fig. 6 shows that the effect of pressure under the constant applies electric field. Final sludge cake water content was not particularly marked within the 98.1 to 392.4 kPa range in which most practical conventional filter presses operate. Below 196.2 kPa performance deteriorated, probably reflecting the need for some pressure to maintain good electrical contact between the sludge and electrodes, in addition to reduction in the dewatering force. The final sludge cake water content in the range of 74, 70, 64, and 62 wt% is found to the pressure of 98.1, 196.2, 294.3, and 392.4 kPa, under the constant applies electric field of 80 V/cm.

Fig. 7 shows the electron micrographs of different magnifications of the surface layer of cake dewatered with mechanical pressure filtration. Fig. 7 (a) shows the upper side of the dewatered sludge cake. Deviant presence of particles are not observed as in the dewatered cake. Fig. 7 (b) shows the lower side of the dewatered sludge cake. A layer of sludge in close vicinity of filter medium is ordinarily compacted, that is, porosity in that layer is reduced by fluid pressure.

Fig. 8 shows the scanning electron micrographs of different magnifications of the surface layer of the cake dewatered with EDW to a 58 wt% water content. It shows the negative potential of the particles is created through two different phenomena; electrophoresis and electroosmosis. The electrophoresis phenomena in the anode side and the capillary tubes which is made as the electroosmosis phenomena in the cathode side. Fig. 8 (a) shows the anode side of the dewatered sludge cake, and illustrates that the particles are moved by electrophoresis, so it is prevent filter blacking phenomenon. Fig. 8 (b) shows the cathode side of the dewatered sludge cake, it found that the capillary tubes. In proportion to the negative potential of the particles, the surrounding liquid in the capillary has a positive potential, which is known as the electric double layer in capillary tubes. Therefore, the liquid in the capillary is attracted to the cathode. Thus, the water moves smoothly through the filter cloth on the cathode since few particles, which usually cause clogging, deposit along the cathode as a result of electrophoresis.

Conclusion

A laboratory-scale electrodewatering system by incorporating an electric field as an additional driving force to a conventional pressure dewatering has been developed to decrease the water content of sludges generated in the wastewater treatment. The electrodewatering involving the combination of electric field and pressure enhances both the dewatering rate and final dewatered volume. The water content of sludges in the electrodewatering system can be reduced to 62 wt%, as compared to 78 wt% achieved with the pressure filtration alone. The optimal conditions for maximizing the dewatering efficiency in the electrodewatering system are found to be the electrical field strength of > 80 V/cm and the mechanical pressure of > 294 kPa. The electrodewatering system shows the potential to be an effective method for reducing the water content in sludges.

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