Korean J. Chem. Eng., **19**(1), 41-45 (2002)

Performance Evaluation of Electrodewatering System for Sewage Sludges

Jae-Keun Lee†, Hee-Soo Shin, Chan-Jung Park, Chang-Geon Lee, Jung-Eun Lee and Young-Whan Kim

School of Mechanical Engineering, Pusan National University, San 30,
Changjeon-Dong, Keumjeong-Ku, Busan 609-735, Korea
*Industry and Technology Div., Busan Metropolitan Gov., Busan 611-735, Korea
(*Received 7 March 2001 • accepted 17 August 2001*)

Abstract−A laboratory-scale electrodewatering system, incorporating an electric field as an additional driving force to conventional pressure dewatering, has been developed to decrease the water content of sludges generated in wastewater treatment. Consisting of a piston-type filter press, a power supply and a data acquisition system, the electrodewatering system's performance was evaluated as a function of applied pressure, applied voltage, sludge type and filtration time. Experiments were carried out using sewage sludges with the electric field up to 120 V/cm and pressure ranging from 98.1 to 392.4 kPa. Electrodewatering involving a combination of electric field and pressure enhances both the dewatering rate and final dewatered volume. The final water content of sewage sludges in the electrodewatering system can be reduced to 62 wt%, as compared to 78 wt% achieved with the pressure filtration alone. The electrodewatering system shows the potential to be an effective method for reducing the water content in sludges.

Key words: Electrodewatering, Electrophoresis, Electroosmosis, Final Water Content, Sewage Sludge

INTRODUCTION

The sludge generated from sewage treatment facilities has been increasing in recent years, causing a shortage of disposal sites, creating environmental problems and increasing treatment costs. Since the disposal and reuse of sludge cakes produced from wastewater treatment plants is more tightly regulated and expensive, there is an increasing demand for technology that substantially improves sludge dewaterability [Shin et al., 2000; Tchobanoglous and Burton, 1991]. This would lead to a substantial reduction in the costs of transport and disposal.

Dewatering involves increasing the solid content (or decreasing the water content) of the particulate matter separated out from filtration. Dewatered solids are more easily handled and dewatering is required prior to land disposal of solids. It also reduces the cost of subsequent treatment processes and transportation by reducing their volume and weight. Mechanical dewatering involves processes in which water is forced out of the sludge through mechanically induced pressures. Mechanical dewatering processes such as gravitational settling, pressure and vacuum filtration, centrifugation, or hydraulic flow become ineffective in dewatering suspensions of smaller particles [Barton et al., 1999]. If the water is initially removed by mechanical methods, the particles move closer together, thus decreasing the size of pores through which the water must flow and drastically diminishing the rate of water removal [Ju et al., 1991; Sung and Parekh, 1996]. Most mechanical dewatering devices produce sludge cakes of high water content ranging from 75-85 wt%, but electrodewatering produces sludge cakes of low water content ranging from 50-65% wt% and applied to conventional dewatering devices [Gazber et al., 1994; Kondoh and Hiraoka, 1990; Vijh and Novak, 1997]. Electrodewatering enhancing conventional pressure filtration by an electric field is an emerging technology with the potential to improve dewatering especially for sludges.

Electrodewatering efficiency depends on external electrical fields and sludge properties related to the production sources such as initial water content, total and volatile solids, pH, and conductivity. Most researchers investigated the optimal conditions for maximizing the electrodewatering efficiency using their domestic sludges. Gazber et al. [1994] investigated the effect of combined action of mechanical pressure and electrical field on anaerobically digested sludge from a brewery as a function of sludge conductivity ranging from 1,200 to 3,100 μmhos/cm and showed a dewatering efficiency of 63% in addition of Na_2SO_4 conditioning. Heath and Demirel [1984] investigated the pressurized electroosmotic dewatering of ultra-fine coal suspension under a constant pressure of 70 to 760 kPa above atmospheric pressure with currents of 1.3 to 5.2 A/m^2. They reported that the combination of electric field and pressure increased the dewatering rate compared to dewatering by pressure alone. Yoshida [1993] studied combined field dewatering involving electroosmotic dewatering and expression with bentonite suspensions, preconsolidated under a pressure of 98.1 kPa above atmospheric. Combined field dewatering enhanced both the dewatering rate and final dewatered volume, compared to individual processes.

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 Pusan wastewater treatment. It consists of a piston-type filter press, a power supply and a data acquisition system. Experiments are conducted as a function of applied pressure, applied voltage, and filtration time. Properties of sludges are very important factors in the electrodewatering system and sludges used in this study are the volatile solids of 33.4%, pH of 6.8, and the conductivity of 670 μmhos/cm. Also the optimal conditions for maximizing the electrodewatering efficiency in the electrodewatering system are investigated.

†To whom correspondence should be addressed.
E-mail: jklee@hyowon.pusan.ac.kr

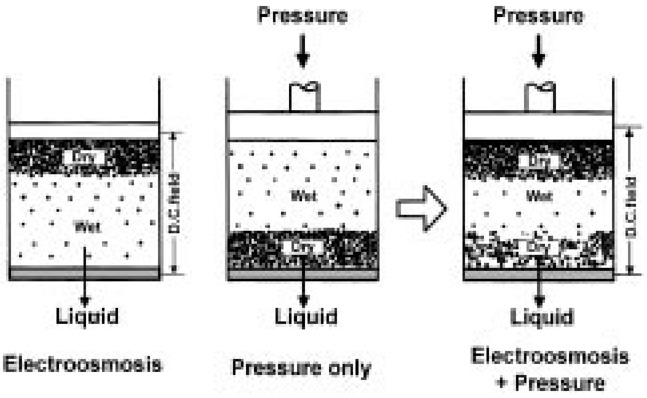
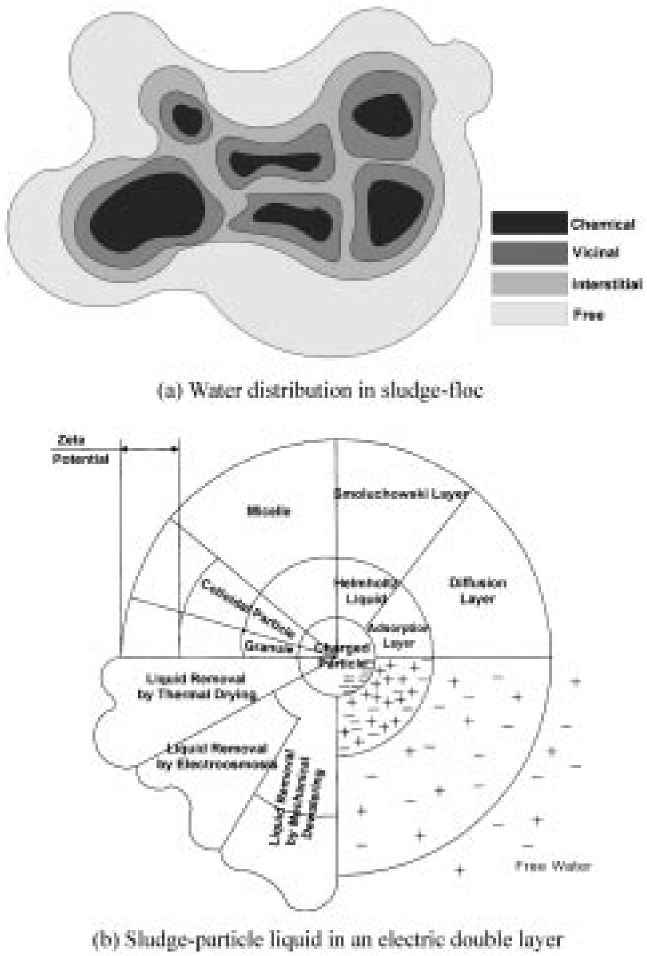


Fig. 1. Schematic diagram of combined dewatering process of electroosmosis and pressure [Vijh and Novak, 1997].

PRINCIPLES OF ELECTRODEWATERING

Fig. 1 shows schematically the process of electroosmotic dewatering combined with pressure filtration. In the case of electroosmotic dewatering only, the decrease of water content in the sludge starts from the upper part of the bed, but at the end of dewatering a large amount of water still remains in the lower part. On the other hand, pressure filtration proceeds from the lower part of the bed. 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 [Vijh and Novak, 1997; 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 to each other, a combination of these dewatering operations must be a useful means 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. 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 through 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].



(a) Water distribution in sludge-floc

(b) Sludge-particle liquid in an electric double layer

Fig. 2. The characteristics of sludges in the liquid [Smollen and Kafaar, 1994].

Fig. 2 shows the water distribution and electrical interaction of sludges consisting of a combination of solid phase with a certain quantity of liquid. Behavior of this liquid is often wrongly assumed to be the same as that of ordinary water. Fig. 2(a) shows water distribution in sludges. There are different physical forms of water in sludges and these different forms play an important role in determining the ease or difficulty of phase separation [Smollen and Kafaar, 1994]. The water is distributed into the following four parts in sewage sludges: (1) free water--not associated with or influenced by suspended particles; (2) interstitial water–physically bound water trapped within flocs or microbes; (3) vicinal water–physically bound multiple layers of water molecules held to the surface of hydrogen bound particles; and (4) chemically bound hydration water removed thermally. Free water can be removed by the mechanical dewatering system, while interstitial and vicinal water can be removed by the electrodewatering system.

Fig. 2(b) shows the particles and liquid of sludges in an electric double layer in relation to the water removal method. It is important to investigate and interpret the physical and chemical phenomena that occur on the surface of a sludge particle being a part of a sludge. Sludge particles are negatively charged. This charge is acquired by the preferential absorption of ions from the solution. The combined system of the surface charge on the particle and the cor-

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 (μm)	23-40	31
pH	6.2-7.3	6.8
Conductivity (μmhos/cm)	620-730	670

[a]TS=Total Solids.
[b]VS=Volatile Solids.

responding 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 [Kuhn and Hoffstetetter, 1993; Smollen and Kafaar, 1994].

EXPERIMENTAL

1. Materials

All sludge samples used in this study were taken from two sewage treatment plants located in Pusan, Korea. All sludges were 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 °C until required for experiment. No samples were kept for longer than 5 days. Total solid content and volatile solids in sludge samples were 3.0% and 13.4% by weight, respectively.

Table 1 shows the properties of digested sludges used in this study. The particle size of digested sludges measured by a particle counter [Malvern Instruments, Master sizer] is 31 μm in mass median diameter (MMD). The conductivity of sludges measured by a conductivity meter [YSI Inc., M3200] has a value of 670 μmhos/cm.

2. Experimental Apparatus and Test Procedures

Fig. 3 shows an experimental apparatus of the electrodewatering system. It consists of a cylinder cell fitted with two electrodes, a power supply [Korea Switching Inc. KSC-N300L5CD], a 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 by 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 μm 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. As the height of the sludge bed gradually decreases 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 through 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 °C for 24 hours.

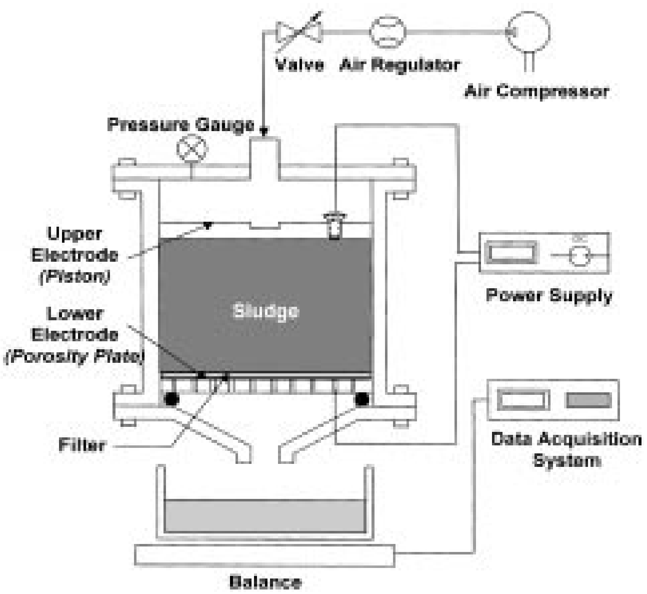


Fig. 3. Schematic diagram of the laboratory scale electrodewatering system.

RESULTS AND DISCUSSION

Fig. 4 shows the test result of mechanical pressure dewatering as a function of applied pressure. For the applied pressure of 98.1, 192.6, 294.3 and 392.4 kPa, the final water contents of sludge cakes at the elapsed time of 15 min are 89, 84, 80 and 78 wt%, respectively. Water content of sludges gradually decreases with increasing applied pressure and elapsed time. In the mechanical pressure dewatering, a layer of sludges in close vicinity of filter medium is ordinarily compacted. Porosity in that layer is reduced by fluid pressure, then blocking of filter medium quickly occurs and consequently the dewatering rate gradually decreases with time. Therefore test results show the limits of mechanical dewaterability for sewage sludges.

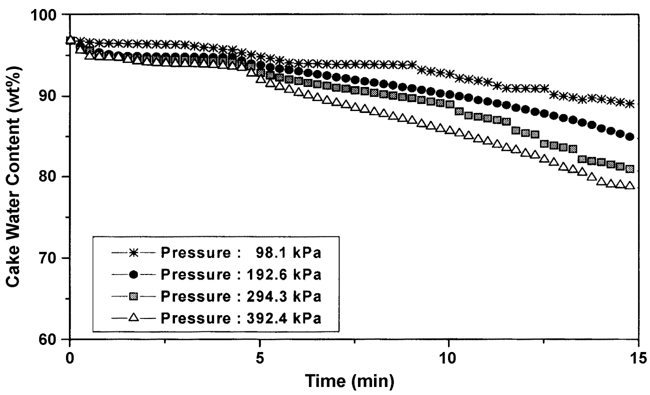


Fig. 4. Test results of the sludge water content in the mechanical pressure dewatering as a function of pressure.

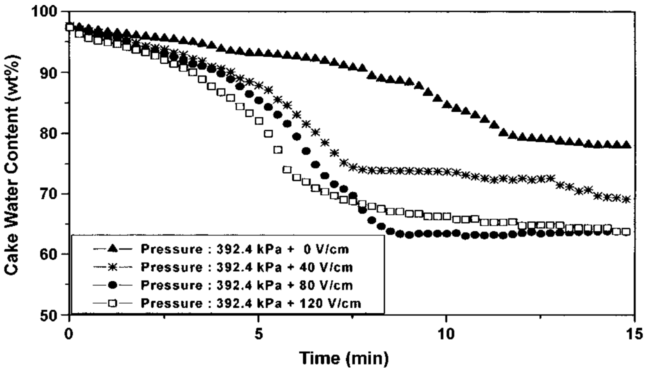


Fig. 5. Test results of the sludge water content in the electrodewatering system as a function of electric field strength.

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 an 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 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 an 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 the effect of electrodewatering as a function of pressure at the constant electric field of 80 V/cm. For the pressure of 98.1, 196.2, 294.3, and 392.4 kPa under the constant applies electric field of 80 V/cm, the final water contents of sludge cakes are in the range of 74, 70, 64, and 62 wt%, respectively. Final water content of sludge cakes is not particularly marked within the pressure range of 294.3 to 392.4 kPa in which most practical conventional filter presses operate. Dewatering performance degrades at the pressure of 196.2 kPa below. It is believed that electrodewatering system for better performance requires minimum pressure to maintain good electrical contact between the sludge and electrodes.

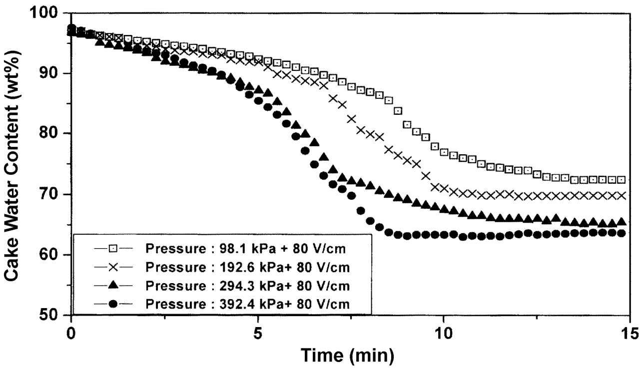


Fig. 6. Test results of the sludge water content in the electrodewatering system as a function of pressure.

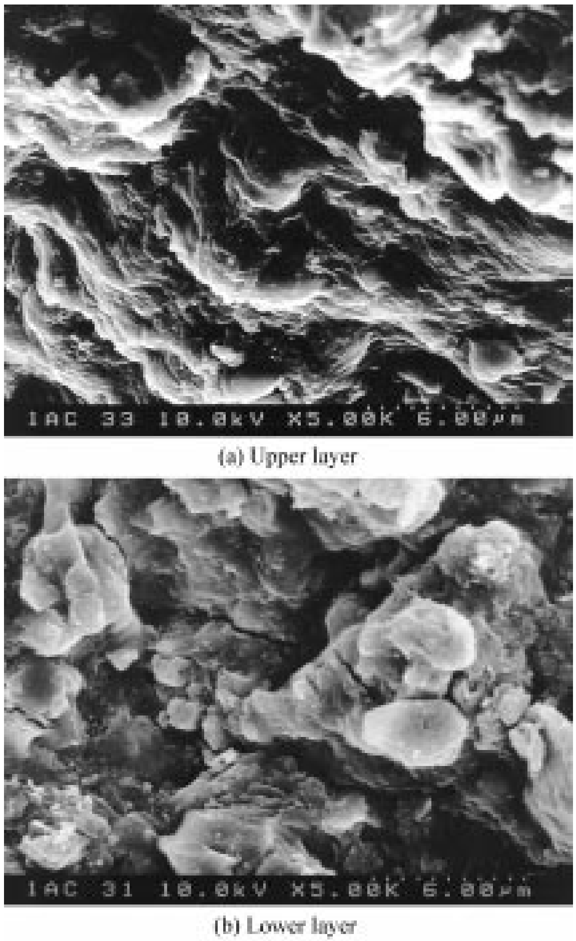


Fig. 7. Scanning electron micrographs of the surface layer of dewatered sludge cakes by mechanical dewatering.

Fig. 7 shows the scanning electron micrographs of the surface layer of sludge cakes dewatered with mechanical pressure filtration alone at the final water content of 80 wt%. In the upper layer of the dewatered sludge cake shown in Fig. 7(a), sludge particles are not observed and sludge cakes are compacted and form the cake. The lower layer of the dewatered sludge cake shown in Fig. 7(b) shows that the particles are locked in position and hence unable to move, that is, porosity in that layer is reduced by fluid pressure in close vicinity of filter medium.

Fig. 8 shows the scanning electron micrographs of the surface layer of the sludge cake dewatered with electrodewatering at the final water content of 62 wt%. Fig. 8(a) shows the upper surface layer of the dewatered sludge cake close to the anode. Particles are observed and moved by electrophoresis, so it prevents filter blocking phenomenon. Fig. 8(b) shows the lower surface layer of the dewatered sludge cake close to the cathode. Many capillary tubes are observed. In proportion to the negative potential of the particles, the surrounding liquid in the capillary has a positive potential known

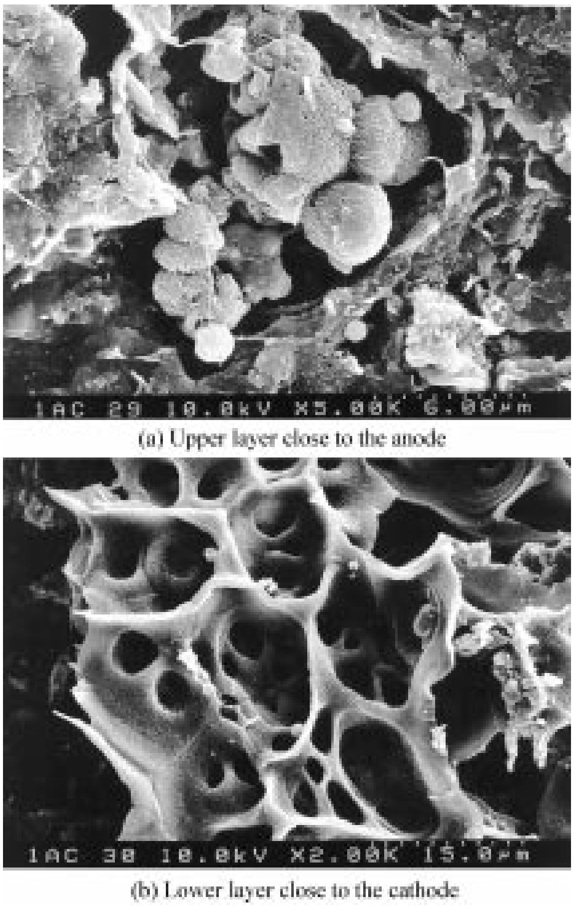


Fig. 8. Scanning electron micrographs of the surface layer of dewatered sludge cakes by electrodewatering.

as the electric double layer in capillary tubes. Therefore, the liquid in the capillary is attracted to the cathode by the electroosmosis phenomena. 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 and the porosity near the filter medium almost does not decrease. Therefore, the electrodewatering for enhancing the conventional filter pressure by an electric field is very effective for reducing the water content of sewage sludges.

CONCLUSION

A laboratory-scale electrodewatering system 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 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.

ACKNOWLEDGEMENTS

This study is supported financially by the Ministry of Commerce, Industry and Energy and by the Institute for Environmental Technology and Industry (IETI), Pusan National University, Korea (Project Number: 00-10-31-99-B-1). The authors gratefully acknowledge the financial support.

REFERENCES

Barton, W. A., Miller, S. A. and Veal, C. J., "The Electrodewatering of Sewage Sludge," *Drying Technology*, **17**(3), 497 (1999).

Gazber, S., Abadie, J. M. and Colin, F., "Combined Action of Electro-Osmotic Drainage And Mechanical Compression on Sludge Dewatering," *Water. Sci. Tech*., **30**(8), 169 (1994).

Heath, L. W. and Demirel, T., "Pressurized Electro-Osmotic Dewatering," Engineering Foundation Conference on Flocculation Sedimentation and Consolidation, Sea Island, Georgia (1994).

Ju, S., Weber, M. E. and Mujumder, A. S., "Electroosmotic Dewatering of Bentonite Suspension," *Separation Technology*, **1**, 214 (1991).

Kondoh, S. and Hiraoka, M., "Commercialization of Pressurized Electroosmotic Dehydrator," *Wat. Sci. Tech*., **22**, 259 (1990).

Kuhn, R. and Hoffstetter, S., "Capillary Electrophoresis: Principles and Practice," Springer-Verlag Berlin Heidelberg (1993).

Orsat, V., Raghavan, G. S. V. and Norris, E. R., "Food Processing Waste Dewatering by Electroosmosis," *Can. Agric. Eng*., **38**(1), 1 (1996).

Smollen, M. and Kafaar, A., "Electroosmotically Enhanced Sludge Dewatering: Pilot-Plant Study," *Wat. Sci. Tech*., **30**(8), 159 (1994).

Sung, D. J. and Parekh, B. K., "Statical Evaluation of Hyperbaric Filtration for Fine Coal Dewatering," *Korean J. Chem. Eng*., **13**, 304 (1996).

Shin, Y. S., Kim H. C. and Chun, H. S., "Drying of Water Treatment Process Sludge in a Fluidized Bed Dryer," *Korean J. Chem. Eng*., **17**, 22 (2000).

Tchobanoglous, G. and Burton, F. L., "Wastewater Engineering, Treatment, Disposal Reuse," McGraw-Hill, Inc. (1991).

Vijh, A. K. and Novak, J. P., "A New Theoretical Approach to Electroosmotic Dewatering (EOD) Based on Non-Equilibrium Thermodynamics," *Drying Technology*, **15**(2), 699 (1997).

Yoshisa, H., "Practical Aspects of Dewatering Enhanced by Electroosmosis," *Drying Technology*, **4**(4), 787 (1993).