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Performance evaluation of electrocoagulation and electrodewatering system for reduction of water content in sewage sludge

Hee-Soo Shin and Jae-Keun Lee†

Department of Mechanical Engineering, Pusan National University, San 30, Jangjeon-dong, Kumjung-gu, Busan 609-735, Korea
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Abstract−Electrocoagulation is applied to sewage sludge as a pretreatment process of an electrodewatering system to reduce the water content of sludge generated in wastewater treatment. The electrodewatering system, by incorporating an electric field as an additional driving force to the conventional pressure dewatering, has been evaluated as a function of an electrode material, applied voltage and filtration time. Experiments were carried out using sewage sludge with a pressure up to 392.4 kPa and applied electrical field ranging up to 120 V/cm. Mass median diameter of the sewage sludge by the effect of electrocoagulation increases from 34.7 μm to the 41.3 μm. The final water content of sewage sludge in the combination of both electrocoagulation and electrodewatering system can be reduced to 55 wt%, as compared to 78 wt% achieved with pressure dewatering alone. The combination of electrocoagulation and electrodewatering system shows a potential to be an effective method for reducing the water content in sludge.

Key words: Electrocoagulation, Electrodewatering, Sewage Sludge

INTRODUCTION

The task of separating solids from sludge is important in sewage treatment facilities and industries. It is important to reduce the water content of the byproducts of sewage treatment. Pretreatment is a useful stage in improving dewatering efficiency as settling, concentration, and digestion. In order to reduce the water content of sludge, many methods have recently been developed, such as chemical coagulation, electrocoagulation, floatation, mechanical dewatering, and electrodewatering (EDW) [Pouet and Grasmick, 1994; Chen and Sheng, 2004; Kobya et al., 2003; Biwyk, 1980; Shin et al., 2004].

Vik et al. [1984] investigated the electrocoagulation using aluminum electrode on removing suspension colloids in potable water, the effect of pH, dissolving amount of aluminum electrode, Chemical Oxygen Demand (COD). Rubach et al. [1997] investigated the electroflocculation installed aluminum anode and stainless steel cathode in waste and potable water pilot plants, the amount of dissolved aluminum, pH, total separation efficiency, energy consumption, conductivity. Chen et al. [2000] investigated electrocoagulation, a feasible process for treating restaurant wastewater, characterized by high oil and grease contents, fluctuating COD, biological oxygen demand (BOD_5) and suspended solid (SS) concentrations.

Most mechanical dewatering devices produce sludge cakes of high water content ranging from 75-85 wt%, but an electrodewatering system 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; Lee et al., 2002; Shin et al., 2003]. Electrodewatering enhanced conventional pressure filtration by an electric field is an emerging technology with the potential to improve dewatering, especially for sludge.

Electrodewatering efficiency depends on the external electrical field and sludge properties related to production sources such as particle size, initial water content, total and volatile solids, pH, and conductivity. Most researchers have investigated the optimal conditions for maximizing the electrodewatering efficiency using their domestic sludge. Gazber et al. [1994] investigated the effect of the 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. Lee et al. [2002] studied combined field dewatering involving electroosmotic dewatering and expression with sewage sludge, a pressure of 394.2 kPa. Combined field dewatering enhanced both the dewatering rate and final dewatered volume, compared to individual processes.

This study is to develop pretreatment for sewage sludge by electrocoagulation to enhance the efficiency of electrodewatering. The dewatering efficiency of electrodewatered sludge treated by electrocoagulation should be evaluated experimentally. Also, the optimal conditions for maximizing the effect of electrocoagulation by using aluminum and iron electrodes in sewage sludge are investigated.

ELECTROCOAGULATION

Electrocoagulation is an effective method for destabilizing colloidal particles in sludge. The electrolytically produced metal ions, such as those of iron and aluminum, neutralize the charge of colloidal particles, thus enhancing their coagulation rate. In addition, ions and particles are removed through deposition or sorption onto the surface of metallic oxides and hydroxides formed by precipitation of the electrolytically produced metal ions. Compared with a conventional water treatment process, in which chemicals are added to water to cause precipitation and enhance flocculation, electrocoagulation has several advantages including reduction of waste volume, lower cost and improved solid-liquid separation [Tsouris et al., 2001].

The bubbles are generated by electrolysis of water in the sludge; the water exists between two electrodes and is reduced to hydro-

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

gen at the cathode and oxidized to oxygen at the anode [Koren and Syversen, 1995]. Electrocoagulation has been used to reduce suspended solids as well as to generate ions that have been found to be effective in the treatment of wastewater. The electrophoretic motion simultaneously concentrates negatively charged particles in the region of the anode. The released ions neutralize the charge of the particles, thereby facilitating coagulation [Vik et al., 1984]. During electrolysis in the electrocoagulation procedure, the sacrificial iron anode is oxidized to Fe^{2+}, which in turn is further oxidized to Fe^{3+} ions, as illustrated by the following:

$$Fe \rightarrow Fe^{2+}(aq) + 2e^{-} \tag{1}$$

$$Fe^{2+} \rightarrow Fe^{3+}(aq) + e^{-} \tag{2}$$

Simultaneously, hydrogen is evolved at the cathode:

$$2H_2O + 2e^{-} \rightarrow H_2\uparrow + 2OH^{-}(aq) \tag{3}$$

The pH of the medium rises as a result of this electrochemical process. The net result of the reactions of Eq. (1) and Eq. (2) is that sludge is destabilized, and the colloidal sludge particles begin to coalesce.

$$Fe^{3+}(aq) + 3OH^{-}(aq) \rightarrow Fe(OH)_3(s)\downarrow \tag{4}$$

The destabilized sludge particles adsorb onto the highly dispersed ferric hydroxide colloid formed by the reaction between the electrogenerated Fe^{3+} and OH^{-} [Ibannez et al., 1995].

In an electrocoagulation system, the electrodes of the reactor are connected to an electrical power supply. Faraday's law can be used to describe the relationship between current density (A/cm^2) and the amount of the electrode which goes into sludge (g/cm^2). Eq. (5) shows the amount of the iron electrodes (g/cm^2) as follows [Vik et al., 1984] :

$$m = \frac{itM}{zF} \tag{5}$$

where M is the molecular weight of iron, i is the current density (A/cm^2), t is the time, z is the number of electrons involved in the oxidation, and F is Faraday's constant.

ELECTRODEWATERING

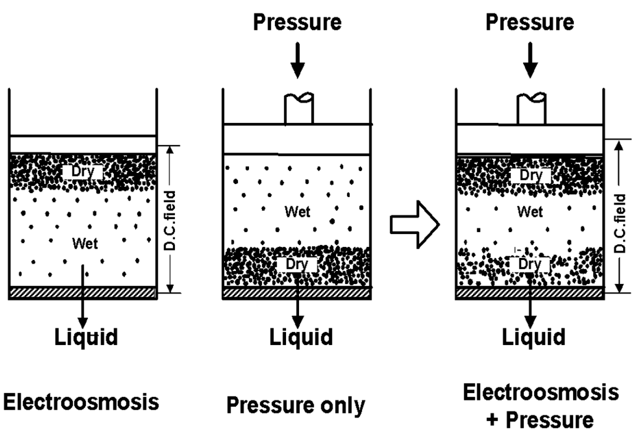


Fig. 1. Schematic diagram of combined dewatering process of electroosmosis and pressure [Vijh and Novak, 1997].

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 considerable amount of the 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 pressure filtration. Finally, a uniform sludge bed with a water content that corresponds to the applied mechanical pressure is formed at an equilibrium state. 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 could 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 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].

MATERIALS AND EXPERIMENTS

1. Materials

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

Table 1 shows the properties of sewage sludge used in this study. The particle size of sewage sludge measured by a particle counter [Malvern Instruments, MasterSizer] is 31 μm in mass median diameter (MMD). The conductivity of sludge measured by a conductivity meter [YSI Inc., M3200] has a value of 670 μmhos/cm. Properties of sludge are very important factors in the electrodewatering

Table 1. Properties of sludge used in the study

Parameters	Range	Average
Initial water content (wt%)	96.6-97.6	97.0
TS[a] (%)	2.4-3.4	3.0
VS[b]/TS (%)	32.2-35.4	33.4
Particle size (mm)	23-45	34.0
pH	6.2-7.3	6.8
Conductivity (mhos/cm)	620-730	670.0

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

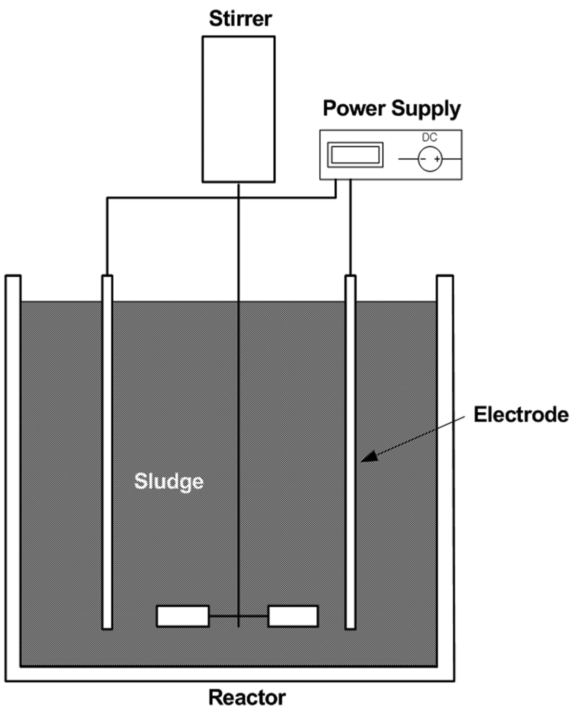


Fig. 2. Schematic diagram of the laboratory-scale electrocoagulation system.

system and sludge in this study are volatile solids of 33.4% and pH of 6.8.

2. Experimental Apparatus and Test Procedures

Fig. 2 shows an experimental apparatus of the electrocoagulation system. It consists of a reactor [3 liter], parallel plates fitted with two electrodes [120×80×3 mm] placed 3 cm apart, a power supply [Korea Switching Inc. KSC-N300L5CD], and a stirrer [DAEHAN Inc.]. The stirrer plays an important role to maintain an unchanged composition of sludge in the electrochemical reactor. Effluent from the electrocoagulation unit is sampled only after steady state operation is achieved. Sludge treated by electrocoagulation process are analyzed for particle size, organic content, water content, and pH by the standard methods [American Public Heath Association (APHA), 1992]. Laboratory-scale experiments of electrocoagulation are performed by using the aluminum electrode and the iron electrode. Subsequently, a D.C. electric field under constant voltage up to 15 V/cm and a current density up to 0.03 A/cm^2 are performed.

Fig. 3 shows an experimental apparatus of the electrodewatering

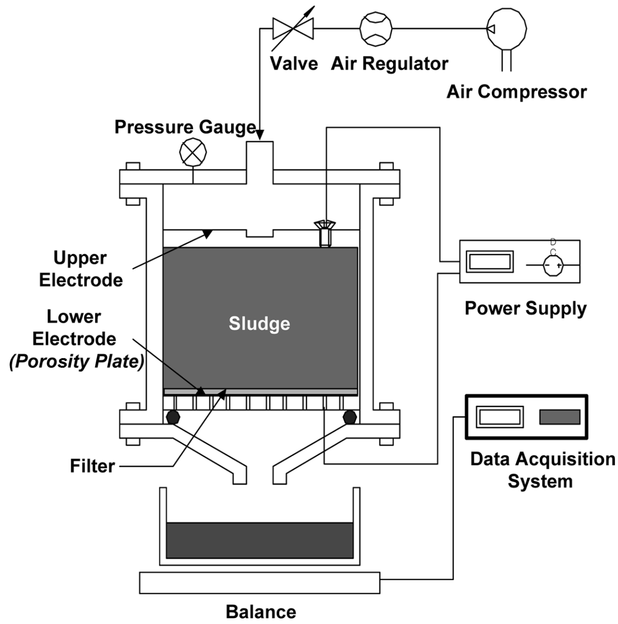


Fig. 3. Schematic diagram of the laboratory-scale electrodewatering system.

system. It consists of a cylinder cell fitted with two electrodes, the power supply, and data acquisition systems. 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. Sludge treated by electrocoagulation to be dewatered is inserted into the cell between two circular electrodes, the upper anode piston ($+V_e$) and the lower cathode ($-V_e$) of perforated nickel plate having a multitude of 3 mm holes for the drainage. 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 mode. 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.

Sludge treated by the electrocoagulation put between two electrodes, and subsequently D.C. electric field under a constant voltage is applied to the sludge bed regulated D.C. power supply and electric current is recorded automatically. As the height of the sludge bed gradually decreases with electrodewatering, from 1 cm to 0.1 cm, 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 final water content of the sludge cake is determined by drying the cake in an oven at 105 °C for 4 hour by the standard methods. Experiments are conducted as a function of applied pressure, applied voltage, and filtration time. Also the optimal conditions for maximizing the dewatering efficiency in the electrodewatering system are investigated.

3. Results and Discussion

Fig. 4 shows the particle size distribution of the sewage sludge without and with electrocoagulation. The retention time for the electrocoagulation is 30 min. The particle size of sewage sludge is changed

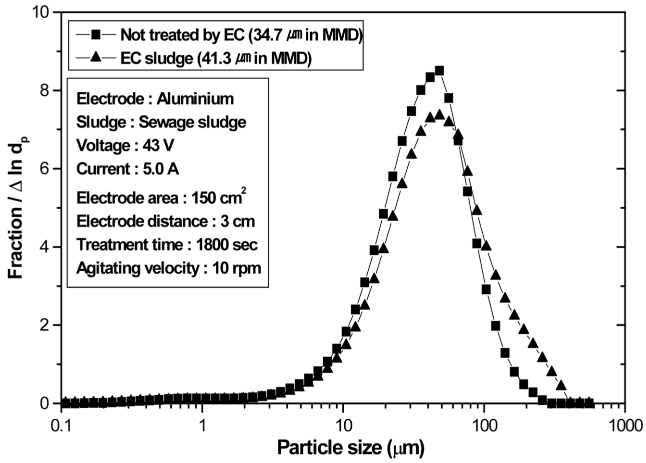


Fig. 4. Particle size distribution of the sewage sludge without and with the treatment of electrocoagulation (EC).

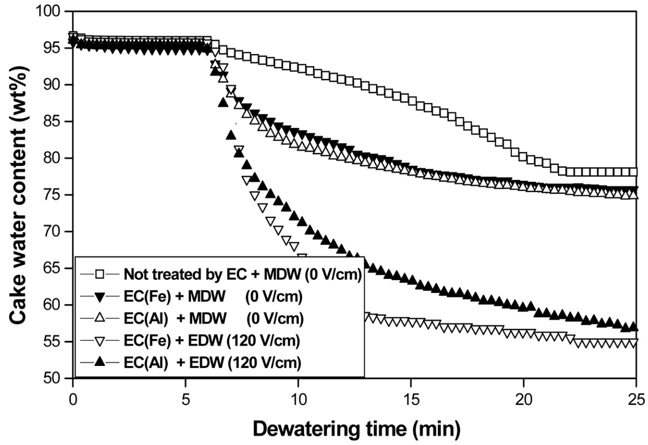


Fig. 6. Test results of the sludge water content in the mechanical dewatering (MDW) and electrodewatering (EDW) system of 392.4 kPa as a function of electrode material.

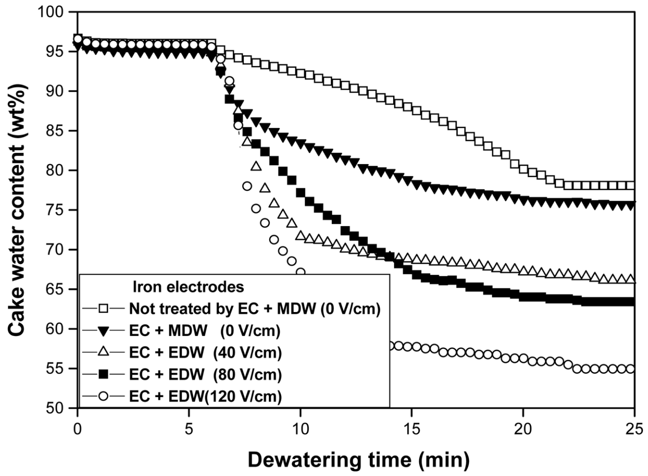


Fig. 5. Test results of the sludge water content in the mechanical dewatering (MDW) and electrodewatering (EDW) system without and with the electrocoagulation (EC) using the iron electrode.

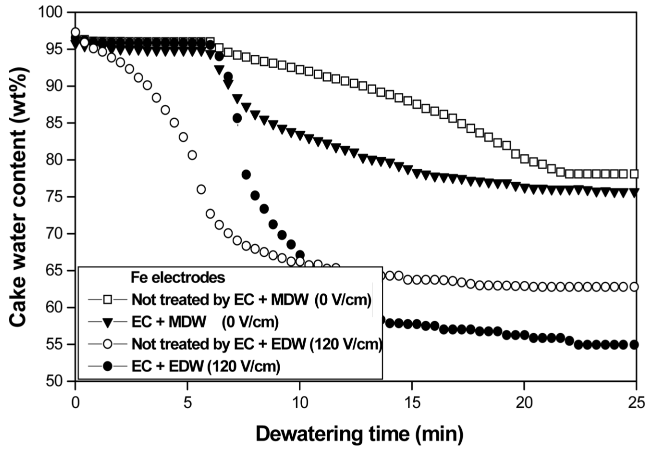
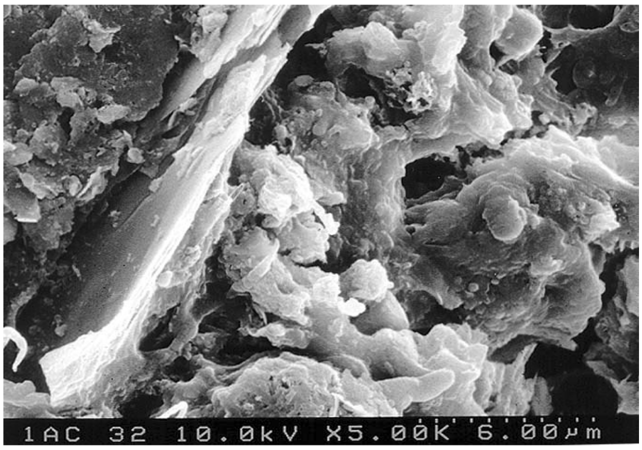


Fig. 7. Test results of the sludge water content in comparison of treatment without and with electrocoagulation (EC) in the mechanical dewatering (MDW) and electrodewatering (EDW) system of 392.4 kPa.

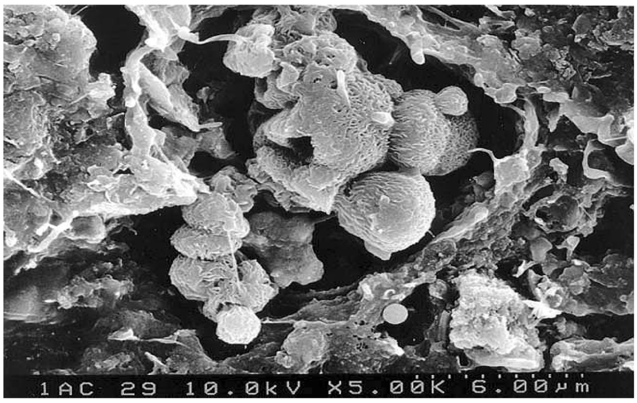
from 34.7 to 41.3 μm (MMD) during electrocoagulation. It is believed that electrocoagulation causes a destabilization of the sludge, accelerates the coagulation between sludge particles, and increases the distribution of particle size. The water content of sludge treated by electrocoagulation is changed from 97.6 wt% to 95.8 wt%.

Fig. 5 shows the test results of the sludge water content in a mechanical dewatering and electrodewatering system without and with electrocoagulation using the iron electrode. The final water content of sludge cake by mechanical dewatering system at a pressure of 392.4 kPa without electrocoagulation process is 78 wt%. For sludge treated by electrocoagulation with the electrodewatering system of 120 V/cm, the final water content of sludge treated by electrocoagulation with electrodewatering system reached 55 wt% compared with only 76 wt% with pressure filtration alone. At the initial stage of dewatering, the electrodewatering profile, up to 7 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 and coulombic heating play an important role in enhancing dewatering. There is no significant rise in filtrate temperature, suggesting the absence of coulombic heating. At a final water content of 55 wt%, the power consumed is 1,520 kWh/ton DS. For an electric field of 0, 40, 80, 120 V/cm (Initial height of sludge bed is 10 mm), the final water content of sludge cakes treated by electrocoagulation at the elapsed time of 25 min is 76, 66, 63, and 55 wt%, respectively. The optimal condition for maximizing the dewatering efficiency in the electrodewatering system is found to be an electrical field strength of 120 V/cm.

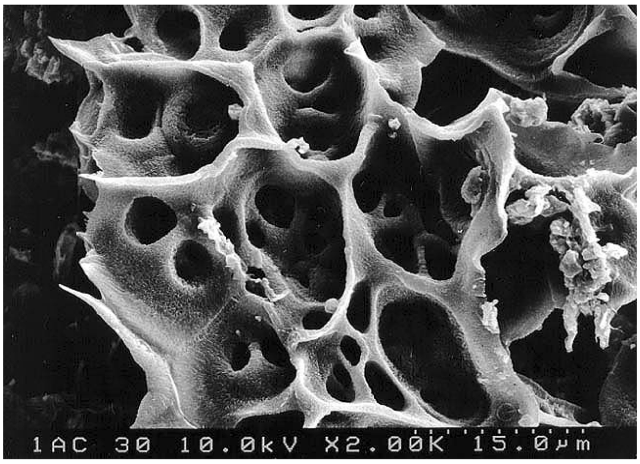
Fig. 6 shows the test results of the sludge water content in the mechanical dewatering and electrodewatering system of 392.4 kPa as a function of electrode material. For the electrode material of iron and aluminum electrodes under the constant applied electric field of 120 V/cm, the final water content of electrodewatering of sludge treated by electrocoagulation is in the range of 55 wt% and 57 wt%, respectively. The efficiency of electrodewatering for the iron electrode material is slightly higher than that of the aluminum electrodes. It is believed to be the difference of the dosage amount of



(a)



(b)



(c)

Fig. 8. Scanning electron micrographs of the surface layer of dewatered sludge cakes, (a) by mechanical dewatering, (b) upper layer by electrodewatering, (c) lower layer by electrodewatering.

electrodes as described in Eq. (5). The theoretically calculated amounts of iron and aluminum material are 0.0463 g/cm^2 and 0.0224 g/cm^2, respectively. The dissolved amount of electrode increases with increasing the sludge conductivity. In general, the electrodewatering efficiency increases with increasing sludge conductivity [Lockhart, 1983; Vik et al., 1984].

Fig. 7 shows the test results of the sludge water content in a comparison of treatment without and with electrocoagulation in the mechanical and electrodewatering system with a pressure of 392.4 kPa. In the mechanical dewatering system, the water content of sludge without and with electrocoagulation using iron electrodes is 78 and 76 wt%, respectively. In case of the electrodewatering system for an electric field of 120 V/cm, the water content of sludge with electrocoagulation using iron electrodes is 55 wt% and lower than that of sludge without electrocoagulation. The dewatering efficiency initially increases, and then more gradually increases with increasing dewatering time. Similar results have been obtained for other test conditions.

Fig. 8 shows the scanning electron micrographs of the surface layer of the sludge cake dewatered with the mechanical dewatering and electrodewatering at a final water content of 55 wt%. Fig. 8(a) shows the sludge cake by the mechanical dewatering. Fig. 8(b) 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. Fig. 8(c) 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 as the electric double layer in capillary tubes. Therefore, the liquid in the capillary is attracted to the cathode by electroosmosis. 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, electrodewatering for enhancing conventional filter pressure by an electric field is very effective to reduce the water content of sewage sludge.

CONCLUSION

A laboratory-scale electrocoagulation system was found to be a feasible process for the pretreatment of sewage treatments using a electrodewatering system for enhancing the dewatering efficiency. The electrocoagulation causes a destabilization of suspension and increases the distribution of particle size. Also, a laboratory-scale electrodewatering system incorporating an electric field as an additional driving force to a conventional pressure dewatering has been developed to increase the solid content of sludge generated in wastewater treatment. Electrodewatering involving a combination of electric field and pressure enhances both the dewatering rate and final dewatered volume. The water content of sludge by electrocoagulation in the electrodewatering system can be reduced to 55 wt%, as compared to 78 wt% applied with pressure filtration alone. The electrocoagulation system shows the potential to be an effective method for mechanical dewatering and electrodewatering for reducing the water content in sludge.

ACKNOWLEDGMENTS

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