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Dewatering of a biological industrial sludge by electrokinetics-assisted filter press

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ABSTRACT

The objective of this work was to evaluate the performance of biological industrial sludge dewatering by a pilot-scale filter press assisted by electrokinetics (EK). In all experiments the following conditions were kept constant: (1) dry solids content in the sludge feed: 5.0 wt%; and (2) constant electric-current mode. Application of 1 A and 4 A of electric current for 45 min for dewatering was capable of yielding sludge filter cakes with moisture contents of 65.0% and 53.2%, respectively. However, the former would provide a better compromise between the residual moisture content and the electricity cost. This practice has been shown to be cost-effective. The reduction of sludge moisture content might be ascribed to the mechanisms of mechanical pressure, electroosmosis, and ohmic heating in said dewatering system. The estimated electroosmotic permeability was found to be comparable to that of reported by other researchers.

1. Introduction

Various types of water found in sludge have been reported [1–6]. Although differing in nomenclature, they all resemble each other in a general sense. According to the Vesilind group, water in sludge can be categorized as follows: (1) free water (bulk water) – water not associated with solid particles including void water not associated with capillary forces; (2) interstitial water – water trapped in crevices and interstitial spaces of flocs and microbes; (3) vicinal water – water held to particle surfaces by adsorption and adhesion, for instance by hydrogen bonding; and (4) water of hydration – water chemically bound within the particle structure which only can be removed by thermal drying. In the literature, water in sludge has also been divided into just two major categories, namely bulk water and bound water. In this case, bound water is often defined as water not readily removed by mechanical means.

For dewatering, mechanical processes are preferred over thermal ones based on economic considerations. Among various dewatering devices, filter presses, filter belt presses, rotary drum filters, and decanter centrifuges are widely used in the industry. In general, the efficiency of sludge dewatering is affected by the sludge type, conditioning of sludge, dewatering device, and operating conditions. It is commonplace to find filter cakes with a moisture content of around 80%. Generally, sludge particles are negatively charged. A diffuse double layer of water surrounding the particles, with the characteristic zeta potential at the boundary between the fixed and mobile portions of this layer, is thus developed. It is well known that the flow of water induced by an electrical potential difference is not limited by pore size. Thus, electroosmosis has the potential to remove interstitial water from the sludge flocs resulting in a greater dewatering efficiency. In the literature, many researchers have reported the successful use of electrokinetically enhanced processes for dewatering of various sludges [4,7–16]. This process is called electrodewatering (EDW), also known as electroosmotic dewatering (EOD). The basic principles of such an electrokinetics-assisted dewatering process can be found elsewhere [17]. Very recently, a historical review on the application and contributions of an electric field in wastewater sludge dewatering has been reported by Mahmoud et al. [18].

In the literature, a great majority of EOD or EDW studies reported using a vertical electric field coupled with mechanical pressure imposed on the upper anode in order to facilitate water removal. Some disadvantages of this vertical type of equipment design have been noticed including difficulty in the dissipation of gases generated at electrodes and the drying of sludge near the anode due to continuous water discharge from the outlet at the bottom, thereby reducing the applied electric field on the bulk sludge. Relevant studies using a horizontal electric field are scarce. Zhou et al. [19] reported a bench-scale study on EDW of a cultivated waste activated sludge using a horizontal electric field. In that study, a carbon graphite plate was used as the anode and a copper net as the cathode, which was covered with cotton cloth as filter media. The cross-sectional area of the loading compartment was 85 mm × 42 mm and the distance between two electrodes was 65 mm.

Electrodewatering techniques have been used in conjunction with belt filter presses [4,10,20,21] and filter presses or diaphragm filter presses [8,13,17] on laboratory, pilot, and industrial scales.

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However, technical problems have hampered its widespread application to date. These problems include the requirement for corrosion resistant electrode materials and high electrical energy consumption [10]. Therefore, this work aimed to evaluate the synergistic effect on dewatering of a biological industrial sludge by a filter press coupled with electrokinetics. In addition, the mechanisms of water removal involved and electroosmotic permeability were also included in this investigation.

2. Experimental

2.1. Source of sludge

In this study a biological sludge filter cake with a moisture content of ca. 79.3% was obtained from a centralized wastewater treatment plant of an industrial park in northern Taiwan. To comply with the filtration mechanism of the test equipment, tap water was added to a fixed amount of the sludge filter cake to restore the water content of sludge back to 95.0% prior to each test. The resultant sludge in a slurry form (i.e., wet sludge) was used as the feed to a pilot-scale filter press. At this stage, the sludge feed was characterized and subjected to the TCLP test (i.e., Toxicity Characteristic Leaching Procedure) as well. In all tests, wet sludge with a weight of 5–8 kg was used as the feed.

2.2. Equipment and methods

The plate and frame filter press consisted of sets of solid plates and frames (with a cross-sectional area of 561 cm^2 for each filter chamber), pieces of filter cloth, carbonaceous electrodes, an air compressor providing a vacuum pump with intermittent application of a pneumatic pressure up to 6 kg/cm^2 for sucking the sludge feed into the modified filter press, a DC power supply with adjustable voltage and current, and a wattmeter. Unless otherwise specified, all tests were conducted under conditions of constant electric current. In this work the applied electric currents of 0 A, 1 A, 4 A, and 7 A were tested for a period of 15–60 min with an increment of 15 min. Details are given in Table 1. During each test, the following were monitored: (1) the filtration pressure; (2) the electrical potential gradient; (3) the filtrate pH; and (4) the cumulative quantity of removed water. After each test, analysis of moisture content was conducted for three specimens of the sludge filter cake from different areas of the filter chamber.

3. Results and discussion

3.1. Characteristics of the sludge

As indicated above, the as-received sludge cake had an average moisture content of 79.3%. For the purpose of conducting tests of sludge dewatering, tap water was added to the said sludge cake to restore its moisture content to 95%. The thus-modified sludge had a pH value in the range of 6.9–7.9. Its conductivity was determined to be 4.5–5.5 mS/cm. The result of the TCLP test showed that the leached concentrations of Cu and Pb were 1.36 mg/L and 1.69 mg/L, respectively. The rest of the heavy metals of concern were non-detectable. All these concentrations were below Taiwan EPA's regulatory standards. Therefore, the concerned biological industrial sludge cake was categorized as a non-hazardous waste.

3.2. Variations in filtration pressure

The monitored results have indicated that generally as the time elapsed the filtration pressure decreased. This trend of filtration pressure change was exemplified by the results for various tests with dewatering times of 30 min and 45 min as shown in Figs. 1 and 2, respectively. In these tests, it was found that there was a filtration pressure drop of 1–3 kgf/cm^2 after 10 min of dewatering. This observation can be further delineated in Fig. 3. The effect of applied electric current on filtration pressure appeared to be irrelevant. As indicated in Table 1, the influent pipe diameter for Tests $T_{30}A_z$ and $T_{45}A_z$ were different. Based on the results shown in

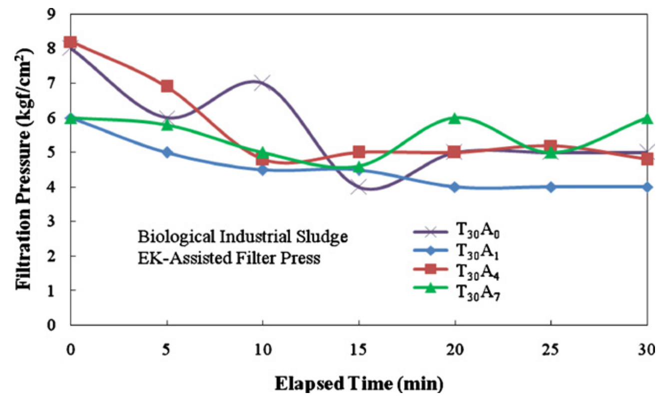

Fig. 1. Variations in filtration pressure for various electrodewatering tests of a biological industrial sludge with different constant-current electric fields applied for a period of 30 min.

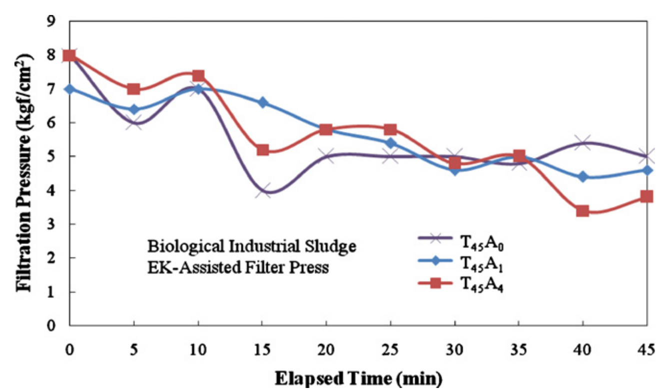

Fig. 2. Variations in filtration pressure for various electrodewatering tests of a biological industrial sludge with different constant-current electric fields applied for a period of 45 min.

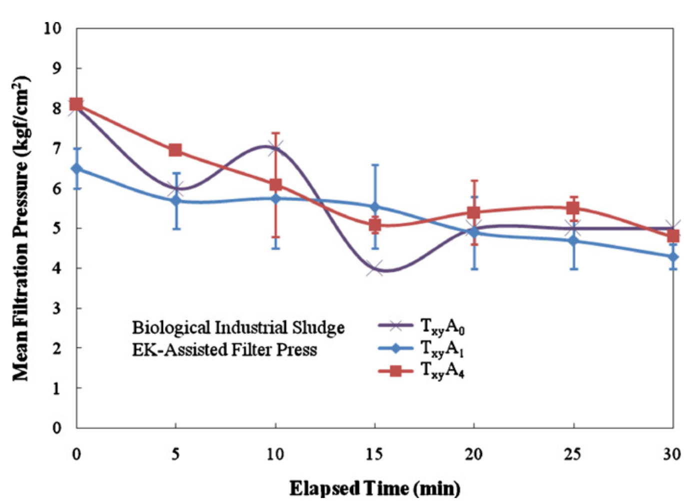

Fig. 3. Variations in mean filtration pressure for various electrodewatering tests of a biological industrial sludge with different constant-current electric fields applied for a period of 30 min.

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Table 1
Designations of various electrodewatering tests and their experimental conditions for the selected biological industrial sludge.

Dewatering time (min)	Test designation[a]			
	No electric current applied	1 A of electric current applied	4 A of electric current applied	7 A of electric current applied
15	$T_{15}A_0$[b]	$T_{15}A_1$[b]	$T_{15}A_4$[b]	$T_{15}A_7$[b]
30	$T_{30}A_0$[b]	$T_{30}A_1$[b]	$T_{30}A_4$[b]	$T_{30}A_7$[b]
45	$T_{45}A_0$[c]	$T_{45}A_1$[c]	$T_{45}A_4$[c]	$T_{45}A_7$[c]
60	$T_{60}A_0$[c]	$T_{60}A_1$[c]	$T_{60}A_4$[c]	$T_{60}A_7$[c]

[a] Tests carried out in this work were designated as $T_{xy}A_z$ with "*xy*" denoting the dewatering time in minutes and "*z*" denoting the applied electric current in amperage.
[b] Tests were carried out using an influent pipe with an inner diameter of 1.3 cm.
[c] Tests were carried out using an influent pipe with an inner diameter of 3.0 cm.

Figs. 1 and 2, such a difference in the influent pipe diameter yielded no significant effect on the filtration pressure variation.

Variations in filtration pressure could also be correlated with the feeding frequency and total amount of feed inside the filter chamber (i.e., the space of the filter frame). As indicated in Section 2, in this work an air compressor was used to provide a vacuum pump with intermittent application of a pneumatic pressure for sucking the sludge feed into the modified filter press. Therefore, the feeding frequency for a specific test period would vary for different dewatering tests and conditions depending on the space available in the filter chamber for incoming sludge to be fed. As shown in Figs. 1 and 2, generally, there is a trend that the feeding frequency was lower for the tests without application of electric current and with application of a small electric field. This observation could be explained as follows: in general, mechanical pressure could easily remove free water in sludge, but not bound water. The application of an external field would result in electroosmosis, which would be capable of removing the concerned interstitial water and vicinal water. When ohmic heating occurs, as evidenced by the emission of hot water vapor, some extent of water of hydration could also be removed. As a result, it would cause a much higher degree of sludge particle compaction, thereby leaving more space available for incoming feed to enter the filter chamber. In short, the greater the feeding frequency is, the greater the treated sludge quantity would be, until all removable water has been removed from the bulk sludge in the filter chamber.

3.3. Variations in electrical potential gradient

Variations in electrical potential gradient for various tests with dewatering times of 30 min and 45 min are shown in Figs. 4 and 5, respectively. It is evident that a greater applied constant electric current would give rise to a greater electrical potential gradient over the course of test period as shown in both figures. However, it is noticed that the initial value of the electrical potential gradient under Test $T_{30}A_4$ in Fig. 4 seems too big as compared with the corresponding value for Test $T_{45}A_4$ in Fig. 5. This is ascribed to the possible existence of a discontinuous phase in the filter chamber at the very beginning of Test $T_{30}A_4$ resulting from an unsteady pneumatic suction of wet sludge into the chamber of the filter press and rather poor repeatability in this regard. For 45-min electrodewatering tests conducted using a bigger influent pipe, overall electrical potential gradients were found to be lower than in counterpart tests using a smaller influent pipe (Fig. 5 vs. Fig. 4). However, there was a trend that the electrical potential gradient would decrease to 10–20 V/cm and level off as the operating time elapsed. Nonetheless, there was an exception for Test $T_{30}A_7$. In this test, an abrupt increase of the electrical potential gradient to over 35 V/cm was noticed after 20 min of operation. It is postulated that a rather higher applied electric current would render a rapid evaporation of water of hydration due to ohmic heating. This was evidenced by the emitted water vapor from the top of the filter press. As a result of the drying out of the surface of the cake inside the filter chamber, the continuous phase in the filter cake was broken, thereby increasing the electrical resistance of the filtration system. According to Ohm's law, a constant electric current with an increased electrical resistance would yield a higher voltage. This would explain why the electrical potential gradient increased when ohmic heating occurred.

3.4. Variations in filtrate pH

Among other parameters, the filtrate pH was also monitored in the course of dewatering. It was found that the filtrate collected from the effluent discharge increased from pH 7.8 to 12.0–13.0

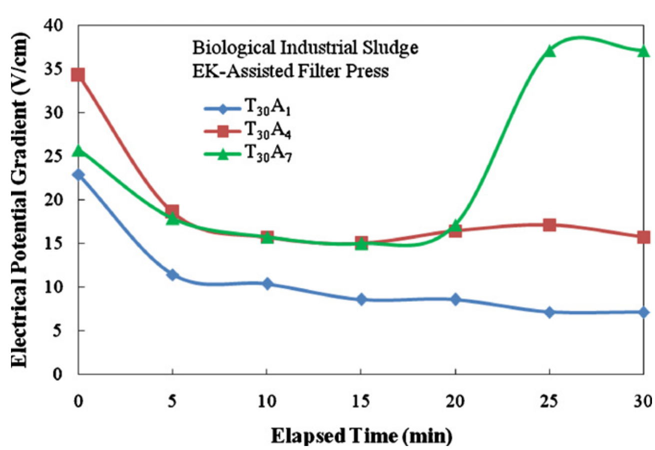

Fig. 4. Variations in electrical potential gradient for various electrodewatering tests of a biological industrial sludge with different constant-current electric fields applied for a period of 30 min.

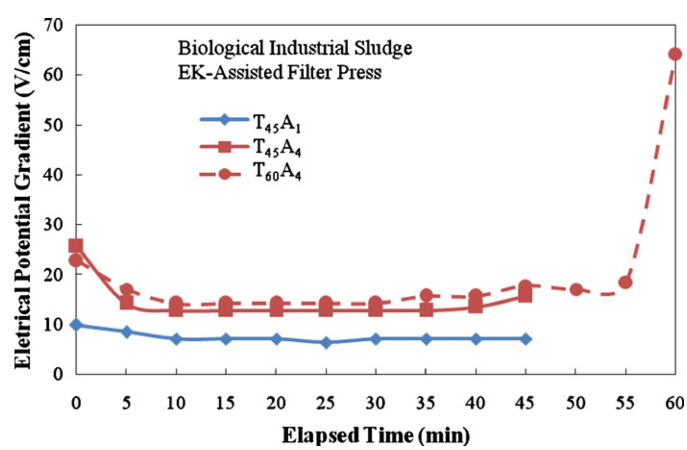

Fig. 5. Variations in electrical potential gradient for various electrodewatering tests of a biological industrial sludge with different constant-current electric fields applied for a period of 45 min.

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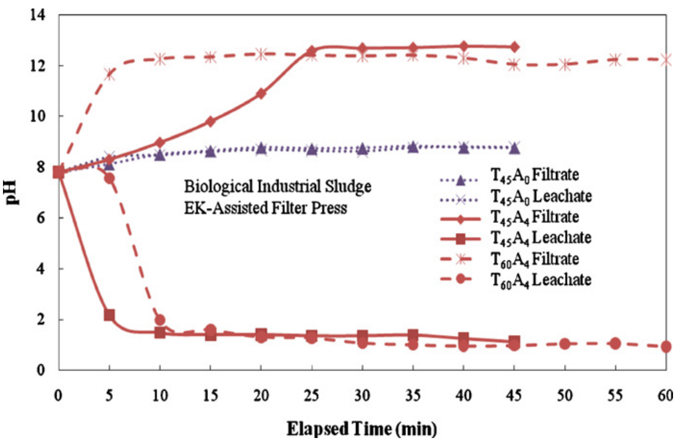

Fig. 6. Variations in pH values of filtrate and leachate for various electrodewatering tests of a biological industrial sludge with different constant-current electric fields applied for a period of up to 60 min.

as operating time elapsed. A similar finding was also observed by Zhou et al. [19]. This is due to the electrolysis of water in the neighborhood of the cathode, generating OH^-. The longer the time of electrolysis, the greater the concentration of OH^-. As for the leachate collected at the bottom of the filter cloth near the influent end, the corresponding pH was found to decrease from 7.8 to about 2.0. Again, this is due to H^+ generated by the electrolysis of water in the neighborhood of the anode. The above phenomena are illustrated in Fig. 6.

3.5. Variations in cumulative quantity of removed water and its flow rate

As reported in the literature, electroosmosis would enhance the removal of water from the sludge. The test results obtained in this work are no exception. The cumulative quantity of removed water (i.e., the sum of filtrate and leachate) for any test with an applied constant electric current was greater than that of its counterpart without application of an electric field. This is exemplified in Fig. 7 for tests having a dewatering time of 45 min. It was noticed that there was a remarkable increase of collected water quantity after 15–20 min of the EK-assisted dewatering operation. As compared with the result of Test $T_{45}A_0$, such an increase in removed water quantity would be ascribed to electroosmosis in effect from this point in time. Comparison of the quantities of removed water in Tests $T_{45}A_4$ and $T_{60}A_4$ showed that the difference between those results were within the bounds of imperfect test repeatability.

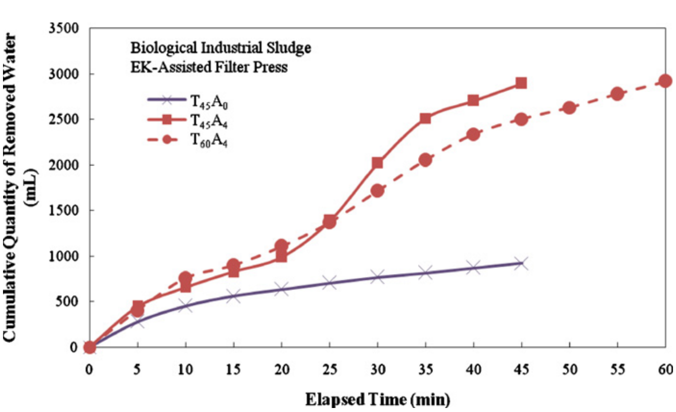

Fig. 7. Variations in cumulative quantity of removed water for various electrodewatering tests of a biological industrial sludge with different constant-current electric fields applied for a period of up to 60 min.

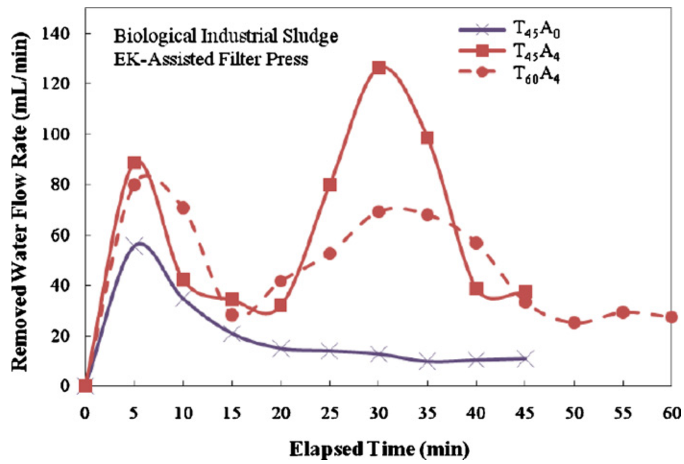

Fig. 8. Variations in removed water flow rate for various electrodewatering tests of a biological industrial sludge with different constant-current electric fields applied for a period of up to 60 min.

Fig. 8 showed the removed water flow rates for the tests appearing in Fig. 7. There were two obvious peaks in the concerned flow rate. Keeping in mind that these peaks only reflect the average values of removed water accumulated during different 5-min time fractions. The first peak, appearing at 5 min of operation time for all tests, was due to the removal of free water in the loaded sludge by mechanical pressure. This would be justified by the same observation for Test $T_{45}A_0$ in which no electric current was applied. The second peak, appearing at 30 min of dewatering time in both Tests $T_{45}A_4$ and $T_{60}A_4$, was ascribed to the removal of interstitial water, vicinal water, and residual free water in sludge.

To further elucidate the observations in Fig. 8, the results can be analyzed in two sections, separated at the time point of 15 min. The cumulative quantity of removed water in Fig. 7 for the time period of 0–15 min was considered as the quantity of free water removed mainly by mechanical pressure and partially by EK, whereas the remainder of the removed water was considered as bound water and residual free water removed mainly by EK and partially by mechanical pressure. The calculated average removed water flow rates in two time periods for various dewatering tests are given in Table 2. For Test $T_{45}A_0$, a greater portion of free water in sludge was removed during the first 15-min period (i.e., 0–15 min from the beginning) than during the following 30-min period (i.e., 15–45 min from the beginning). Moreover, the average removed water flow rate for the first time period was much greater than for the second time period (0.62 mL/s vs. 0.20 mL/s). As for Tests $T_{45}A_4$ and $T_{60}A_4$, their respective corresponding average removed water flow rates are much greater than that of Test $T_{45}A_0$ in both time periods. This finding was ascribed to the enhancement of EK. Further analysis of variations in flow rate with time under EK (i.e., Tests $T_{45}A_4$ and $T_{60}A_4$) showed that the average removed water flow rate was nearly constant, about 0.99 mL/s in both time periods.

3.6. Electroosmotic permeability analysis

As discussed above, in this work electroosmosis enhanced the removal of water in sludge. Therefore, it is worthwhile to analyze the electroosmotic permeability (K_e) of loaded sludge in the filter chamber in the course of electrodewatering tests of interest. Following the same pattern of evaluating the removed water flow rates in Fig. 8, K_e of concern was estimated in two time periods, separated at the time point of 15 min. To this end, only the net flow quantity due to non-mechanical pressure should be taken into consideration. It is also worth pointing out that the volume of the emitted hot water vapor due to ohmic heating is not taken into account of

Table 2
Cumulative quantities of removed water and average removed water flow rates of various electrodewatering tests for the selected biological industrial sludge.

Test no.	Cumulative quantity of removed water during 0–15 min (mL)	Average removed water flow rate during 0–15 min (mL/s)	Cumulative quantity of removed water during 15–45 min (mL)	Average removed water flow rate during 15–45 min (mL/s)
$T_{45}A_0$	557	0.62	365	0.20
$T_{45}A_4$	827	0.92	2067	1.15
$T_{60}A_4$	895	0.99	1610	0.89

Table 3
Estimated magnitudes of electroosmotic permeability (K_e) of various electrodewatering tests for the selected biological industrial sludge.

Test no.	K_e for the period of 0–15 min [a] (cm²/V s)	K_e for the period of 15–45 min[a] (cm²/V s)	K_e for the entire period of 0–45 min [a] (cm²/V s)
$T_{45}A_4$	3.3×10^{-5}	1.2×10^{-4}	8.5×10^{-5}
$T_{60}A_4$	4.2×10^{-5}	8.1×10^{-5}	6.6×10^{-5}

[a] The mean magnitudes of electrical potential gradient for Tests $T_{45}A_4$ and $T_{60}A_4$ are: (1) 16.4 V/cm and 17.1 V/cm, respectively for the period of 0–15 min; (2) 13.5 V/cm and 15.4 V/cm, respectively for the period of 15–45 min; and (3) 14.6 V/cm and 16.1 V/cm, respectively for the entire period of 0–45 min.

removed water for calculations of K_e. The calculated values of K_e were given in Table 3. It is clear that the magnitudes of K_e for the second time period (i.e., 15–45 min) were much greater than for the first time period. This is self-explanatory because water removal by mechanical pressure was predominant during 0–15 min, then electroosmosis predominated afterwards till the end of the test. For Tests $T_{45}A_4$ and $T_{60}A_4$, their estimated values of K_e for the entire period of 0–45 min were 8.5×10^{-5} cm²/V·s and 6.6×10^{-5} cm²/V·s, respectively. The estimated values of K_e obtained in this work were found to be comparable with that reported by Glendinning et al. [14] for sewage sludge, but they are an order of magnitude greater than that reported by Yuan and Weng [22] for a mixed sludge cake from a belt press of a wastewater treatment plant.

3.7. Variations in moisture content of filter cake

It was noticed that the moisture content of the final sludge cake would be affected if there was a load of feed into the filter press immediately before the test period ended. In addition, the filter cake obtained in this work could be visually divided into "moist", "semi-moist", and "dry" fractions. Specimens of these three fractions were collected for the analysis of their respective moisture contents. Thus, the final moisture contents of the sludge filter cake reported in this work all had substantial standard deviations.

The results of triplicate experiments showed that dewatering by the EK-assisted pilot-scale filter press would greatly lower the moisture content of the sludge filter cake as compared with tests without the enhancement of electrokinetics (see Table 4). For instance, Test $T_{15}A_0$ yielded a filter cake with moisture content of 80.0 ± 2.1%, compared with 70.9 ± 9.4% for Test $T_{15}A_4$. A similar trend in findings was obtained by comparing the results of Tests $T_{45}A_0$ and $T_{45}A_4$. When an external electric field was applied, an increase in treatment time would further reduce the concerned moisture content. This statement could be demonstrated by comparing the results of Tests $T_{15}A_4$ and $T_{45}A_4$ (70.9 ± 9.4% vs. 53.2 ± 3.0%). As for an unexpected, slightly greater moisture content in Test $T_{60}A_4$, it might be due to a possible suction of the wet sludge into the filter chamber just a short while before the end of the test resulting in a greater average value of moisture content and much greater standard deviation (i.e., 60.8 ± 9.3%) as compared with that of Test $T_{45}A_4$ (i.e., 53.2 ± 3.0%). By further comparing the results of the test group of $T_{30}A_z$, one would find that the residual moisture content of the filter cake decreased as the applied constant electric current increased, resulting in the lowest moisture content for Test $T_{30}A_7$. However, this was due partly to ohmic heating resulting in removal of water of hydration, as discussed in Section 3.2. The test results were very promising as compared with the results reported by other researchers. In the cited literature, the dry solids content of the sewage sludge filter cake resulting from electrodewatering was in the range of 35–46 wt% [17].

Table 4
Moisture contents of the filter cakes resulting from various electrodewatering tests for the selected biological industrial sludge.

Test no.	Moisture content of the sludge filter cake[a] (%)
$T_{15}A_0$	80.0 ± 2.1
$T_{15}A_4$	70.9 ± 9.4
$T_{30}A_1$	77.8 ± 2.8
$T_{30}A_4$	63.5 ± 6.5
$T_{30}A_7$	61.2 ± 3.6
$T_{45}A_0$	78.9 ± 2.7
$T_{45}A_1$	65.0 ± 7.8
$T_{45}A_4$	53.2 ± 3.0
$T_{60}A_4$	60.8 ± 9.3

[a] An average value of the moisture content for three specimens of the sludge filter cake obtained from different areas of the filter chamber after each test.

A reduction of moisture content of the sludge filter cake by electrodewatering could be ascribed to three main mechanisms: (1) mechnical pressure, (2) electroosmotic (EO) flow, and (3) ohmic heating of the feed and all components therein. Mechanical dewatering would remove free water (also known as bulk water) and a part of the diffuse layer around the solid particles. EO flow would enhance the movement of interstitial water from the anode end towards the cathode end. Moreover, in this work it was noticed that about 20 min after the application of electric current, hot water vapor began to evolve, as suggested in Figs. 7 and 8. This phenomenon, also observed in Test $T_{30}A_7$ as shown in Fig. 4, might be due to a great increase in electrical resistance between the anode and the cathode as a result of water depletion (i.e., the existence of a discontinuous phase). This viewpoint was verified by the fact that the temperature of the sludge filter cake increased substantially after each electrodewatering test. The greater the applied electric field, the higher the cake temperature. The mean values of filter cake temperature for the test group of $T_{30}A_z$ are given as follows: (1) $T_{30}A_1$, 32.5 °C; (2) $T_{30}A_4$, 65.5 °C; and (3) $T_{30}A_7$, 78.0 °C.

3.8. Energy requirements and related cost analysis

Table 5 further showed the electrical energy requirements and the corresponding electricity costs for various electrodewatering tests. Logically, the electrical energy requirement increased as the the magnitude of applied electric current increased. Likewise, the

Table 5
Evaluation of treatment performance and energy efficiency of various electrodewatering tests for the selected biological industrial sludge.

	Test no.		
	$T_{45}A_1$	$T_{45}A_4$	$T_{60}A_4$
Cumulative quantity of removed water (mL)	4600	2894	2505[b]
Electrical energy required (kWh)	0.10	0.60	0.75
Electrical energy requirement per unit volume or weight of removed water (kWh/L = kWh/kg for water)	0.02	0.21	0.30
Weight of the filter cake (dry tons)	1.29×10^{-3}	1.07×10^{-3}	1.25×10^{-3}
Electrical energy requirement per unit weight of filter cake (kWh/dry ton)	77.5	560.7	590.6
Electricity cost per unit weight of filter cake (NT$/dry ton)[a]	242–249	1750–1806	1868–1927
Electricity cost per unit weight of filter cake (US$/dry ton)[a]	8.07–8.30	58.33–60.20	62.27–64.23

[a] Based on 3.02–3.76 NT$/kWh and 1 US$ = 30 NT$.
[b] For the ease of comparison, here 2505 mL is the cumulative quantity of removed water for Test $T_{60}A_4$ during the period of 0–45 min.

corresponding electricity costs also increased. The above statement also applies to the group of $T_{30}A_z$ electrodewatering tests conducted using an influent pipe of a smaller diameter. From Tables 4 and 5, although Test $T_{45}A_4$ yielded a filter cake of the lowest moisture content (ca. 53.2%), its electricity cost was about 7.25 times greater as compared with that of Test $T_{45}A_1$. The latter yielded a filter cake having a moisture content of about 65.0% and required the lowest amount of electrical energy. To find a compromise between the moisture content in the filter cake and the electrical energy requirement, Test $T_{45}A_1$ would be the preferred one to put into practice. This statement was justified by the following reasons: (1) from Fig. 5, application of an electrical potential gradient as low as 8 V/cm for a period of 45 min could achieve the same goal of a substantial reduction of the sludge moisture content; (2) by taking into account the disposal cost of so-dewatered sludge, its total cost (the sum of electricity cost and disposal cost) would be lower than that of the same sludge cake having a moisture content of 80%; and (3) according to Table 5, the electrical energy requirement per unit weight of removed water for Test $T_{45}A_1$ was only 0.02 kWh/kg, which is much lower than the water vaporization enthalpy (i.e., the minimal drying energy requirement) of about 0.617 kWh/kg required in thermal processes [23]. With regard to electrical energy requirements per unit weight of removed water, the test with a higher applied constant electric current would be inferior, namely it would not be energy-effective. In other words, it is more appropriate to operate the electrodewatering test at a lower magnitude of applied electric field, in this case at a lower constant electric current. A similar conclusion has also been made by Zhou et al. [19] in their study using a horizontal electric field. The electrical energy requirement per unit volume of removed water for Test $T_{45}A_1$ (with an average electrical potential gradient of about 8 V/cm) is also comparable with that reported by Zhou et al. [19] in their test with an applied voltage of 80 V (i.e., 12 V/cm) and operation time of 60 min. Further comparing the moisture content in the filter cake and the corresponding energy cost of Test $T_{45}A_1$ with the test having best results reported by Yuan and Weng [22], the overall performance in this work is superior. A study on electrodewatering of sewage sludges in four Australian plants has shown that there were considerable differences in the values of power consumption, which varied from 1570 to 3185 kWh/tDS to achieve a filter cake with 40 wt% of solids [24]. However, it was also reported in the same study that the power consumption was much lower (i.e., 880 kWh/tDS) using a bench scale filter press with a cross-sectional area of 0.1 m^2. In summary, the practice of Test $T_{45}A_1$ was energy-effective as compared with that reported in the literature.

4. Conclusions

Application of an electric field to a pilot-scale filter press has been proven to substantially enhance its dewatering performance for a biological industrial sludge. By applying 1 A of constant electric current for 45 min, the moisture content in the sludge filter cake could be lowered to about 65.0%. This practice was determined to be cost-effective. Therefore, further studies on a larger scale EK-assisted filter press for dewatering of various sludges are warranted.

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