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A study of the improvement in dewatering behavior of wastewater sludge through the addition of fly ash

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Abstract−Wastewater sludge is classified as a difficult dewatering material (DDM) due to the high cake specific resistance (CSR). On the other hand, fly ash is classified as an easy dewatering material (EDM), which suggests that it might be able to improve the dewaterability of wastewater sludge. The water content and cake specific resistance of dewatered sludge without the addition of fly ash were 80% and 2.9×10^{14} kg/m, respectively. When 50% (by dry weight) fly ash was added to the sludge, the water content and cake specific resistance decreased to 29.4% and 2.9×10^{13} kg/m, respectively. The cake specific resistance and water content decreased with increasing fly ash additions. Therefore, the production of sludge cake can be reduced by adding fly ash, which can help minimize the social and environmental problems caused by the need to dispose of wastewater sludge.

Key words: Dewatering, Wastewater Sludge, Fly Ash, Difficult Dewatering Material, Easy Dewatering Material, Cake Specific Resistance

INTRODUCTION

The amount of wastewater sludge has increased in recent years due to the expansion of urbanization, increase in the number of wastewater facilities, and the advancement of treatment technologies. The shortage of disposal sites for dewatered sludge has created a number of environmental problems and increased the cost of handling sludge. Producing cake with low water content from wastewater sludge is essential for solving these problems. Dewatering technology is a solid-liquid separation technology and essential technology for sludge reduction.

The ash generated from power plants was used to help improve the dewatering rate and increase the amount of reusable dewatered cake. Dewaterability is determined by the dewatering velocity. Adding ash to the process not only decreases the water content of the cake but also produces a high strength cake. This study is expected to help reduce the social and environmental problems resulting from the handling the wastewater sludge by using the waste product from power plants in the filtration process.

A number of methods for reducing the sludge water content have been reported. The dewaterability of sludge has been improved by both the development of highly efficient dewatering technology and the addition of an aid material to the filtration process. Highly efficient dewatering technologies include electro-osmotic dewatering, thermal-dewatering and microwave-dewatering [1-3]. These new technologies need to be applied to improve the dewaterability of conventional dewatering equipment. But the economic feasibility of using these new technologies is dubious because of the additional heat or electrical requirement [4,5]. Several researchers have evaluated the effectiveness of adding ash to sludge during the dewatering process. Nelson [6] has measured the bound water distribution properties surrounding ash particle and wastewater sludge particle, and he found that bound water of ash particles was less than wastewater sludge. He examined the dewaterability improvement of mixed sludge with adding ash into wastewater sludge on the basis of the above result. Also, Thapa [7] has conducted experiments about methods to make use of fuel of dewatered cake as well as improvement of dewaterability as adding lignite into wastewater sludge [6,7]. However, these studies only examined the dewatering efficiency of adding ash, and not the adjustments to the actual dewatering equipment that will be necessary or a specific analysis of dewaterability, such as the cake specific resistance [8,9].

Wastewater sludge is considered as a difficult dewatering material (DDM), while ash is an easy dewatering material (EDM). The changes of the dewaterability resulting from mixing these two materials were determined in two steps:

(1) dewaterability by adding glass beads of EDM into the bentonite of DDM

(2) dewaterability by adding ash to wastewater sludge.

Bench and pilot-scale equipment was set up for performing the above two types of dewaterability experiment. The dewaterability was determined by the water content and cake specific resistance (CSR) by adding an amount of EDM after analyzing each material [5].

EXPERIMENTAL AND METHODS

1. Dewatering Equipment

A piston-type dewatering experimental device and a filter press dewatering device were used for the bench-scale and pilot scale experiments, respectively. Before carrying out the experiment on waste-

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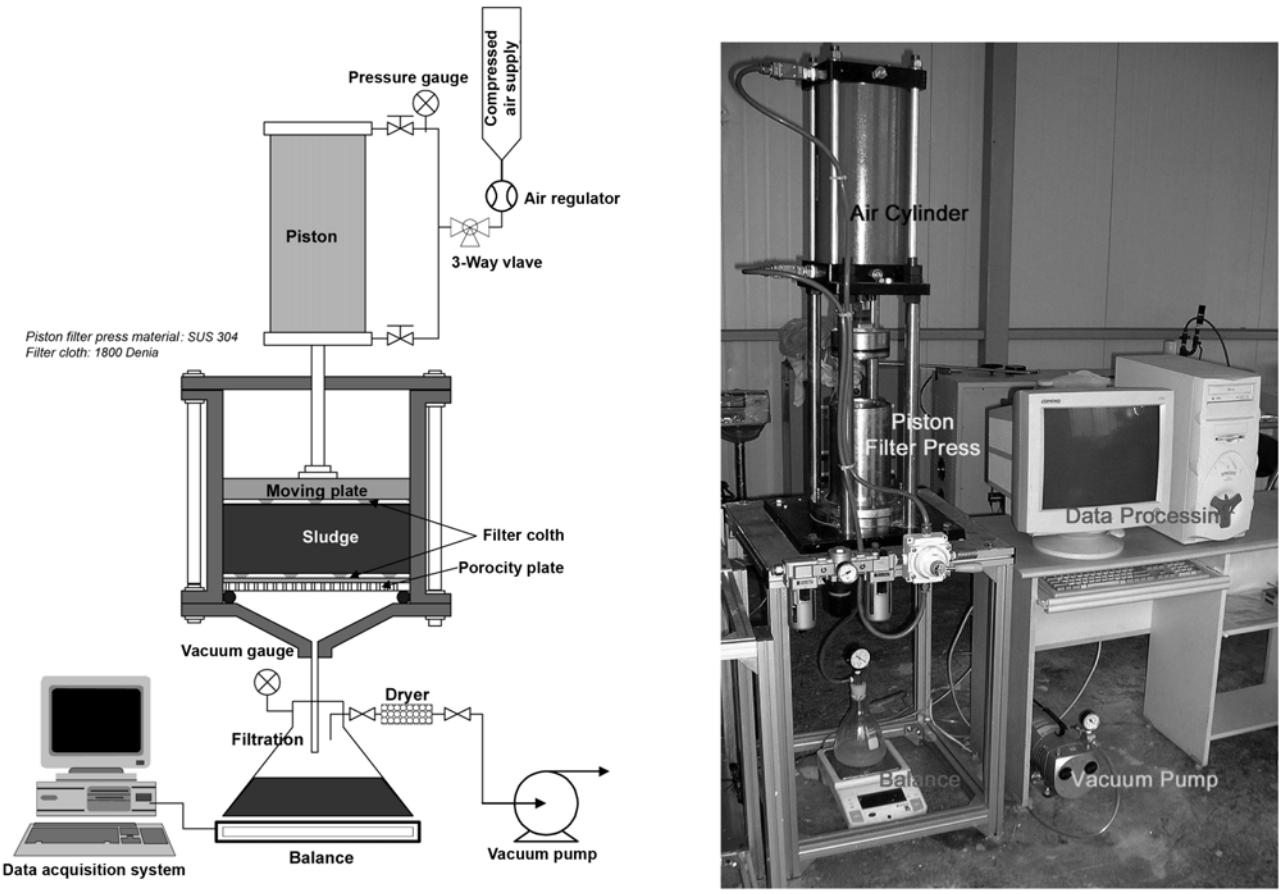
water sludge, we conducted an experiment on sludge mixed with the bentonite of DDM and glass beads of EDM using the bench-scale experiment device. After that, the wastewater sludge mixed with fly ash was processed using the pilot filter press device.

Fig. 1 shows a schematic diagram and photograph of the piston type dewatering equipment, and Table 1 lists the design and operating conditions of this equipment. The suspension was held in a vertical cylinder with an inner diameter and length of 140 mm and 250 mm, respectively, with flanges at each end. The lower part of the cylinder was equipped with a perforated plate with 90 holes, 3 mm in diameter. A nylon filter cloth with a pore-size of 50 μm was placed on top of the perforated plate. The water removed passed through



(a) (b)

Fig. 1. Piston type dewatering experimental device for bench scale experiment. (a) schematic diagram, (b) photograph.

Table 1. Experimental conditions

Apparatus	Experimental conditions		Value
Piston dewatering apparatus (Bench-scale)	Design conditions	Filter area (cm^2)	154
		ID of cylinder (mm)	140
		Height of cylinder (mm)	250
	Operating conditions	Pressure (kg_f/cm^2)	5
		Dewatering time (minutes)	180
		Vacuum (mmHg)	300
Filter press dewatering (Pilot-scale)	Design conditions	Filter plate size (mm)	470×470
		Filter plate area (m^2/ch)	0.29
		Filter plate volume (m^3/ch)	3.15
		Chamber thickness (mm/ch)	24
	Operating conditions	Dewatering time (min)	160
		Feeding pressure (kg_f/cm^2)	5
		Squeezing pressure (kg_f/cm^2)	15

ch: chamber

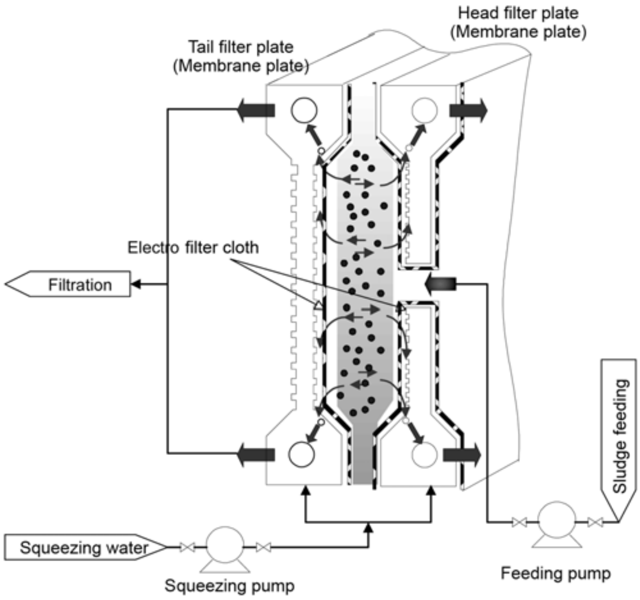


Fig. 2. Schematic diagram of filter press dewatering equipment for pilot scale experiment.

the lower side of a vessel, and was measured with a balance (model, GT410, OHAUS). The filtration weight was recorded on a personal computer. This type is called a mechanical dewatering (MDW) device with a pressure and vacuum of 5 kg_f/cm^2 and 300 mmHg, respectively. The dewatering time was approximately 180 min and the filtration area was 154 cm^2.

Fig. 2 and Table 1 show the filter press used in the pilot-scale study. The dewatering time ranged from 80 to 140 min, and varied according to the sludge types and dewatering methods. If cake formation occurred inside the chamber, the sludge supply was eliminated and a hydraulic pressure was then applied to the membrane plates at a pressure of approximately 15 kg/cm^2, which is called the squeezing process. After these processes, the filter plates were opened and the cake was removed from the chamber. Table 1 shows the design and operating variables of the experimental equipment. The squeezing plate, which is also called the membrane plate, was made of polypropylene. The size of these plates was 470×470 mm and the chamber thickness of the filter press was 24 mm. The filtration area per chamber was 0.29 m^2. The filter cloth was made from 1800 denier polypropylene (Hwashin Filter Co. Ltd. of Korea). The surface of the plate was uneven, which allowed the liquid to flow down and be expelled through the drain holes in the lower part of the plate. The results of the dewatering experiment were evaluated by calculating the dewatering velocity and specific cake resistance from the cake weight and final water content of the cake.

2. Measuring Method of Sludge Characteristics

Sludge with water content of 95% was manufactured by mixing bentonite containing glass beads of 0, 5, 10, 20% with water. SEM (FEG-SEM, S-4200, Hitachi) and particle size analysis (Malvern, Mastersizer) were used to determine the shape and size of the particles. The DDM and EDM were classified by the SiO_2 to Al_2O_3 ratio, organic content, particle size, cake strength and pH at the point of zero. This data was used to determine the dewatering characteristics of the wastewater sludge and power plant fly ash. The organic content of the sludge was measured from the weight loss after being heated to 600 °C in an electric furnace for one hour. The SiO_2 to Al_2O_3 ratio was measured using an X-ray fluorescence sequential spectrometer (Phillips, PW1480). The sludge and cake water content before and after the dewatering experiments were obtained by gravimetry after the cakes were dried at 105 °C for four hours. The surface potential was determined by measuring the pH at the point of zero using a Zeta meter The filter press device was used for the wastewater sludge dewatering experiment. The ratio of ash was 0, 30, 5 0% according to the dry base. The dewaterability was determined by the water content and cake specific resistance. The wastewater sludge was taken from Suyoung Wastewater Treatment Plant and the fly ash was obtained from the Samchenpo Power Plant in Korea.

RESULTS

1. Dewaterability of the Bentonite Sludge Mixed with Glass Bead Particles

Fig. 3 shows the particle shape and size of the bentonite and glass beads. Bentonite is non-spherical with a mass median diameter (MMD) of 4.4 μm, which makes the diameter of the capillary tubes in the cake small for dewatering creating difficulties when discharging liquid from the cake. Therefore, it is classified as a DDM. On

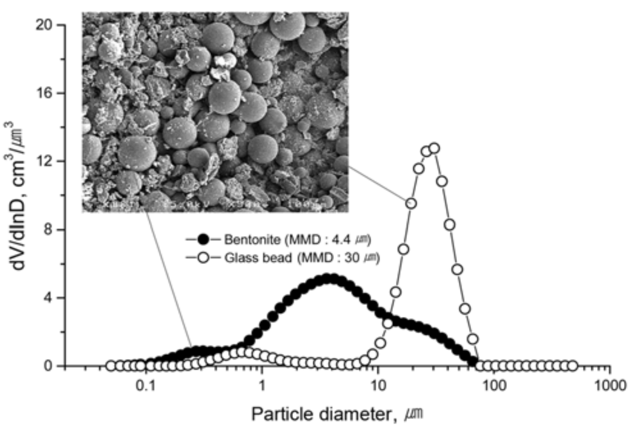


Fig. 3. Particle shape and size of bentonite and glass beads.

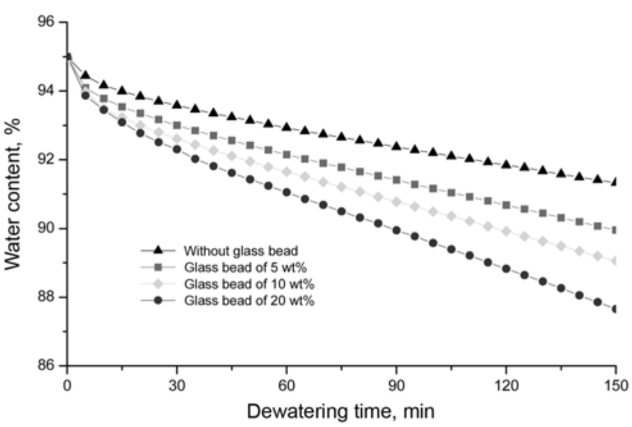


Fig. 4. Test results for the bentonite sludge without the added glass bead and with 5, 10, 20% of dry base.

the other hand, the glass bead is a sphere with an MMD of 30 μm, which makes it easy to discharge liquid from the cake. Therefore, this material is classified as an EDM.

Fig. 4 presents the test results for the bentonite sludge without the added glass beads and with 5, 10, 20% of the dry base. At that time, the initial water content was 95%. The change in the water content of the cake was measured from the lapse in dewatering time. The distribution of the water content decreased with increasing amount of EDM. This suggests that the dewaterability improved as the amount of EDM was increased, because the cake specific resistance (SCR) of the DDM decreased as EDM was added.

2. Characteristic of Wastewater Sludge and Fly Ash

Table 2 shows the physical and chemical properties of the wastewater sludge and ash particles analyzed by items such as the SiO_2 to Al_2O_3 ($SiO_2 : Al_2O_3$) ratio, organic content, particle size, cake strength and pH at the point of zero. The low SiO_2 to Al_2O_3 ratio, high organic content, low cake strength and high pH at point of zero of the wastewater sludge revealed it to be a DDM because these characteristics make it difficult to remove the residual liquid from the cake. On the other hand, an EDM has a high SiO_2 to Al_2O_3 ratio, low organic content, high cake strength and relatively low pH at point of zero. Therefore, the dewaterability of the fly ash was superior to that of the wastewater sludge due to the higher $SiO_2 : Al_2O_3$ ratio of the fly ash, and much lower organic carbon content and pH at point of zero [10]. This suggests that adding fly ash may improve the dewatering efficiency of wastewater sludge.

Table 2. Chemical properties of wastewater and ash particles

Materials	Variables analyzed	Values
Wastewater sludge	$SiO_2 : Al_2O_3$	2.2
	Organic carbon content (wt%)	46
	Mass median diameter (μm)	30
	Cake strength (kg_f/cm^2)	0.3
	pH at point of zero charge	6
Fly ash particles	$SiO_2 : Al_2O_3$	3.7
	Organic carbon content (wt%)	5
	Mass median diameter (μm)	17.8
	Cake strength (kg_f/cm^2)	2.2
	pH at point of zero charge	3

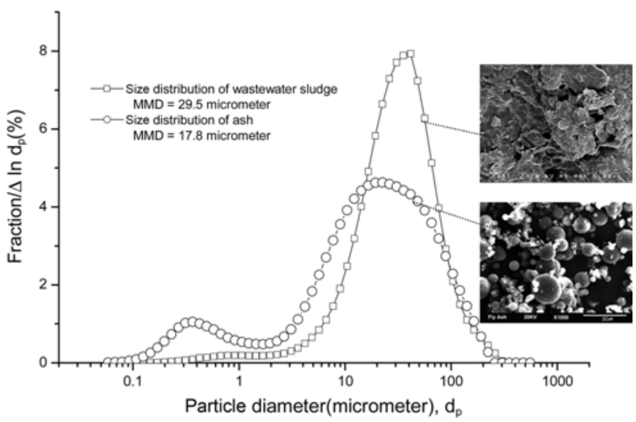


Fig. 5. Size distribution and shape of wastewater sludge and ash particles.

Fig. 5 shows the particle shapes and size distribution of the wastewater sludge and ash particles. The wastewater sludge particles are non-spherical and sticky due to the high organic content, making the particles aggregate easily. The ash particles were spherical and easily formed pores between the particles. The particle size of the wastewater sludge, 29.5 μm, was larger than that of the ash, 17.8 μm. The particle size has little effect on the porosity of the cake compared to the organic content, shape and other variables.

Therefore, wastewater sludge is a DDM, and it was hypothesized that the dewaterability of wastewater sludge could be improved by adding fly ash. Fig. 6 shows the change in water content of the sludge, as a result of adding fly ash at various concentrations during dewatering in a piston dewatering device. As described above, the experiments were designed to determine whether adding fly ash to wastewater sludge can improve significantly the dewatering efficiency of the sludge. Fly ash was added at concentrations of 0, 20, and 50% (dry weight) and the material was then dewatered by using the bench-scale equipment. Fig. 6 shows the change in water content according to the dewatering time. The dewatering rate increased with increasing fly ash concentration. When no fly ash was added, the decrease in water content was so small that a dewatered cake with a water content as high as 88% was obtained after 20 minutes.

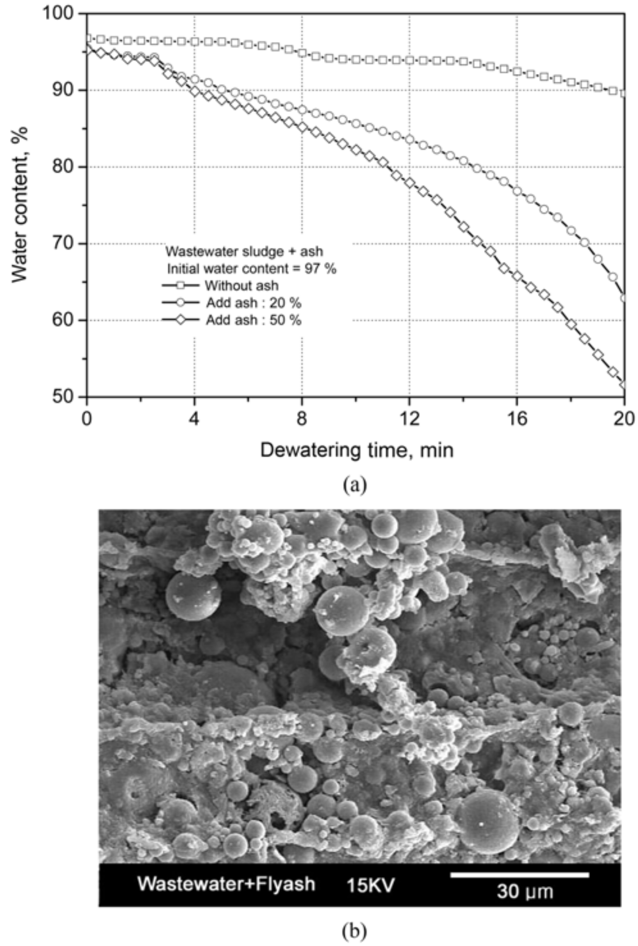


Fig. 6. Change in the water content of the sludge as adding ash concentration. (a) water content profile, (b) photograph of mixed sludge.

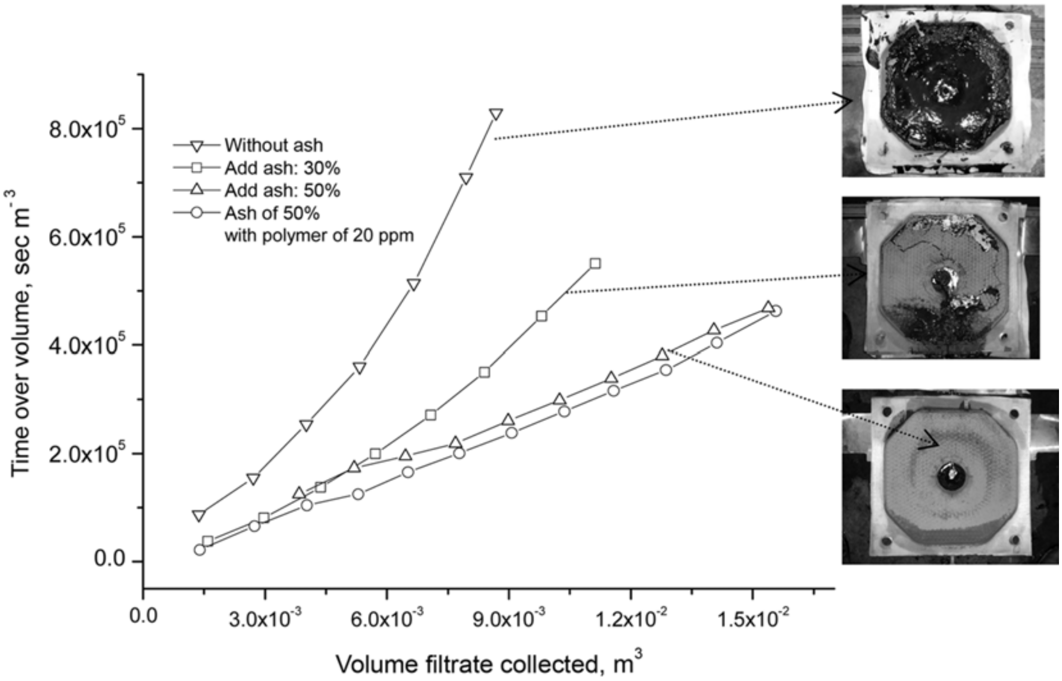


Fig. 7. Dewatering properties of wastewater sludge dewatered in a filter press (pilot-scale) as a function of the rate of addition of fly ash.

Table 3. Cake water content and CSR of wastewater sludge dewatered using a filter press (pilot-scale)

Conditions			Results	
Ash addition by dry weight (%)	Initial water content (%)	Organic content (%)	Cake water content (%)	CSR (kg/m)
0	97.7	24.5	80	2.9×10^{14}
30	97.8	19.2	66.2	1.3×10^{14}
50	98.3	14.5	29.4	4.2×10^{13}
50	98.3	14.5	28.2	3.6×10^{13}

However, the water content decreased rapidly when 20% and 50% fly ash was added, resulting in a final water content of 63% and 52%, respectively. This can be explained by the higher level of porosity in the cake, with more fly ash causing an increased rate of water removal from the cake. The results shown in Fig. 6 suggest that the dewatering of wastewater sludge can be improved by adding fly ash, and the improvement in dewatering efficiency increases with increasing concentration. However, it is not feasible to add more than 50% fly ash as this would increase the amount of wastewater sludge for disposal. These results show that 20% is the most appropriate concentration of fly ash in wastewater sludge.

3. Dewaterability of Wastewater Sludge as Adding Ash

Pilot-scale filter-press dewatering equipment was used to determine the dewaterability of wastewater sludge as a result of adding fly ash or polymer does. Fly ash dose was 30% and 50% respectively, and polymer dose was 20 ppm in the case of sludge with 50% fly ash. The dewaterability of wastewater sludge was initially tested without adding the fly ash. The process was then repeated after adding 30% fly ash to the total amount of sludge with a water content of 97%. Further experiments were carried out using 50% fly ash, and 50% fly ash with polymer added at 20 ppm. Fig. 7 shows the relationship between the volume of filtrate collected and the dewatering time. The low slope of the lines in the graph (Fig. 7) indicates that the amount of filtrate collected per unit time was large, showing an improvement in dewaterability resulting from the added fly ash [11]. The photograph on the right-hand side of Fig. 7 shows the fly ash mixed with the wastewater sludge. Table 3 summarizes the cake water content and CSR, obtained from the results shown in Fig. 7. The slope of the response of time per unit volume to the volume of filtrate collected when no fly ash was added was quite high, as shown in Fig. 7. This means that considerable time is needed to remove the residual liquid from the sludge, which confirms the classification of wastewater sludge as a DDM, as illustrated in Table 2. The photograph shows that no sludge cake was formed after dewatering when no fly ash was added and that the final water content and CSR was 80 wt% and 2.9×10^{14} kg/m, respectively. When fly ash was added at 30% (dry weight), the slope of the response curve in Fig. 7 decreased markedly and cake formation could be clearly observed, as shown in the photograph. In that treatment, the water content and CSR decreased to 66.2 wt% and 1.3×10^{14} kg/m, respectively. When 50% fly ash was added, the slope of the response curve in Fig. 7 decreased further and perfect cake formation was observed. The cake water content decreased to 29.4% and the CSR decreased to 4.2×10^{13} kg/m. Therefore, the dewaterability was improved greatly by adding 50% fly ash. Adding fly ash to wastewater sludge reduced the CSR and produced a cake with low water content. The dewatering tests carried out using 20 ppm of a polymer mixed with the sludge in addition to 50% fly ash showed a similar slope of the response curve to the sludge with 50% fly ash but no polymer (Fig. 7). The final water content and CSR of the sludge was 28.2% and 3.6×10^{13} kg/m, respectively. This result is similar to the sludge where no polymer was added. The essential purpose to get low water content cake from wastewater sludge is for recycling. Dewatering without polymer is important because the polymer to use for dewatering of wastewater sludge has some problems in the recycling process. It is not nearly different to dewatering efficiency with polymer or without polymer as shown in Fig. 7. This means that mixed sludge dewatering without polymer is more economical and useful at the side of resources application than dewatering with polymer.

CONCLUSION

This study evaluated the possibility of improving the dewaterability, specifically the water content of the cake and cake specific resistance, of wastewater sludge by adding fly ash, a dewatering aid material. The dewaterability of fly ash is superior to that of wastewater sludge. The results of the bench-scale experiments showed that the dewatering efficiency of wastewater sludge increased with increasing amount of fly ash. When 50% (dry weight) fly ash was added, the water content and CSR of the cake decreased to 29.4% and 4.2×10^{13} kg/m, respectively. The observed improvement after adding fly ash was attributed to the increased porosity of the cake. This means that the amount of sludge cake can be reduced, which will help minimize the social and environmental problems caused by the difficulties in disposing of wastewater sludge.

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