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Enhancement of thickening and dewatering characteristics of sewage sludge using cement kiln dust

A.M. Aboulfotoh*, A.M. Dohdoh

Environmental Engineering Department, Faculty of Engineering, Zagazig University, Zagazig, Sharkia 44519, Egypt, Tel./Fax: +0020552304987; emails: aseaf_1@yahoo.com, asalem@zu.edu.eg (A.M. Aboulfotoh), aydohdoh@gmail.com, aymandohdoh@zu.edu.eg (A.M. Dohdoh)

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ABSTRACT

Sewage sludge conditioning with chemicals has been employed widely to improve thickening and dewatering processes. Although it is a good alternative for process improvement, its cost is high. It is important to find effective and cheap conditioners. Large quantities of cement kiln dust (CKD), which proved to be a good chemical stabilizer of sewage sludge, are emitted from cement factories. In this study, the effect of using CKD on the thickening and dewatering performance of sewage sludge were investigated by zone settling test, free gravity drainage test, specific resistance to filtration (SRF) and natural drying tests. The results indicated that adding CKD to sewage sludge by 60% of total solid could improve the sludge thickening, dewatering as well as stabilization. The settleability of sludge was improved as follows: the zone settling velocity increased from 43.2 to 98.4 m/d, the SRF decreased from 5.93 (10^3·m/kg) to 0.76 (10^3·m/kg) and the actual dewatering time required to achieve sludge with solid content more than 20% reduced from 5 to 2 d, while the pH value remained in the required range for stabilization.

Keywords: Cement kiln dust; Conditioning; Dewatering; Sewage sludge; Thickening

1. Introduction

The continuous increase in population resulted in a significant increase in the amount of wastewater that needs to be treated. Thus, the number of wastewater treatment plants (WWTPs) increased dramatically all over the world. Sewage sludge treatment is one of the processes that require a high cost and therefore it attracted a considerable attention by many researchers. Barberio et al. [1] reported that the cost of sludge treatment ranges from 20% to 50% of the total management cost of a WWTP.

In Egypt, the total number of WWTPs reached 303 plants by 2008. These plants treated about 11.85 × 10^6 m^3/d of wastewater (including industrial wastewater) and produced about 5,800 tons of dry solids per day. The current and common applied scenario for sewage sludge treatment and disposal in about 78.9% of WWTPs in Egypt is as follows: (i) the sewage sludge (primary and secondary) is pumped to the thickening facilities (gravity thickeners) then it is directed to the dewatering facilities (natural drying beds) and (ii) the dewatered sludge is stored for a period of 1.5–6 months before using in agriculture. This scenario does not contain facilities for sludge stabilization processes. Additionally, the quality of the produced sludge in most of the WWTPs does not fit with the Egyptian or international standards, especially pathogens' limits. Therefore, alternative methods have to be developed to meet the standards [2,3]. Alkaline stabilization provides the most common and cost-effective process for wastewater solids stabilization. This holds true for situations in which alkaline by-products were used. In this process, the pH of the sludge/alkaline materials mixture must be above 12 for 2 h and subsequently remains above 11.5 for 22 h to meet the pathogen and vector attraction reduction requirements by alkaline addition. The importance of measuring the pH during alkaline stabilization arises from the strong correlation between the pH and the pathogen destruction [4,5].

* Corresponding author.

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The effectiveness and cost of sludge treatment and disposal operations depend strongly on the water content and/or solids concentration. Thus, thickening and dewatering are important steps in the sludge treatment processing train and play a vital role in reducing the cost and increasing the effectiveness. Chemical additives named as sludge conditioners may be used to improve solids recovery, supernatant quality and enhance performance of thickening and dewatering processes [6]. The moisture content in sludge consists of 70% free water, 20% interstitial water, 7% adsorbed water and 3% bound water. Except for sludge properties, the dewatering performance was mainly dependent on selection of sludge devices and chemical conditioning methods [7].

Cement kiln dust (CKD) is a fine grained alkaline material, which is a by-product of cement clinker production. In Egypt, approximately 1 million tons of cement dust are discarded annually from the cement manufacturing facilities. CKD, when properly used, will be a valuable soil conditioner and partial fertilizer [8]. X-ray diffraction analysis of CKD showed that the main constituents are calcite ($CaCO_3$), quartz (SiO_2) and calcium sulfate ($CaSO_4$). CKD has the potential of neutralization of acidity and adsorption or removal of aqueous metals and nutrients [9]. Motivated by the no-cost material, CKD was used as a chemical coagulant in wastewater and sludge treatment for heavy metal scavenging, such as chromium, iron, cobalt, and copper, from aqueous solutions and industrial wastewater [8]. Some researchers [8,10–13] tested the utilization of CKD to separate the organic matters and suspended solids and reduce the organic micropollutants and heavy metals in sewage sludge while some others [9,11,14,15] used the CKD to improve the quality of wastewater treatment and irrigation water.

Based on the abovementioned review, the main goal of the current paper is to evaluate the effect of CKD addition on sewage sludge stabilization, thickening and dewatering.

2. Materials and methods

The experimental work presented in this paper was conducted at the Environmental Engineering Laboratory, Faculty of Engineering, Zagazig University, Zagazig, Egypt.

2.1. Sludge characteristics

Sludge samples were taken from El Kinayat WWTP, Zagazig, Sharkia, Egypt. This sludge is a mixture of primary and trickling filters hummus. pH, total solids (TS) and volatile solids (VS) were measured for each influent sewage sludge sample before the addition of CKD. These parameters were measured according to the standard methods for the examination of water and wastewater [16]. The results of these measurements are summarized in Table 1.

Table 1
Characteristics of the influent sewage sludge

Parameter	TS (ppm)	VS (%, TS)	pH value
Range	38–66	60–75	6.2–6.8

2.2. Cement kiln dust

The CKD utilized in the present study was collected from Helwan Portland Cement Factory territory and was characterized by chemical composition, specific gravity, and pH. The chemical composition of the used CKD was reported in Badrawi [17] and is shown in Table 2.

The required dose of CKD for achieving stabilization was determined at first and then the thickening and dewatering characteristics of stabilized sludge was evaluated as shown in the following experimental tests.

2.3. Sludge stabilization test

The effect of CKD on sludge stabilization was compared with the chemical stabilization using lime, which was considered as a benchmark. The dosage of CKD and lime added to the sludge was increased gradually until the pH value reaches about 12.5 then the pH value was recorded after 2, 24 and 48 h (the dosage of the CKD was presented in terms of the dry solids (DS) percentage as g CKD/g DS). Sewage sludge with two different solid concentrations ranges was tested. The first was concentrated sludge from the WWTP with solid concentration range 4%–6% while the second was diluted sludge with 1%–3% solid concentration. The diluted sludge was obtained by the addition of raw wastewater to the concentrated thickened sludge.

2.4. Zone settling test

To evaluate the thickening characteristics of CKD-treated sludge, zone settling test had been conducted using two pilot-scale settling columns, depicted in Fig. 1, which were made of Pyrex (Plexiglas) cylinders (1.00 m tall and 14 cm internal diameter). One valve was installed at the bottom of each column and was used to collect settled sludge samples and to drain the contents of each column. The sludge conditioning with CKD was carried out as follows: (1) a certain dosage of CKD – that has been determined from the sludge stabilization test – was added to 12 L of sludge in a container, (2) the mixture was stirred rapidly with a speed of 250 rpm for 30 s followed by a slow agitation for 1 min at a speed of 30 rpm. Untreated and treated diluted sludge samples were poured into the two settling columns. An extended settling test (24 h) was also performed.

Table 2
Chemical composition analysis of CKD [17]

Compound	% Weight
CaO	51.50
SO_3	5.12
SiO_2	15.15
Al_2O_3	5.40
Fe_2O_3	1.83
MgO	1.63
Na_2O	2.36
K_2O	2
Loss on ignition	21.8

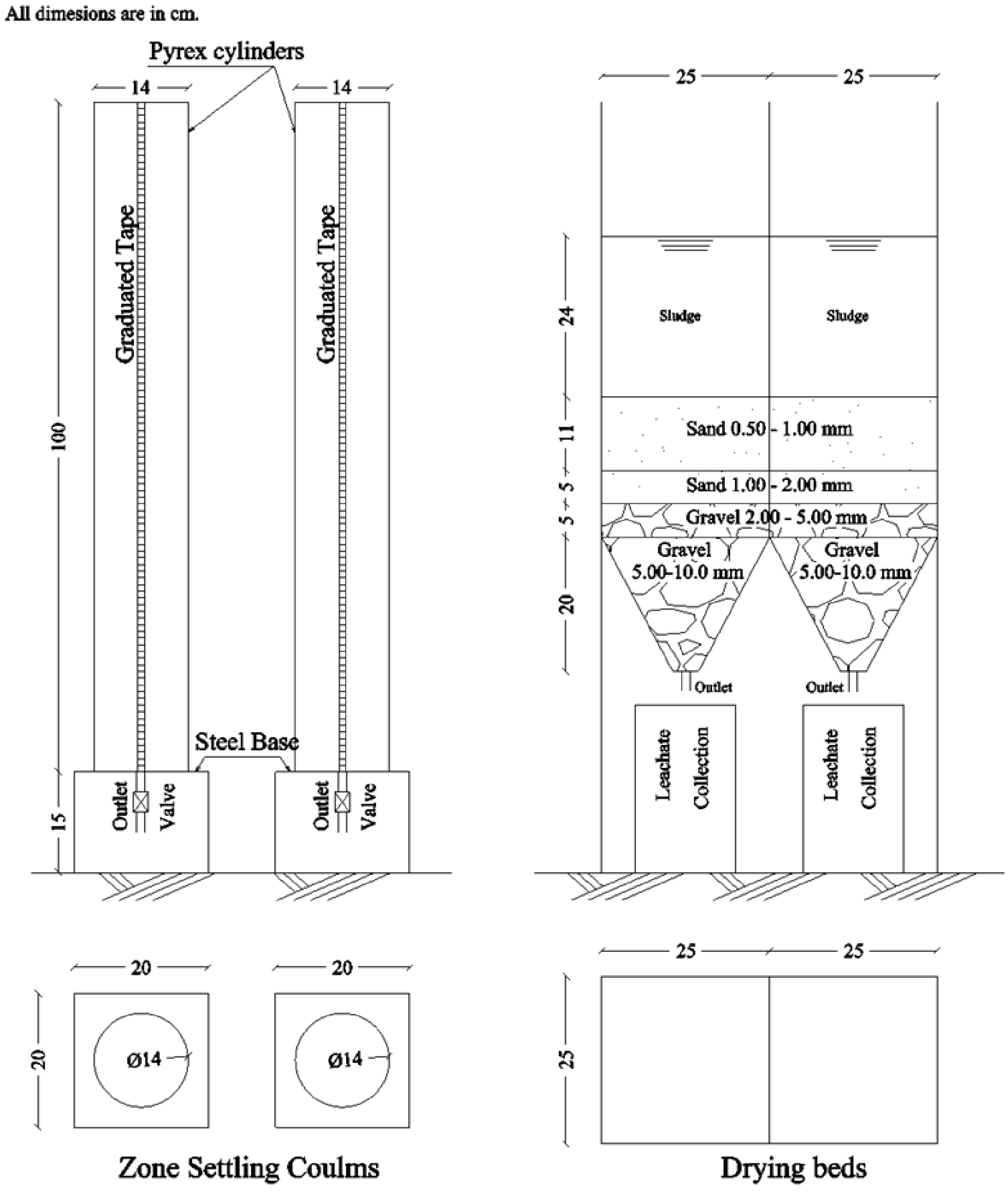

Fig. 1. Zone settling columns and drying beds pilot.

2.5. Free gravity drainage test and specific resistance of filtration

Specific resistance to filtration (SRF) test was used for the evaluation of sludge dewaterability and filterability. A certain dosage of CKD (10%, 30%, 40%, 50%, 60% and 100%) was added to 250 mL of sludge in a beaker of 500 mL and stirred as described in section 2.4. The treated sludge was then quickly poured into a Buchner funnel (fitted with a circular piece of belt press fabric). The Buchner funnel was set on top of a graduated cylinder allowing for the filtrate volume to be recorded against time. Hence, the volume of the filtrate (V) is proportional to the solid content (C) and plotting the time/volume of filtrate against the solid content (C) gave a linear relationship with slope (b). Then, the SRF could be calculated using the following Eq. (1):

$$R = \left(\frac{\rho g h A^2}{\mu C} \right) b \tag{1}$$

where R = specific resistance (m/kg), A = area of filtration (m^2), C = solid content (kg/m^3), $\rho g h$ = hydrostatic pressure

(N/m^2), V = volume of filtrate (m^3), μ = dynamic viscosity ($N\ s/m^2$), b = slope (s/m^6).

2.6. Sludge drying bed test

The optimum dosage of CKD obtained from stabilization and SRF tests was applied in natural drying bed test. The drying beds used in this study was 25 × 25 cm^2 surface area, sludge height was 24 cm, the drainage system consisted of 11.0 cm fine sand (0.50–1.00 mm), 5.0 cm coarse sand (1.00–2.00 mm), 5 cm fine gravel (2–5 mm) and the bottom conical part of the drying beds contained medium gravel (5–10 mm). Beneath all these layers, a 4-mm steel strain was installed above the 0.5-inch outlet pipe (Fig. 1). The drying beds were placed in a covered place in order to decrease the evaporation effect of direct sunlight. The pH value (for sludge and filtrate) and filtrate volume were measured on daily basis.

3. Results and discussion

Results presented in the following sections were mean values of at least two experimental tests; as each experiment was duplicated and if the difference between the average value and any basic value was greater than 5% the experiment was repeated again.

3.1. Sludge stabilization

As mentioned in section 2.3, CKD and lime dosages were increased gradually in order to raise pH above 12. Table 3 summarizes the effect of CKD and solids concentration on sludge stabilization compared with chemical stabilization using lime. The table indicates that the CKD dosage that achieves stabilization was 50% and 60% for thickened and diluted sludge, respectively, while the required dosage of lime ranged from 22% to 29%. The required lime dosage complies with the results of EPA [4], Wang et al. [18], Rahman et al. [11] and Salah et al. [12]. From Table 2, it is clear that calcium oxide represents only 50% of the CKD composition which explains why the required CKD dose was higher than twice that of lime.

3.2. Zone settling rate

Zone settling test was conducted for diluted sludge samples with CKD dose of 60%; Fig. 2 shows the change of sludge interface height with the settling time. It is obvious from the figure that the addition of the CKD improved the sludge thickening. At any operating time, the sludge interface height for the treated sludge is lower than that for the untreated sludge. The zone settling velocity is determined as the slope of the linear part, which in the calculations was defined as the steepest slope in the curve [16]. Based on these criteria, the zone settling velocity increased from 43.2 m/d for the untreated sludge to 98.4 m/d for the treated sludge. For a factor of safety equals to 2, the hydraulic loading rate of gravity thickeners will be 21.06 and 49.20 m/d for the untreated and treated sludge, respectively.

The hydraulic loading rate for the untreated sludge complies with the hydraulic loading rate of the Water Environment Federation (WEF) [19,20], which ranged from 16 to 32 m/d for a mixture of primary sludge and trickling filter hummus and also with the recommended design hydraulic loading values by Metcalf & Eddy [21] and Wang et al. [18].

Regarding the extended settling test for the treated sludge, no floating sludge was observed which implies that the use of CKD did not result in biological actions, gases formation and thus good stabilization could be assumed. On the contrary, floating sludge was clearly observed within the untreated column.

3.3. Free gravity drainage testing and SRF

The effect of CKD on sludge dewaterability characteristics has been evaluated; Figs. 3(a) and (b) show the relation between sludge solid content and filtrate time for the

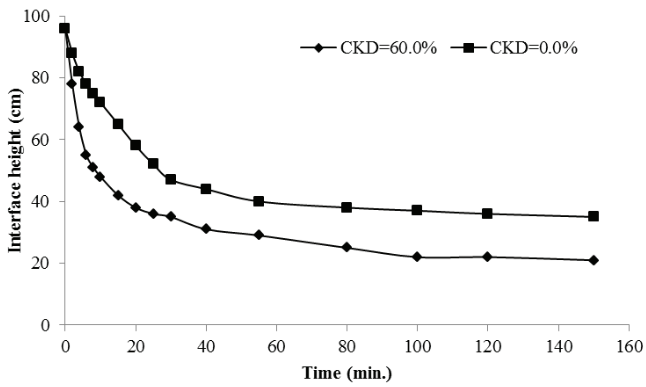

Fig. 2. Relation between sludge interface height and settling time.

Table 3
pH for treated sludge with CKD and lime

Sludge type	TS%	CDK dosage (TS%)	pH[a]			
			$T = 0$	After 2 h	After 24 h	After 48 h
Diluted	1–3	60	12.2	12.1	12.0	11.9
Concentrated	4–6	50	12.4	12.3	12.1	11.9
Sludge type	TS%	Lime dosage (TS%)	pH			
			$T = 0$	After 2 h	After 24 h	After 48 h
Diluted	1–3	29	12.4	12.3	12.3	12.2
Concentrated	4–6	22	12.5	12.4	12.3	12

[a]Initial untreated sludge pH values were as in Table 1.

different CKD dosage. Fig. 3(a) shows that adding only 10% of CKD reduced the filtrate time by third while Fig. 3(b) shows that increasing the dosage to 50% improved the dewaterability by decreasing the filtrate time while increasing the dosage above 50% had a reversible effect.

SRF is an important parameter for sludge dewaterability characteristics; Fig. 4 shows the relation between different CKD dosage and SRF. As shown the sludge SRF decreased dramatically with the increase of the CKD, the SRF of the untreated sludge was around 5.91 (10^3 m/kg) while for the 50% addition of CKD the SRF decreased to 0.676 (10^3 m/kg). When the CKD dosage exceeded 50%, the sludge SRF increased with the increase of CKD dosage. Therefore, the CKD was a good conditioner. These results comply with the results of Chen et al. [22] who used coal fly ash to improve the dewaterability of sewage sludge and found that a dosage of 273% is the optimum dose for fly ash. Also the results comply with the results obtained by Shihab [23], Lihong et al. [24] and Ademiluyi and Arimieari [25].

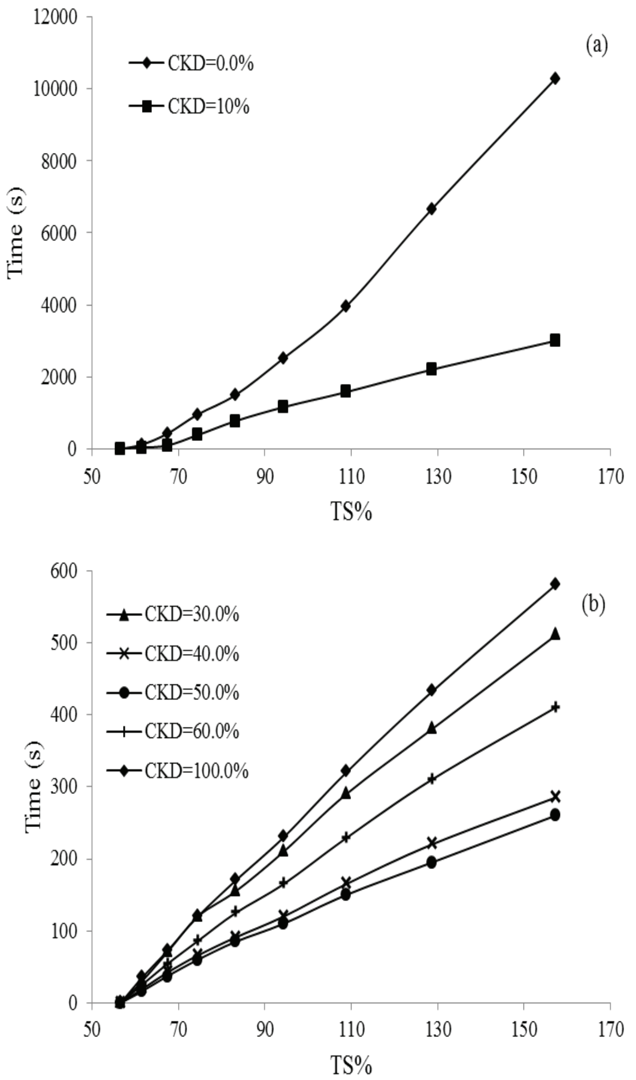

Fig. 3. Relation between sludge solid content and filtrate time for different CKD dosage.

3.4. Sludge drying bed

From stabilization, zone settling and SRF tests, the optimum CKD dosage was around 50% of sludge dry solid content, that percentage was used for the sludge drying bed test in order to evaluate the effect of CKD treatment on the performance of the drying beds and checking sludge stabilization conditions for long time performance. Fig. 5(a) shows the relation between drying time and sludge solid content and Fig. 5(b) shows the relation between drying time and filtrate volume. The figure shows that CKD improved the dewaterability of sludge as the solid content of treated sludge overall the time period is higher than that of untreated. The results of the untreated sludge comply with the results of Wang et al. [18] who found, for natural sand drying beds, that water drainage during the first 1–3 d is the most important and it leaves solid concentrations as high as 15%–25%. Using CKD, the filtrate volume increased, which increased the sludge solid content as it reaches 36% after 5 d, which was 80% higher than untreated sludge. The results of the treated sludge comply with the results published by EPA [4] as they found that only 2 d are enough for the treated sewage sludge with lime and some other conditioners to get sludge solid content varied between 20% and 30%.

Fig. 6 shows the relation between drying time and sludge pH value. The results of the treated sludge show that the pH value remains above 10.50 for the whole test, which lasts 5 d. This result complies with the results of Salah et al. [12] who studied using CKD as a stabilizer for thickened and dewatered sludge and found that using CKD with dosage more than 30% increased the pH value to 11 for 7 d.

3.5. Additional sludge production

The main problem associated with the use of chemical additives in the treatment process was the increase in the sludge production. In this research, the increase of solid concentration due to the addition of CKD was measured by conducting mass balance for the tested sludge and comparing with the actual solid content. It was found that using the CKD increased the solid content by almost 1.00 (g SS/g CKD). These results comply with Mamais et al. [26] who reported an increase in the total suspended solids concentration. They measured the suspended solids concentration before and after inorganic chemicals addition and found

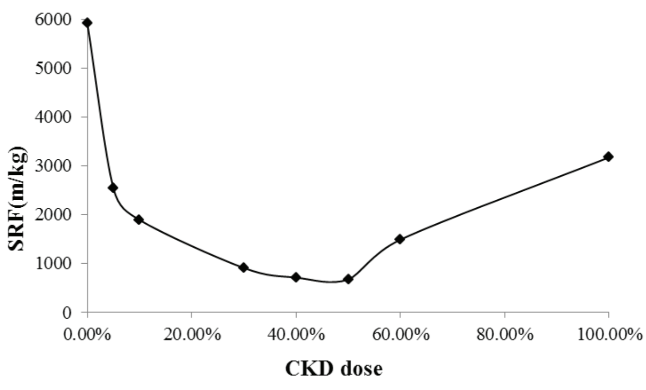

Fig. 4. Relation between specific resistance of filtration and CKD dosage.

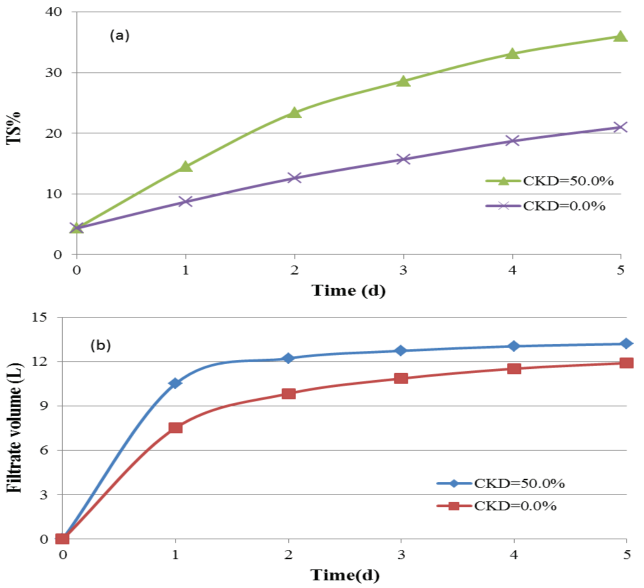

Fig. 5. Relation between drying time and (a) sludge solid content and (b) filtrate volume.

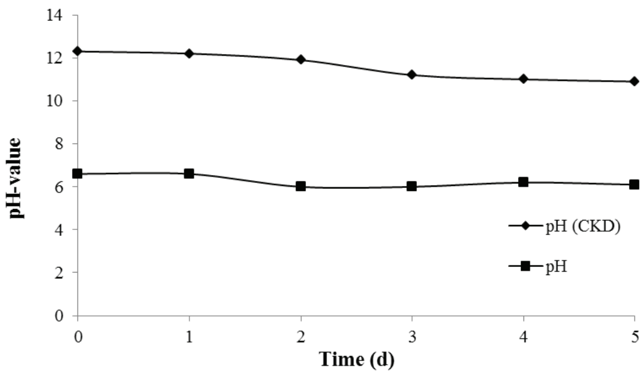

Fig. 6. Relation between drying time and pH value for treated and untreated sludge.

an average increase of approximately 3.3 (g SS/g Al^{3+}) and 2.0 (g SS/g Fe^{3+}) added, respectively.

4. Conclusions

Based on the experimental results obtained in this study, treatment of sewage sludge with CKD improved the thickening and dewatering properties of a mixture of primary and trickling filters hummus in the same time sludge had been stabilized. The settleability and dewaterability of the conditioned sludge were investigated by zone settling test, free gravity drainage test, SRF and natural drying tests. Results showed that CKD dose of 50% as adequate for achieving sludge stabilization, also results showed that using of CKD improved the settleability of sludge as zone settling velocity increased from 43.2 to 98.4 m/d, which leads to an increase in the hydraulic loading rate of the gravity thickeners by 227%. In addition, using CKD decreased the possibility of flotation of sludge. The dewaterability of sludge was also improved as the SRF decreased from 5.93 (10^3m/kg) to 0.76 (10^3m/kg) and reduced the actual dewatering time required to achieve sludge with solid content more than 20% from 5 to 2 d; while the pH value remained in the required range for stabilization. Hence, by adding CKD dose of 0.6 (g CKD/g DS) in the beginning of the sludge treatment stream, the total time required for thickening and dewatering could be reduced to half in order to have sludge with solid content higher than 20% and in the meantime the product sludge should be stabilized sludge compatible with EPA-Class B regulation.

References

[1] G. Barberio, L. Cutaia, V. Libric, Treatment and disposal of sewage sludge: comparative life cycle assessment on Italian case study, Environ. Eng. Manage. J., 12 (2013) 7–10.

[2] M. Ghazy, T. Dockhorn, N. Dichtl, Sewage sludge management in Egypt: current status and perspectives towards a sustainable agricultural use, World Acad. Sci. Eng. Technol., 57 (2009) 299–307.

[3] M. Ghazy, T. Dockhorn, N. Dichtl, Economic and Environmental Assessment of Sewage Sludge Treatment Processes Application in Egypt, 15th International Water Technology Conference, IWTC-15, Alexandria, Egypt, 2011.

[4] EPA, Environmental Regulations and Technology Control of Pathogens and Vector Attraction in Sewage Sludge (Including Domestic Septage), Office of Research and Development, National Risk Management Research Laboratory, Center for Environmental Research Information, Cincinnati, OH, 2003.

[5] EPA, Environmental Regulations and Technology: Control of Pathogens and Vector Attraction in Sewage Sludge; EPA/625/R-92/013, Office of Research and Development, 1999. Available at: http://www.epa.gov/ORD/NRMRL.

[6] P. Ginisty, J. Olivier, J. Vaxelaire, S. Fortuny., Influence of Flocculation on Sewage Sludge Thickening and Dewatering, 3rd European Conference on Sludge Management, Leon, Spain, 2012.

[7] Z. Chen, W. Zhang, D. Wang, T. Ma, R. Bai, Enhancement of activated sludge dewatering performance by combined composite enzymatic lysis and chemical re-flocculation with inorganic coagulants: kinetics of enzymatic reaction and reflocculation morphology, Water Res., 83 (2015) 367–376.

[8] M.H. El-Awady, S.A. Ali, Nonconventional treatment of sewage sludge using cement kiln dust for reuse and catalytic conversion of hydrocarbons, Environmentalist, 32 (2012) 464–475.

[9] W.M. Salem, W.F. Sayed, S.A. Halawy, R.B. Elamary, Physicochemical and microbiological characterization of cement kiln dust for potential reuse in wastewater treatment, Ecotoxicol. Environ. Safety, 119 (2015) 155–161.

[10] M. Abou-Seeda, A.M. Zaghloul, A. AbdEl-Galil, The role of cement dust in chemical remediation of the sludge treated soil, Ass. Univ. Bull. Environ. Res., 8 (2005) 89–107.

[11] M.K. Rahman, S. Rehman, O.S.B. Al-Amoudi, Literature review on cement kiln dust usage in soil and waste stabilization and experimental investigation, Int. J. Recent Res. Appl. Sci., 7 (2011) 77–87.

[12] F.A.S. Salah, S.U. Shadeed, CKD use as a sludge stabilizing, dewatering and disinfection agent in Iraq, Int. J. Sci. Eng. Res., 3 (2012) 1–24.

[13] E.K. Mahmoued, Application of cement kiln dust for chemically enhanced primary treatment of municipal wastewater, Desal. Wat. Treat., 52 (2014) 4698–4704.

[14] A.H. Mostafa, Effect of cement kiln dust addition on activated sludge process without primary settling for reuse applications, HBRC J., 8 (2012) 14–25.

[15] E.K. Mahmoud, Cement kiln dust and coal filters treatment of textile industrial effluents, Desalination, 255 (2010) 175–178.

[16] APHA, Standard Methods for Examination of Water and Wastewater, 20th ed., American Public Health Association. American Water Environment Federation, Washington, D.C., 1999.

[17] E.F. Badrawi, Geotechnical Properties of Flowable Fill from Excess Foundry Sand and Cement Kiln Bypass Dust, MSc Thesis, Zagazig University, Egypt, 2006.

[18] L.K. Wang, N.K. Shammas, Y.T. Hung, Handbook of Environmental Engineering – Biosolids Treatment Processes, Vol. 6, Humana Press, Totowa, New Jersey, 2007.
[19] WEF, Design of Municipal Wastewater Treatment Plants, Manual of Practice No. 8, 4th ed., Alexandria, Virginia, 1998.
[20] WEF, Clarifier Design, Manual of Practice No. FD-8, 2nd ed., McGraw-Hill, New York, 2005.
[21] Metcalf & Eddy, Wastewater Engineering: Treatment, Disposal and Reuse, 4th ed., McGraw-Hill Inc., New York, 2003.
[22] C. Chen, P. Zhang, G. Zeng, J. Deng, Y. Zhou, H. Lu, Sewage sludge conditioning with coal fly ash modified by sulfuric acid, Chem. Eng. J., 158 (2010) 616–622.
[23] M.S. Shihab, Assessment of using chemical coagulants and effective microorganisms in sludge dewaterability process improvement, J. Environ. Sci. Technol., 3 (2010) 35–46.
[24] D. Lihong, C. Xu, L. Wenping, Z. Qixin, A study on enhancement of filtration process with filter aids diatomaceous earth and wood pulp cellulose, Chinese J. Chem. Eng., 19 (2011) 792—798.
[25] J.O. Ademiluyi, L.W. Arimieari, Evaluating the specific resistance of conditioned sludge filtration on natural drying bed, Int. J. Curr. Res., 4 (2012) 157–161.
[26] D. Mamais, E. Kalaitzi, A. Andreadakis, Foaming control in activated sludge treatment plants by coagulants addition, Global NEST J., 13 (2011) 237–245.