Desalination and Water Treatment
www.deswater.com
doi:10.5004/dwt.2021.27224

225 (2021) 104–111
June

Reuse of by-products material as a conditioner to improve thickening and dewatering of sludge

A.A. Elbaz[a], A.M. Aboulfotoh[a,*], A.M. Dohdoh[a], A.M. Wahba[b]

[a]*Environmental Engineering Department, Faculty of Engineering, Zagazig University, Zagazig, Sharqia 44519, Egypt, Tel./Fax: 0020552304987; Mobile No.: 00201064411131; email: Elbaz50@hotmail.com (A.A. Elbaz), Tel./Fax: 0020552304987; Mobile No.: 00201111784499; email: aseaf_1@yahoo.com/asalem@zu.edu.eg (A.M. Aboulfotoh), Tel./Fax: 0020552304987; Mobile No.: 00201007126099; email: aydohdoh@gmail.com/aymandohdoh@zu.edu.eg (A.M. Wahba)*
[b]*Housing and Building National Research Center (HBRC), Cairo 12411, Egypt, Tel./Fax: 0244781997; Mobile No.: 00201148618864; email: ayadesigner923@gmail.com*

Received 2 December 2020; Accepted 8 March 2021

ABSTRACT

Although sludge conditioning using chemicals has been employed widely to improve the thickening and dewatering processes and considered as is a good alternative for process improvement, however, its cost is high. Therefore, it is important to find effective and cheap conditioners. Large quantities of cement kiln dust (CKD) – from cement factories, and fly ash (FA) – from power plants, are promising conditioning agents. Accordingly, the experimental work presented in this study was designed to investigate the effect of using these by-products and their mixture on the thickening and dewatering performance of different types of sewage and drinking water sludge. The results show that the mixture of the CKD and FA had the higher effect and it increased the settling velocity, hydraulic loading rate and solid loading rate of all tested sludge types. The percent increase ranged between 67% and 225%, the dewaterability of the treated and untreated sludge was investigated by gravitational settling test, specific resistance to filtration with indicators for drying beds – solid loading rate and dewatering time and indicators of mechanical dewatering yield. Dewaterability tests show that using the CKD is more effective than the FA or the mixture for dewatering and it could decrease the drying time by values ranged from 37% to 87%.

Keywords: Alum; By-products; Cement kiln dust; Dewatering; Fly ash; Sludge; Thickening; Wastewater

1. Introduction

It is well known that wastewater treatment processes produce large amounts of sludge with extremely high-moisture content, which increases the handling and disposal costs. This moisture content can exceed 95% as reported by Qi et al. [1]. Accordingly, there is a need to reduce the volume of sludge in order to reduce the handling and disposal costs, which can be achieved by improving the performance of existing treatment processes and/or the use of low-cost materials in the treatment process. In Egypt, the total number of drinking water and wastewater treatment plants (WTPs and WWTPs) reached 2,694 and 391 plants, respectively by 2016. These plants treated about 9,297 × 10^6 m^3/y of water and 3,755.3 × 10^6 m^3/y of wastewater (including industrial wastewater). This led to a significant increase in the volume of the produced sludge and consequently increased the costs of sludge handling and disposal as well as caused undesirable impacts of bio-solids on the environment [3]. In Egypt, the commonly applied scenario for sewage sludge treatment and disposal in about 80% of the WWTPs is as follows: (1) the sewage sludge (primary and secondary) is pumped to the thickening facilities (gravity thickeners) then it is directed to the dewatering facilities (natural drying

* Corresponding author.

beds) and (2) the dewatered sludge is stored for a period of 1.5–6 months before using as a fertilizer in agriculture. In the WTPs, the alum sludge is collected with filter backwash then being disposed in the nearby canals or in the raw water canal just after the intake point [4].

Sludge is a colloidal system in which fine particles form a stable suspension in water and are very difficult to be separated from the water phase [1]. These fine particles may clog the channels through which water can be removed. Thus, to avoid this clogging issue, conditioning materials are used to help the agglomeration of fine particles into larger flocks [5,6] which makes it easy to separate from the water. Conditioning is a process in which the biosolids are treated either chemically and/or physically to enhance the water removal and thus improve the solids capture. The most commonly adopted conditioning systems use inorganic chemicals, organic polymers, and/or heat treatment [7].

Cement kiln dust (CKD) is a fine-grained alkaline material, which is a by-product of cement clinker production. It is worth mentioning that the global cement production capacity in 2017 was almost 4.99 billion tons per year, while the CKD production rate ranged from 54 to 200 kg per ton of the produced cement clinker. The main constituents of the CKD are calcite ($CaCO_3$), quartz (SiO_2) and calcium sulfate ($CaSO_4$). One of the inherent advantages of CKD is that it has the potential of neutralization of acidity and adsorption or removal of aqueous metals and nutrients [8]. Motivated by the no-cost material, CKD was used by the study of Aboulfotoh and Dohdoh [4] as a sludge conditioner and stabilizing chemical. Some other researchers [9–11] tested the utilization of CKD to separate the organic matter and suspended solids and reduce the organic micropollutants and heavy metals in sewage sludge.

Another material that could be used in sludge conditioning is the fly ash (FA) produced from the coal/biomass combustion plants. The total amount of FA generated all over the world reaches 750 million tons per year (China produced almost 77% of this amount), and according to statistics, the global average utilization rate of FA is about 25% [12]. The FA consists mainly of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3). It is a finely separated residue that outcomes from the ignition of pounded coal and are transported from the burning chamber by the exhaust gases [13]. The general trend all over the world is the reuse of the various industrial wastes or by-products, particularly solid wastes, in useful applications in order to prevent, or at least to reduce the environmental pollution. Fly ash along with other ash types such as power plant ash and biosolids incinerator ash are being used as conditioning agents to increase biosolids dewatering rate, improve cake release, increase cake solids, and in some cases reduce the dosage of other types of conditioning agents [2,5–7,14].

Based on the abovementioned review, the main goal of the current paper is to evaluate the effect of CKD, FA and their mixture on the characteristics of sewage and drinking water sludge thickening and dewatering.

2. Materials and methods

The experimental work presented in this research paper was conducted at the Environmental Engineering Laboratory, Faculty of Engineering, Zagazig University, Zagazig, Egypt. All tests were performed in triplicate (three times) and the results presented in this paper are the average values.

2.1. Sludge characteristics

The sludge samples used in this study were collected from 5 local WWTPs and WTP in Egypt comprising different treatment technologies as follows: (i) combined primary and waste activated sludge (PS + AS) from Menia El Qamh WWTP, (ii) combined primary and trickling filter humus (PS + TF) from Al Elqunat WWTP, (iii) waste activated sludge (WAS) from Al Tell WWTP – extended aeration system, (iv) anaerobic digested combined sludge (AnD) from El Gabal El Asfar WWTP, and (v) alum sludge (AlS) from El Abasa WTP. The pH, total solids and volatile solids (VS) were measured for each type of the raw sewage sludge samples. These parameters were measured according to the standard methods for the examination of water and wastewater [15].

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 is shown in Table 1.

2.3. Fly ash

The FA was collected from SIKA EYGPT and was characterized by chemical composition as shown in Table 1.

2.4. Optimum CKD and FA doses

This stage was used to determine the optimum coagulant dosage according to the following procedure. Six laboratory beakers with capacity of 1 L were filled with raw sewage sludge. The by-products materials (sludge conditioners) were added to the beakers with the following dosages: CKD doses (0%, 10%, 20%, 30%, 40%, and 50%) (g CKD/g DS) [4] and FA doses (0%, 2%, 4%, 6%, 8%, and 10%) (g FA/g DS) [2,16–18]. The sludge with the applied dosage was stirred rapidly at a speed of 250 rpm for 30 s followed by a slow agitation for 15 min [18] at a speed of 30 rpm, then the sludge was allowed

Table 1
Characteristics of CKD and FA (wt.%)

Chemical	CKD	FA
Al_2O_3	3.5	25.56
SiO_2	15.37	51.11
CaO	58.85	4.30
Fe_2O_3	3.08	12.48
K_2O	7.00	0.70
MgO	1.55	1.45
Na_2O	4.37	0.77
SO_3	5.66	0.24
Loss on ignition	23.79	0.57

to settle for 45 min period during which the position of the suspension/liquid interface is measured at different time intervals. The dose which produced the lowest sludge height at the end of the test was considered as the optimum dose.

2.5. Optimum (CKD and FA) mixture dose

Based on the optimum dose obtained from the previous set of experiments, mixtures of CKD and FA doses with CKD/FA percentage (20%/80%, 60%/40%, 50%/50%, 40%/60%, 80%/20%, 100 %/100%) were used these values represent the percent of the optimum doses. The settling test was re-performed against a blank sample to determine the optimum mixture composition.

2.6. Batch settling test

Batch settling tests were performed with the optimum doses obtained from the first stage to measure the hindered settling velocity. In a batch settling test, the height of the solid/liquid interface is determined as a function of time. At first, the initial sludge sample is allowed to settle in the column for a specific time (15 or 30 min or … FOR HOW LONG?). Next, the procedure is done at a lower treated sludge concentration and a new batch settling curve is recorded. This experiment is repeated until a set of settling curves at different sludge concentrations are obtained. The linear slope of each curve gives information on the hindered settling velocity at that concentration. The batch settling tests were conducted in a glass column of 1 L volume and 6.71 cm diameter. The column was filled with a sludge sample of known solid concentration, then the sludge was allowed to settle and the position of the suspension/liquid interface is measured at different time intervals. By conducting a number of settling tests at 6 different concentrations, the zone settling velocity for different solid concentrations is obtained [19].

The height of the sludge blanket was measured at a higher time resolution during the first 15 min of the test in order to ensure that the linear part of the settling curve is captured accurately. During the following part of the test at times above 15 min, the settling velocity diminishes and hence the frequency of measurements is also decreased.

2.7. Free gravity drainage test and specific resistance of filtration

In this stage, the specific resistance to filtration (SRF) was used using free gravity test [20] to evaluate the effect of the used conditioning materials (by-products) on sludge dewaterability and filterability. The optimum doses obtained from the previous experiments were added to a beaker of 500 mL volume containing 250 mL of the raw sludge. The beaker was stirred rapidly at a speed of 250 rpm for 30 s followed by a slow agitation at a speed of 30 rpm for 15 min. The treated sludge samples and the untreated sample were then poured quickly into a Büchner funnel with a diameter of 14 cm (fitted with a circular piece of belt press fabric). The Büchner funnel was set on top of a 1 L graduated cylinder allowing for the filtrate volume to be recorded against time. Owing to the fact that the volume of the filtrate is directly proportional to the solid content, plotting the time/volume of filtrate against the solid content gave a linear relationship with slope (b). Then the specific resistance to filtration could be calculated using Eq. (1) below.

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

where SRF is the specific resistance (m/kg), A is the area of filtration (m²), C is the solid content (kg/m³), (ρgh) is the hydrostatic pressure (N/m²), V is the volume of filtrate (m³), μ is the dynamic viscosity (N s/m²), b is the slope (s/m⁶).

The standard vacuum pressure (P) in the Büchner funnel test that was used for the determination of specific resistances is 38.1 cm Hg ≈ 51 KPa. The SRF at different pressure (P_2) can be calculated if the SRF is known at pressure (P_1) using Eq. (2):

$$\mathrm{SRF}_2 = \left(\frac{P_1}{P_2} \right)^{\sigma} \mathrm{SRF}_1 \tag{2}$$

where σ is the sludge compressibility factor, which can be taken as (0.60–0.90) for anaerobically digested sludge [21], (0.60–1.40) for waste activated sludge [22,23], and (0.60–0.80) for alum hydroxide sludge [24,25].

It is worth mentioning that the initial solid concentration of sludge sample had an effect on the dewaterability indicators [22,23], therefore in order to eliminate/reduce this effect all tested sludge samples were adjusted to have the same initial solid concentration.

3. Results and discussion

3.1. Optimum doses

Table 2 shows the optimum doses of the different by-products and their mixtures that were used as sludge conditioners in the present study. It was found that the sludge from the WWTPs had the same optimum dose except for the AnD, which required a larger dose. This may be attributed to the fine particles and the surface charge of the AnD sludge. Radaideh et al. [26] found that the percent of particles in the fine range in case of anaerobically digested sludge are higher compared to that in case of extended aeration sludge. Also, the microscopic photos captured by Radaideh et al. [26] showed that the extended aeration sludge is characterized by larger colonies of flocs and more open structure than the anaerobically digested sludge. Nirdosh and Ostaff [27] performed bench-scale flocculation tests on the anaerobic digester effluent and found that the zeta-potential measurements indicated a negative surface charge on the particles. Additionally, the major particle size was below 2.5×10^{-6} m,

Table 2
Optimum dose for CKD, FA and their mixture (wt.%)

By-product	PS + AS	PS + TF	WAS	AnD	AlS
CKD	40	40	40	50	20
FA	4	4	4	8	8
Mixed	100:100	100:100	100:100	100:100	50:50

which required the consumption of more conditioners. For the alum sludge, the average size ranged from 0.002 to 0.039 mm [25], which is larger than the size distributor of the wastewater sludge and thus the required dosage of by-products and their mixture is reduced.

These results comply with the results of Aboulfotoh and Dohdoh [4] who found that the optimum dose of CKD for enhancing thickening and dewatering of PS + TF was in the range 40%–60%. Zlatkovskyi et al. [17] found that the optimum dose of applying FA to waste-activated sludge is in the range of 4%–5%. Also, the results of the present study agree with the recommended conditioner consumption of [7,28–31].

3.2. Determined Vesilind velocity

The zone settling velocity (V_{zs}) is determined from the slope of the linear part of the sludge batch settling test (which in the calculations is defined as the steepest slope in the curve). The obtained data points were used to estimate the zone settling parameters of the settling function of Vesilind. The two parameters describing the function are V_0 and k. V_0 is the initial settling velocity derived from the extension of the curve to zero concentration intercept, and k is the hindered settling parameter in L/g or m^3/kg [32].

$$V_{zs} = V_0 \times e^{-k.X} \quad (3)$$

The obtained values, which are summarized in Table 3, show that the used by-products enhanced the thickening of the tested sludge as they increased the zone settling velocity. The increase in the settling velocity ranged from 2% to 175% for CKD, 0% to199% for FA, and 56% to 263% for the mixture. It is worth saying that for the same type of sludge, k values are almost constant.

The hydraulic loading rates (HLR) were calculated from the zone settling velocity for a fixed initial sludge concentration and safety factor. Based on an initial solid concentration of 1% (most common concentration of different types of sludge) and safety factor of 2, the zone settling velocity of the blank, CKD, FA and their mixture is summarized in the table. The results in Table 4 demonstrate that the HLR of the treated sludge is higher than that of the untreated sludge for all tested types of sludge. Additionally, the use of a mixture of the studied by-products (two components) had a higher effect than using a single component. Fig. 1 shows the solid flux curves for the untreated and treated sludge samples. It illustrates that the solid flux curve of the treated sludges is higher than the control sludge which implies that the use of byproducts increased the solid loading of sludge thickeners. Based on a final required solid concentration of 4% (except for AlS as the final solid concentration was 6%) and a factor of safety of 1.50, the solid loading rate is also included in Table 4.

The hydraulic and solid loading rates of the untreated sludge agree with the recommended values by [7,28–31].

3.3. Sludge dewaterability

3.3.1. Specific resistance of filtration

The specific resistance of filtration was calculated based on Eqs. (1) and (2) and the results are shown in Fig. 2.

Table 3
Vesilind velocity parameters for different sludge types

Sludge type	Sample	V_0 (m/d)	K (m^3/kg)	R^2	V_t/V_u
PS + AS	Blank	55.68	0.127	0.986	1.00
	CKD	91.615	0.124	0.988	1.65
	FA	61.43	0.129	0.976	1.10
	Mixed	114.64	0.127	0.987	2.06
PS + TF	Blank	101.09	0.121	0.973	1.00
	CKD	204.16	0.123	0.982	2.02
	FA	134.23	0.128	0.967	1.33
	Mixed	216.72	0.119	0.977	2.14
WAS	Blank	14.912	0.133	0.960	1.00
	CKD	15.241	0.100	0.900	1.02
	FA	13.799	0.125	0.951	0.93
	Mixed	23.263	0.112	0.969	1.56
AnD	Blank	4.265	0.148	0.983	1.00
	CKD	11.716	0.171	0.980	2.75
	FA	12.77	0.186	0.983	2.99
	Mixed	15.472	0.159	0.991	3.63
AlS	Blank	270.17	0.084	0.987	1.00
	CKD	258.85	0.080	0.989	0.96
	FA	423.74	0.084	0.964	1.57
	Mixed	383.47	0.078	0.983	1.42

$V_t = V_{zs}$ of treated sludge and $V_u = V_{zs}$ of untreated sludge.

Table 4
Hydraulic and solid loading rates of untreated and treated sludge types

Sludge type	Hydraulic loading rate ($m^3/m^2/d$)				Solid flux ($kg/m^2/d$)			
	Blank	CKD	FA	Mixed	Blank	CKD	FA	Mixed
PS + AS	7.82	13.26	8.45	16.10	120	166.67	130.67	200.00
PS + TF	15.07	29.84	17.99	32.97	213.33	400.00	266.67	480.00
WAS	1.97	2.80	1.98	3.80	17.33	50.67	20.00	56.00
AnD	0.49	1.06	1.11	1.58	10	17.33	18.67	23.33
AlS	58.32	58.15	91.47	87.89	533	593	622	933

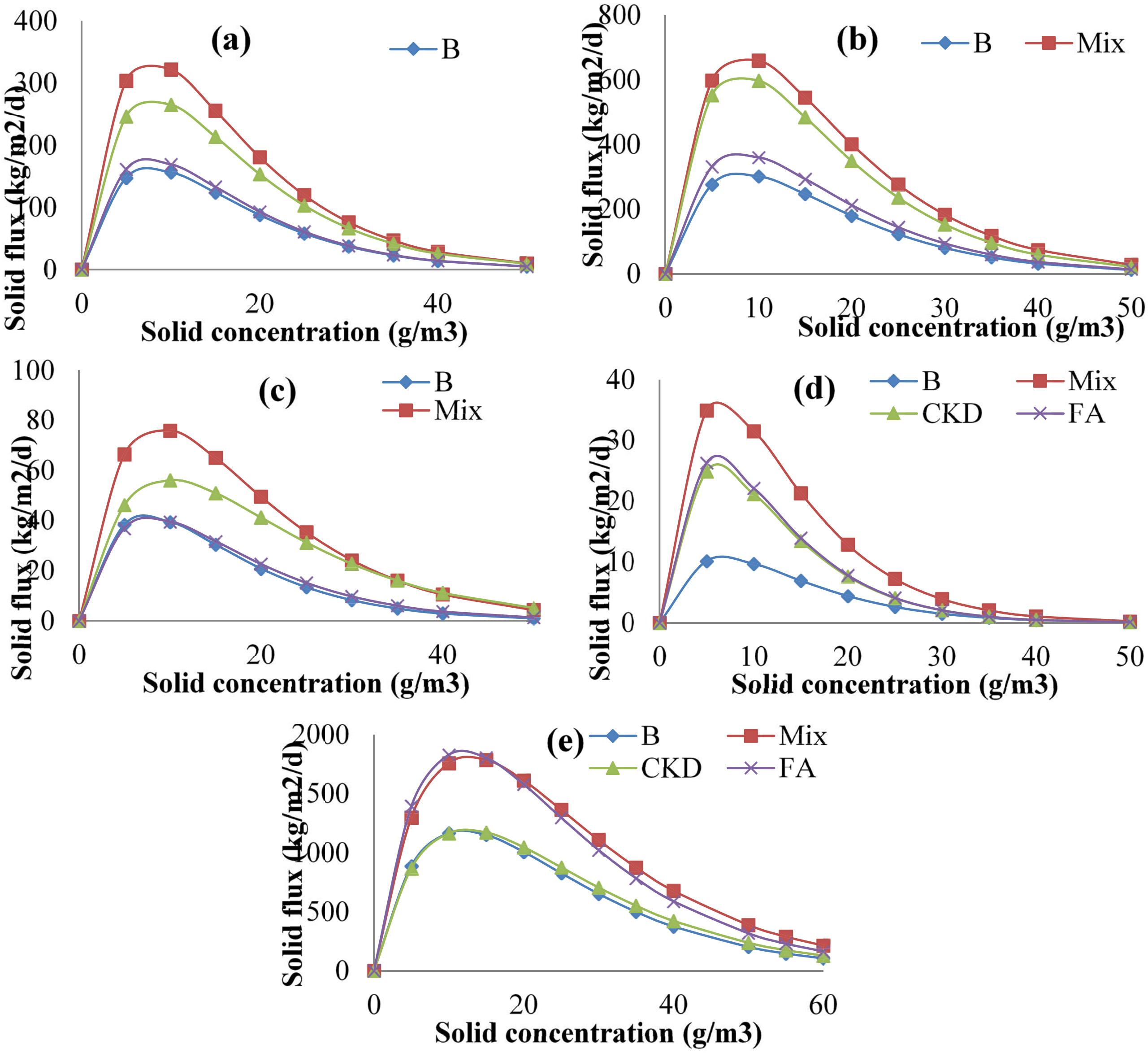

Fig. 1. Flux for untreated and treated sludge: (a) PS + AS, (b) PS + TF, (c) WAS, (d) AnD, and (e) AlS.

The results indicated that the SRF of the untreated sludge were 5.44 × 10^{13}, 5.58 × 10^{13}, 4.28 × 10^{13}, 8.28 × 10^{13} and 2.84 × 10^{-13} (m/kg) for PS + AS, PS + TF, WAS, AnD and AlS, respectively. These values agree well with the values given by [22–25].

Górka et al. [33] found that the anaerobic digestion increased the values of CST and SRF. Also, conditioning of the sewage sludge with sludge from the water treatment processes improved the sewage sludge dewatering characteristics, which implies that the AlS dewatering properties are better than the sewage sludge properties. These results comply with Smollen [22,23] who determined the SRF of different types of municipal sludge from eleven municipal waste-water treatment plants throughout South Africa (primary, waste activated, anaerobically digested primary, anaerobically digested primary mixed with waste activated, anaerobically digested humus and aerobically digested waste activated). Also, current study results also comply with the results of [5,6,34].

Regarding the sewage sludge, the results show also that the higher resistance of filtration is related to the AnD while the lowest resistance is the WAS. These results are similar to that given by Phuong [35] who compared the SRF of anaerobically digested sludge, waste activated sludge and aerobically digested sludge, respectively. It was found by Phuong [35] that the SRF was higher for the anaerobically digested sludge followed by the waste activated sludge while the SRF was the lowest for the aerobically digested sludge gave. Also, current study results comply with the results of [1,7,16,18].

Using the by-products decreased the SRF of all tested sludge types with CKD exhibiting a better effect compared to the mixed by-products. This may be attributed to the clogging of the draining due to the increased thickening. The current results comply with the results of Aboulfotoh [18] who found that using FA decreased the SRF by 55%, 15%, 37% and 24% for the PS + TF, And, PS + AS and WAS, respectively. Aboulfotoh and Dohdoh [4] found that using the CKD deceased the SRF and the required dewatering time in drying beds by almost 50%. Qi et al. [1] reported that using the FA as a sludge conditioner could decrease the SRF by almost 50%. Also, current study results comply with the results of [16,17,34,36,37].

3.3.2. Natural drying indicators

The most important factor for sand drying bed is the land requirement [7,29]. This area can be calculated based on the annual solid loading rate or the required drying time of sludge. Ceronio et al. [38] performed pilot plant studies in England on sludge dewatering and found that the bed loading (kg/m²/y) is related to the specific resistance (R_c) and could be calculated using the following empirical formula:

$$\text{Solid Load} = \frac{10^7}{R_c^{0.5}} \quad (4)$$

where R_c is the specific resistance at the applied sludge depth h_c (s²/g):

$$\text{SRF} = \left(\frac{h}{h_c}\right)^{\sigma} R_c \quad (5)$$

The model proposed by Adrian [21] Eq. (6) was found to be the most commonly used model for the calculation of the required dewatering time of sewage sludge.

$$t = \frac{\mu \cdot R_c \cdot S_0}{100(h_c)^{\sigma}(\sigma+1)}\left[h^{\sigma+1} - \frac{\sigma+1}{\sigma}H_0 h^{\sigma} - H_0^{\sigma+1} + \frac{\sigma+1}{\sigma}H_0^{\sigma+1}\right] \quad (6)$$

Table 5 shows the expected solid loading rate for different types of sludge and different flocculation time, it was calculated based on sludge layer thickness of 25 cm as the recommended sludge layer thickness ranged between 20 and 30 cm [7,28,31]. The solid loading rate of the untreated samples complies with the recommendation given by Qasim [31] for solid loading. He suggest solid loading in the range of 100–300 (kg/m²/y) for open drying bed and150–400 (kg/m²/y) for covered drying beds. Also, the results agree with [39,40]. The use of by-products increased the solid loading for all tested sludge types and the CKD was more efficient than FA or the mixture.

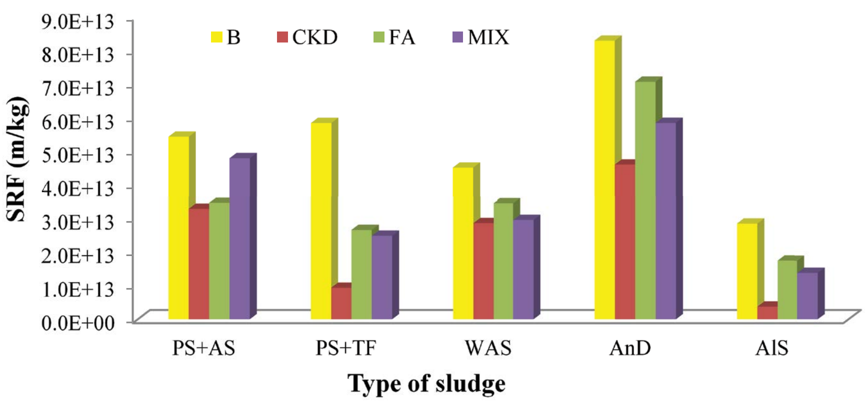

Fig. 2. SRF for different types of sludge (treated and untreated).

Table 5
Expected solid loading rate and drying time for different types of sludge

Sludge type	Solid load (kg/m²/y)				Drying time (d)			
	Blank	CKD	FA	Mixed	Blank	CKD	FA	Mixed
PS + AS	404.12	520.94	507.34	430.15	4.90	2.95	3.11	4.32
PS + TF	340.04	851.45	505.36	522.94	6.91	1.10	3.13	2.92
WAS	443.24	558.35	508.30	549.37	4.07	2.56	3.09	2.65
AnD	285.69	382.80	309.27	340.00	9.80	5.46	8.36	6.92
AlS	735.26	2,031.01	939.45	1,056.49	1.48	0.19	0.91	0.72

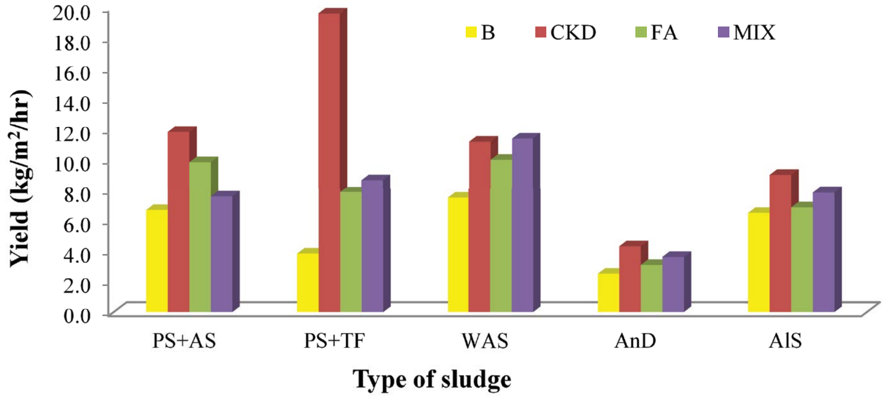

Fig. 3. Yield for different types of sludge (treated and untreated).

Also, Table 5 shows the expected drying time for all tested sludge samples based on the following assumptions: initial solid content 4.0%, initial sludge layer depth 25 cm, and required final solid contents 25% [7,28,31,38].

The drying time for the untreated sludge was 4.90, 6.91, 4.07, 9.80 and 1.48 PS + AS, PS + TF, WAS, AnD and AlS, respectively. Aboulfotoh and Dohdoh [4] found that using the CKD decreased the actual drying time from 6 to 2 d for the PS + TF sludge. Radaideh et al. [26] found that, in lab and full-scale experiments, drying of extended aeration sludge takes almost half the time as the drying of anaerobically digested sludge for the same operating conditions. The results also comply with [7,28–31]. Górka et al. [33] found that conditioning of sewage sludge with sludge from water treatment processes improved the dewatering characteristic.

3.3.3. Mechanical dewatering indicators

In case of using conditioner and in order to evaluate a sludge filtration process with additional solids added, the rate of total solids filtered per unit area per unit time yield (Y) (kg/m²/h) defined by Eq. (7) [2] can be used as an indicator.

$$Y = \left(\frac{2 \cdot P \cdot w}{\mu \cdot t \cdot \text{SRF}} \right)^{1/2} \tag{7}$$

The use of different types of by-products increased the yield of all tested sludge types as shown in Fig. 3, while the CKD have a better performance than the FA or the mixture.

These results agree with the results of Goknil [41] who studied the effect of different types of conditioners on the dewaterability of anaerobic and aerobically digested sludge. They found that the effect of conditioners on the anaerobic sludge is lower than its effect on the aerobic sludge also Qi et al. [1] found that using FA could increase the yield by almost 200%, results also comply with the results of [16,18,36,37].

4. Conclusion

The experimental results obtained in this study showed that treatment of different types of sewage and drinking water sludge with by-products materials (CKD and FA) could enhance the thickening and dewatering performance of all tested sludge types. The optimum doses of the CKD was determined to be 40%, 40%, 40%, 50% and 20% for PS + AS, PS + TF, WAS, AnD and AlS, respectively. With the use of FA, the optimum doses were found to be 4%, 4%, 4%, 8% and 8% for PS + AS, PS + TF, WAS, AnD and AlS, respectively. The mix ratio was 100:100 for the sewage sludge and 50:50 for the AlS. The used by-products increased the settling velocity and therefore the hydraulic and solid loading rate increased which emphasis that the use of products can enhance the thickeners performance. The dewaterability of the treated and untreated sludge was investigated by gravitational settling test, SRF with indicators for drying beds – solid loading rate and dewatering time and indicators of mechanical dewatering yield. The results also showed that the use of by-products decreased the SRF, which lead to an increase in the solid loading of mechanical or natural drying beds with a decrease in the required time of dewatering for all types of the tested sludge.

References

[1] Y. Qi, K.B. Thapa, A.F.A. Hoadley, Application of filtration aids for improving sludge dewatering properties – a review, Chem. Eng. J., 171 (2011) 373–384.

[2] H. Shi, J. Zhu, J. Chen, X. Qiu, Experiment Study on the Effects of Natural Zeolite on Sludge Dewatering Performance and Nitrogen Losses, Proceedings of the International Conference on Material and Environmental Engineering (ICMAEE 2014), Atlantis Press, Paris, 2014, pp. 91–94.

[3] CAPMAS, The Central Agency for Public Mobilization and Statistics (CAPMATH), Central Agency for Public Mobilization and Statistics, Egypt Statistical Book, 2017.

[4] A.M. Aboulfotoh, A.M. Dohdoh, Enhancement of thickening and dewatering characteristics of sewage sludge using cement kiln dust, Desal. Water Treat., 81 (2017) 40–46.

[5] M. Wojcik, F. S tachowicz, A. Malson, The Possibility of Sewage Sludge Conditioning and Dewatering with the Use of Biomass Ashes, Eng. Prot. Environ., 20 (2) (2017) 153–164

[6] M. Wojcik, Examinations of the effect of ashes from coal and biomass co-combustion on the effectiveness of sewage sludge dewatering, Eng. Prot. Environ., 21 (2018) 273–288.

[7] L.K. Wang, N.K. Shammas, Y.-T. Hung, Volume 6 – Handbook of Environmental Engineering, Biosolids Treatment Processes, Humana Press, Totowa, New Jersey, eISBN 9781592599967, 2007.

[8] M. Seo, S.-Y. Lee, C. Lee, S.-S. Cho, Recycling of cement kiln dust as a raw material for cement, Environments, 6 (2019) 1–7, doi: 10.3390/environments6100113.

[9] 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.

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

[12] C. Wang, J. Li, L. Wang, X. Sun, Study on adsorption of Cr(VI) using single phase zeolites synthesized from fly ash, Chin. J. Environ. Eng., 2 (2008) 1121–1126.

[13] A. Dwivedi, M.J. Kumar, Fly ash – waste management and overview: a review, Recent Res. Sci. Technol., 6 (2014) 30–35.

[14] A.A. Elbaz, A.M. Aboulfotoh, A.M. Dohdoh, A.M. Wahba, Review of beneficial uses of cement kiln dust (CKD), fly ash (FA) and their mixture, J. Mater. Environ. Sci., 10 (2019) 1062–1073.

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

[16] C.-H. Hou, K.-C. Li, Assessment of sludge dewaterability using rheological properties, J. Chin. Inst. Eng., 26 (2003) 221–226.

[17] O. Zlatkovskyi, A. Shevchenko, T. Shevchenko, Use of fly ash for conditioning the excess activated sludge during deliquefaction at chamber-membrane filter presses, East.-Eur. J. Enterp. Technol., 99 (2019) 17–23.

[18] A.M. Aboulfotoh, Effect of flocculation time on the performance of fly ash as sludge conditioners, J. Mater. Environ. Sci., 10 (2019) 1296–1303.

[19] A.M. Aboulfotoh, Secondary settling tanks enhancement using effective microorganisms, Int. J. Curr. Eng. Technol., 7 (2017) 1791–1796.

[20] 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.

[21] D.D. Adrian, Sludge Dewatering and Drying on Sand Beds, EPA-600/2-78-141, United States Environmental Protection Agency (USEPA), Municipal Environmental Research Laboratory, Cincinnati OH, 1978.

[22] M. Smollen, Dewaterability of municipal sludges 1: a comparative study of specific resistance to filtration and capillary suction time as dewaterability parameters, Water SA, 12 (1986) 127–132.

[23] M. Smollen, Dewaterability of municipal sludges 2: sludge characterization and behaviour in terms of SRF and CST parameters, Water SA, 12 (1986) 133–138.

[24] A.M. Gharaibeh, Drying of Potable Water Treatment Plant Residuals, Ph.D. Thesis, School of Civil, Mining and Environmental Engineering, Faculty of Engineering, University of Wollongong, 2009.

[25] A.A. Aldeeb, S.R. Qasim, A.J. Puppala, C.F. Anderson, Physical and engineering properties of treatment plant residuals and disposal, J. AWWA, 95 (2003) 127–137.

[26] J.A. Radaideh, B.Y. Ammary, K.K. Al-Zboon, Dewaterability of sludge digested in extended aeration plants using conventional sand drying beds, Afr. J. Biotechnol., 9 (2010) 4578–4583.

[27] I. Nirdosh, R.M. Ostaff, Thickening of a starch anaerobic digester effluent, Water Air Soil Pollut., 59 (1991) 369–379.

[28] EPA, Process Design Manual for Sludge Treatment and Disposal, 625/1–79011, U.S. Environmental Protection Agency, 1979.

[29] Metcalf & Eddy, Wastewater Engineering: Treatment, Disposal and Reuse, 4th ed., McGraw-Hill Inc., New York, eISBN 0071122508, 2003.

[30] WEF, Design of Municipal Wastewater Treatment Plants, 4th ed.; Manual of Practice No. 8, Water Environment Federation, Alexandria, Virginia, 1998.

[31] S. Qasim, Wastewater Treatment Plants, CRC press, 1999, ISBN-13: 978–1566766883.

[32] G.A. Ekama, J.L. Barnard, F.W. Gunthert, P. Krebs, J.A. McCorquodale, D.S. Parker, E.J. Wahlberg, Secondary Settling Tanks: Theory, Modelling, Design and Operation, IWA Publishing, 1997.

[33] J. Górka, M. Cimochowicz-Rybicka, M. Krylów, Use of a water treatment sludge in a sewage sludge dewatering process, water, wastewater and energy in smart cities, E3S Web Conf., 30 (2018) 02006, doi: 10.1051/e3sconf/20183002006.

[34] M.S. Shihab, Assessment of using chemical coagulants and effective microorganisms in sludge dewaterability process improvement, J. Environ. Sci. Technol., 3 (2010) 35–46.

[35] V.H. Phuong, Improved Conditioning for Biosolids Dewatering in Wastewater Treatment Plants, M.Sc., Sydney Faculty of Engineering and IT, University of Technology, 2015.

[36] C.Y. Chen, P.Y. Zhang, G.M. Zeng, J.H. Deng, Y. Zhou, H.F. Lu, Sewage sludge conditioning with coal fly ash modified by sulfuric acid, Chem. Eng. J., 158 (2010) 616–622.

[37] B.T. Liu, P.J. Ding, Experimental study on fly ash for conditioning of specific resistance of sludge water, J. Geosci. Environ. Prot., 1 (2013) 22–25.

[38] A.D. Ceronio, L.R.J. Vuuren, A.P.C. Warner, Guidelines for the design and operation of sewage sludge sand drying beds, Water Research Commission Pretoria, 1999.

[39] O.O. Cofie, S. Agbottah, M. Strauss, H. Esseku, A. Montangero, E. Awuah, D. Kone, Solid–liquid separation of faecal sludge using drying beds in Ghana: implications for nutrient recycling in urban agriculture, Water Res., 40 (2006) 75–82.

[40] K. Badji, P.H. Dodane, M. Mbéguéré, D. Kone, Fecal Sludge Treatment: Elements Affecting the Performance of Non-planted Full-Size Drying Beds and Drying Mechanisms, Proceedings of the International Symposium on the Management of Drain Sludge, Dakar, 2011.

[41] E. Goknil, Improving of Dewatering Capacity of Aerobic and Anaerobic Stabilized Sludges, M.Sc., School of Natural and Applied Sciences of Dokuz Eylül University, 2005.