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Effect of Flocculation Time on the Performance of Fly Ash as Sludge Conditioners

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Abstract

Fly Ash (FA) 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. Different flocculation time proposed by literature varied from 1min to 20 minutes without focusing on the optimum time required for flocculation, so the main goal of this research paper was to determine the optimum flocculation time of FA. Experimental results obtained in this study showed that treatment of different types of sewage sludge with FA could enhance the dewatering properties of all tested sludge types. The dewaterability of the conditioned sludge was investigated by gravitational settling test, specific resistance to filtration (R) with indicators for mechanical dewatering - the net yield- and indicators of drying beds – solid loading rate and dewatering time-. The optimum FA dose was 4% for PS+TF, PS+AS, EAS and 8% for AnD sludge, also the optimum flocculation time was 15 minutes. Using of FA decreased specific resistance of filtration (R) by 55%, 15%, 37% and 24% for PS+TF, AnD, PS+AS and EAS respectively, also results showed that using of FA could lead to an increase in the solid loading of mechanical or natural drying beds with decreasing of the required time of dewatering for all types of tested sewage of sludge, sorting of the increasing effect of FA on sewage sludge could be in the following order PS+TF, PS+AS, EAS and AnD, with the least effect on the AnD.

1. Introduction

Large amounts of sludge that commonly contain over 95% water produced from Wastewater treatment processes, this high moisture content combined by high costs of transportation and handing. So one of the most important parts of sludge treatment prior to disposal is the reduction of sludge volume [1]. Sludge is a colloidal system in which small sludge particles form stable suspension in water and are very difficult to be separated from the water phase [2]. Fine sludge particles clog the channels through which water could be removed. The solution that determines intensification of sludge dewatering is offered by using of conditioning materials (flocculation), which ensures the agglomeration of fine particles into larger flocks [3, 4]. Conditioning involves the chemical and/or physical treatment of biosolids to enhance water removal and improve solids capture. The three most common conditioning systems use inorganic chemicals, organic polymers (covered in another chapter), or heat treatment [5]. 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% [6]. Fly ash is a fine grained powder left as residue after the burning of coal during the production of electricity. It mainly consists of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3). It is finely separated residue that outcomes from the ignition of pounded coal and is transported from the burning chamber by fume gases [7]. The general trend all over the world is the reuse of the various industrial wastes or by-products, particularly the solid wastes, in useful applications in order to prevent, or at least to reduce the environmental pollution [8]. Fly Ash (FA) 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, 3, 4, 5].

The selection of the mixing system is dependent on the dewatering method. Separate mixing and flocculation tanks are typically provided ahead of pressure filters. If a belt-filter press is to be used, either an upstream flocculation tank or direct addition to the feed line may be employed. In-line mixers are typically used with centrifuges [5, 9]. Most of the previous researches concerned on studying the effect of the used FA dose or combined action of FA and other conditioners, assuming a mixing time of varied between 1 to 20 minutes as follow; Aboulfotoh and Dohdoh [10] used 1 min, Chen et al [11] used 2 min, Liu and Ding [12] used 10 min, Huo and Li [13], Wojcik [3, 4] used 15 min, and Shihab [14] used 20 min.

The main goal of current research is to evaluate the effect of flocculation time on the performance of FA as sludge conditioner.

2. Material and Methods

The experimental work presented in this paper was conducted at the Environmental Engineering Laboratory, Faculty of Engineering, Zagazig University, Zagazig, Egypt. All the tests were performed in triplicate and shown results is the average values.

2.1 Sludge characteristics

Sludge samples used in this study were collected from 3 local WWTP in Egypt comprising different treatment technologies as follow; combined primary and trickling filter humus (PS+TF), Anaerobic digested combined sludge (AnD), Combined primary and waste activated sludge (PS+AS) and Extended aeration sludge (EAS), noted that the second and third sludge types were collected from the same WWTP. pH, total solids (TS) and volatile solids (VS) were measured for each type of raw sewage sludge samples. 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	**PS+TF**	**AnD**	**PS+AS**	**EAS**
TSS (g/l)			40*	
VSS (%,TS)	72	55	70	78
pH value	6.4	7.2	6.7	6.8

* Smollen [15, 16] show that the initial solid concentration of sludge sample had an effect on the dewaterability indicators as for anaerobically digested sludge there is an increase in R values with a decrease in solids concentration. While for activated sludge slurries there was a decrease in R with a decrease in solids concentration, so in order to eliminate the effect of initial solid concentration the all tested sludge samples were adjusted to have the same initial solid concentration.

2.2 Fly Ash

The Fly ash utilized in the present study has the following chemical composition

Table 2: Chemical composition analysis of FA

Compund	**% weight**	**Compund**	**% weight**
CaO	4.30	**MgO**	1.45
SO_3	0.24	**Na_2O**	0.77
SiO_2	51.11	**K_2O**	0.70
Al_2O_3	25.56	**Loss on ignition**	0.57
Fe_2O_3	12.48		

The optimum dose of FA for dewatering was determined first then the effect of contact time was evaluated.

2.3 FA optimum dose experiment

This stage was used to determine the optimum FA dosage according to the following procedure. Seven laboratory beakers with capacity of 1 liter were filled with raw sewage sludge. FA was applied to beakers with the following doses (0, 2, 4, 6, 8, 10 and 12%) (gm FA/gm DS) [2, 13 and 17]. Sewage sludge with applied FA was stirred rapidly with a speed of 250 rpm for 30 s followed by a slow agitation for 5min at a speed of 30 rpm, then sludge was allowed to settle for 120 min during which the position of the suspension/liquid interface is measured at different time instants. The dose which produced the lowest sludge height at the end of the test was selected to be the optimum dose.

2.4 Effect of flocculation time on FA dewatering capacity

In this stage the Specific Resistance to filtration (R) was used - using free gravity test [18] - to evaluate the effect of flocculation time on sludge dewaterability and filterability. The selected FA dose from the previous experiment was added to a beaker of 500 ml containing 250 ml of raw sludge and stirred rapidly with a speed of 250 rpm for 30 s followed by a slow agitation at a speed of 30 rpm for (0, 5, 10, 15, and 30min) -expressed as FA(0,5, ….etc.)-. The treated sludge samples and an untreated sample were then quickly poured into a Buchner Funnel with diameter 14 cm (fitted with a circular piece of belt press fabric). The Buchner Funnel was set on top of a 1 liter graduated cylinder allowing for the filtrate volume to be recorded against time. Hence, the volume of the filtrate is proportional to the solid content and 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 equation (1) below.

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

Where R = Specific Resistance (m/kg), A = Area of Filtration (m^2), C = Solid Content (kg/m^3), ρgh = Hydrostatic Pressure (N/m^2), V = Volume of Filtrate (m^3), μ = Dynamic Viscosity ($N.s/m^2$), b = Slope (s/m^6).

The standard vacuum pressure (P) for Buchner funnel test for determination of Specific Resistances is 38.1 cm Hg ≈ 51 KPa, and in case of using different pressures R at any known pressure could be calculated by using eq. (2):

$$R_2 = \left(\frac{P_1}{P_2}\right)^{\sigma} R_1 \qquad \text{eqn. 2}$$

Where σ = compressibility factor of sludge, (0.60 – 0.90) for anaerobically digested sludge [19] and (0.60 – 1.40) for waste activated sludge [15, 16].

3. Results and discussion

3.1 Optimum FA Dose

The optimum FA dose was 4% for (PS+TF, PS+AS and EAS) and 8% for AnD sludge -It is worth saying that for EAS the effect of 6% dose was slightly higher than the effect of the 4% addition, but the selected dose of 4% was based on the economical point of view in order to decrease the cost of handling excess sludge production and FA cost of transportation and handling-, results comply with Nirdosh and Ostaff [20] who performed bench scale flocculation tests on anaerobic digester effluent and found that the major digested sludge particles was below $2.5*10^{-6}$ m size and Zeta-potential measurements indicated a negative surface charge on the particles which required more conditioners consumption. Radaideh et al, [21] performed sieve analysis for extended aeration and anaerobic digested sludge and results clearly shows that the grain portions in the fine range in case of anaerobically digested sludge are more than that in case of extended sludge, also microscopic photos showed that extended aeration sludge are characterized by larger colonies of flocs and more open structure than anaerobically digested sludge. Also Zlatkovskyi et al [17] found that the optimum dose of applying FA to waste activated sludge is in the range of 4 to 5% by weight. Also these results complying with the recommended conditioner consumption of [5, 22, 23 and 24], as these references proposed approximate equal consumption for combined primary and biological sludge (TF/AS) and higher values for anaerobically digested sludge.

3.2 Sludge dewaterability

3.2.1 Specific resistance of filtration

Figure (1) shows relation between sludge solid concentration and filtrate time for the four tested sludge types; using of fly ash decreased the required time for filtration for all types of sludge, also increasing of flocculation time from 0 to 15 minutes give the same trend but in the other hand increasing the flocculation time for more than 15 have a diverse effect this is mainly due to the brake down of the forces of attraction between FA and sludge particles due to the continues flocculation.

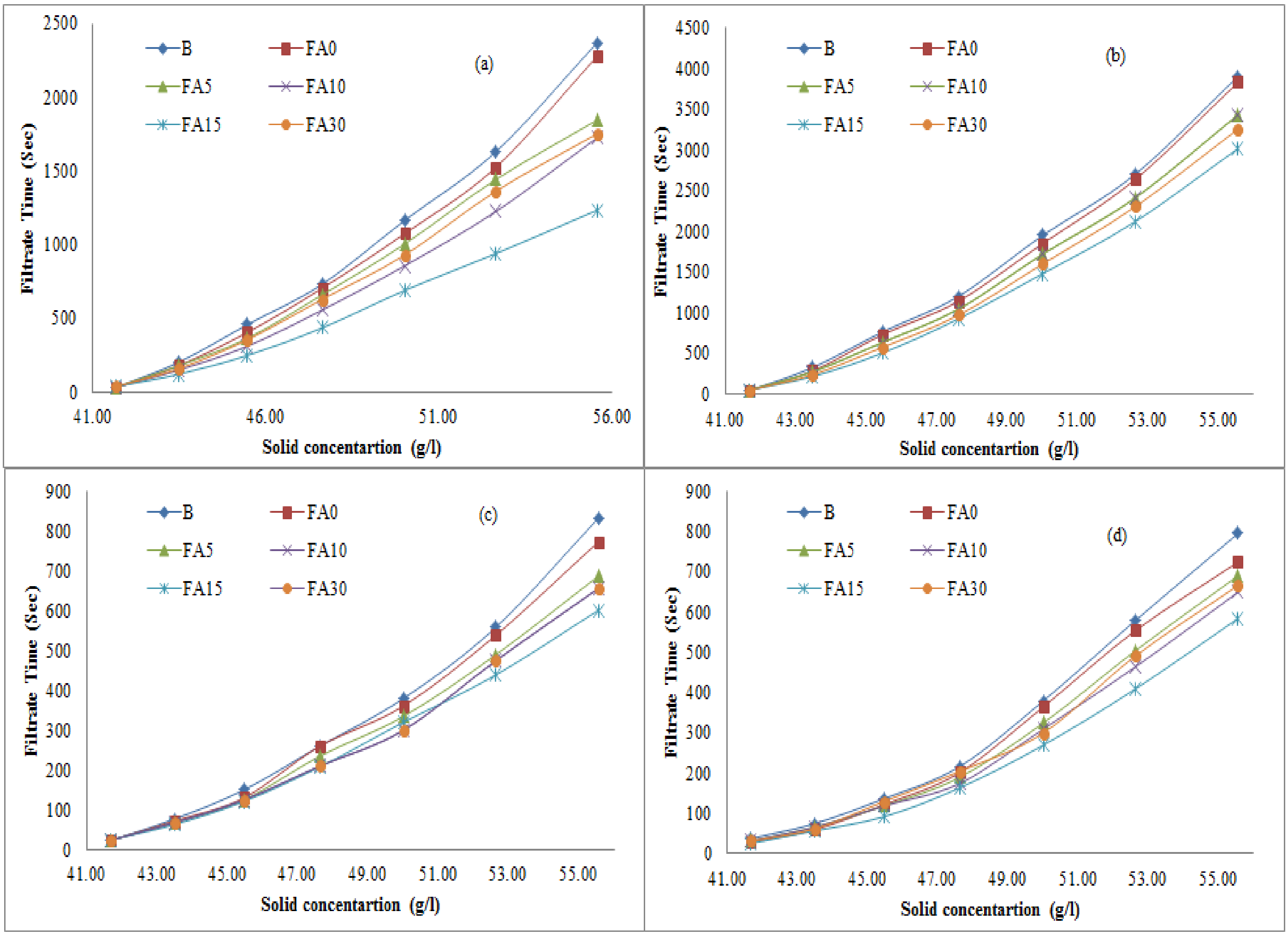

Figure 1: Relation between solid concentration and filtrate time for a) PS+TF, b) AnD, c) PS+AS and d) EAS

Specific resistance of filtration was calculated based on equations (1 & 2), as shown in figure (2) R of the untreated sludge were $5.58*10^{13}$, $8.28*10^{13}$, $5.44*10^{13}$ and $4.28*10^{13}$ (m/kg) for PS+TF, AnD, PS+AS and EAS respectively.

These results comply with Christensen [25] who reported R for all types of sewage sludge based results from 9 different references, and also comply with the obtained results of Smollen [15, 16] who determined R of different types of municipal sludge (primary, waste activated, anaerobically digested primary, anaerobically digested primary mixed with waste activated, anaerobically digested humus and aerobically digested waste activated) from eleven municipal waste-water treatment plants throughout South Africa. Also results comply with results of [3, 4 and 14].

Results show also that the EAS has the lowest R then the combined two types of sludge (PS+AS and PS+TF) and the higher value of resistance related to AnD sludge, these results complies with Phuong [26] who calculated R of 3 different types of sludge anaerobically digested sludge, waste activated sludge and aerobically digested sludge respectively; and found that the above mentioned order is the sorting order from higher to lower values of R. Also these results comply with the results of [1, 5, 13 and 22].

Using of FA decreased the R of all tested sludge types and the optimum flocculation time was 15 minutes, R decreased by 55%, 15%, 37% and 24% for PS+TF, And, PS+AS and EAS respectively –at 15 minutes flocculation time-, these results complies with the results of Qi et al [2] who found that using FA could decreased the R by almost 50% in case of being used as a conditioner of sewage sludge, also these results complies with the results of [11, 12, 13, 14 and 17].

3.2.2 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 ($kg/m^2/h$) could be used and called yield (Y) which could be calculated using eq. (3) Rebhun et al. [27].

$$Y = \left(\frac{2.P.w}{\mu.t.R}\right)^{1/2} \qquad \text{Eqn. 3}$$

A correction factor (F) is used to minimize the effect of the additional solids of the conditioner, the net sludge solids yield (Y_N) can be expressed as:

$$F = \frac{S_o}{S_o + Dose} \qquad \text{Eqn. 4}$$

$$Y_N = F\left(\frac{2.P.w}{\mu.t.R}\right)^{1/2} \qquad \text{Eqn. 5}$$

Using of FA increased the net yield of all tested sludge types and the optimum flocculation time was 15 minutes, Y_N increased by 198%, 114%, 142% and 129% for PS+TF, And, PS+AS and EAS respectively–at 15 minutes flocculation time (Figure 3).

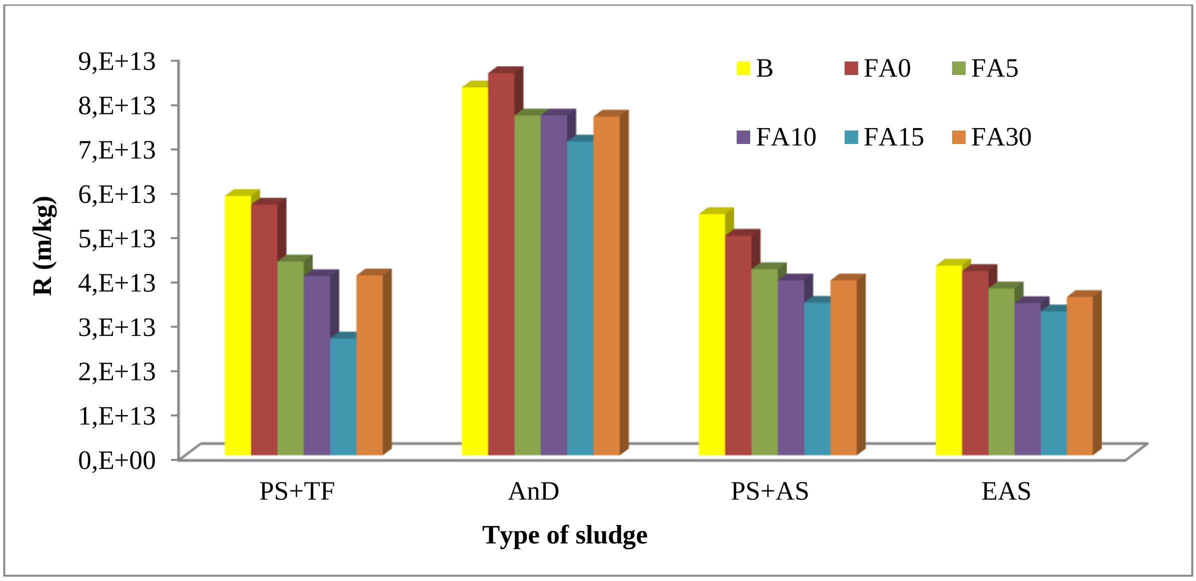

Figure 2: Relation between R and flocculation time for different types of sludge

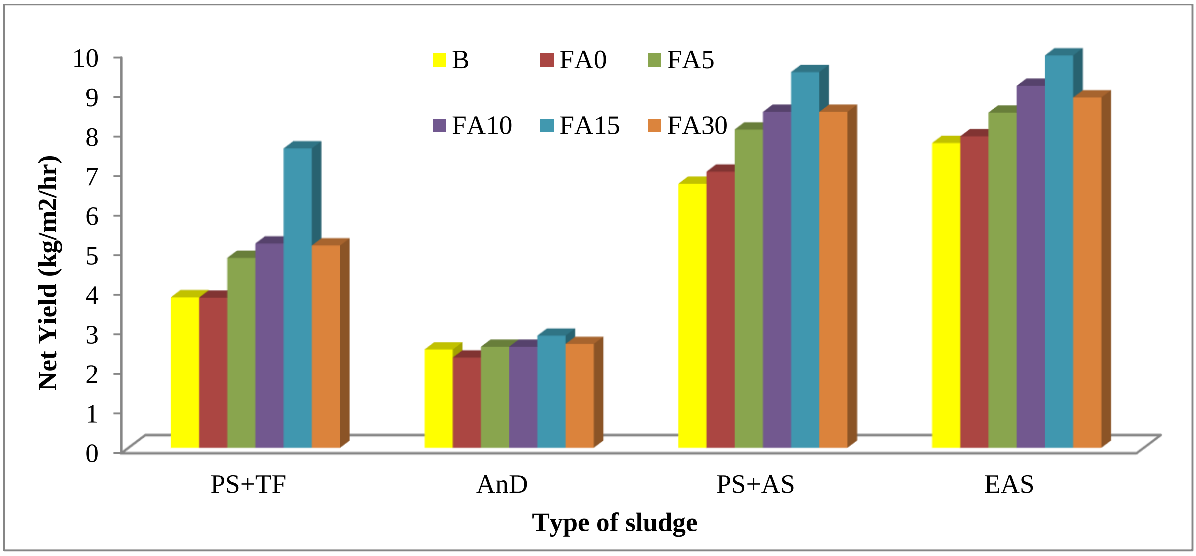

Figure 3: Relation between Net Yield and flocculation time for different types of sludge

These results complies with the results of Goknil [28] who studied the effect of different types of conditioners on the dewaterability of anaerobic and aerobically digested sludge and found that the effect of conditioners on the anaerobic sludge is lower than its effect on the aerobically sludge also Qi [2] found that using FA could increase the N_Y by almost 200%, results also complies with the results of [11, 12, 13 and 29].

3.2.3 Drying beds indicators

Land requirement of drying bed is the most important factor, it could be calculated based on annual solid loading rate or required drying time of sludge. Ceronio et al [30] found that bed loading (kg/m²/year) could be calculated using the following empirical formula is related to Specific resistance (Rc) based on pilot plant studies in England on sludge dewatering.

$$Solid\ \ Load = \frac{10^7}{R_c^{0.5}} \qquad \text{Eqn. 6}$$

Where Rc = Specific Resistance at applied sludge depth hc (s²/g),

$$R = (\frac{h}{h_c})^{\sigma} R_c \qquad \text{Eqn. 7}$$

Table 3 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 [5, 22 and 31]. Solid loading rate of the untreated samples complies with recommendation of Qasim [31] for solid loading as he suggest solid loading in the range of 100-300 (kg/m²/year) for open drying bed and150-400 (kg/m²/year) for covered drying beds. Also results comply with [32 and 33]. Using of FA increased the solid loading and for flocculation time of 15 minute the percent increase in solid load ranged between 8 and 49%.

Table3: Expected Solid loading rate for different types of sludge

Sludge type	Solid load (kg/m²/year)					
	B	**FA0**	**FA5**	**FA10**	**FA15**	**FA30**
PS+TF	340.04	345.83	393.07	408.70	505.36	407.87
AnD	285.69	280.33	297.20	297.20	309.27	297.67
PS+AS	404.12	423.43	459.74	474.09	507.34	474.09
EAS	455.38	461.97	485.13	507.94	522.23	498.10

The model proposed by Adrian [19] –Eq. 9- was found to be the most used model for calculation of the required dewatering time of sewage sludge. Table 4 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, required final solid contends 25% [5, 22, 23, 24 and 30].

$$t = \frac{\mu . R_c . S_0}{100(h_c)^{\sigma}(\sigma+1)}\left[h^{\sigma+1} - \frac{\sigma+1}{\sigma} H_0 h^{\sigma} - H_0^{\sigma+1} + \frac{\sigma+1}{\sigma} H_0^{\sigma+1}\right] \qquad \text{Eqn. 9}$$

Table4: Expected drying time for different types of sludge

Sludge type	Drying time (d)					
	B	**FA0**	**FA5**	**FA10**	**FA15**	**FA30**
PS+TF	6.91	6.68	5.17	4.79	3.13	4.81
AnD	9.80	10.17	9.05	9.05	8.36	9.02
PS+AS	6.43	5.86	4.97	4.67	4.08	4.67
EAS	5.07	4.92	4.46	4.07	3.85	4.23

Drying time for untreated sludge was 6.91, 9.80, 6.43 and 5.07 for PS+TF, And, PS+AS and EAS respectively; According to Radaideh et al, [21] drying of extended aeration sludge take almost half the time of the drying of anaerobic digested sludge for the same operating conditions in lab and full scale experiments, results also complies with [5, 22, 23, 24 and 30]. Using of FA decreased the required dewatering time and for flocculation time of 15 minute the percent decrease in dewatering time ranged between 15 and 55%.

Conclusion

Experimental results obtained in this study showed that treatment of different types of sewage sludge with FA could enhance the dewatering properties of all tested sludge types, The dewaterability of the conditioned sludge was investigated by gravitational settling test, specific resistance to filtration (R) with indicators for mechanical dewatering - the net yield- and indicators of drying beds – solid loading rate and dewatering time-. Results showed that the optimum FA dose was 4% for PS+TF, PS+AS and EAS respectively and 8% for AnD sludge. Using of FA decreased R of all tested sludge types and the optimum flocculation time was 15 minutes, R decreased by 55%, 15%, 37% and 24% for PS+TF, And, PS+AS and EAS respectively –at 15 minutes flocculation time-, also results showed that using of FA could lead to an increase in the solid loading of mechanical or natural drying beds with decreasing of the required time of dewatering for all types of tested sewage of sludge, sorting of the increasing effect of FA on sewage sludge could be in the following order PS+TF, PS+AS, EAS and AnD, with the least effect on the AnD.

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