Journal of Advanced Engineering Trends
ISSN : 2682 - 2091
Vol.41, No. 1. January 2022
http://jaet.journals.ekb.eg

COMPARATIVE STUDY ON DIFFERENT TYPES OF ALUM SLUDGE CONDITIONERS

Ehsan Kh. Ismaeel[1] and Aghareed M. Tayeb[2*]
[1] El Minia High Institute of Engineering and Technology
ae.noornada@gmail.com
[2] Faculty of Engineering, Minia University, Minia, Egypt
*Corresponding author, aghareed1@yahoo.com

ABSTRACT:

A conditioning treatment is performed on alum sludge for the object of enhancing its filterability, thus enhancing water removal from sludge. The sludge used in the experiments is obtained from Kedwan plant, Minia city, Egypt. Conditioners of different types are used, e.g., ferric chloride and lime (as an example of inorganic chemicals), Fenton reagent (adopted as one of the advanced oxidation processes) and Chitosan (adopted as a type of bio-polymers). The parameters studied are: effect of: conditioner dose, rate of mixing, time of reaction and pH value. The results of experiments showed that the minimum values for SRF (target of experiment) are $4.3*10^{12}$, $1.5*10^{12}$, $1.1*10^{12}$, $1.9*10^{11}$ and $3.2*10^{11}$ for conditioning with lime, $FeCl_3$, Lime+$FeCl_3$, Fenton reagent and Chitosan, respectively. These values represent a percentage reduction in SRF, compared to that of raw sludge, of 79.81, 92.96, 94.83, 99.11 and 98.49% for conditioning with lime, $FeCl_3$, lime+$FeCl_3$, Fenton reagent and Chitosan, respectively. Thus, Fenton reagent proved to be the best conditioner, among the conditioners examined, for conditioning alum sludge, followed by Chitosan, then comes (lime+$FeCl_3$), $FeCl_3$ and lastly lime.

Keywords: Alum sludge, conditioning, Fenton process, Chitosan, Specific Resistance to Filtration (SRF)

1. Introduction:

Large amounts of residual wastes are produced as by-products in potable water treatment plants. These wastes may include alum sludge, ions, or polymers resulting from coagulation and sedimentation [1]. It is not reasonable, environmentally or economically to dispose off sludge directly to the environment prior to a conditioning step which is then followed by mechanical dewatering.

Alum sludge is produced in huge amounts as a result of adding aluminum sulphate [$Al_2(SO_4)_3.14H_2O$] as a flocculant in the process of drinking water treatment (Eq. (1)). The resultant sludge is a two-phase mixture of solids and water and its level of water content is generally in between 99% (before thickening) and 95% (after thickening). Such alum sludges are often regarded as "difficult-to-dewater" [2-4]. Its color varies from light brown to black; depending on the source of water and the chemicals used for treatment. It has pH value that ranges between 5 and 7.

$$2Al^{+3} + 6HCO_3^- \rightarrow 2Al(OH)_3 + 6CO_3 \quad (1)$$

One common method of disposing alum sludge is by landfilling it. However, it should be subjected to adewatering step, prior to landfilling, in order to reduce its volume. Dewatering is done by physical or chemical means. Physical methods such as vacuum filtration or thermal methods such as heating or solar drying and chemical method through the addition of coagulants, polymers and stabilizers could be used. The suitable choice of the technique is mainly dependent on the type of sludge and space available. The efficiency of dewatering process is highly dependent on the type of sludge [5].

Received:3October, 2020, Accepted:8October, 2020

Sludge conditioning is a process in which sludge solids are processed with chemicals or various other ways to prepare the sludge for dewatering operations [6, 7]. Various organic and inorganic chemicals including Chitosan, ferric chloride, ferric sulphate, lime, and polymers are used for conditioning. Recently, Fenton's reagent (Fe^{+2}/H_2O_2), which has not been examined sufficiently so far, is used as a chemical conditioner [8].

Adding the chemicals to the sludge reduces or raises its pH value to a point where small particles coagulate into larger ones and the water in the sludge solids is given up most readily [9, 10]. Mixing of alum sludge and coagulant is essential for proper conditioning [11].

Inorganic conditioning usually uses chemicals, such as lime and ferric chloride. Ferric chloride is added before lime because it hydrolyzes in water and forms positively charged iron complexes that neutralize negative charged sludge solids and allow them to aggregate together [12]. The addition of lime gives greater porosity to the sludge, thereby achieving an inert sludge of greater dryness [13].

Besides, organic polymers are most widely employed conditioners in water and wastewater industry. However, the use of polymers especially the improper use such as overdose of polymers may cause a problem in the supernatant water generated during alum sludge dewatering. Furthermore, residual polymers in conditioned sludge cakes may pose a long-term risk to the surrounding environment when the cakes are subject to landfill as the final disposal [14, 15].

Thus, natural polymers have found great interest in recent researches. One of these natural polymers is Chitosan (figure 1). It is the most important derivative of Chitin. Chitin is a natural polymer derived mainly from two marine crustaceans; shrimps and crabs and Chitosan is obtained by partial de-acetylation of chitin under alkaline conditions or enzymatic hydrolysis [16]. Chitosan is not soluble in water or organic solvents but in dilute organic acids such as acetic acid (CH_3COOH) and inorganic acids (e.g. HCl), the free amino groups are protonated, and the biopolymer becomes fully soluble [17, 18].

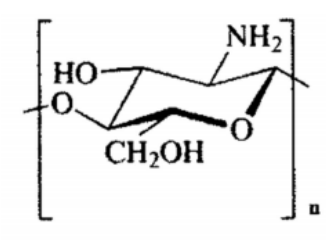

Figure 1: Chitosan (poly (D-glucosamine)) repeated units

When treated with Chitosan, the moisture content of alum sludge cake decreases, and the sludge volume is reduced. It was considered that Chitosan changed the properties and structure of the flocculation surface; causing dissolution of organic matter. After these hydrophilic organic substances are dissolved, the performance of dewatering of the sludge is improved [19, 20].

A relatively recent technique for dewatering alum sludge is the use of **Fenton's reagent.** Fenton's reagent is a substance that contains H_2O_2 and Fe ions [21].

Ferrous iron (Fe^{+2}) is oxidized by hydrogen peroxide to ferric iron (Fe^{+3}), a hydroxyl radical and a hydroxyl anion [22, 23] (Eqs. 2 and 3).

$$Fe^{+2} + H_2O_2 \rightarrow Fe^{+3} + OH^{\bullet} + OH^{-} \quad (2)$$

$$Fe^{+3} + H_2O_2 \rightarrow Fe^{+2} + OOH^{-} + H^{+} \quad (3)$$

In the net reaction iron presence is truly catalytic and two molecules of H_2O_2 are converted into two hydroxyl radicals and water. The produced radicals are then engaged in secondary reactions. Iron (Fe^{+2}) sulphate is a typical iron compound in Fenton's reagent [24-26].

These $OH^{\bullet}$ species are responsible for the reaction as mentioned before and responsible for attaching the organic molecules in the sludge.

The present study is an investigation for the different types of conditioners for determining its performance.

2. Experimental part:

Experiments are run on a sludge taken out from the water treatment plant in Kedwan, Minia City, Egypt. The raw sludge is dark brown with a pH value 7-7.8. It has the values 2.13×10^{14} m/kg, 71.54 gm/l and 243 NTU for SRF, D.S. and turbidity (supernatant), respectively.

In this station, aluminum sulphate (alum) is used as a coagulant to treat water taken from the River Nile and forming alum sludge.

2.1. Materials and Measurements:

2.1.1. Materials:

The materials used are:

Chitosan: ((1, 4)-2-Amino-2-desoxy- beta-D-glucan)) ($C_6H_{11}(NO_4)_n$) (El Nasr pharmaceutical chemical co.), **ferrous chloride:** $FeCl_2.XH_2O$ (crystals of molecular weight 126.75) (Oxford laboratory, India), **ferric chloride:** ($FeCl_3$, anhydrous, with molecular weight 126.75) (Oxford laboratory, India) and **lime**: (CaO with molecular weight 56) (El Nasr pharmaceutical chemical co.) are used as conditioners.

Hydrogen peroxide: H_2O_2 (ADWIC, with density of 1.1, 30 vol.) is used in the Fenton reaction.

Sodium hydroxide (NaOH) and **Hydrochloric acid** (HCl) are used for adjusting pH (El Nasr pharmaceutical chemical co.).

Acetic acid (El Nasr pharmaceutical chemical co.) is used for dissolving Chitosan.

2.1.2. Measurements:

Specific Resistance to Filtration (SRF):

The device used for the SRF test consists of a 100 cm^3 graduated cylinder with a built- in adapter and fitted glass side arm. A Buchner funnel is fixed to the top of the adapter with a rubber stopper. A tube is connecting the side arm to a vacuum pump, through a vacuum tank (Figure 2) [27].

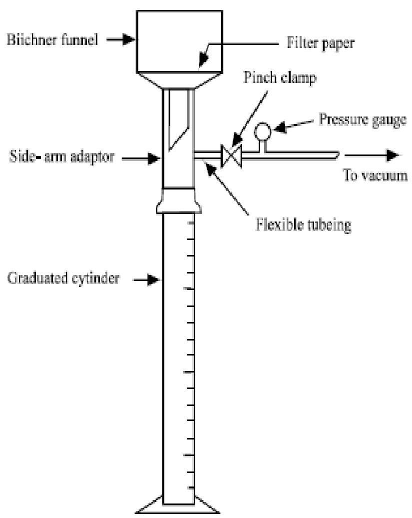

Figure 2: Schematic of the SRF device

Before performing the filtration test, temperature, pH and solids content of the sludge sample are determined. The filtration process is carried out according to the following steps:

1- A moist filter paper is put in the Buchner funnel. Then vacuum is applied for a few seconds to drain out the moisture in the filter paper.

2- Exactly 100 ml of alum sludge sample was gently poured into Buchner funnel and a vacuum of 15 in-Hg was applied at zero time. At the same time a stopwatch is started.

3- For the first 10 minutes the filtrate volume collected in the cylinder was noted every minute.

4- When vacuum begins, the sludge cake gently forms. By the end of the experiment the filter paper is removed from Buchner funnel and the weight of the total solid cake is determined.

5- For the filtrate, the solid content and pH value are determined.

The time (t) taken for the collection of volume (V) of filtrate is listed. A graph of (t) versus (V_t) is plotted. Then the SRF of the sludge is calculated as follows (Eq. 4):

$$SRF = \frac{2A^2Pb}{\mu C} \qquad (4)$$

where:

SRF = the specific resistance to filtration ($m.kg^{-1}$)

P = the pressure of filtration process (Nm^{-2}) ($= 0.5*10^5$)

A = the area of the filter paper (m^2) ($= 38.5 *10^{-4}$)

μ = viscosity of filtrate, taken the same as that of water (Nsm^{-2}) ($= 0.798*10^{-3}$)

b = slope of filtrate discharge curve (plot T/V against V) (sm^{-6})

C = cake solids, weight per unit volume of filtrate ($kg\ m^{-3}$) (= 92.6)

The calculation of SRF was evaluated as a reduction percent according to equation (5):

$$SRF\,\% = [(Co-C)/Co]*100 \qquad (5)$$

where C_o and C are the SRF of alum sludge before and after the conditioning process, respectively.

2.2. Parameters studied:

The effect of conditioner dose, speed of rotation and pH value on the conditioner performance is studied in the present investigation. Preliminarily experimentations on alum sludge indicated that a reaction time of one minute is enough to show the behavior of the treated sludge towards filterability. For that reason, the effect of reaction time is not considered in the present study.

3. Results and discussion:

The performance of a specific conditioner is evaluated by measuring the Specific Resistance to Filtration (SRF) of the treated sludge (given as columns). Besides, the percentage reduction in the value of SRF of the treated sludge is calculated; compared to the SRF of the raw sludge (given as tables). A higher percentage reduction in SRF means a more favorable conditioner.

3.1. Conditioning of Alum Sludge Using Lime:

3.1.1. Effect of lime concentration (as percentage of ddry solids, DS) on alum sludge dewaterability:

Lime concentrations of 5, 10, 15, 25, 35 and 45% DS (as a percentage of dry solid) were used in this test at fixed reaction time (1min), pH (normal) and speed of mixing (600 rpm). The results of this test are presented in figure (3) and table (1).

Examination of the results indicates that the dewatering rate of alum sludge increases with the increase of lime concentration till a certain limit after which it becomes slower. The optimum concentration of lime is 25% and it gave the lowest value of $0.54*10^{13}$ for SRF. This corresponds to a percentage reduction in the value of SRF of 74.65, compared to the value of raw sludge. The attitude of the results agrees with the work performed by Hwa, T.J. and S. Jeyaseelan [28] who indicated that the CST (capillary suction test) and SRF decrease with increasing lime dosage.

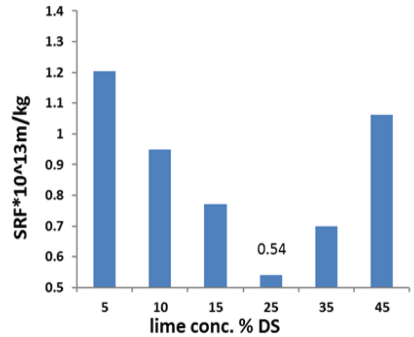

Figure 3: Effect of lime conc. on sludge conditioning at pH 7, 1 min reaction time and 600 rpm

Table (1): Effect of lime concentration (as percentage of DS) on alum sludge dewaterability at normal pH, 1min reaction time and 600 rpm

Lime Conc., %DS	$SRF*10^{13}$, m/kg	SRF red., %
5	1.205	43.427
10	0.95	55.399
15	0.77	63.849
25	**0.54**	**74.647**
35	0.7	67.136
45	1.061	50.188

3.1.2 Effect of rpm on alum sludge dewaterability using lime:

Values of rpm in the range from 200 to 1000 are examined.

The results presented in figure (4) and table (2) indicate that increasing the speed of mixing (rpm) decreases the value of SRF till a speed of 400 rpm where a minimum value of $0.49*10^{13}$ m/kg for SRF is obtained. This corresponds to a percentage reduction of 76.99%. Further increase in the value of rpm beyond 400rpm results in increasing SRF again. The attitude of the results agrees with the work performed by Yin, X. [29], who reported that the SRF of conditioned sludge decreases with increasing the mixing conditions, thus decreasing the initial strength of the floc.

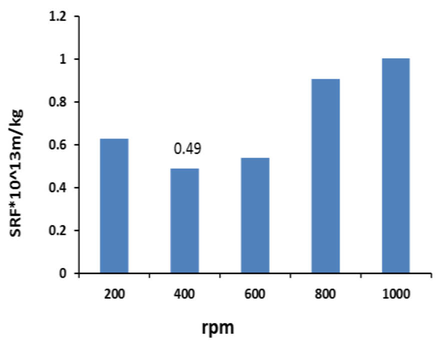

Figure 4: Effect of rpm. on SRF in conditioning with lime at normal pH, 1 min. reaction time and 25% DS lime dose

Table 2: Effect of rpm on conditioning With lime at normal pH, 25% DS lime dose and 1 min reaction time

Speed of rotation, rpm	SRF $*10^{13}$, m/kg	SRF red., %
200	0.63	70.422
400	**0.49**	**76.995**
600	0.54	74.648
800	0.907	57.418
1000	1.003	52.911

3.1.3 Effect of pH on alum sludge dewaterability using lime:

The experimental values of this test are given in Figure (5); which indicates that conditioning of alum sludge at acidic medium is more effective than neutral or basic medium. A minimum value of SRF $=0.43*10^{13}$ m/kg is obtained at pH value of 4. This minimum value corresponds to the highest percentage SRF reduction of (79.81%) as seen in Table 3. The attitude of the results agrees with the work performed by Huan Liu [30], who examined the effects of initial pH in the range of 2–8 and reported that the acidic environment could clearly improve sludge dewaterability and reached the minimum SRF value at pH of 5

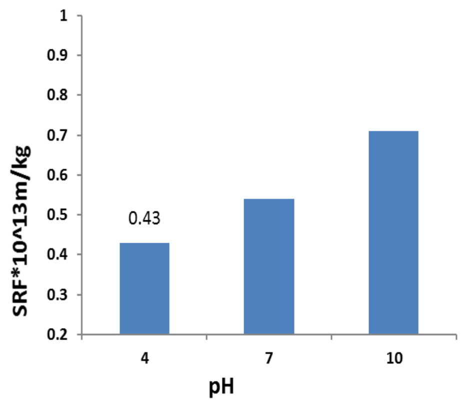

Figure 5: Effect of pH value on SRF at 1 min. reaction time, 600 rpm and 25% DS lime dose

Table 3: Effect of pH on conditioning with lime at 1min reaction time, 25%DS lime dose and 600 rpm

pH	SRF$*10^{13}$ m/kg	SRF red., %
4	**0.43**	**79.812**
7	0.54	74.648
10	0.71	66.667

3.2. Conditioning of alum sludge using Ferric Chloride ($FeCl_3$):

3.2.1 Effect of Ferric chloride dose (as percentage of DS) in alum sludge conditioning:

Results of the present test are plotted in figure (6). The results clarify that the SRF value of alum sludge decreased with increasing ferric chloride dose from 1 to 3% DS, and further increase in the amount of ferric chloride increases the SRF value. The filtrate was clear during experiments with low concentrations of ferric chloride and it changed gradually to red with increasing concentration of ferric chloride dose. The optimum conditions were at 3% $FeCl_3$ that gave

SRF= $0.23*10^{13}$m/kg and SRF reduction % = 89.20%; as shown in table (4). The attitude of the results agrees with the work performed by El-Gohary, et al. [31], who reported that the rate of dewatering of alum sludge increases with increasing $FeCl_3$ concentration to a certain limit after which it becomes slower.

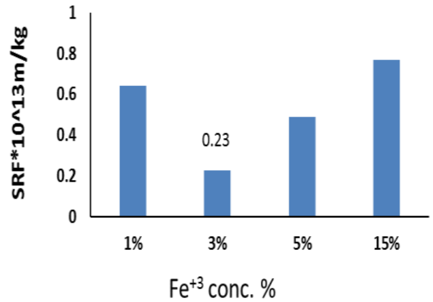

Figure 6: Effect of Ferric chloride conc. on conditioning at normal pH, 1min reaction time and 400 rpm

Table 4: Effect of $FeCl_3$ dose (as % DS) on alum sludge conditioning at 1 min reaction time, 400 rpm and normal pH

$FeCl_3$ Conc. %DS	SRF*10^{13} m/kg	SRF red., %
1%	0.64	69.95305
3%	**0.23**	**89.20188**
5%	0.49	76.99531
15%	0.77	63.84977

3.2.2 Effect of rpm on alum sludge conditioning using $FeCl_3$ conditioner:

The experimental values of this test are given in Figure (7) and Table (5). The optimum values of SRF and SRF percentage reduction were $0.23*10^{13}$m/kg and 89.20%, respectively at 400 rpm. These results indicate that increasing the mixing speed leads to an increase in SRF because the high mixing speed results in cracking of the aggregates formed by the addition of ferric chloride. The attitude of the results agrees with the work performed by Tony, M.A. et al. [32], who used a high-speed stirrer (250-300 rpm) to provide intense mixing conditions to achieve optimum results.

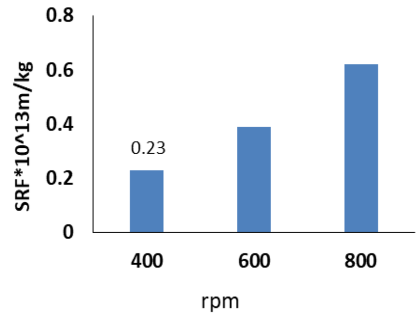

Figure 7: Effect of rpm. on SRF when conditioning with $FeCl_3$ at normal pH, 1min reaction time and 3%DS $FeCl_3$ dose

Table 5: Effect of rpm on conditioning with $FeCl_3$ at normal pH, 3% DS $FeCl_3$ dose, 1min reaction time

Mixing speed, rpm	SRF*10^{13} m/kg	SRF red., %
400	**0.23**	**89.202**
600	0.39	81.690
800	0.62	70.892

3.2.3 Effect of pH on alum sludge conditioning using $FeCl_3$ conditioner:

Sludge conditioning experiments at initial pH values of 3, 7 and 10 are performed. The experimental results of this test are given in figure (8). The results clarify that the SRF value of alum sludge increased by increasing the pH of the medium. The optimum values of SRF and percentage reduction in SRF are $0.15*10^{13}$ and 92.96%, respectively at pH 10. Tony, M.A., et al [33], achieved a similar level of dewaterability of alum sludge when it was subjected to conditioning with ferric chloride at pH in the range of (5-12).

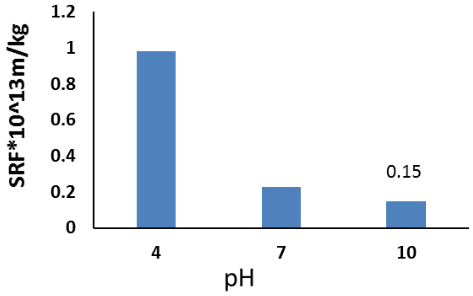

Figure 8: Effect of pH on SRF in conditioning with $FeCl_3$ at 400 rpm, 1min reaction time and 3% DS $FeCl_3$ dose

3.3 Conditioning of alum sludge using (ferric chloride + lime):

In this test ferric chloride is added before lime because $FeCl_3$ hydrolyzes in water and forms positively charged iron complexes that neutralize the negatively charged sludge solids and allow them to aggregate. Lime is then added to raise the sludge pH of the medium so that the hydroxides form more efficiently because of the ferric chloride reaction. Experiments were run at 25% lime (the optimum dose from the previous experiments) and only $FeCl_3$ dose was varied.

To explore how the combined conditioner of $FeCl_3$ with lime acts, it is important to refer to the results obtained previously for $FeCl_3$ alone and lime alone.

3.3.1 Effect of ferric chloride dose using (ferric chloride +lime) conditioner:

Experiments similar to those given in section 3.2.1 are run (using fixed lime dose of 25%), 400 rpm and normal pH. The results of this test have the same attitude shown in section 3.2.1.; i.e., a decrease in the value of SRF with increasing $FeCl_3$ dose till a certain concentration of $FeCl_3$ after which the values of SRF increase again. The minimum value attained for SRF was $0.11*10^{13}$ m/kg (compared to $0.23*10^{13}$ m/kg when using $FeCl_3$ alone). The maximum value of SRF percentage reduction was 94.83% (compared to 89.2% when using $FeCl_3$ alone). Thus it could be stated that the presence of lime in combination with $FeCl_3$ has a positive effect towards further reducing the value of SRF and raising the value of percentage reduction in SRF as will be shown later in figures 10 and 11. These dosage ranges are comparable to those reported by Knocke, W.R., J.W. Nash, and C.W. Randall [34] who reported that coupled addition of both lime and ferric chloride resulted in significant improvements in sludge dewatering rate.

3.3.2 Effect of pH when using (ferric chloride + lime) conditioner:

Series of experiments were performed on alum sludge with pH adjustment. Values of pH examined were (4, 7 and 10) at 25% lime dose, 3% ferric chloride dose, 1min reaction time and 400 rpm. The experimental values of this test showed that a minimum value of SRF of $0.11*10^{13}$m/ kg is attained at pH 7 (compared to $0.15*10^{13}$ m/kg at pH 10 when using $FeCl_3$ alone in section 3.2.3) and this corresponds to a maximum percentage reduction in SRF of 94.83% in the present test (compared to 92.96% when using $FeCl_3$ alone). Thus, the addition of lime to $FeCl_3$ conditioner reduces the pH value at which minimum SRF is attained, raising the minimum value of SRF and raising the value of maximum percentage reduction in SRF. Thus, addition of lime to $FeCl_3$ conditioner has a positive effect in the conditioning treatment. This will be shown later in figures 10 and 11. The attitude of these results agrees with the work performed by Liu, F., et al. [35], who achieved good conditioning to alum sludge at the original pH value of the sludge.

3.3.3 Effect of rpm for (ferric chloride + lime) conditioner:

Velocities of 400, 600 and 800 rpm were used in these tests at fixed reaction time (1min), pH (normal), 3% DS ferric chloride dose and 25% DS lime dose. The best experimental results were obtained at 600 rpm with a minimum value of $0.081*10^{13}$m/kg for SRF (compared to $0.23*10^{13}$m/kg at 400 rpm in section 3.2.2. when using $FeCl_3$ alone). The maximum value of percentage SRF reduction was 96.20 (compared to 89.20% when using $FeCl_3$ alone). Thus, it could be stated that the presence of lime in addition to $FeCl_3$ necessitates stronger stirring than when using $FeCl_3$ alone (600 rpm in the present test compared to 400 rpm for the test of $FeCl_3$ alone) to satisfy the minimum value for SRF. However, its addition has the advantage of lowering the value of SRF and raising the value of percentage reduction in SRF. The attitude of these results agrees with the work performed by Christensen, G.L. [36]. .

3.4 Conditioning of alum sludge using Fenton reagent:

3.4.1 Effect of amount of iron salt (%DS) in the Fenton reaction conditioner:

Series of experiments, varying in the concentration of iron salt and having the other parameters fixed, were carried out. Experiments were run at constant H_2O_2=1.3% DS, 1min reaction time and normal pH. The results of this test are presented in Figure (9).

The results showed a decrease in the SRF of alum sludge with increasing Fe^{+2} concentration from 0.5 to 2.0 % DS, after which it increases again. Thus, the dewatering rate of alum sludge increases with the Fe^{+2} concentrations to a certain limit after which it becomes slower. A concentration of 2.0 % DS for Fe^{+2} gave the best results with the value of SRF of $0.093*10^{13}$ m/kg (Figure 9) and 97.93% of SRF reduction percentage; when using 1.3% DS of H_2O_2. This means that the amount of Fe^{+2} should be in equilibrium with the amount of H_2O_2 to produce the hydroxyl radicals. If the amount of Fe^{+2} is more than the optimum, this will result in Fe^{+2} precipitation in the solution rather than reacting with H_2O_2 to form the hydroxyl radicals; and thus, the reaction rate will be slower. The attitude of these results agrees with the work performed by Tony, M.A., et. al. [37], who experimented on various concentrations of iron salt in the range of 0.35– 35.0 % DS and reached the same trend of the results.

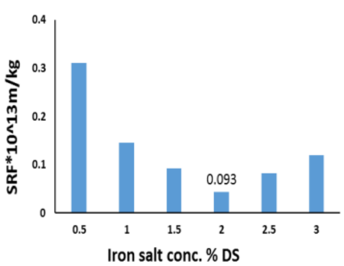

Figure 9: Effect of amount of iron salt (% DS) on SRF when conditioning with Fenton reagent at 1.3% DS H_2O_2, 1min reaction time and normal pH

3.4.2 Effect of amount of H_2O_2 (% DS) using Fenton reagent conditioner:

Variable concentrations of H_2O_2 were applied at constant values of 2.0% DS $FeCl_2$, 1min reaction time and normal pH. The experimental values of this test showed that increasing the concentration of hydrogen peroxide results in generation of more hydroxyl radicals, and thereby enhancing the water release from the sludge, so it has a positive influence on the SRF reduction rate. The optimum concentration seems 1.5% DS and it gives the lowest SRF ($0.043*10^{13}$ m/kg) and highest SRF reduction percent (97.98%). However, at concentrations of H_2O_2 higher than 1.5% DS, the reduction rate is negatively affected, and excessive hydrogen peroxide can act as an OH scavenger. This may be related to the amount of hydroxyl radicals. When H_2O_2 concentration increases to a critical level, a so-called scavenging effect will occur. The results of this test are shown in table (6). These results are comparable to those reported by Tony, M.A., et al. [38] who attained the same results by using variable concentrations between 10.0 and 80.0% DS H_2O_2.

Table 6: Effect of amount of H_2O_2 (% DS) using Fenton reagent conditioner at 2% DS $FeCl_2$ and normal pH

H_2O_2 Conc. (%DS)	$SRF*10^{13}$ (m/kg)	SRF red., %
0.5	0.195	90.845
1.5	**0.043**	**97.981**
2.5	0.103	95.164
3.5	0.253	88.122

3.4.3 Effect of pH using Fenton reagent conditioner:

Fenton reagent at dosage of 2.0% DS $FeCl_2$ and 1.5% DS H_2O_2 and reaction time of 1 min was examined. The experimental values of this test indicated that pH adjustment has a significant effect on alum sludge dewaterability. The acidic environment can clearly improve sludge dewaterability with pH of 5 being the best that gave the minimum value of SRF ($0.019*10^{13}$m/kg) and the maximum value of SRF reduction percent (99.11%). The basic environment, however, exhibited negative effect on the sludge dewaterability. The attitude of the results agrees with the work performed by Buyukkamaci, N. [39] who reported the effectiveness of pH on SRF in the range (2-7).

3.5 Conditioning of alum sludge using Chitosan conditioner:

3.5.1 Effect of amount of Chitosan on sludge conditioning:

In this test, different dosages of Chitosan were tested (0.05, 0.1, 0.2, 0.3, 0.5, 1.0, 1.5 and 2.0 % DS). The experimental values of this test (Table 7) indicated that the optimum amount of Chitosan was 1.0% DS that gave the lowest SRF value of $0.032*10^{13}$ m/kg and the maximum SRF reduction percent of 98.498%. The attitude of the results agrees with the work performed by Zhang, J., et al. [40] who reported that, when Chitosan dosage ranged from 0.001 to 0.005% DS, the SRF of the sludge decreased.

Table 7: Effect of amount of Chitosan conditioner on alum sludge dewaterability; at 5 pH and 250 rpm

Chitosan Conc., %DS	$SRF*10^{13}$, mkg^{-1}	SRF red., %
0.05	0.963	54.78873
0.1	0.881	58.6385
0.2	0.545	74.41315
0.3	0.303	85.77465
0.5	0.093	95.6338
1.0	**0.032**	**98.49765**
1.5	0.146	93.14554
2.0	0.293	86.24413

3.5.2 Effect of rpm using Chitosan conditioner:

Mixing speeds of 150, 250 and 350 rpm were used in this test at fixed amount of Chitosan (1.0% DS) and 5 pH. The experimental values of this test indicated that the value of percentage SRF reduction of the treated alum sludge increases with increasing the speed of mixing till a value of 250 rpm after which the SRF reduction % begins decreasing again. At this value of mixing speed (250rpm), a minimum value for SRF of $0.032*10^{13}$ and a maximum percentage SRF reduction of (98.498%) were attained. These results agree with the trend of the work performed by Hassan, Hassan, et al. [41] who run his experiments at 250 rpm and accomplished good results.

3.5.3 Effect of pH using Chitosan conditioner:

The value of pH will not only affect the surface charge of coagulants, but also affects the stabilization of the suspension. Besides, the solubility of Chitosan in aqueous solution is influenced by pH value. Therefore, the study of pH was essential to determine the optimum pH condition of the treatment system. The effect of pH was analyzed at optimum dosage, 1.0% DS and 250 rpm of mixing rate for a range of pH which varied from pH 3 to pH 9. Results of this test clarified that the SRF value of the treated alum sludge reaches a minimum value of ($0.032*10^{13}$ m/kg) in acidic medium (pH 5) and a maximum value of 98.49 for percentage reduction in SRF. The attitude of the results agrees with the work performed by Shi, C., et al. [42] who reported that, good conditioning and dewatering performance on the sludge takes place at pH 5-6.

3.6. Comparative study between different conditioners:

Table (8) summarizes the best conditions of alum sludge conditioning, as well as, the best results obtained at these conditions. Comparison plots are given in Figure (10) for the effect of conditioner type on the value of SRF and in Figure (11) for the effect of the conditioner type on SRF percentage reduction. Examination of results in table (8) indicates that Fenton reagent is the most favorable conditioner with a minimum SRF of $0.019*10^{13}$ m/kg and a maximum SRF percentage reduction of 99.11%. This is followed by Chitosan which gave values of $3.2*10^{11}$ m/kg and 98.49% for SRF and percentage reduction in SRF, respectively.

Table 8: Effect of different conditioners on alum sludge dewaterability

Material	Optimum condition			Optimum results	
	Concen-tration, % DS	**pH**	**Mixing speed, rpm**	**SRF, m/kg**	**SRF, reduc-tion,%**
Raw sludge		7-7.8		$2.13*10^{14}$	0%
Lime	25% DS	4	400	$4.3*10^{12}$	79.81%
$FeCl_3$	3% DS	10	400	$1.5*10^{12}$	92.96%
$FeCl_3$+ Lime	25%DS lime 3% DS $FeCl_3$	7	600	$1.1*10^{12}$	94.83%
Fenton reagent	2.0% $FeCl_2$ 1.5% H_2O_2	5	400	**$1.9*10^{11}$**	**99.1%**
Chitosan	1.0% DS	5	250	$3.2*10^{11}$	98.49%

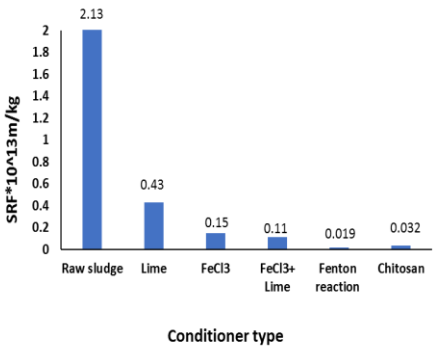

Figure 10: Effect of different conditioners on the value of SRF

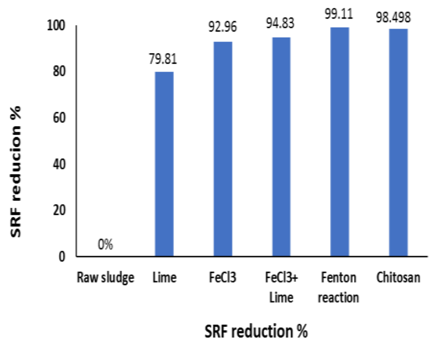

Figure 11: Effect of different conditioners on the value of SRF reduction, %

Conclusion:

Different types of conditioners are used for treating alum sludge for the object of enhancing its dewaterability. The conditioners used are: inorganic chemicals (lime and $FeCl_3$; either individually or combined), Fenton reagent ($FeCl_2+H_2O_2$) and bio-polymer (Chitosan). The following conclusions are obtained: minimum values of $4.3*10^{12}$, $1.5*10^{12}$, $^{1.1}*10^{12}$, $1.9*10^{11}$, and $3.2*10^{11}$ are obtained for SRF when using lime, $FeCl_3$, lime+$FeCl_3$, Fenton reagent or Chitosan, respectively. The corresponding values for the percentage reduction in SRF (compared to the value of raw sludge) were 79.81, 92.96, 94.83, 99.11 and 98.49% for the same conditioners in the same order. Fenton reagent showed the best performance among the reagents examined with a value of $1.9*10^{11}$ for SRF and 99.11 for percentage reduction in SRF. This is followed by Chitosan with values of $3.2*10^{11}$ and 98.49 for SRF and percentage reduction in SRF, respectively, then comes (lime+$FeCl_3$) (SRF= $1.1*10^{12}$), $FeCl_3$ (SRF= $1.5*10^{12}$) and lastly lime (SRF=$4.3*10^{12}$).

Acknowledgement:

The authors would like to acknowledge the support given by the team of Solar Energy Lab., Faculty of Engineering, Minia University; where this work was performed

References:

1. Eckenfelder, W.W. and C.J. Santhanam, *Sludge treatment*, in *Pollution engineering and technology*. 1981, Marcel Dekker.
2. Gregory, R. and G. Dillon, *Minimising Sludge Production at Water-Treatment Plants.* Water and Environment Journal, 2002. **16**(3): p. 174-179.
3. Simpson, A., P. Burgess, and S. Coleman, *The management of potable water treatment sludge: present situation in the UK.* Water and Environment Journal, 2002. **16**(4): p. 260-263.
4. Zhao, Y. and D. Bache, *Integrated effects of applied pressure, time, and polymer doses on alum sludge dewatering behaviour.* Waste Management, 2002. **22**(7): p. 813-819.
5. Jin, B., B.-M. Wilén, and P. Lant, *Impacts of morphological, physical and chemical properties of sludge flocs on dewaterability of activated sludge.* Chemical Engineering Journal, 2004. **98**(1-2): p. 115-126.
6. Chen, G., P. Lock Yue, and A.S. Mujumdar, *Sludge dewatering and drying.* Drying Technology, 2002. **20**(4-5): p. 883-916.
7. Visvanathan, C. and R.B. Aim, *Water, wastewater, and sludge filtration*. 1989: CRC Press.
8. Tony, M.A., et al., *Conditioning of aluminium-based water treatment sludge with Fenton's reagent: Effectiveness and optimising study to improve dewaterability.* Chemosphere, 2008. **72**(4): p. 673-677.
9. Lu, M.-C., et al., *Dewatering of activated sludge by Fenton's reagent.* Advances in Environmental Research, 2003. **7**(3): p. 667-670.
10. Ali, I. and V. Gupta, *Advances in water treatment by adsorption technology.* Nature protocols, 2006. **1**(6): p. 2661.
11. Bratby, J., *Coagulation and flocculation in water and wastewater treatment*. 2016: IWA publishing.

12. Deneux-Mustin, S., et al., *Ferric chloride and lime conditioning of activated sludges: an electron microscopic study on resin-embedded samples.* Water Research, 2001. **35**(12): p. 3018-3024.
13. Liang, J., et al., *A highly efficient conditioning process to improve sludge dewaterability by combining calcium hypochlorite oxidation, ferric coagulant re-flocculation, and walnut shell skeleton construction.* Chemical Engineering Journal, 2019. **361**: p. 1462-1478.
14. Abiola, O.N., *Polymers for Coagulation and Flocculation in Water Treatment*, in *Polymeric Materials for Clean Water*. 2019, Springer. p. 77-92.
15. Bolto, B. and J. Gregory, *Organic polyelectrolytes in water treatment.* Water research, 2007. **41**(11): p. 2301-2324.
16. Rinaudo, M., *Chitin and chitosan: properties and applications.* Progress in polymer science, 2006. **31**(7): p. 603-632.
17. Divakaran, R. and V.S. Pillai, *Flocculation of algae using chitosan.* Journal of Applied Phycology, 2002. **14**(5): p. 419-422.
18. Pontius, F.W., *Chitosan as a drinking water treatment coagulant.* American Journal of Civil Engineering, 2016. **4**(5): p. 205-215.
19. Rizzo, L., et al., *Coagulation/chlorination of surface water: A comparison between chitosan and metal salts.* Separation and Purification Technology, 2008. **62**(1): p. 79-85.
20. Neyens, E., J. Baeyens, and R. Dewil, *Advanced sludge treatment affects extracellular polymeric substances to improve activated sludge dewatering.* Journal of hazardous materials, 2004. **106**(2): p. 83-92.
21. Cai, M., et al., *Synergetic pretreatment of waste activated sludge by hydrodynamic cavitation combined with Fenton reaction for enhanced dewatering.* Ultrasonics sonochemistry, 2018. **42**: p. 609-618.
22. Mahdi, Y.S., A.H. Mohammed, and A.K. Mohammed, *Cellulose Fibers Dissolution in Alkaline Solution.* Al-Khwarizmi Engineering Journal, 2018. **14**(2): p. 107-115.
23. Koppenol, W.H., *The Haber-Weiss cycle–70 years later.* Redox Report, 2001. **6**(4): p. 229-234.
24. Waddell, J.P. and G.C. Mayer. *Effects of Fenton's reagent and potassium permanganate applications on indigenous subsurface microbiota: a literature review*. 2003. Georgia Institute of Technology.
25. Antoniadis, A., et al., *Development and evaluation of an alternative method for municipal wastewater treatment using homogeneous photocatalysis and constructed wetlands.* Catalysis Today, 2007. **124**(3-4): p. 260-265.
26. Vlyssides, A., H. Loukakis, and P. Karlis, *Small sewage treatment works using a Fenton oxidation method.* Environmental technology, 2003. **24**(8): p. 931-935.
27. Shihab, M., *Assessment of using chemical coagulants and effective microorganisms in sludge dewaterability process improvement.* Journal of Environmental Science and Technology, 2010. **3**(1): p. 35-46.
28. Hwa, T.J. and S. Jeyaseelan, *Comparison of lime and alum as oily sludge conditioners.* Water science and technology, 1997. **36**(12): p. 117-124.
29. Liu, H., et al., *Conditioning of sewage sludge by Fenton's reagent combined with skeleton builders.* Chemosphere, 2012. **88**(2): p. 235-239.
30. Liu, H., et al., *A comprehensive insight into the combined effects of Fenton's reagent and skeleton builders on sludge deep dewatering performance.* Journal of hazardous materials, 2013. **258**: p. 144-150.
31. El-Gohary, F., A. Tawfik, and U. Mahmoud, *Comparative study between chemical coagulation/precipitation (C/P) versus coagulation/dissolved air flotation (C/DAF) for pre-treatment of personal care products (PCPs) wastewater.* Desalination, 2010. **252**(1): p. 106-112.
32. Tony, M.A., et al., *Use of a fenton-like process based on nano-haematite to treat synthetic wastewater contaminated by phenol: Process investigation and statistical optimization.* Arabian Journal for Science and Engineering, 2018. **43**(5): p. 2227-2235.
33. Tony, M.A. and A.A. Tayeb, *Response Surface Regression Model in Optimization of Alum Sludge Drying Facility: Solar-Fenton's Reagent Dewatering.* International Journal of Chemical Engineering and Applications, 2016. **7**(5): p. 331.
34. Knocke, W.R., J.W. Nash, and C.W. Randall, *Conditioning and Dewatering of Anaerobically Digested BPR Sludge.* Journal

of Environmental Engineering, 1992. **118**(5): p. 642-656.

35. Liu, F., et al., *Enhancing sewage sludge dewaterability by bioleaching approach with comparison to other physical and chemical conditioning methods.* Journal of Environmental Sciences, 2012. **24**(8): p. 1403-1410.
36. Christensen, G.L. and D.A. Stulc, *Chemical reactions affecting filterability in iron-lime sludge conditioning.* Journal (Water Pollution Control Federation), 1979: p. 2499-2512.
37. Tony, M.A., et al., *Conditioning of aluminium-based water treatment sludge with Fenton's reagent: effectiveness and optimising study to improve dewaterability.* Chemosphere, 2008. **72**(4): p. 673-677.
38. Tony, M.A., P.J. Purcell, and Y. Zhao, *Oil refinery wastewater treatment using physicochemical, Fenton and Photo-Fenton oxidation processes.* Journal of Environmental Science and Health, Part A, 2012. **47**(3): p. 435-440.
39. Buyukkamaci, N., *Biological sludge conditioning by Fenton's reagent.* Process Biochemistry, 2004. **39**(11): p. 1503-1506.
40. Zhang, J., et al., *Study on the effect of chitosan conditioning on sludge dewatering.* Water Science and Technology, 2019. **79**(3): p. 501-509.
41. Hassan, M.A., T.P. Li, and Z.Z. Noor, *Coagulation and flocculation treatment of wastewater in textile industry using chitosan.* Journal of Chemical and Natural Resources Engineering, 2009. **4**(1): p. 43-53.
42. Shi, C., et al., *Synthesis, characterization, and sludge dewaterability evaluation of the chitosan-based flocculant ccpad.* Polymers, 2019. **11**(1): p. 95.