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Application of Chemical Coagulants and Biopolymers for Sewage Sludge Dewatering

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In this work, effects of chemical coagulants [$Fe_2(SO_4)_3$, $Al_2(SO_4)_3$, $FeCl_3$ and CaO] and biopolymers (chitin, carboxymethylcellulose (CMC) and chitosan) on sewage sludge dewatering were studied. According to the results, $Fe_2(SO_4)_3$ was the most suitable substance for dewatering of the returned activated sludge and $FeCl_3$ was found to be the best coagulant for the aerobic digested sludge. The results showed that sludge dewatering speed compared with control samples increased by about 77.6 and 80.5 %, respectively. Also, among natural polymers being used, chitin having the lowest consumption level in comparison with other coagulants increased the dewatering speed for the digested sludge by about 59.5 %. In this case, the sludge moisture content compared with that of the control decreased by 12.8 %. In all cases, chitosan had a negative effect on the dewatering speed and reducing the sludge moisture content. The effect of carboxymethylcellulose on decreasing the sludge time to filteration was also negligible.

Key Words: Sludge dewatering, Sludge conditioning, Chemical coagulant, Biopolymer.

INTRODUCTION

For lower exorbitant costs of investment and operating sludge treatment and stabilization installations, it is necessary to reduce the produced sludge volume at sewage treatment plants as much as possible and to do so, sludge thickening and dewatering method is used. Generally, sludge dewatering is considered as one of the most difficult environment engineering issues with regards to its disposal. Since modified sludge is easily thickened and dewatered, sludge conditioning operations at sewage treatment plants are of great importance. In fact, conditioning or modifying the sludge's chemical quality is a physico-chemical process that facilitates water removal and recovering sludge solids. In sludge treatment operations, this process is often done before sludge thickening and dewatering and leads to higher efficiency of these units[1,2].

The first objective of sludge conditioning is to increase particle size, overcoming hydration effects and repelling electric charges between particles. In other words, it

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causes dispersed and colloidal fine particles in the sludge to accumulate and their bonding water molecules to release.

In most cases, minerals and organic polyelectrolyte systems are used for sludge conditioning. Though thermal processes are applicable in this regard, their usage is not usually common. In a research, the effects of chitin, polyacrylamide and aluminum sulfate on chemical conditioning of emulsified sewages of a vegetable oil producing factory were studied[2]. The results showed that the time needed for sludge clarification when using aluminum sulfate was more than that of polyelectrolytes. However, the time was reduced by increasing $Al_2(SO_4)_3$ concentration. In another research[3] using sulfuric acid and surfactants for sludge dewatering by a centrifuge has been reported effective. In another study on sewage sludge conditioning, a combination of polymers with substances such as burned sludge ash, bagasse and cement soil was used[4] where sludge conditioning by using 37 % bagasse and 1.33 % polymer had the best result and the sludge solids content increased to 1260 %. It should be mentioned that sludge conditioning is a two staged process including coagulation and flocculation. During the coagulation stage, surface features of sludge particles change. Here, by applying pressure on the double electrical layer, electrostatic forces between particles decrease which leads to particles instability. Then, during the flocculation stage, unstable colloidal particles get closer to each other through stirring and form floccules. In this stage, if the flocculated is strained, floccules will curdle. Therefore, when water freely flows through porous flocculated particles, the sludge is conditioned and the flocculation process will be complete[5]. Moreover, inorganic salts and natural or synthetic organic polymers are among the common sludge conditioning chemicals with the former, being coagulants and supplementary coagulants which are often used before dewatering and by applying suction or press filters. Lime (CaO) and $FeCl_3$ are minerals mostly used for sewage sludge treatment. Of course, metallic salts such as $Fe_2(SO_4)_3$ and $Al_2(SO_4)_3$ are applicable in some cases as well[6,7]. Polyelectrolytes are the second group of compounds that are used for sludge conditioning and have a wide range of uses in water purification and sewage treatment. Recently, unlike chemical coagulants and due to decreasing the produced sludge's mass, feasibility of exploitation and maintenance of relevant installations, using these compounds in the said process has an ever-increasing trend. In fact, their significant effect in such processes has caused them to be used in all dewatering methods including sludge drying beds, suction filters, press filters and centrifuges. Sludge conditioning by polyelectrolytes is often carried out through one or more processes such as adsorption of the bonding water in sludge particles, neutralizing electric charges of the particles and accumulating fine particles by creating bridges among them and the end-result would be the formation of a sludge cake capable of releasing water[6,8].

Based on their constituents, polymers can be classified into two categories: synthetic and natural. It is interesting to know that walnut and almond shells along with bean pods were the first coagulants used for filtering the drinking water. Among other natural coagulants, starch and its derivatives, resins, algae and cellulose/protein derivatives can be mentioned as well[9]. On the other hand, polyacrylamide is one of the synthetic polymers which are used for water purification. This linear homopolymer is made from acrylic monomers including acrylic acid, metacrylic, esters along with the equivalent amides and nitriles. This polymer is used as a thickening and flocculating agent in water purification[10].

In the present research, effects of some biopolymers on sludge dewatering by a vacuum filter has been studied and then their efficiency is compared with those of chemical coagulants.

EXPERIMENTAL

In this study, a number of chemical coagulants such as $Fe_2(SO_4)_3$, $FeCl_3$, $Al_2(SO_4)_3$ (alum) and CaO along with biopolymers such as chitin, chitosan and carboxymethylcellulose (CMC) were used. It is noteworthy that chitosan and CMC were chosen from an industrial type while other coagulants were all of the pure (laboratory) type (Merck or Fluka). The test sludge was provided on a daily basis, by the sewage treatment plant in Pirbazar town in Rasht. Tests were done on two different sludge samples including the sludge returned to aeration tank (surplus activated sludge) and the sludge coming out of an aerobic digestion tank. During the test period, aerobic digested sludge's pH was almost neutral and the returned activated sludge had a very poor acidic property (pH 6.7). Also, the total solids (TS) concentration for the returned activated sludge and aerobic digested sludge was measured to be 0.5 and 0.9 %, respectively. The proportion of volatile solids (VS) to the total solids of the returned activated and digested sludges was 44 and 28 %, respectively.

Detection method: In this research, a device for measuring the sludge time to filtration (TTF), which according to the method mentioned in reference[11] was made in a laboratory, was used. A view of the device is illustrated in Fig. 1. A digital pH meter (Metrohm Co.) for measuring pH values and an electronic balance (Sartorius, Germany) with a precision of 0.0001 g, was used for weighing chemicals and filter papers (MN Co., Germany) were used for measuring solids.

General procedure: Among the most common factors involved in determining the sludge filtration speed, specific resistance to filtration (SRF), capillary suction time (CST) and time to filtration (TTF) can be mentioned[12-14].

To assess the sludge dewatering ability, the TTF measuring method was used. Therefore, at first, sludge samples (100 mL) were poured in beakers. Then, by using sodium hydroxide and sulfuric acid solution, their pH was set at a 4-9 range. Next, a constant concentration of chemical coagulants and natural polymers was added to them after which they were quickly mixed. Then samples were transferred to Buchner funnel. By creating vacuum (100 torr) inside the TTF measuring device they were filtered. In all samples, the TTF for 50 mL of liquid was measured and

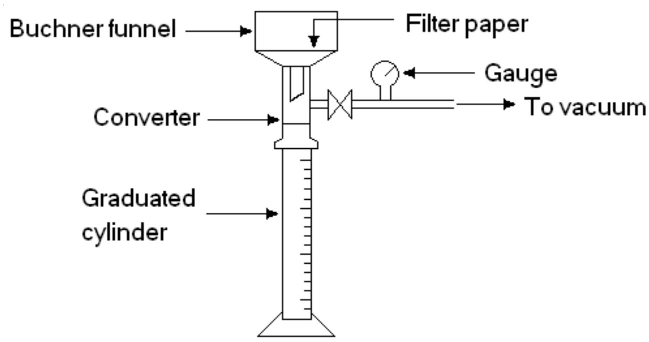

Fig. 1. General view of the device used for determining the sludge time to filtration

thus, the optimum pH was determined (the shorter the time to filtration, the more the sludge dewatering ability). To determine the most suitable consumption level of coagulants, sludge samples were prepared at a constant pH (optimum pH). Then, different amounts of coagulants were added to them with the previous stages repeated. In this stage, the shortest TTF was that of the sample containing on optimum coagulant concentration.

In this stage, all samples were filtered for a constant time of 2 min. Then, the sludge cake, formed on the filter paper was carefully weighed. After that, until complete drying, samples were put in an oven and when dried, the cake's weight was once again recorded. Finally, having both wet and dry cake weights, its moisture content was calculated by the following equation:

$$W_c = \frac{(W_1 - W_2)}{W_1} \times 100$$

(1) where W_1 = wet filtered cake's weight, W_2 = filtered cake's weight after drying at 105 °C for 2.5 h and W_c = sludge cake's moisture content. All tests were done based on the methods as mentioned[11].

RESULTS AND DISCUSSION

Nowadays estimating the time to filtration (TTF), capillary suction time (CST) and specific resistance to filtration (SRF) methods are widely used for assessing the sludge dewatering ability. Of course, these methods only measure the sludge filtration ability and do not give any information on the dewatered sludge's moisture content (part of the water in a sludge floccule is in the from of water bonding which is not easily extracted by mechanical techniques). In other words, the sludge might be easily filtered, but with so much water left in the dewatered sludge[3]. This is the reason that TTF and the remained moisture in the sludge cake were simultaneously used for measuring the sludge dewatering ability. Coagulants which were used here are divided into two groups *i.e.*, minerals and polymers. The former group consisted of alum $Al_2(SO_4)_3$, $Fe_2(SO_4)_3$, $FeCl_3$ and CaO and chitin, carboxy-methylcellulose (CMC) and chitosan. Based on the performed tests, the following results were obtained:

• Among chemical coagulants, $Fe_2(SO_4)_3$ had the highest efficiency in dewatering the returned activated sludge. As it can be seen in Fig. 2, at pH 6 and the optimum concentration (1000 ppm), it increased the activated sludge's dewatering speed by about 77.6 %. According to Fig. 3, in such a case, the resulting sludge cake with 72.5 % moisture content, was 12.7 % drier than the control sample.

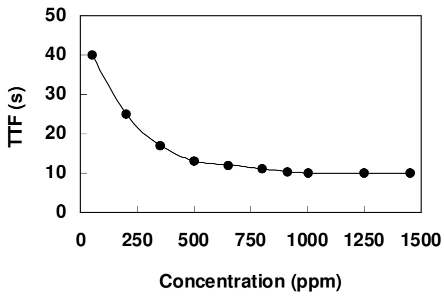

Fig. 2. Effect of $Fe_2(SO_4)_3$ concentration on the sludge TTF at pH 6

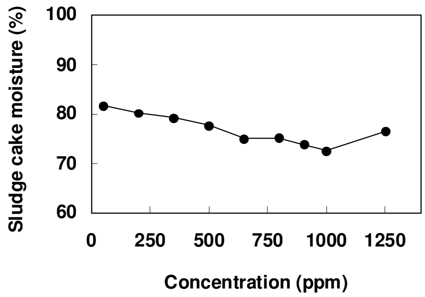

Fig. 3. Effect of $Fe_2(SO_4)_3$ concentration on the sludge cake moisture content

• As observed in Fig. 4, $FeCl_3$ with an optimum concentration of 1250 ppm at pH 5 and by taking the shortest TTF, increased the dewatering speed for aerobic digested sludge by 80.5 %. According to Fig. 5, in this case too, the sludge cake's moisture content was 76 %, being 16.2 % less than that of the sample without the coagulant.

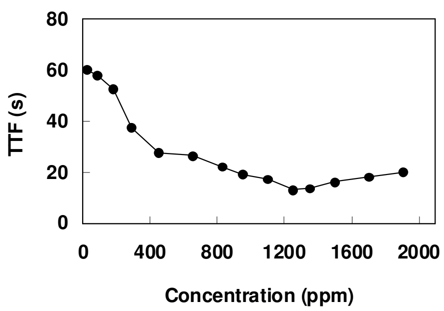

Fig. 4. Effect of $FeCl_3$ concentration on the sludge TTF at pH 5

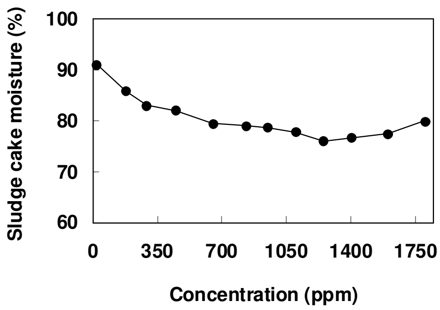

Fig. 5. Effect of $FeCl_3$ concentration on the sludge cake moisture content

• Among natural coagulants, chitin had a very considerable effect on increasing the sludge dehydration ability. This substance, having the lowest consumption level compared with other coagulants (10 ppm for aerobic digested sludge and 50 ppm for the returned activated sludge) increased the sludge dewatering speed by about

59.5 % at pH = 6 (Fig. 6). According to Fig. 7, when using chitin, the cakes resulted from aerobic digested and returned activated sludges were about 12.8 and 10.6 % drier than that of the control sample, respectively.

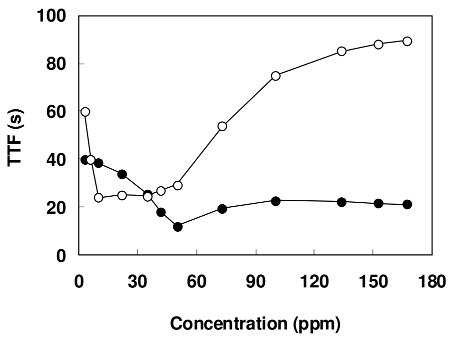

Fig. 6. Effect of chitin concentration on the sludge TTF at pH 6, (O) digested sludge, (●) activated sludge.

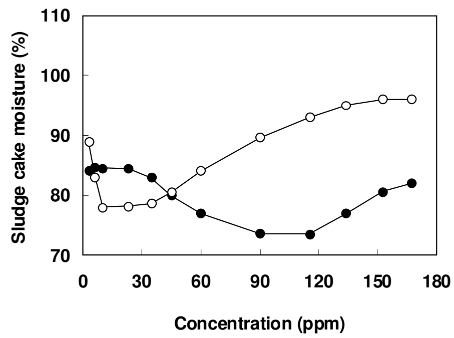

Fig. 7. Effect of chitin concentration on the sludge cake moisture content, (O) digested sludge, (●) activated sludge

• The results showed that the effect of CMC on reducing the sludge TTF was almost negligible. In fact, its 75 ppm concentration at the optimum pH (pH 7) decreased the TTF for activated and aerobic digested sludges by about 5.2 and 9.5 %, respectively. In this case, the moisture content of the aerobic digested sludge cake was estimated almost 1 % less than that of the control sample. In case of the returned activated sludge too, the sample without CMC was drier. Thus, its positive effect on the activated sludge's dewatering speed could be overlooked.

• Chitosan too, almost in all cases, had a negative effect on the TTF and sludge dewatering compared with the control sample. For this reason, the relevant information have not been given. A summary of the test results is presented in Table-1.

TABLE-1
SUMMARY OF TEST RESULTS AT THE OPTIMUM POINT

Coagulants	Consumption level (ppm)		Optimum pH		TTF (s)		Sludge cake moisture decrease compared with the control sample (%)	
	Returned activated sludge	Aerobic digested sludge	Returned activated sludge	Aerobic digested sludge	Returned activated sludge	Aerobic digested sludge	Returned activated sludge	Aerobic digested sludge
$Fe_2(SO_4)_3$	1000	1050-1200	6	6	9	16	12.7	15.9
$Al_2(SO_4)_3$	300-400	700	4.5	5.5	23	26	5.4	15.1
$FeCl_3$	500	1250	5	5	12	12	11.3	16.2
CaO	6000	15000	5	5	22	44	12	6.2
Chitin	50-75	10	6.5	6	16	22	10.6	12.8
CMC	75	75	7	7	40	56	-3	1.1

Conclusion

The tests that were done in this research gave results, the summary of which are as follows: (i) Studies showed that almost in all cases, there was a direct relationship between sludge samples TTF and the moisture of the resulted cake. (In other words, while using each coagulant at the optimum point, minimum sludge cake moisture content was observed at the minimum TTF). Therefore, the best used coagulant was a substance that could increase the speed at which water was removed from the conditioned sludge and reduce the moisture content of the cake resulted from applying different dewatering methods. (ii) In general, adding chemical coagulants significantly increased the sludge dewatering speed. (iii) Among chemical coagulants, $Fe_2(SO_4)_3$ had the highest efficiency in the returned activated sludge dewatering. At the optimum concentration (1000 ppm), it increased the activated sludge's dewatering speed by about 77.6 %. Also, the resulted cake having 72.5 % moisture was 12.7 % drier than that of the control sample. (iv) For aerobic digested sludge, a 1250 ppm concentration of $FeCl_3$, taking the shortest time to filtration, increased the dehydration ability by 80.5 %. In such a case, the sludge cake moisture content was about 76.3 % *i.e.*, 16.2 % less than that of the control sample. (v) Among natural coagulants, chitin had a considerable effect on increasing sludge dehydration ability. Having the lowest consumption level in comparison with other coagulants, it increased the sludge dewatering speed by about 59.5 %. In this case, the cakes resulted from filtering aerobic digested and returned activated sludges were about 12.8 and 10.6 % drier than those of the control samples, respectively. (vi) The effect of CMC (carboxymethylcellulose) on decreasing the sludge TTF was negligible. In fact, it reduced the TTF for activated and aerobic digested sludges by about 5.2 and 9.5 %, respectively. In this case, the digested sludge cake's moisture content was 1 % less than that of the control sample. Moreover, for the returned activated sludge, the sample without CMC was drier than others. Thus, its positive effect on increasing the activated sludge's dewatering speed could be overlooked. (vii) Almost in all cases, chitosan had a negative effect on the dewatering speed and reducing the sludge moisture content. (viii) Since in most of Iran's treatment plants, drying beds are used for sludge dewatering, adding coagulant, especially during the rainy season is suggested for accelerating the sludge drying process. In such cases, using $Fe_2(SO_4)_3$ for returned activated sludge and $FeCl_3$ for aerobic digested sludge could be effective. (ix) With the significant efficiency of chitin in reducing the sludge cake moisture content taken into account and its very low consumption level compared with other coagulants, using this polymer is justifiable as well.

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