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Cost Effective Liquid Poly-Aluminium Chloride (PAC) Used as a Coagulant Agent for Treatment and Recycling Industrial Waste Water

Md. Rajiur Rahaman[1], Sharmin Sultana Dipti[1], Mohammad Mahfuz Enam Elahi[2], Md. Anwarul Karim[1]*

[1]Department of Applied Chemistry and Chemical Engineering, University of Rajshahi, Rajshahi 6205, Bangladesh.

[2]Department of Pharmacy, University of Asia Pacific, Dhaka, Bangladesh.

Abstract

This study was done by using three basic coagulating agents for solid-liquid separation processes to reuse the industrial waste water and reduce an effective amount of chemical consumption as well as cost for treatment of textiles/ceramics industries waste water. The experiment was conducted using jar tester to determine the optimum doses of Poly Aluminum Chloride, Alum and Lime for treatment of industrial waste water. The three basic concentration was used in this investigation which were 1% liquid Poly Aluminum Chloride (PAC), 2 % Potassium Aluminum Sulfate (Alum), 4% Calcium Hydroxide (Lime). Here 0.05% Polyacrylamide was added with each chemical dose as coagulant. These three coagulating substances were used successfully to make the waste water reusable. The turbidity, color hazen and Total Suspended Solid (TSS) was reduced up to 90%, 91% and 99.5% respectively. Among those chemicals only 1% liquid Poly Aluminum Chloride dosing was more effective both in physic-chemical and economic suspects for removing significant amount of turbidity, color hazen and TSS. On the other hand, this chemical consumption was lower than that of others. This investigation suggests that using 1% liquid Poly Aluminum Chloride (PAC) coagulation agent is cost effective chemical treatment process which may be useful in primary water treatment process for the industrial waste water.

Keywords— Poly-aluminium chloride, coagulant agent, flocculation agent, recycling, cost, waste water.

1. Introduction

Water treatment is a process of making water suitable for its application or returning its natural state. Water treatment involves science, engineering, business and art. The treatment may include mechanical, physical, biological and chemical methods. All water treatments involve the removal of solids, bacteria, algae, plants, inorganic compounds and organic compounds. Removal of solids is usually done by filtration and sediment. Bacteria digestion is an important process to remove harmful pollutants. Waste water treatment is a process used to remove contaminants from waste water and convert it into acceptable water with no bad impact on the environment, or that can be recycled or reused for various purposes [1]. About 97% of the water stored in the ocean is salt water. Only 3% of the world's water supply is a fresh water where two-third out of the 3% of that water is frozen, forming the polar ice caps and icebergs [2]. So almost two-thirds of the surface of the planet is covered with water, but only 2.5% of this water is fresh water and just 0.3% is fit for human consumption[3]. According to global research, a large number of people at their early ages die from water borne diseases in most of the developing countries. Thus, it is very important to get the proper treatment of the water for a healthy living. Water treatment can be very helpful for the society today because it is saving the lives of many innocent human beings who die from fatal diseases such as cholera, typhoid which cause by consuming contaminated water [4]. Many industries discharged their waste water with significant levels of toxic metals such as lead, mercury, cadmium and chromium, arsenic, selenium and nitrogen compounds (nitrates and nitrites)including flue-gas desulfurization, ash, bottom and flue gas mercury. Industrial plants waste water with air pollution are controlling by wet scrubbers typically transfer that captured the pollutants and discharged it into the waste water stream [5]. They also used ash ponds; ash pond is a type of surface impoundment which are a widely used treatment technology at coal-fired plants. These ponds are using the gravity to settle out large particulates (measured as total suspended solids) from power plant waste water [6-7]. Technological advancements in ion exchange membranes and electrodialysis systems has enabled high efficiency treatment of flue-gas desulfurization waste water to meet recent Environmental Protection Agency (EPA) discharge limits [8]. Textile dyeing plants generate waste water that contain synthetic dyes (e.g., reactive dyes, acid dyes, basic dyes, disperse dyes, vat dyes, sulphur dyes, mordant dyes, direct dyes, ingrain dyes, solvent dyes, pigment dyes) [9] and natural dyestuff, gum thickener (guar) as well as various wetting agents, pH buffers, dye retardants or accelerators. These types of industries are following treatment process with polymer-based flocculants and settling agents, with typical monitoring parameters include BOD, COD, color (ADMI), sulfide, oil and grease, phenol, TSS and heavy metals (chromium, zinc, lead, copper). According to the IUPAC definition, flocculation is "a process of contact and adhesion whereby the particles of a dispersion form larger-size clusters". Flocculation is synonymous with agglomeration and coagulation / coalescence [10-13]. Basically, coagulation is a process of addition of coagulant to destabilize a stabilized charged particle. Meanwhile, flocculation is a mixing technique that promotes agglomeration and assists in the settling of particles. The most common used coagulant is alum, $Al_2(SO_4)_3\cdot14H_2O$ [14]. The choice of coagulant chemical depends upon the type of suspended solid to be removed, raw water conditions, facility design and cost of chemical. Final selection of coagulant (or coagulants) should be made with jar testing and plant scale evaluation as well as consideration must be given to required effluent quality, effect upon downstream treatment process performance, cost, method and cost of sludge handling,disposal, cost of the dose required for effective treatment. Inorganic coagulants may alter the pH of the water, since they consume alkalinity. Lime is used to remove chemicals that cause carbonate hardness. Soda ash is used to remove chemicals that cause non-carbonate hardness. When lime and soda ash are added, hardness-causing minerals form nearly insoluble precipitates. They also require corrosion-resistant storage and feed equipment. It is important to note that large volumes of settled flock must be disposed in an environmentally acceptable manner. These different coagulants are mainly used: $FeSO_4$ (Iron (II) sulfate), $Al_2 (SO_4)_3$ (Aluminium sulfate), $FeCl_3$ (Iron (III) chloride), $[Al_2(OH)nCl_6\text{-}n]m$ ($1 \le n \le 5$, $m \le 10$) (Poly Aluminum Chloride (PAC)) [15]. In the recent days in waste water treatment those chemicals are randomly being used for better water quality by the industries. And some industries are discharging the waste water in the environment without treatment because of high treatment cost. They think, it is better for them to use ground water rather than recycling the waste water by high treatment cost and large duration of time for treatment process.

The main objective of this research is to find a better chemical for waste water treatment, with optimized concentration of the chemicals which will be cost effective, short time duration for treatment process and simple inoperation. Another concern of this research is to determine the optimum volume of that chemical which will be consumed for treating a definite amount of industrial waste water. Because when both the optimum concentration and optimum volume are found, then the optimum cost can be easily calculated to analysis cost effectiveness.

2. Materials and methods

2.1. Materials

Liquid and powder poly aluminum chloride (PAC, Henan Yuanbo), Polyacrylamide (BASF), Decolorant (Blu-Wat, China), Hydrochloric Acid (37%, E. Merck, Germany), Alum (Potassium Aluminum Sulfate, E. Merck, Germany), Calcium Hydroxide (95%, E. Merck, Germany), Al (OH)3 Bauxite (E. Merck, Germany), Sodium Hydroxide (E. Merck, Mumbai), Isopropyle alcohol (E. Merck, Germany) were brought from reported company and used as it was.

2.1.1. Preparation of 100 mL Poly Alumino Chloride solution (0.5 % w/v)

To prepare 0.5 % Poly Alumino Chloride solution about 1.80g of solid PolyAlumino Chloride powder (28%) was weighed out and was transferred to a 100 mL volumetric flask. Dissolved with 30mL distilled water. The flask was shaken for a while so that all the taken solute dissolved into water. Then the flask was made up to the marked with the same distilled water. Similarly, 1% (w/v), 2% (w/v), 4% (w/v) solution were made. We also made Polyacrylamide, Lime solution and Alum solutions at 0.5% (w/v), 1% (w/v), 2% (w/v), 4% (w/v). And De-color solution were made at 5%(w/v) and 10% (w/v) [16-21].

2.1.1.1. Preparation of 100 mL Poly Alumino Chloride solution (0.5% v/v)

To prepare 0.5 % PolyAlumino Chloride solution about 4.2 mL of liquid PolyAlumino Chloride (12%) was measured by a 5 mL graduated pipette and transferred to a 100 mL volumetric flask. Then it was diluted with 30 mL distilled water. The flask was shaken for a while so that all the taken solution were mixed and diluted properly into water. Then the flask was made up to the marked with the same distilled water. Similarly, 1% (v/v), 2% (v/v), 4% (v/v) solution were made [16-21]. We also made 2.0 N Sodium Hydroxide and 2.0 N Hydrochloric Acid.

The Hazen color test uses a Pt/Co solution and was developed for water treatment facilities where the color of water could be used as a measure of concentration of dissolved and particulate material. Slight discoloration is measured in Hazen units (HU).

2.2. Methods

Jar testing is a method of simulating a full-scale water treatment process [22-23]. Specifically, the initial coagulation process that helps remove suspended solids from water. For each sample, several beakers (Jars) are filled with the sample water. Chemical agents (flocculation agents) are then added in different doses and the stirrer continuously. After the stirring process is complete, the amount and quality of floc is compared in each jar to see which results are better. Other parameters such as mixing rate, aeration level, time, filtration type, etc. data are also collected for each jar to see how they affect coagulation process. In a summery, jar testing is set up as a pilot-scale testing process for chemicals treatment of waste water for a particular water plant. It is a simulating the coagulation/flocculation process in a water treatment plant and helps to determine the right amount of treatment chemicals and thus improve the plants performance.

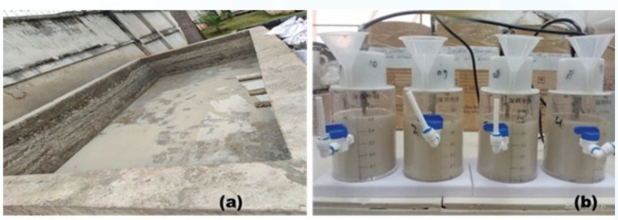


Fig.1:(a) Source of waste water Effluent Treatment Plant (ETP), (b) Jar Testing of samples

We collected the waste water sample from different industries. Preparing four different solutions of gradually increasing concentrations of the respective chemicals which were responsible for treating the waste water. Applying those chemicals into the jar testing unit (where the waste water was placed in four jars for small scale treatment), it gradually increasesthe volume. Here, it this jar testing, we observed the sludge forming duration as well as sludge precipitating duration.The treated water was collected from the respective jars and compared the water quality before and after treatment. Similarly, we conducted several jar testing procedures to optimize the condition of chemicals used in this process. When the operational conditions were optimized then calculation the cost of chemicals used to optimize the treatment process.

Turbidity Meter (Metler Toledo, Switzerland) are used to quickly measure the turbidity (or cloudiness) of water, caused by suspended solid particles. pH Meter (Metler Toledo, S20, Switzerland) was used to measure hydrogen-ion activity (acidity or alkalinity) in solution.

3. Results and discussions

We collected four samples of waste water from four different industries. We kept pH constant and then treated the samples with 0.5 % Poly Alumino Chloride, 1.0 % Poly Alumino Chloride, 2% Poly Alumino Chloride and 4% Poly Alumino Chloride in Jar tester with continuous stirring and the Poly Alumino Chloride/Alum/Lime was added slowly to the jar tester. Figure 2 (a) is showing different turbidity and color hazen of treated water sample which were treated respectively by 2,3,4,5 mL of 0.5 % Poly Alumino Chloride.

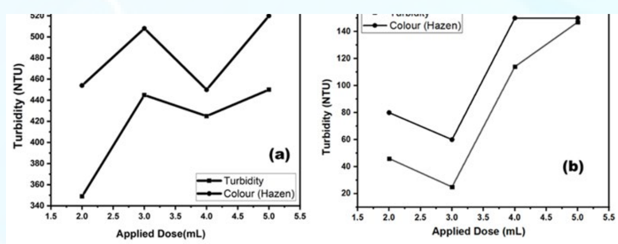


Fig. 2: Turbidity vs Applied dose (a) Treatment by 0.5 % Poly Alumino Chloride, (b) Treatment by 1.0 % Poly Alumino Chloride

Figure 2(b) it can be observed that, there was no remarkable changes found in water quality, though different increasing volume was repeatedly applied. From the above experiment, it was indicated that, the applied concentration was not appropriate for executing the treatment. It was lower than the optimum chemical concentration and it was insufficient for making the flocks successfully.

Table1: Represents the parameters such as pH, turbidity and color hazen of treated water which was treated by different concentrations of Poly Alumino Chloride

Coagulant agent composition	Sample ID	Applied Dose (mL)	Results		
			pH	Turbidity (NTU)	Color (Hazen)
Treatment by 0.5 % Poly Alumino Chloride	Sample-01	2	6.0	330	350
	Sample-02	3	6.0	455	500
	Sample-03	4	6.0	411	400
	Sample-04	5	6.0	388	430
Treatment by 1.0 % Poly Alumino Chloride	Sample-01	2	6.0	46	80
	Sample-02	3	6.0	25	60
	Sample-03	4	6.0	114	150
	Sample-04	5	6.0	147	150
Treatment by 2.0 % Poly Alumino Chloride	Sample-01	1	6.5	349	450
	Sample-02	2	6.5	415	500
Treatment by 4.0 % Poly Alumino Chloride	Sample-01	0.5	6.5	430	400
	Sample-02	1	6.5	522	450

From table-1 it can be observed that, treatment by 1.0 % Poly Alumino Chloride (PAC) was better than others. It is seen that, the turbidity and color hazen was reduced effectively. By the comparison between the waste water and treated water, which was treated by 2,3,4,5 mL of 1.0 % PAC respectively. From the table 1, using 1.0 % PAC 3 mL having good results. It took minimum time length to make the flocks. But when the applied chemical volume was increased then the water quality parameters also begun to rise. Therefore, we may say that the treatment was suitable at 1% PAC 3 mL volume compared to 2.0 % Poly Alumino Chloride (PAC) and 4.0 % Poly Alumino Chloride in different volume.

Table 2: Summary of pH, turbidity and color hazen of treated water which was treated by different concentrations of Alum

Coagulant agent composition	Sample ID	Applied Dose (mL)	Results		
			pH	Turbidity (NTU)	Color (Hazen)
Treatment by 0.5 % Alum	Sample-01	2	6.5	251	353
	Sample-02	3	6.5	258	329
	Sample-03	4	6.5	228	327
	Sample-04	5	6.5	238	348
Treatment by 1.0 % Alum	Sample-01	2	6.5	241	343
	Sample-02	3	6.5	248	319
	Sample-03	4	6.5	218	317
	Sample-04	5	6.5	218	328
Treatment by 2.0 % Alum	Sample-01	2	6.5	193	290
	Sample-02	3	6.5	189	275
	Sample-03	4	6.5	55	92
	Sample-04	5	6.5	75	105
Treatment by 4.0 % Alum	Sample-01	0.5	6.5	98	211
	Sample-02	1	6.5	102	232

From the above experiment, it was indicated that, the applied concentration 2.0 % and 4% was higher than the chemical concentration 1.0% 3 mL, which was required for that treatment. The 2.0% PAC didn't show effective result because, it was making more fine and lighter flocks for its higher concentration which made the water turbid again. And it took long time to settle down the flocks by gravitational force as well as for their lighter weight.

Table-1 is showing different turbidity and color hazen of treated water sample, which were treated respectively by 0.5, 1 mL of 4.0 % Poly Alumino Chloride (PAC). It can be observed that, there was no changes found in water quality. The parameters were increasing with increasing volume of PAC. From the above experiment, it was indicated that, the applied higher 4.0% concentration PAC didn't show effective treatment result.Because, it was making more fine and lighter flocks due to its higher concentration which was making the water turbid again like the previous experiments.

Table 3: Represents the parameters, pH, turbidity and color hazen of treated water which was treated by different concentrations of Lime

Coagulant agent composition	**Sample ID**	**Applied Dose (mL)**	**Results**		
			pH	**Turbidity** (NTU)	**Color** (Hazen)
Treatment by 0.5 % Lime	Sample-01	2	6.0	470	533
	Sample-02	3	6.0	468	508
	Sample-03	4	6.0	471	550
	Sample-04	5	6.0	459	531
Treatment by 1.0 % Lime	Sample-01	2	6.0	476	538
	Sample-02	3	6.0	460	510
	Sample-03	4	6.0	465	551
	Sample-04	5	6.0	450	529
Treatment by 2.0 % Lime	Sample-01	2	6.0	421	451
	Sample-02	3	6.0	411	490
	Sample-03	4	6.0	163	310
	Sample-04	5	6.0	124	260
Treatment by 4.0 % Lime	Sample-01	2	6.5	197	374
	Sample-02	3	6.5	123	292
	Sample-03	4	6.0	55	93
	Sample-04	5	6.0	72	133

Table 4: Represents the parameters, pH, turbidity and color hazen of treated water which was treated by different concentrations solution of Poly Alumino Chloride

Coagulant agent composition	Sample ID	Applied Dose (mL)	Results		
			pH	Turbidity (NTU)	Color (Hazen)
Treatment by 0.5 % Poly Alumino Chloride	Sample-01	2	6.0-7.0	258	350
	Sample-02	3	6.0-7.0	263	333
	Sample-03	4	6.0-7.0	228	315
	Sample-04	5	6.0-7.0	210	290
Treatment by 1.0 % Poly Alumino Chloride	Sample-01	2	6.0-7.0	96	180
	Sample-02	3	6.0-7.0	75	142
	Sample-03	4	6.0-7.0	35	60
	Sample-04	5	6.0-7.0	247	390
Treatment by 2.0 % Poly Alumino Chloride	Sample-01	1	6.0-7.0	179	330
	Sample-02	2	6.0-7.0	215	390
Treatment by 4.0 % Poly Alumino Chloride	Sample-01	0.5	6.0-7.0	220	335
	Sample-02	1	6.0-7.0	242	366

Similarly, we studied with Alum and Lime to treat the industrials waste water with different % concentration. From table-2 it can be observed that, treatment by 2 % Alum was better than others concentration. Because it was observed that the turbidity and color hazen was reduced significantly and from the table -3, it can be observed that, treatment by 4 % Lime was better than others concentration. Because it was clearly observed that, the turbidity and color hezen was reduced effectively.

Table 4 represents the parameters, pH, turbidity and color hazen of treated water which was treated by different concentrations of Poly Alumino Chloride solution. It was clearly observed that, treatment by 1 % Poly Alumino Chloride (PAC) was better than others. Because it was clearly observed that the turbidity and color hazen was reduced effectively. The comparison between the waste water and treated water, which was treated respectively by 2,3,4,5 mL of 1% PAC. And 1% PAC solution took minimum time length to make the flocks. From table-5, it can be observed that, treatment by 2 % Alum was better than others concentration.

Table 5: Represents the parameters, pH, turbidity and color hazen of treated water which was treated by different concentrations solution of Alum.

Coagulant agent composition	**Sample ID**	**Applied Dose (mL)**	**Results**		
			pH	**Turbidity** (NTU)	**Color** (Hazen)
Treatment by 0.5 % Alum	Sample-01	2	6.5	251	353
	Sample-02	3	6.5	258	329
	Sample-03	4	6.5	228	327
	Sample-04	5	6.5	238	348
Treatment by 1.0 % Alum	Sample-01	2	6.5	241	343
	Sample-02	3	6.5	248	319
	Sample-03	4	6.5	218	317
	Sample-04	5	6.5	218	328
Treatment by 2.0 % Alum	Sample-01	2	6.5	193	290
	Sample-02	3	6.5	189	275
	Sample-03	4	6.5	55	92
	Sample-04	5	6.5	75	105
Treatment by 4.0 % Alum	Sample-01	0.5	6.5	98	211
	Sample-02	1	6.5	102	232

Because it was seen that the turbidity and the color hazen was reduced effectively. The 2% alum concentration was higher than that of PAC solution. And optimum 2% Alum volume was 4 mL and it took minimum time length to make the flocks. The 0.5 %, 1 % Alum didn't work because it was insufficient for making the flocks successfully. They could not make any change in physical condition of the taken waste water. On the other hand, 4% alum didn't show effective result because it was making more fine and lighter flocks for its higher concentration.

Coagulant agent composition	Sample ID	Applied Dose (mL)	Results		
			pH	Turbidity (NTU)	Color (Hazen)
Treatment by 0.5 % Lime	Sample-01	2	6.8	246	325
	Sample-02	3	6.8	252	343
	Sample-03	4	6.8	235	332
	Sample-04	5	6.8	231	350
Treatment by 1.0 % Lime	Sample-01	2	6.8	233	341
	Sample-02	3	6.8	242	316
	Sample-03	4	6.8	221	311
	Sample-04	5	6.8	225	326
Treatment by 2.0 % Lime	Sample-01	2	6.8	224	331
	Sample-02	3	6.8	232	306
	Sample-03	4	6.8	211	301
	Sample-04	5	6.8	197	295
Treatment by 4.0 % Lime	Sample-01	2	6.8	117	274
	Sample-02	3	6.8	112	252
	Sample-03	4	6.8	62	123
	Sample-04	5	6.8	50	96

Table 6: The pH, turbidity and color hazen properties of treated water which was treated by different concentrations solution of Lime

Table-6 showing the pH, turbidity and color properties of treated water, which was treated by 2,3,4,5 mL of 4% Lime respectively. And optimum 4% Lime volume (5mL) was taking minimum time length to make the flocks. The 0.5 %, 1 %, 2% Lime didn't work because it was insufficient for making the flocks successfully which was remained the waste water like previous condition.

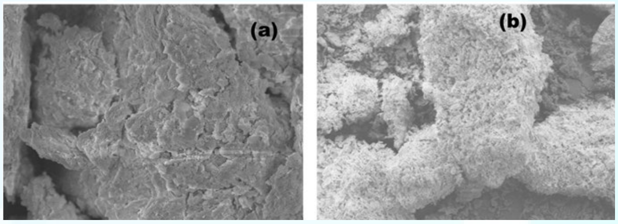


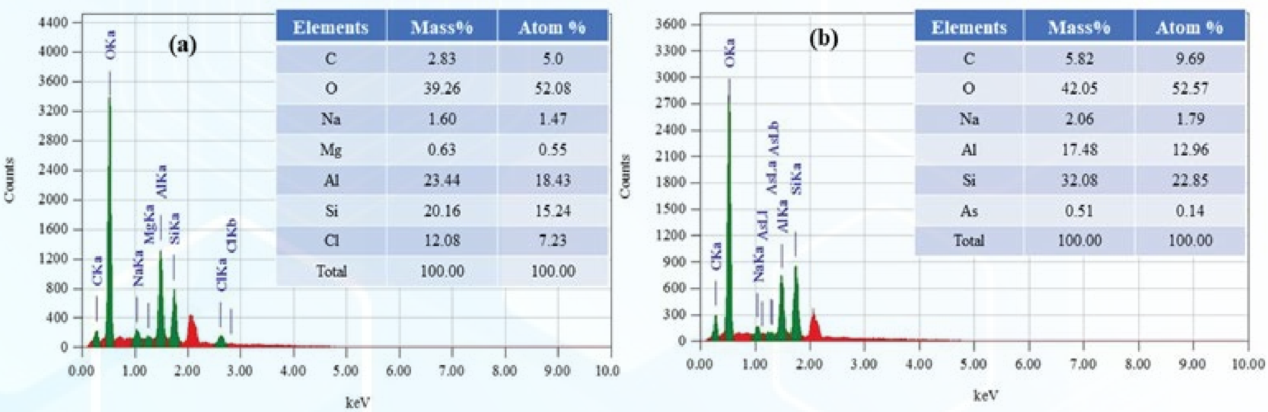
Fig.3: SEM image to observe surface morphology of Poly Alumino Chloride (a) raw and (b) after treatment with waste water.

Fig. 4: The turbidity during test in Jar tester (a) with waste water and (b) after treatment.

Figure 3 is showing the surface morphology of Poly Alumino Chloride raw and the surface after absorbed or treatment of waste water. The surface of the raw Poly Alumino Chloride was very dry and rough. But the surface of Poly Alumino Chloride after treatment waste water become swell like white flower shape, which indicate the better absorption. Since liquid Poly Alumino Chloride having better performance therefore, we didn't investigate other agents SEM images.

Figure 4 (a) showing the turbidity of waste water and figure 4 (b) representing the treated water turbidity. The treated water was clearer than the untreated waste water. This is also indicted the successful coagulation with liquid Poly Alumino Chloride.

The figure 5 was representing the EDX spectrum of raw Poly Alumino Chloride and the Poly Alumino Chloride after treating waste water by coagulation process. In figure 5(b), the element Mg and Cl was totally removed compare to 5 (a) as shown in spectrum and inset table. The treatment process was also removed arsenic and sodium as well as silicon mass value were increases as shown in figure 5(b) inset table in spectrum. The oxygen mass value increased meant that the settling was successful. Since liquid Poly Alumino Chloride having better performance therefore, we didn't investigate other agents EDX spectrums.



Elements	Mass%	Atom %
C	2.83	5.0
O	39.26	52.08
Na	1.60	1.47
Mg	0.63	0.55
Al	23.44	18.43
Si	20.16	15.24
Cl	12.08	7.23
Total	100.00	100.00

Elements	Mass%	Atom %
C	5.82	9.69
O	42.05	52.57
Na	2.06	1.79
Al	17.48	12.96
Si	32.08	22.85
As	0.51	0.14
Total	100.00	100.00

Fig. 5: EDX spectrum of Poly Alumino Chloride raw (a) and (b) after treatment.

3.1. Cost Analysis

Running market price of these following chemicals:
(Industrial Grade)
Liquid PAC = 50 L, around 850 BDT
Alum raw = 50kg bag, around 570 BDT
Lime raw = 50kg bag, around 400 BDT
But the cost of these following chemicals, which were consumed for treating 1 L waste water:
(Industrial Grade)

- Liquid PAC = 0.5mL, tk 0.0085 tk/ L
- Alum raw = 200mg, tk 2.28 tk/L
- Lime raw = 337mg, tk 2.69 tk/L

4. Conclusion

In this research Poly Alumino chloride, Alum and Lime were used as flocculants. The consumption of Poly Alumino chloride was remark lower than Alum and Lime for better treatment of waste water. That also made a lower chemical cost than others. Industrial people nowadays using solid Poly Alumino chloride (28-30%) as flocculant. But according to this study, the use of Liquid Poly Alumino Chloride (12%) is quite enough to treat the waste water effectively with low chemical consumption and low cost. The use of Liquid Poly Alumino Chloride (12%) can be beneficiary for both the manufacturers and the consumers. In cost analysis it has shown that, the running market price (per unit volume) of Poly Alumino Chloride (liquid) is lower than that of Alum and Lime, which may reduce approximately 30% of the total manufacturing cost. Therefore, we may conclude that the liquid phase of poly alumino chloride can be used for treating the waste water which may reduce significant amount of treatment cost with simple operational techniques and very lower-level consumption of chemicals.

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Conflict of interest

No conflict of interest.

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