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ALUM vs. ALUMINIUM CHLORIDE FOR WATER TREATMENT AT DIFFERENT OPERATION CONDITIONS

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ABSTRACT

The aim of the present work is to compare between the alum and aluminum chloride as a coagulant in water treatment process in order to replace the alum, which used for a century in the water treatment process, by aluminum chloride as a coagulant for water treatment of Nile water. Aluminum chloride is the coagulant of choice for many industrial and sanitary wastewater treatment applications, due to its highly efficiency and effectiveness in clarification. The dose of both alum and aluminum chloride were developed and evaluated at different operation conditions. Bench-scale jar tests that simulated

conventional coagulation, flocculation, and sedimentation processes were used. Turbidity, pH, residual aluminum and other different parameters were selected for best achievements.

The optimum doses were varied between (20 – 23) and (5.5 – 6.4) mgL-1 for Alum and aluminum chloride, respectively, at pre-chlorination dose 5 mgL-1, flash mixing 100 rpm for 1.0 min, slow mixing 40 rpm and sedimentation time for 20 min which is the most efficient at turbidity and algae removals with suitable residual chlorine.

Keywords: Alum, aluminum chloride, conventional treatment, Nile water, optimum doses and turbidity removal.

Introduction

Energy and environmental concerns have lately drawn worldwide attention. Using surface water as a drinking water source brings new challenges to engineers and utilities due to a variety of factors, including increased water quality variability, organic content and other water contaminants.

In addition to removing turbidity from the water, coagulation and flocculation are beneficial in other ways. The processes remove many bacteria which are suspended in the water (Prakash et al., 2014).

In water treatment, coagulation is the process through which suspended, colloidal and dissolved matter are destabilized by the addition of coagulant. Flocculation is the process by which the destabilized particles agglomerate and form flocculent particles, or "floc." (Yonge, 2012). It was observed that the flocs formed at the pH range would not settle as efficient as those formed at the basic pH range (Yan et al., 2007).

Coagulation is an essential step in water treatment process and when carried out properly; the amount of residual aluminum left in the water should be similar to or lower than the non-treated water (Nilsson et al., 1990).

This paper presents jar–test results evolution based on the usage of Alum and Aluminium chloride coagulants in an attempt to replace Alum by Aluminium chloride.

Aluminium Sulphate can also be identified as Alum. The usage of Alum was noticed by early Romans (Bratby, 2006). The commercial product has a chemical formula $Al_2(SO_4)_3.14H_2O$ which is the most common chemical used for the coagulation of the particles. Equation (*i*) represented the reaction between Alum and the alkalinity of the water.

$$Al_2(SO_4)_3.14\,H_2O + 3Ca(HCO_3)_2 \longrightarrow 2Al(OH)_3 + 3CaSO_4 + 6CO_2 + 14H_2O \qquad (i)$$

Most particles (including microorganisms) have a negative electric charge and, rather than clump together to form larger particles, the particles repel each other to form larger clumps, this negative charge must be neutralized (Schulz et al., 1984). This can be done by adding positive ions, such as Aluminium ions, which react with the negative particles and form clusters of particles called micro flocs, then grows and will either settle out or can be filtered out of the water by a treatment system such as sand filtration. The flocs are of larger size, strongly bound and porous in case of flocculation (Tripathy et al., 2006).

Aluminium chloride has a chemical formula $AlCl_3$ and its hydrated form $AlCl_3.6H_2O$ (hexa hydrated Aluminium chloride). Aluminium chloride is used in either anhydrous or hydrated form. In the hydrate form, it is used as catalyst, in the Friedel – Crafts reactions, in the manufacture of rubber and in the cracking of petroleum (Das Sarma et al., 2013). In its hydrate form, it is used by pharmaceutical industries, paint pigment and fertilizer. In water treatment, it is used mainly in polymeric forms as a coagulant; the chemical coagulants have inhibition effects on microorganism activity, with the influence degree of:

PAC (poly-Aluminum chloride) > $AlCl_3$ > $Fe_2(SO_4)_3$ (Chen, 2013).

Aluminium chloride reacts with the alkalinity of the water as in equation (*ii*):

$$2AlCl_3.6H_2O + 3Ca(HCO_3)_2 \longrightarrow 2Al(OH)_3 + 3CaCl_2 + 6CO_2 + 12H_2O \qquad (ii)$$

Al(III) undergoes a series of hydrolysis, polymerization, precipitation and aggregation process. Moreover, amorphous $Al(OH)_3$ has a low solubility around neutral pH and can remove impurities by a combination of adsorption and precipitate enmeshment (Wenzheng et al., 2015).

In this work, coagulation of turbid particles has been carried out with different operation conditions.

The main aims of the work were:

- To determine optimum dose of Alum and Aluminium chloride coagulants with suitable operation condition.
- To investigate the effect of the two coagulants on different water parameters.

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- To evaluate the costs of Alum and Aluminium chloride coagulants in the local market.

For the possibility of exchange Alum by Aluminium chloride in water treatment plants in Egypt.

MATERIALS AND METHODS

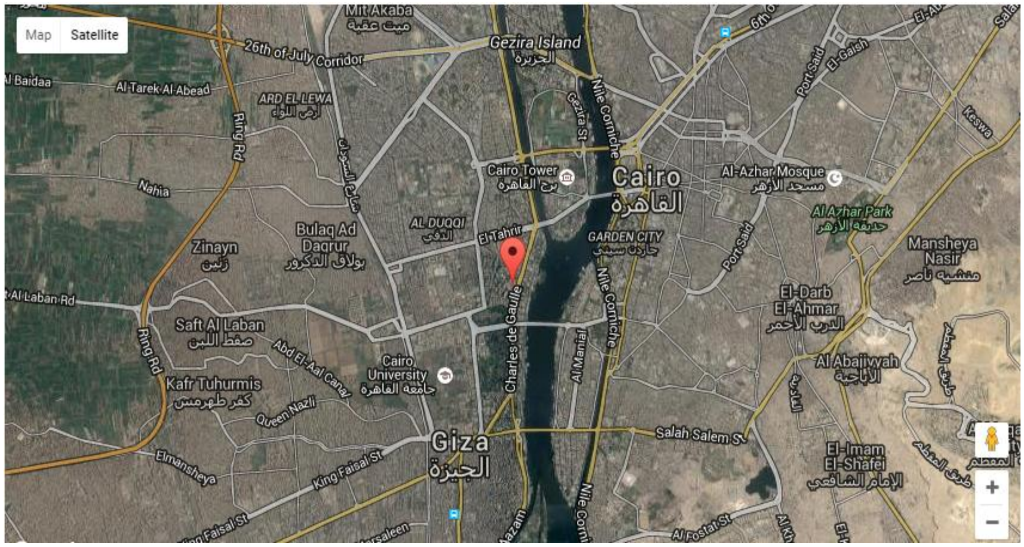
Materials and Reagents

$AlCl_3.6H_2O$ and $Al_2(SO_4)_{3.}14H_2O$ (Alum) solutions were provided commercially and prepared freshly by accurately weighing of 1.00 g of each solution, and diluted by bi-distilled water up to 1000 ml in a volumetric flask and the two targets operated in parallel.

Furthermore, all chemicals and reagents used in analytical investigation of alkalinity, chlorides and determination of amount of aluminium were of analytical grade and of analytical reagent and prepared as illustrated in Standard Methods for the Examination of Water and Wastewater, 19^{th} ed. (SMWW, 1995).

Collection, storage and pre-treatment of all raw water samples were carried out as illustrated in Standard Methods for the Examination of Water and Wastewater, 19^{th} ed. (SMWW, 1995) and analyzed within 4 hrs. of collection. 1000 mL of water samples were collected by using horizontal Van Dorn sampler, and taken blow the surface of the Nile water by 30 cm; the samples were carefully with-drawn and then transferred to 1000 mL sample bottles.

The water intake site map was represented by picture (1) blow.

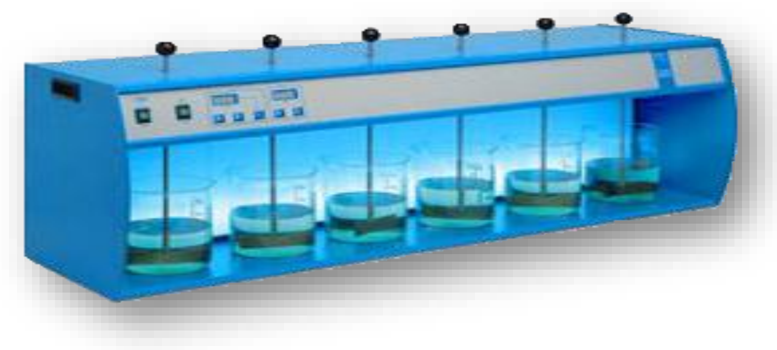


Picture 1. Google map of Giza water plant location site.

Jar Test For Optimal Doses Determination

Twenty Six Jars were conducted for this study, A typical procedure for conducting a jar test is provided in AWWA Manual M12 (Manual M12, Simplified Procedures for Water Examination, 1978), the tests were divided into three subdivisions, the first eight Jars without pre-chlorination, flash mixing 100 rpm for 1 min, slow mixing 40 rpm for 20 min and the sedimentation time for 20 min. The second twelve Jars were carried out by the addition of 5 mgL^{-1} chlorine solution and with the same conditions as the first eight Jars. The third six Jars were carried out by adding of 5 mgL^{-1} chlorine solution, flash mixing 100 rpm for 1 min, slow mixing 20 rpm for 20 min and sedimentation time for 20 min.

The jar tests were carried out with a flocculator JL T6 (Velp, Italy) with 6 places for jar test and leaching test which enables setting of speed by microprocessor and visualization of speed by a LCD display from 10 to 300 rpm. with 1 rpm selection speed/electronic timer.



Picture 2. Velp flocculator JL T6 with 1-liter round glass beakers.

Mathematical and Statistical Procedures

A common goal for the mathematical and statistical procedures is to draw a conclusion on how far the values of the proposed methods far from the values obtained from the reference method. The mathematical and statistical procedures are summarized as following:

The mean value (average) or $\bar{x}$ is simply the sum of all values (x) divided by the number of values (n).

The standard deviation or SD is a measure of how precise the average is; how well the individual numbers agree with each other. It was calculated using Excel, taking into consideration that the number of replicates (n) = 3.

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$$\%\boldsymbol{Removal} = \frac{\text{Avarage result of Raw water} - \text{avarage result of sample}}{\text{Avarage result of Raw water}}$$

All the above equations and formulas are used for the result evaluations.

Selected Parameters

All the measured parameters, alkalinity, turbidity, pH, Aluminium, conductivity, chlorides and algae count for both Raw Water and Treated Water were measured as illustrated in the Standard Methods for the Examination of Water and Wastewater 19th ed. (SMWW, 1995).

Aluminium concentration was conducted by diluted 250 mL of water sample in 500 mL volumetric flask up to 250 mL of the bidistilled water and measured by using Eriochrome cyanine R method.

All the parameters of the raw water samples were analysed as soon as possible within less than one hour from collection without preservation. Table (1), illustrated the mean Raw Water data parameters for Giza water plant intake, for all Jar tests.

Test	Methods	Instruments	Units	Results	
				Range	Mean±SD*
pH	4500-H^+ B Electrometric method	Jenway 3510 pH meter	pH unit	8.0-8.3	8.1± 0.17
Turbidity	2130 B Nephelometric method	Hach 2100N Turbidimeter	NTU	4-12	6±1.86
Electrical Conductivity	2510 B Laboratory method	Jenway 4310 conductivity meter	µS/cm	350-450	375±35
Total Alkalinity	2320 B Alkalinity method	Hirschman Opus titrator	mgL^{-1} as $CaCO_3$	130-145	132±11.1
Chlorides	4500-Cl^- Argentometric method	Hirschman Opus titrator	mgL^{-1} as Cl	21-45	27±2.93
Aluminum	3500-Al B Eriochrome Cyanine R method	Jenway Spectrophotometer 6505 providing path length 1 cm.	mgL^{-1} as Al	0.02-0.04	0.03±0.02
Algae count	10200 F Photo plankton counting techniques	MPW-260 centrifuge and A1 Zeiss imager microscope	Unit mL^{-1}	3000-12000	4500±853

Table (1). Selected parameters of Nile Water at Giza plant intake.

*Number of replicates (n) = 3

Dose Calculations

To calculate the dose of a coagulant in mgL^{-1}, you will need to know its (% w/w), strength and specific gravity, and the calculations were carried out as illustrated in 31st Annual Water Industry Workshop – Operations Skills (Gebbie, 2006).

Alum is most commonly delivered as a liquid concentration having a solids level of 8.3% as Al_2O_3 or about 50% as a hydrated form. By measuring the Specific density of 25 ml concentrated solution:

$$Specific\ density = \frac{33.14}{25} = 1.33$$

Table (2). The volume added (ml) to 1000 ml of water samples and the corresponding doses (mgL^{-1}) of Alum and $AlCl_3.6H_2O$.

Volume, ml added of (Alum)	**Dose, mgL^{-1} of (Alum)**	**Volume, ml added of ($AlCl_3.6H_2O$)**	**Dose, mgL^{-1} of ($AlCl_3.6H_2O$)**
2.0	10.09	2.0	2.80
2.5	12.62	2.5	3.56
3.0	15.14	3.0	4.27
3.5	17.66	3.5	4.98
4.0	20.19	4.0	5.69
4.5	22.72	4.5	6.40

Alum solution was titrated against 0.2 M NaOH solution, the concentration of Alum was equal to 69% (w/v). The hydrated solution concentration represented as (w/w).

$$Concentration\ of\ Alum.(w/w) = \frac{69}{1.32} = 52.27\%$$

$$\therefore 1.0\ ml\ of\ the\ concentrated\ Alum\ solution = \frac{52.27}{50} = 1.045\ mgL^{-1}$$

$AlCl_3.6H_2O$ provided as 25% as concentrated solution. The weight of 25 ml of concentrated $AlCl_3.6H_2O$ was 31.25 mg.

$$\therefore \text{specific denisty} = \frac{\text{Wt}}{\text{V}} = \frac{31.25}{25} = 1.25$$

$$\text{N}_{\text{conc.}} = \frac{\text{Sp. gr} \times 10 \times \%}{\text{e. wt}} = \frac{1.25 \times 10 \times 25}{80.5} = 3.88\ \text{gL}^{-1}$$

RESULTS AND DISCUSSION

Three operation conditions were conducting for this research and applied for jar tests; without pre-chlorination, flash mixing 100 rpm for 1 min, slow mixing speed 40 rpm and sedimentation time for 20 min, and with 5 mgL^{-1} pre-chlorination, flash mixing 100 rpm for 1 min, slow mixing speed 40 or 20 rpm and sedimentation time for 20 min.

From the bench-scale jar testing evaluation, in general, treatment with each coagulant studied achieved the Egyptian guideline for the drinking water. However, for Aluminum and turbidity removal were not probably attainable with the use of the combined processes of coagulation, flocculation and sedimentation. For example, as shown in Table (5), the lowest turbidity achieved after the settling period of the jar tests was 0.96 NTU for $AlCl_3.6H_2O$ and for Alum, turbidity was 1.04 NTU. For the Aluminum, as shown in Table (4), the lowest concentrations of Aluminum were 0.243 and 0.079 mgL^{-1}, for both Alum and $AlCl_3.6H_2O$, respectively. Although, the Egyptian guidelines are less than (1) NTU for turbidity and not more than 0.2 mgL^{-1} for residual Aluminum, so, filtration techniques need to be supplemented to meet the drinking water's Egyptian guidelines.

Undergo the treatment without pre-chlorination in order to show the possibility of the addition of the coagulant first. Table (3) shows the effect of both coagulants on the selected water parameters without the addition of chlorine gas. As shown in Table (3), each coagulant has a narrow effect on the reduction of pH values. This will be lead to problem of high residual Aluminum in the finished water and the problem will increase when the raw water has a high alkalinity or pH this is can be clear when comparing the results of residual Aluminum in case of pre-chlorination (Table(4&5)) with those in case of without pre-chlorination (Table(3)).

Moreover, the doses used for both coagulants in case of non pre-chlorination condition are not sufficient for better removal of algae compared to those used after pre-chlorination. Although, Aluminum chloride was effective at algae removal under non chlorinated conditions compared with Alum at the same conditions but still required higher concentration of coagulant as illustrated in Table (3).

This indicated that the pre-chlorination enhances the performance of the coagulant and coagulation process and pre-chlorination is still needed for healthy purpose. So, the condition of the addition of coagulants before pre-chlorination is excluded.

Tables (4&5) show the analysis of the selected parameters under the operation conditions of 5 mgL^{-1} chlorine solution, flash mixing 100 rpm for 1 min, slow mixing 40 or 20 rpm for 20 min and sedimentation time for 20 min, respectively. As shown in Table (4&5), the maximum turbidity removal seemed to be more correlated to the pH ranges. pH of the water affects the surface charge of the coagulants as well as the degree of the stabilization of the suspension (Altaher, 2012). As shown in Tables (3, 4&5), the turbid particles removals were more efficient at lower pH values as the doses of the coagulants increase. $AlCl_3.6H_2O$ showed, on average, less turbidity removal relative to Alum. Moreover, the turbidity removal was slightly effective at 20 rpm relative to 40 rpm slow mixing as shown in Figures (1 & 2). The % of average of turbid particles removal in case of 40 rpm slow mixing were varied from 34 to 74% for 10.09 to 22.72 and 2.80 to 6.40 mgL^{-1} of Alum and Aluminum chloride doses, respectively, while in case of 20 rpm slow speed, the % removal of average turbidity were varied from 42 to 79.5% for 10.09 to 22.72 and 2.80 to 6.40 mgL^{-1} of Alum and Aluminum chloride doses, respectively.

As shown in Tables (4&5), there is no significance difference in the total Alkalinity and conductivity between the two coagulants. Additionally, Chlorides remained constant in the case of Alum as a coagulant and increase gradually by increase the dose using aluminum chloride as a coagulant but still within the limits.

With chlorine dose 5 mgL^{-1}, residual chlorine obtained under the conducting operation procedures for the both coagulants which is desirable in order to lowering the algae and bacterial count levels.

By operating Jars with chlorine dose 5 mgL^{-1}, flash mixing 100 rpm for 1 min, slow mixing 40 rpm for 20 min and the sedimentation time for 20 min, the average values of the Aluminum, as shown in Table (4), were significantly increased up to 0.715 mgL^{-1} and 0.401 mgL^{-1} by increasing $AlCl_3.6H_2O$ and alum doses, respectively. On the other side at 20 rpm slow mixing, Aluminum

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exhibits the same behavior using both Alum and $AlCl_3.6H_2O$ coagulants, reached maximum concentration up to 0.454 and 0.443 mgL^{-1}, respectively, as shown in Table (5).

It is important to note that the algae removal is more effective at chlorine dose 5 mgL^{-1}, flash mixing 100 rpm for 1 min, slow mixing 40 rpm for 20 min and sedimentation time for 20 min for both Alum and $AlCl_3.6H_2O$, as shown in Figure (3). The results of the jars evaluation indicated that Alum was the more effective coagulant at the algae removal even at the lowest dose under the pre-chlorination conditions as shown in Figures (3&4).

The % of the average algae removal varied from 84.4 to 94.4% and 75.3 to 89.1% for Alum and Aluminum chloride, respectively, under chlorine dose of 5 mgL^{-1}, flash mixing 100 rpm for 1 min, slow mixing 40 rpm for 20 min and the sedimentation time for 20 min.

For chlorine dose of 5 mgL^{-1}, flash mixing 100 rpm for 1 min, slow mixing 20 rpm for 20 min and the sedimentation time for 20 min, % of the average algae removal varied from 76.8 to 90% and 60.6 to 84.1% for Alum and Aluminum chloride, respectively.

As indicated from above analysis of the results, the suitable operation condition is by the addition of chlorine dose 5 mgL^{-1}, flash mixing 100 rpm for 1 min., slow mixing 40 rpm for 20 min and sedimentation time for 20 min. for both Alum and $AlCl_3.6H_2O$.

As shown in Table (4), the average of the turbid particles and the algae contents decreased by increasing dose of Alum and Aluminum chloride. The % removal of the turbidity was 70-74.2% and 67.7-74.2%, for Alum and

Aluminum chloride doses from 20 to 23 mgL^{-1} and 5.5 to 6.4 mgL^{-1}, respectively.

On the other hand, as shown in Table (4), the algae contents decreased by increasing dose of Alum and Aluminum chloride. The % removal of algae was 92.4-94.4% and 88.5-89.1%, for Alum and Aluminum chloride doses from 20 to 23 mgL^{-1} and 5.5 to 6.4 mgL^{-1}, respectively.

As shown in Table (4), the optimum dose of Alum and Aluminum chloride is between 20-23 mgL^{-1} and 5.5-6.4 mgL^{-1}, respectively, at chlorine dose of 5 mgL^{-1}, flash mixing 100 rpm for 1 min., slow mixing 40 rpm for 20 min and sedimentation time for 20 min. with efficient at turbidity and algae removals, low aluminum concentration and suitable residual chlorine.

Moreover, the % removals of turbid particles of the proposed methods together with suitable operation conditions were compared with those of the reference methods as tabulated in Table (6). In Table (6), the Alum shows higher % removal of turbidity under the selected operation conditions compared to others listed in the table. $AlCl_3.6H_2O$ is more effective in turbidity removal when it used in the preparation of poly-aluminum chloride (Gao et al., 2007).

Table (3).The mean values of 8 jar tests without pre-chlorination, flash mixing 100 rpm for 1 min, slow mixing 40 rpm for 20 min and the sedimentation time for 20 min for Alum and $AlCl_3.6H_2O$.

		Does of Alum (mgL^{-1})						Does of $AlCl_3.6H_2O$ (mgL^{-1})					
		10.09	**12.62**	**15.14**	**17.66**	**20.19**	**22.72**	**2.80**	**3.56**	**4.27**	**4.98**	**5.69**	**6.40**
pH	Min.	7.83	7.81	7.78	7.69	7.66	7.66	7.67	7.59	7.49	7.44	7.35	7.33
	Max.	8.05	8.06	8.02	8.07	7.83	7.90	7.70	7.72	7.83	7.84	7.76	7.74
Turbidity (NTU)	Min.	3.86	2.96	2.01	1.47	1.10	1.04	3.79	3.17	2.04	1.46	1.22	1.00
	Max.	4.05	3.62	2.19	1.58	1.43	1.11	4.00	3.79	2.72	1.84	1.29	1.54
	Average	3.94	3.26	2.08	1.52	1.27	1.07	3.89	3.40	2.36	1.67	1.25	1.29
	±SD	±0.09	±0.33	±0.09	±0.05	±0.17	±0.04	±0.11	±0.34	±0.34	±0.19	±0.04	±0.27
Conductivity (µS/cm)	Min.	436	429	378	413	433	432	440	429	423	441	445	424
	Max.	453	454	455	453	454	469	457	457	458	456	458	453
Total alkalinity	Min.	144	140	138	136	130	132	142	140	138	136	132	130
	Max.	151.6	147.8	147.8	147.4	142.8	142.6	149.0	145.5	142.8	141.6	138.0	137.6

(mgL^{-1} as $CaCO_3$)	Average	148.5	144.6	142.6	141.8	137.6	136.9	145.5	142.7	141.0	139.3	135.9	132.5
	±SD	±4.00	±4.08	±4.92	±5.70	±6.73	±5.35	±3.50	±2.75	±2.57	±2.95	±3.35	±4.39

Chlorides (mgL^{-1} as Cl)	Min.	28	28	28	28	28	28	39	38	36	35	34	32
	Max.	29	29	29	29	29	29	40	39	38	37	35	34
	Average	28.7	28.7	28.7	28.7	28.7	28.7	33.3	34.7	36	37	38.3	39.3
	±SD	±0.58	±0.58	±0.58	±0.58	±0.58	±0.58	±1.15	±0.58	±1.00	±1.00	±0.58	±0.58
Aluminum (mgL^{-1} as Al)	Min.	0.355	0.378	0.377	0.387	0.363	0.368	0.310	0.351	0.322	0.310	0.311	0.280
	Max.	0.363	0.380	0.377	0.404	0.363	0.368	0.382	0.394	0.380	0.393	0.410	0.440
	Average	0.34	0.37	0.36	0.37	0.34	0.35	0.353	0.37	0.36	0.36	0.36	0.37
	±SD	±0.03	±0.02	±0.02	±0.04	±0.02	±0.03	±0.03	±0.02	±0.03	±0.04	±0.05	±0.08
Algae count (unit ml^{-1})	Min.	380	430	150	360	110	250	700	340	220	380	170	170
	Max.	1130	1240	1120	850	480	400	1040	640	1280	1700	590	480

Average	797	763	520	530	353	410	860	490	690	853	343	303
±SD	±381	±423	±524	±277	±186	±335	±170	±150	±540	±734	±219	±329

Min= minimum; Max= maximum; SD= standard deviation, where (n) = 3 and average = average of 8 data.

Table (4).The mean values of twelve Jars with chlorine dose 5 mgL^{-1}, flash mixing 100 rpm for 1 min, slow mixing 40 rpm for 20 min and the sedimentation time for 20 min for Alum and $AlCl_3.6H_2O$.

		Does of Alum (mgL^{-1})						Does of $AlCl_3.6H_2O$ (mgL^{-1})					
Parameter		**10.09**	**12.62**	**15.14**	**17.66**	**20.19**	**22.72**	**2.80**	**3.56**	**4.27**	**4.98**	**5.69**	**6.40**
Residual chlorine (mgL^{-1})	Min.	1.5	1.4	1.4	1.2	1.2	1.4	1.4	1.3	1.5	1.2	1.3	1.6
	Max.	2.7	2.7	2.7	2.7	2.8	2.6	2.8	2.9	2.5	2.6	2.8	2.4
	Average	2.23	2.17	2.13	2.25	2.20	2.18	2.30	2.20	2.10	2.00	2.13	2.02
	±SD	±0.54	±0.57	±0.52	±0.70	±0.70	±0.53	±0.59	±0.68	±0.44	±0.57	±0.54	±0.33
pH	Min.	7.18	7.05	7.04	7.11	7.02	7.06	7.67	7.59	7.49	7.44	7.35	7.33

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	Max.	7.97	7.93	7.89	7.79	7.74	7.63	7.70	7.72	7.83	7.84	7.76	7.74
Turbidity (NTU)	Min.	3.70	2.62	2.21	1.52	1.29	1.05	3.47	3.11	2.25	1.68	1.19	1.2
	Max.	4.86	5.40	5.13	4.97	3.90	3.70	4.84	4.98	4.73	4.64	4.03	2.85
	Average	3.98	3.59	2.85	2.24	1.79	1.55	3.95	3.85	3.08	2.56	1.94	1.55
	±SD	±0.43	±0.91	±1.05	±1.23	±0.94	±0.96	±0.45	±0.63	±0.81	±0.96	±0.96	±0.59
Conductivity (µS/cm)	Min.	367	350	358	350	365	369	367	368	346	346	356	348
	Max.	433	431	429	433	427	427	451	440	435	433	431	428

Total alkalinity (mgL^{-1} as $CaCO_3$)	Min.	100	98	94	90	84	80	120	118	112	110	108	100
	Max.	134	132	130	124	120.8	128	134.8	131.8	125.2	124.6	124.6	119.4
	Average	125.1	123.7	119.6	116.8	113.7	109.4	127.5	125.0	119.9	118.1	115.0	112.9
	±SD	±11.69	±11.76	±12.02	±12.18	±13.32	±15.91	±5.40	±4.52	±4.12	±4.67	±5.40	±6.59
Chlorides	Min.	26	26	26	26	26	26	31	32	33	34	35	36

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(mgL^{-1} as Cl)	Max.	32	32	32	32	32	32	37	38	40	41	42	44
	Average	30	30	30	30	30	30	33.83	35	36	36.83	37.83	39.33
	±SD	±2.56	±2.56	±2.56	±2.56	±2.56	±2.56	±2.14	±2.28	±2.61	±2.64	±2.64	±3.01
	Min.	0.243	0.321	0.367	0.377	0.378	0.451	0.142	0.176	0.103	0.079	0.098	0.568
Aluminum	Max.	0.647	0.734	0.914	0.972	0.952	0.982	0.332	0.456	0.892	0.968	0.838	0.862
(mgL^{-1} as Al)	Average	0.132	0.221	0.324	0.345	0.398	0.401	0.154	0.239	0.487	0.524	0.508	0.715
	±SD	±0.17	±0.17	±0.24	±0.25	±0.25	±0.25	±0.22	±0.21	±0.29	±0.33	±0.31	±0.21
	Min.	510	400	350	260	178	98	510	430	350	360	210	210
Algae count	Max.	1100	1050	1000	800	500	276	1920	1300	1250	1300	1100	1060
(unit ml^{-1})	Average	702	659	538	408	340	250	1110	909	762	726	516	492
	±SD	±226	±265	±262	±225	±140	±76	±562	±379	±425	±426	±359	±339

Min= minimum; Max= maximum; SD= standard deviation, where (n) = 3 and average = average of 12 data.

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Table (5).The mean values of twelve Jars with chlorine dose 5 mgL^{-1}, flash mixing 100 rpm for 1 min, slow mixing 20 rpm for 20 min and the sedimentation time for 20 min for Alum and $AlCl_3.6H_2O$.

		Does of Alum (mgL^{-1})						Does of $AlCl_3.6H_2O$ (mgL^{-1})					
		10.09	**12.62**	**15.14**	**17.66**	**20.19**	**22.72**	**2.80**	**3.56**	**4.27**	**4.98**	**5.69**	**6.40**
Residual chlorine (mgL^{-1})	Min.	1.4	1.5	1.5	1.5	1.5	1.3	0.60	0.60	0.60	0.60	0.50	0.50
	Max.	1.6	1.7	1.6	1.7	1.6	1.5	2.00	2.00	1.70	1.80	1.60	1.70
	Average	1.50	1.65	1.55	1.65	1.55	1.40	1.42	1.40	1.30	1.27	1.10	1.00
	±SD	±0.14	±0.14	±0.07	±0.14	±0.07	±0.15	±0.72	±0.72	±0.61	±0.67	±0.61	±0.69
pH	Min.	7.31	7.25	7.22	7.21	7.20	7.17	7.16	7.15	7.12	7.08	7.05	7.00
	Max.	7.32	7.29	7.29	7.26	7.24	7.22	7.31	7.22	7.16	7.12	7.07	7.05
Turbidity (NTU)	Min.	3.18	2.74	1.86	1.43	1.14	1.05	3.11	2.62	1.89	1.37	1.21	0.96
	Max.	3.78	3.43	2.98	2.31	1.78	1.50	4.41	3.60	3.81	2.75	1.95	1.49

	Average	3.51	3.19	2.51	1.93	1.44	1.23	3.74	3.26	2.59	2.08	1.53	1.23
	±SD	±0.31	±0.39	±0.58	±0.45	±0.32	±0.23	±0.65	±0.56	±1.02	±0.69	±0.38	±0.27
Conductivity (µS/cm)	Min.	343	338	336	350	337	333	371	345	341	330	345	365
	Max.	399	395	393	390	390	387	406	398	400	398	396	396

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	Min.	130.0	129.2	127.8	124.6	119.4	104.0	130.6	127.8	125.6	121.0	118.0	111.2
Total Alkalinity	Max.	131.4	130.4	130.0	129.2	124.0	122.8	133.6	129.2	126.0	124	121.2	119.4
(mgL^{-1} as $CaCO_3$)	Average	130.7	129.7	128.7	127.2	122.3	115.6	131.6	128.3	125.8	122.1	119.7	115.6
	±SD	±0.70	±0.61	±1.13	±2.36	±2.55	±10.14	±1.73	±0.81	±0.20	±1.68	±1.60	±4.13
	Min.	24	24	24	24	24	24	30	31	32	32	34	35
Chlorides	Max.	26	26	26	26	26	26	31	32	33	35	35	36
(mgL^{-1} as Cl)	Average	24.7	24.7	24.7	24.7	24.7	24.7	30.67	31.67	32.67	33.33	34.33	35.67
	±SD	±1.00	±1.00	±1.00	±1.00	±1.00	±1.00	±0.58	±0.58	±0.58	±1.53	±0.58	±0.58
	Min.	0.331	0.358	0.367	0.377	0.366	0.356	0.340	0.357	0.323	0.381	0.341	0.278
Aluminum	Max.	0.362	0.381	0.376	0.369	0.369	0.454	0.381	0.394	0.382	0.399	0.421	0.443
(mgL^{-1} as Al)	Average	0.343	0.371	0.361	0.372	0.343	0.347	0.353	0.367	0.358	0.360	0.364	0.368
	±SD	±0.03	±0.02	±0.02	±0.04	±0.02	±0.03	±0.03	±0.02	±0.03	±0.04	±0.05	±0.08
Algae count	Min.	978	864	721	636	500	340	1050	890	760	710	650	570
(unit ml^{-1})	Max.	1130	1110	810	794	760	630	2300	2008	1980	1840	1700	880
	Average	1046	984	762	709	613	450	1770	1434	1313	1200	1118	717

±SD	±77	±123	±49	±80	±133	±157	±646	±559	±618	±580	±534	±156

Min= minimum; Max= maximum; SD= standard deviation, where (n) = 3 and average = average of 12 data.

Table (6). Comparison between the proposed operation conditions along with the %turbidity removal with the previous work.

Coagulant	Optimum dose, mgL^{-1}	Suitable operation conditions	Initial water turbidity, NTU	Initial water pH	% of turbidity removal	Reference
Alum	20	100 rpm rapid mixing for 1 min., 30 rpm slow mixing for 10 min. and 30 min. settling time.	10	7.6	55-67	[7]

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Alum	35	70 rpm rapid mixing for 1 min., 30 rpm slow mixing for 15 min. and 20 min. settling time.	10-1000	---	50	[6]
Alum	25	100 rpm rapid mixing for 2 min., 25 rpm slow mixing for 30 min. and 30 min. settling time.	100	6-8	64	[8]
Alum	20-23	5 mgL^{-1} Chlorine dose, 100 rpm rapid mixing for 1 min., 40 rpm slow mixing for 20 min. and 20 min. settling time.	4-12	8-8.3	70-74	[Present work]
PACSiC	15	120 rpm rapid mixing for 2 min., 40 rpm slow mixing for 10 min. and 15 min. settling time.	6.6	6.72	88.2	[4]
$AlCl_3.6H_2O$	5.5-6.4	5 mgL^{-1} Chlorine dose, 100 rpm rapid mixing for 1 min., 40 rpm slow mixing for 20 min. and 20 min. settling time.	4-12	8-8.3	67.7-74.2	[present work]

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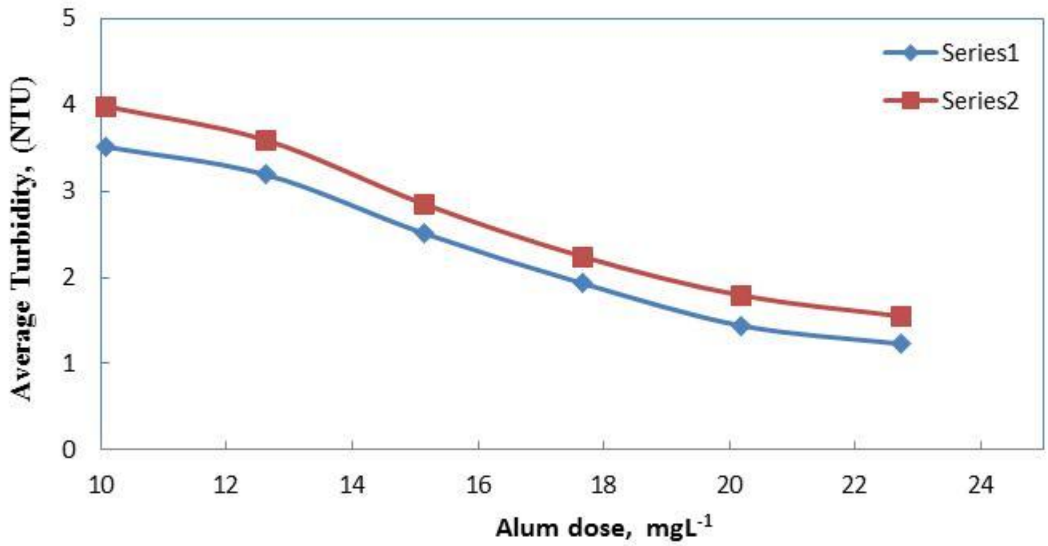

Fig. (1). Series (1)& (2): Average turbidity determined through the jar testing evaluation with chlorine dose 5 mgL^{-1}, flash mixing 100 rpm for 1 min, slow mixing 20 or 40 rpm, respectively, for 20 min and the sedimentation time for 20 min various Alum dose.

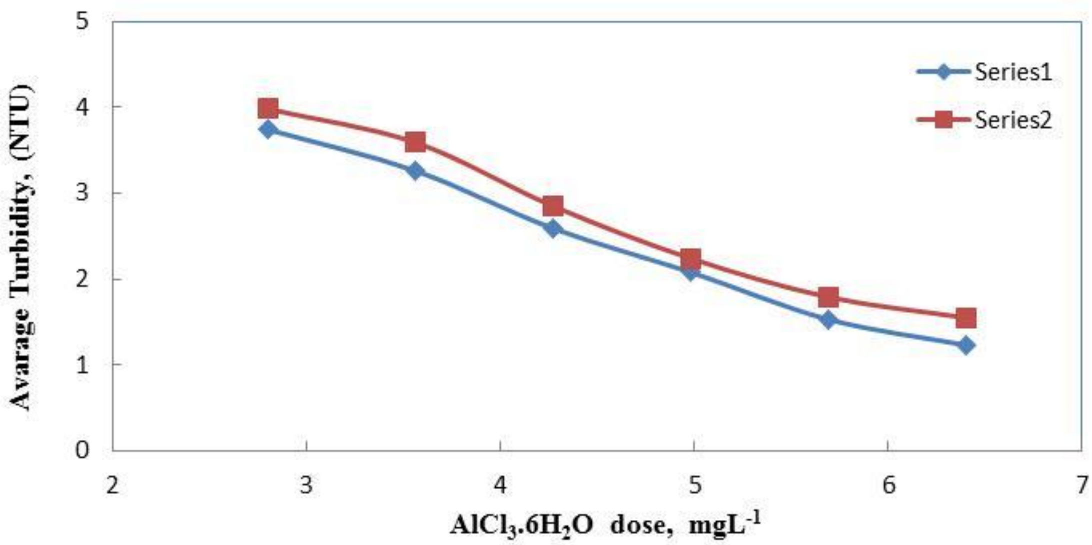

Fig. (2). Series (1)& (2): Average turbidity determined through the jar testing evaluation with chlorine dose 5 mgL^{-1}, flash mixing 100 rpm for 1 min, slow mixing 20 or 40 rpm, respectively, for 20 min and the sedimentation time for 20 min various $AlCl_3.6H_2O$ dose.

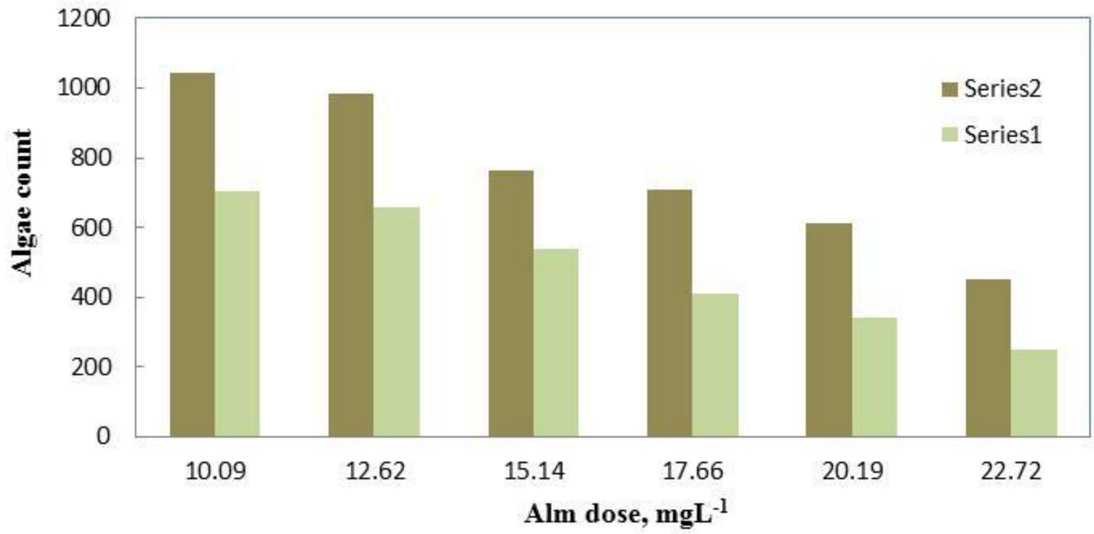

Fig. (3). Series (1)& (2): Average algae count through the jar testing evaluation with chlorine dose 5 mgL^{-1}, flash mixing 100 rpm for 1 min, slow mixing 40 or 20 rpm, respectively, for 20 min and the sedimentation time for 20 min various Alum dose.

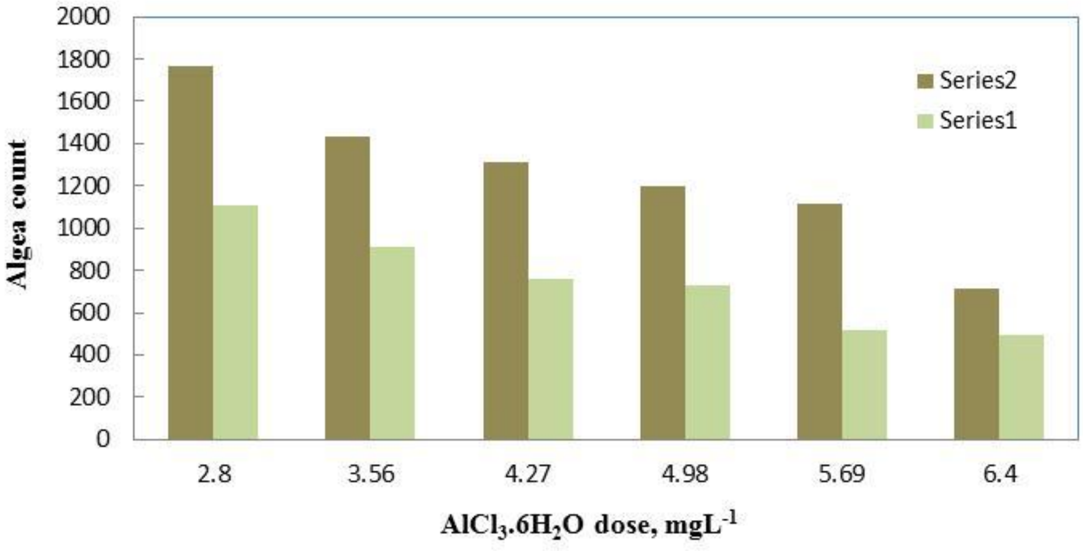

Fig. (4). Series (1)& (2): Average algae count through the jar testing evaluation with chlorine dose 5 mgL^{-1}, flash mixing 100 rpm for 1 min, slow mixing 40 or 20 rpm, respectively, for 20 min and the sedimentation time for 20 min various $AlCl_3.6H_2O$ dose.

Sludge Settling and Coagulate-Sludge Ratios

Of the coagulants tested, alum was found to have a rapid sludge settling under the conditions tested in this study. However, the more effective coagulants in terms of settling also produced the highest quantities of sludge; moreover at the optimum dose of the alum, the sludge settled in cones. This apparent trade-off also was reflected when turbidity removal effectiveness was considered. That is, the more effective coagulant for turbidity removal produced the greatest amount of settle able sludge.

Coagulant Cost and Performance

Plant operation is most efficient when the lowest turbidity is obtained in finished water with the lowest cost for coagulant chemicals (Water Quality, 1995).

During the local market evaluation of coasts, $AlCl_3.6H_2O$ was shown to have the highest cost relative to the alum coagulant, while alum was shown to have three times less cost. Note that indirect costs as well as costs for transportation and storage were not taken into consideration for the development of Figure (5).Figure (5) shows the relationship between coagulant costs, in local market, by tons relative to each other.

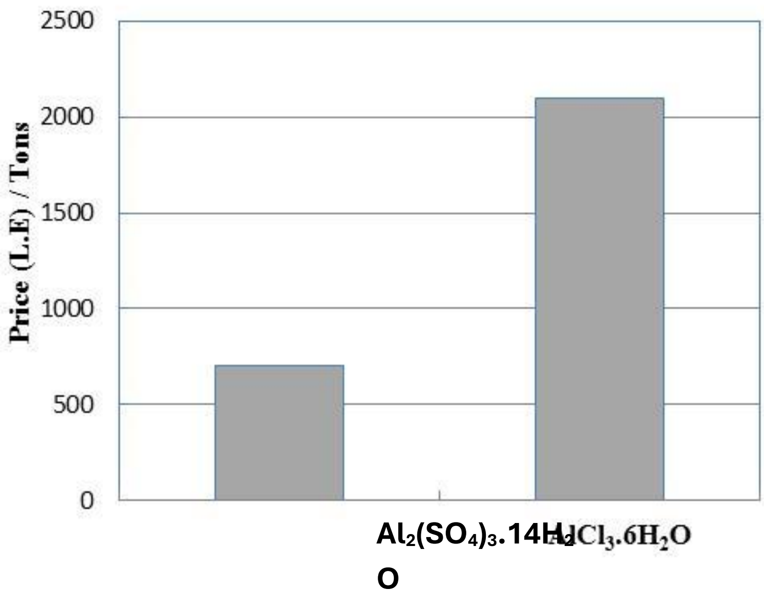

Fig.(5). Coagulant Cost Estimations in local market

CONCLUSION

This study on coagulant performance revealed that the optimum dose of alum was varied between (20 – 23) mgL^{-1} at pre-chlorination dose 5 mgL^{-1}, flash mixing 100 rpm for 1 min, slow mixing 20 or 40 rpm for 20 min and the sedimentation time for 20 min which is the most efficient at turbidity and algae removals, low aluminum concentration and suitable residual chlorine.

When compared to Aluminum chloride, its optimum dose was varied between (5.5 – 6.4) mgL^{-1} at pre-chlorination dose 5 mgL^{-1}, flash mixing 100 rpm for 1 min, slow mixing 20 or 40 rpm, for 20 min and sedimentation time for 20 min which is the most efficient at turbidity and algae removals.

The recommended operation conditions for both coagulants are pre-chlorination dose 5 mgL^{-1}, flash mixing 100 rpm for 1 min, slow mixing 40 rpm for 20 min and sedimentation time for 20 min.

Aluminum chloride as a coagulant is still need a coagulant aid to improve the settling time.

Extensive cost analysis is recommended to determine which coagulants would be most economical for the treatment of the Nile water. This qualitative assessment would suggest that when compared Alum despites its lower chemical cost could be considered as a viable coagulant for treatment of the Nile water. However, conventional treatment with Alum and Aluminum chloride did not meet Egyptian drinking water guidelines as regulated for turbidity and residual aluminum which should be lower than 1.0 NTU and not higher than 0.2 mgL^{-1}, respectively, therefore membrane filtration or conventional filtration may need to be considered.

Aluminum chloride coagulant should be scrutinized prior for selection. Furthermore, pilot testing would be required to determine the necessary measures needed to meet drinking water standards. With these data and the detailed economic analysis could be performed to further validate the conclusions of this study.

LIST OF ABBREVIATIONS

Abbreviations	meanings
pH	pH= - log[H^+]
T (°C)	Temperature, in degree Celsius
t (s)	Time, in second
(r^2)	Correlation coefficient
SD	Standard deviation; $S= [\Sigma (\chi- \chi_i)^2/(n-1)]^{1/2}$
n	Number of repeated measurements
v/v	Volume /volume
NTU	Nephelometric turbidity unit
rpm	Revolution per minutes

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