Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2013.792147

51 (2013) 7048–7056
November

Taylor & Francis
Taylor & Francis Group

Optimization of chemical precipitation to improve the primary treatment of wastewater

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Received 1 May 2012; Accepted 26 February 2013

ABSTRACT

Chemically enhanced primary treatment (CEPT) is a wastewater treatment method that serves as an attractive alternative to the conventional primary treatment, and it can also be used as an efficient preliminary step of the biological secondary treatment processes. CEPT adopts coagulation and flocculation and it accomplishes remarkable increases in the removal of common pollutants from the influent. The coagulants used in the present study were alum, sea-salt as a cheap coagulant, and homogenous mixtures of sea-salt (as a coagulant aid) and alum with different doses.These alternatives were tested in the direct precipitation of wastewater. The analytical hierarchy process was applied for the evaluation of different alternatives of coagulants according to four main criteria (i.e. removal efficiencies, sludge volume after 30 min, coagulant cost, and pH variation). In addition, the removal efficiencies were divided into five subcriteria, including COD, BOD_5, TSS, T–P, and T–N removals. The obtained results revealed that the removal efficiencies reached up to 87% of COD, 93% of BOD_5, 94% of TSS, 96% of T–P, and 20% of T–N greatly reducing the settling time in the primary treatment to about 30 min rather than 2 h in the conventional primary sedimentation. This creates a simple procedure for the optimization of chemical precipitation for wastewater treatment.

Keywords: Analytic hierarchy process (AHP); Chemical precipitation; Primary treatment of wastewater; Sea-salt

1. Introduction

Chemical precipitation is one of the principal chemical unit processes used for wastewater treatment using metal salts, such as ferric chloride [$FeCl_3$], alum [$Al_2(SO4)_3 \cdot 18H_2O$], and lime in order to enhance the removal efficiencies of total suspended solids (TSS), 5 days biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), and nutrients (phosphorus and nitrogen) [1]. Ødegaard [2] demonstrated that a very significant part of the contaminants in wastewater is associated with particles, and that, consequently, a significant reduction in contaminants may be expected as a result of direct particle removal. The main idea of chemical precipitation is that it converts

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the dissolved substances into insoluble particles, which can be flocculated and separated from the liquid; removal efficiencies depend on coagulant (type-dosage), mixing times, and the care with which the processes are monitored and controlled. With chemical precipitation, it is possible to remove about 80–90% of TSS, 50–80% of BOD_5, 30–70% of COD, 80–95% of the phosphorus as well as 20–25% of the nitrogen in the primary sedimentation. In comparison, well-designed and operated primary settling tanks without addition of chemicals may remove about 50–70% of TSS, 25–40% of BOD_5 and 5–10% of phosphorus [1–5].

The amount of chemicals required for treatment depends on the nature of wastewater, pH value, the phosphate level, point of injection, and mixing modes [3,6,7]. Experiments with lime resulted lower removal efficiency as well as the suitable lime dose raised the pH value to about 11 (this value inhibits the activation of micro-organisms in the system of biological treatment) [5,8].

In general, at their optimum dose and pH value, alum achieved high removal efficiencies for TSS, BOD_5, and COD than $FeCl_3$. In addition, it has been chosen to be the most suitable coagulant for the treatment of wastewater in Egypt due to many factors (i.e. best removals obtained, cost-effectiveness, and suitable pH range for biological activation and disposal) [5,8,9]. As reported in [8], mixtures of coagulants were tested in different proportions in order to obtain better results with reference to chemical cost and to try modifying the pH of wastewater effluents. It was observed that mixtures with lime, in general, did not give better removal efficiencies than using alum alone; this is because even if lime dosage was too small, the effect on increasing pH value was very great. Both alum and ferric chloride did not act effectively with high pH value [8].

Seawater was used in enhancing the chemical treatment of wastewater as a chemical coagulant and/or a coagulant aid. As demonstrated in [10], the most optimal dosages for the chemical precipitation of sewage are 40 mg/L ($FeCl_3$), 0.1 mg/L polymer, and 5% of seawater by volume. In addition, the presence of calcium (Ca^{+2}) and magnesium (Mg^{+2}) ions in seawater has a positive effect on removal efficiencies as mentioned in [11]. On the other hand, the addition of seawater to lime improves the removal efficiencies at a concentration of 2–4% by volume. The best combination between lime and seawater was 500 mg/L lime and 4% seawater (by volume), which gave the highest removal efficiencies. With alum, some improvements in the removals have been observed with seawater concentration of 2% (by volume) [8]. Hence, as discussed in [8,10,11], seawater was evaluated as an inexpensive coagulant for wastewater treatment, while sea-salt (about 95% sodium chloride) as a sole coagulant did not evaluate for the same directly.

The advantages of chemical precipitation of wastewater include a well-established technology with ready availability of equipment and many chemicals, higher removal efficiencies in terms of TSS, BOD_5, COD, and nutrients, as well as a reduction in the size of the subsequent secondary treatment. The disadvantages could include competing reactions, varying levels of alkalinity, increasing of operator safety concern, as well as increased volumes of primary sludge production that are sometimes more difficult to thicken and needs additional cost for its disposal [12,13]. Although primary sludge contains a valuable content of organic matter, it can be manipulated to produce a great quantity of biogas.

The undertaken work is devoted to define a simple procedure (i.e. analytic hierarchy process, AHP) [14–16] to select the best coagulant or coagulant mixture according to the quality and quantity, and to optimize the chemical precipitation of wastewater based on alum and alum supported with sea-salt, taking into consideration the following aspects:

- Enhancing the removal efficiencies for TSS, BOD_5, COD, and nutrients before the biological treatment in order to reduce the influent organic load to the secondary treatment.
- Reduction of the costs of coagulant to achieve the economic feasibility of using chemical precipitation in the development of wastewater treatment plants.
- Controlling of pH variation to meet the suitable range for biological treatment.

2. Materials and methods

2.1. Experimental plan

The experimental work was executed in Sanitary Engineering laboratory, Faculty of Engineering, Tanta University, Tanta, Egypt as well as laboratory of Saft Trab WWTP, El-Mahalla El-Kobra, El-Gharbia Governorate, Egypt. This plant was designed to treat about 10,000 m^3/d of municipal wastewater from Saft Trab and El-Hayatem villages where activated sludge is operated with oxidation ditches system. Table 1 represents the wastewater characteristics in Saft Trab WWTP; the true raw sewage slightly as seen in Figs. 2–6.

Direct precipitation process, as demonstrated in Fig. 1, has been simulated in a standard "jar test".

Table 1
Wastewater characteristics in Saft Trab WWTP

Parameter	Raw sewage*				Final effluent**				No. of samples
	Max.	Min.	Average	Standard deviation	Max.	Min.	Average	Standard deviation	
pH	8.1	7.3	7.6	0.2	8.2	6.1	7.5	0.48	26
Total suspended solids (TSS) mg/L	473	350	415	32.3	39	21	30	5.2	25
COD mg/L	800	500	730	83	78	50	66	9.2	17
BOD_5 mg/L	530	250	330	94.5	82	24	45	18.2	7
T–P mg/L	10.6	8.9	9.8	0.72	–	–	–	–	6
T–N mg/L	26	21	24.5	2.72	–	–	–	–	6

Notes: *Samples of raw sewage were collected after grit removal; **Samples of the final effluent were collected after final clarifiers following the oxidation ditches.

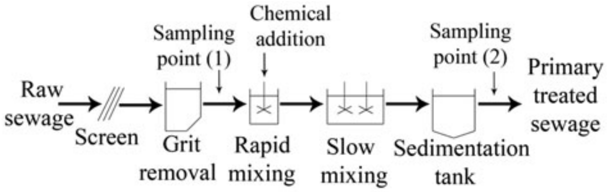

Fig. 1. Direct precipitation for sewage treatment [3,5].

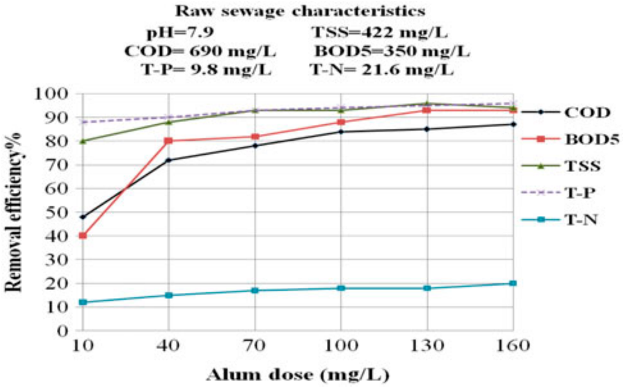

Fig. 2. Effect of alum doses on COD, BOD_5, TSS, T–P, and T–N removal efficiencies.

Samples of de-gritted raw wastewater were distributed among six jars followed by the addition of specified concentration of given coagulant to give a total volume of one liter in each jar to complete coagulation, flocculation, and sedimentation processes; rapid mixing was started through one minute with rotational speed of 200 rpm followed by 15 min with rotation of 30 rpm for slow mixing, and then left the six jars for 30 min to complete the clarification [3,5,8,9,11]. The samples were taken from the supernatant for analysis of different parameters (i.e. coagulant type, coagulant dose, removal efficiencies, sludge volume, and pH variation) as well as cost reduction.

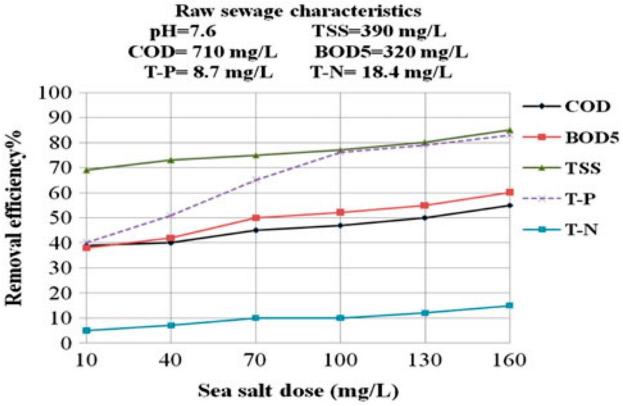

Fig. 3. Effect of sea-salt doses on COD, BOD_5, TSS, T–P, and T–N removal efficiencies.

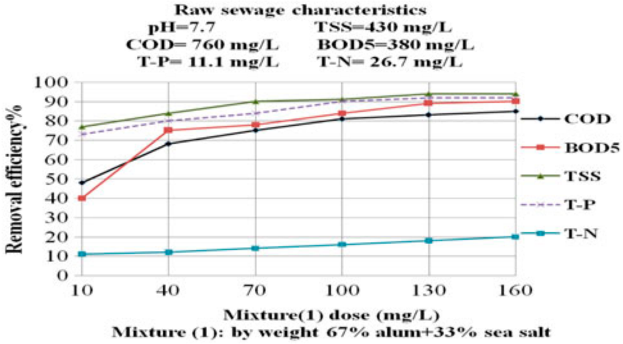

Fig. 4. Effect of mixture (1) doses on COD, BOD_5, TSS, T–P, and T–N removal efficiencies.

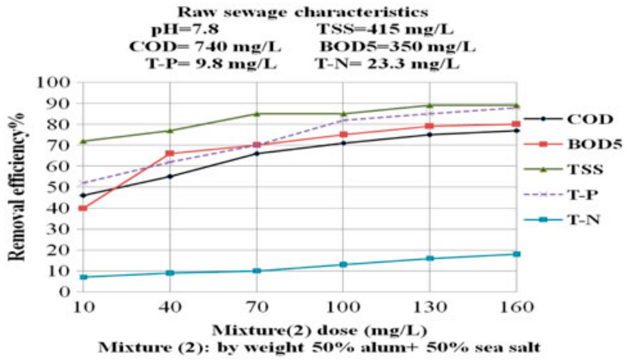

Fig. 5. Effect of mixture (2) doses on COD, BOD_5, TSS, T–P, and T–N removal efficiencies.

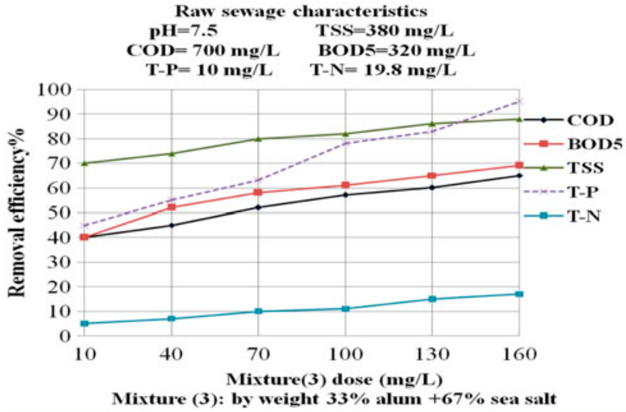

Fig. 6. Effect of mixture (3) doses on COD, BOD_5, TSS, T–P, and T–N removal efficiencies.

Table 2
Equipment utilized in the laboratory tests

Parameter	Product information
TSS	Using paper filter-drying oven (BINDER) company-analytical balance (OHAUS), Germany
BOD	BOD Incubation (Fisher Scientific), USA
COD	COD reactor (DINKO), and Spectrophotometer *(biochrom)* Model Libra S12
pH, temperature	pH/°C Benchtop Meter (WTW) Model pH 3151
Sludge volume after 30 min (V_{SL})	Imhoff Cones

The analyses of raw and treated wastewater samples were conducted using the equipments shown in Table 2 on the basis of Standard Methods, 1998 [17].

2.2. Coagulants

Sea water was used as a cheap coagulant for wastewater treatment as previously mentioned [8,10,11]. In this study sea-salt (CAS number 7647-14-15) was used as a coagulant or a coagulant aid instead of seawater. Sea water contains about 3.5% of sea-salt by weight. The sea-salt consists of about 95% of sodium chloride and 5% other metals which may support the coagulation process, including manganese, calcium, magnesium, and iodine (from natural source) in addition to more than 70 other metallic elements.

In the present research, sea-salt, alum [$Al_2(SO_4)_3.18H_2O$, CAS number 10043-01-3], and homogenous mixtures of sea-salt and alum were applied as coagulants. Stock solutions of these chemicals at 10 gm/L were produced by mixing 10 gm of each coagulant in one liter of distilled water and then adjusting the volume of each sample to one liter for calibrating the required dose.

A series of jar tests had to be carried out in order to optimize the coagulant dose for raw wastewater treatment and to choose the best type of coagulant. There are five coagulants [i.e. alum, sea-salt, mixture (1): by weight, 67% alum + 33% sea-salt, mixture (2): by weight, 50% alum +50% sea-salt, and mixture (3): by weight, 33% alum + 67% sea-salt] which were evaluated at doses of 10, 40, 70,100,130, and 160 mg/L; this means that there are 30 alternatives obtained and tested as shown in Figs. 2–6.

2.3. Analytic hierarchy process (AHP)

The optimization of chemical precipitation for the enhancement of primary wastewater treatment was processed by using AHP, which can be defined as a theory of measurements through pair-wise comparisons and relies on the judgment of the experts to derive priority scales [15,16]. There were four main criteria (i.e. removal efficiencies, sludge volume after 30 min, coagulant cost, and pH variation) as shown in Table 3. In addition, the removal efficiencies were based on five subcriteria, including COD, BOD_5, TSS, T–P, and T–N removals as shown in Table 4. The including numbers in Tables 3 and 4 represent the intensity of importance for each criterion relative to the other criteria [16]; These numbers may be changed according to the operating conditions (e.g. the importance of pH variation was well considered to maintain the efficiency of biological treatment following the improved primary treatment process). Finally, Table 5 shows weights of the different parameters, which were calculated from the column priorities% in Tables 3 and 4.

Table 3
Pair-wise comparison matrix of the main criteria with respect to optimize the selection of coagulant type and dosage [16]

	Removal efficiencies	Sludge volume	Cost	pH variation	Sum	Priorities%
Removal efficiencies	1.00	2.00	0.75	5.00	8.75	37* = (8.75/23.87) × 100
Sludge volume	0.50	1.00	0.33	2.00	3.83	16
Cost	1.33	3.00	1.00	4.00	9.33	39
pH variation	0.20	0.50	0.25	1.00	1.95	8
Sum					23.87	100

Table 4
Pair-wise comparison matrix of sub criteria with respect to removal efficiencies

	COD	BOD_5	TSS	T–P	T–N	Sum	Priorities%
COD	1.00	0.75	0.67	1.50	1.50	5.42	18** = (5.42/29.42) × 100
BOD_5	1.33	1.00	1.50	3.00	3.00	9.83	34
TSS	1.50	0.67	1.00	2.00	2.00	7.17	24
T–P	0.67	0.33	0.50	1.00	1.00	3.50	12
T–N	0.67	0.33	0.50	1.00	1.00	3.50	12
Sum						29.42	100

Table 5
Weights of the different parameters [16]

Parameter	Removal efficiencies					Sludge volume, V_{SL}	Cost	pH variation	Sum
	COD	BOD_5	TSS	T–P	T–N				
Weight	6.6***	12.4	9	4.5	4.5	16	39	8	100

***Note: 6.6 = (18/100)*37 = 6.6.

3. Results and discussion

3.1. Alum and sea-salt

Alum and sea-salt were applied as coagulants to chemical precipitation of wastewater with different doses as mentioned before. Figs. 2 and 3 show that the COD removal efficiency was ranged between 48 and 87% with alum, while for sea-salt it increased from 39 to 55%. On the other hand, alum and sea-salt caused a reduction in the removal efficiency of BOD_5 that ranged between 40–93%, and 38–60%, respectively. The removal efficiency of TSS reached up to 94% for alum and 85% for sea-salt. In addition, the maximum removal efficiencies of T–P were recorded to be 96 and 83% with alum and sea-salt coagulants, respectively, while the removal efficiencies of 20 and 15% of T–N were the highest values with the use of alum and sea-salt, respectively.

Results showed that the application of alum increased the removal efficiencies for all parameters when compared with that achieved from the previous studies [1–5] (i.e. removal efficiencies reached up to 90% of TSS, 80% of BOD_5, 70% of COD, and 95% of T–P), while sea-salt did not give satisfied removal efficiencies for the different parameters specially BOD_5. Doses of sea-salt greater than 160 mg/L may improve the reduction of the different parameters, but inhibition of bacterial activation in the biological treatment may be expected due to overdoses of sea-salt as well as increased pH value. Therefore, sea-salt gives a vulnerable effect in the coagulation process due to its relatively low charge cation. In addition, sea-salt may be used only as a coagulant aid to support other coagulants such as alum.

3.2. Homogenous mixtures of alum and sea-salt

Homogenous mixtures of alum and sea-salt were applied as coagulants for the chemical precipitation of wastewater to reach to satisfied values of removal efficiencies of the different pollutants as well as to obtain a relative reduction in the cost of chemical coagulants.

Figs. 4–6 show that COD removal efficiency was ranged between 48 and 85% with mixture (1); while for mixture (2), it increased from 46 to 77%; as well as the range between 40 and 65% of COD removal was recorded with mixture (3). Furthermore, mixture (1), mixture (2), and mixture (3) caused a reduction in BOD_5 that ranged between (40–90%), (40–80%), and (40–69%) in that order. The removal efficiency of TSS reached up to 94% for mixture (1), 89% for mixture (2), and 88% for mixture (3). In addition, the maximum removal efficiencies of T–P were recorded to be 92, 88, and 95% with mixture (1), mixture (2), and mixture (3) correspondingly, while removals of 20, 18, and 17% of T–N were the highest values with the use of mixture (1), mixture (2), and mixture (3), respectively.

Results confirmed that the application of mixture (1) increased the removal efficiencies for all parameters which were very close to that obtained from alum. Moreover, there was slight reduction in the removal efficiencies obtained from mixture (2) when compared with that obtained from alum and mixture (1). On the other hand, the application of mixture (3) recorded a significant increase in removal efficiencies compared with that obtained from sea-salt.

3.3. Effect of different coagulants on pH value of primary treated wastewater

Fig. 7 shows that pH value was in the range between 6 and 9 through all experiments, but pH variation differed according to the type and dose of coagulant. The pH value tapered from 7.9 to 7.5 with a relative increase in alum dose, while increase in the doses of sea-salt caused a corresponding increase in the pH value from 7.5 to 8.8. Moreover, the pH variation was relatively decreased when using homogenous mixtures of alum and sea-salt as coagulants. This makes pH value of primary treated sewage suitable for optimization of consecutive biological treatment contrary to the use of sea-salt in the present study as well as using mixtures of alum and lime in the previous study [8], which did not give satisfactory results; this is because even if the lime dosage was too small, the effect on increasing pH value was very great. Hence, the pH variation reflects a comparative advantage for the use of homogenous mixtures of alum and sea-salt as coagulants.

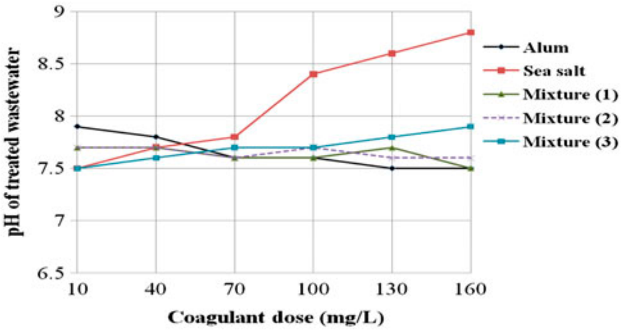

Fig. 7. pH values of primary treated wastewater vs. doses of different coagulants.

3.4. Effect of different coagulants on sludge production from chemical precipitation of wastewater

Fig. 8 shows the relationship between the volumes of sludge (V_{SL}) after 30 min of sedimentation and the doses of different coagulants. Volumes of sludge reached to close values with the application of alum, mixture (1), and mixture (2) which located in the ranges of (7–25), (7–23), and (6–23) ml/L in that order, while sea-salt, and mixture (3) recorded a relative decline in the values of sludge that ranged between 3 and 16 ml/L in case of sea-salt as well as range between 5 and 19 ml/L was recorded with the use of mixture (3). These results indicate to some extent, on the efficiency of the chemical precipitation with the use of the different coagulants which are summarized in the direct proportion between volume of sludge production and removal efficiencies.

3.5. Analysis of results using AHP

Table 6 presents the results of the different alternatives which resulted in BOD_5 removal of more than 60% (i.e. the lowest value acceptable to maximize the capacity of primary sedimentation and biological treatment). Moreover, Table 7 shows the rating of the different alternatives according to each criterion. Fig. 9 represents sorting and order of the different alternatives according to AHP analysis and its relative efficiencies.

Results of AHP demonstrated that mixture (1) was established as the best coagulant with a dose of

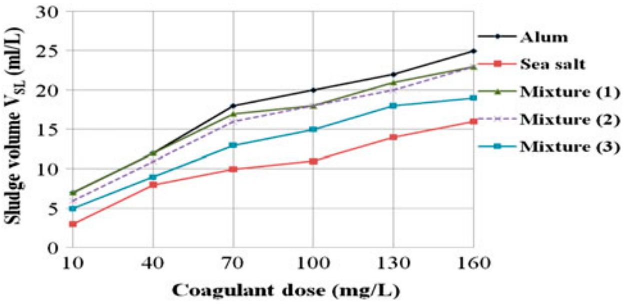

Fig. 8. Sludge volumes vs. doses of different coagulants.

Table 6
Results of the different alternatives

No.	Coagulant type-dose (mg/L)	Removal efficiencies					V_{SL} ml/L	Cost EGP/m^3	pH variation%
		COD%	BOD_5%	TSS%	T–P%	T–N%			
1	Alum 40	72	80	88	90	15	12	0.06	1.3
2	Alum 70	78	82	93	93	17	18	0.105	3.8
3	Alum 100	84	88	93	94	18	20	0.15	3.8
4	Alum 130	85	93	96	95	18	22	0.195	5
5	Alum 160	87	93	94	96	20	25	0.24	5
6	Mixture (1) 40	68	75	84	80	12	12	0.043	0.01
7	Mixture (1) 70	75	78	90	84	14	17	0.075	1.3
8	Mixture (1) 100	81	84	91	90	16	18	0.107	1.3
9	Mixture (1) 130	83	89	94	92	18	21	0.139	0.01
10	Mixture (1) 160	85	90	94	92	20	23	0.171	2.6
11	Mixture (2) 40	55	66	77	62	9	11	0.034	1.3
12	Mixture (2) 70	66	70	85	70	10	16	0.059	2.6
13	Mixture (2) 100	71	75	85	82	13	18	0.085	1.3
14	Mixture (2) 130	75	79	89	85	16	20	0.11	2.6
15	Mixture (2) 160	77	80	89	88	18	23	0.136	2.6
16	Mixture (3) 100	57	61	82	78	11	15	0.064	2.6
17	Mixture (3) 130	60	65	86	83	15	18	0.083	3.9
18	Mixture (3) 160	65	69	88	95	17	19	0.1024	5.3
	Optimum results	87 max	93 max	96 max	96 max	20 max	25 max	0.034 min	0.01 min

Table 7
Rating of the different alternatives according to each criterion

No.	Coagulant type-dose (mg/L)	Removal efficiencies%					V_{SL}	Cost	pH variation	Total	Relative efficiency%
		COD	BOD_5	TSS	T–P	T–N					
	Weight-from Table 5	6.6	12.4	9	4.5	4.5	16	39	8	100	
1	Alum 40	5.46* = 0.72 × 6.6	10.67** = 0.8 × 12.4	8.25	4.22	3.38	7.68	22.10	0.06	61.81	81.3*** = (61.81/76) × 100
2	Alum 70	5.92	10.93	8.72	4.36	3.83	11.52	12.63	0.02	57.92	76.2
3	Alum 100	6.37	11.73	8.72	4.41	4.05	12.80	8.84	0.02	56.94	74.9
4	Alum 130	6.45	12.40	9.00	4.45	4.05	14.08	6.80	0.02	57.25	75.3
5	Alum 160	6.60	12.40	8.81	4.50	4.50	16.00	5.53	0.02	58.35	76.8
6	Mixture (1) 40	5.16	10.00	7.88	3.75	2.70	7.68	30.84	8.00	76.00 Max.	100
7	Mixture (1) 70	5.69	10.40	8.44	3.94	3.15	10.88	17.68	0.06	60.24	79.3
8	Mixture (1) 100	6.14	11.20	8.53	4.22	3.60	11.52	12.39	0.06	57.67	75.88
9	Mixture (1) 130	6.30	11.87	8.81	4.31	4.05	13.44	9.54	8.00	66.32	87.3
10	Mixture (1) 160	6.45	12.00	8.81	4.31	4.50	14.72	7.75	0.03	58.58	77.1
11	Mixture (2) 40	4.17	8.80	7.22	2.91	2.03	7.04	39.00	0.06	71.22	93.7
12	Mixture (2) 70	5.01	9.33	7.97	3.28	2.25	10.24	22.47	0.03	60.59	79.7
13	Mixture (2) 100	5.39	10.00	7.97	3.84	2.93	11.52	15.60	0.06	57.31	75.4
14	Mixture (2) 130	5.69	10.53	8.34	3.98	3.60	12.80	12.05	0.03	57.04	75
15	Mixture (2) 160	5.84	10.67	8.34	4.13	4.05	14.72	9.75	0.03	57.53	75.7
16	Mixture (3) 100	4.32	8.13	7.69	3.66	2.48	9.60	20.72	0.03	56.63	74.5
17	Mixture (3) 130	4.55	8.67	8.06	3.89	3.38	11.52	15.98	0.02	56.06	73.8
18	Mixture (3) 160	4.93	9.20	8.25	4.45	3.83	12.16	12.95	0.02	55.78	73.4

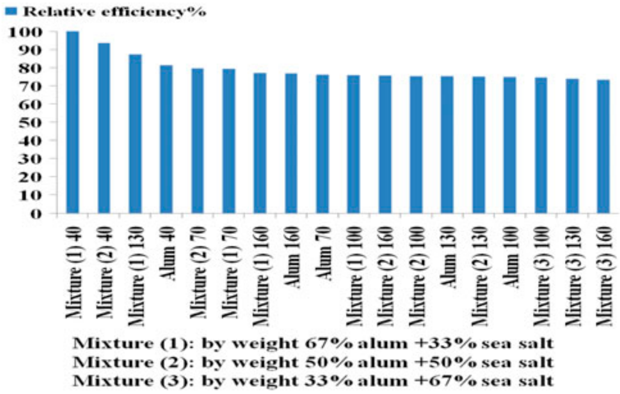

Fig. 9. Ranking of the different alternatives according to relative efficiency.

40 mg/L. In addition, the different alternatives were ordered according to several fundamental parameters which simultaneously were taken into consideration. Furthermore, the relative efficiency of the first position [i.e. mixture (1) 40] was assumed to be 100%, and the relative efficiencies of the other alternatives were related to this value.

Mixtures (1 and 2) as coagulants ranked the first, the second, and the third positions in AHP analysis. This indicates that the homogenous mixtures of coagulants give relatively better results than their individual components (i.e. alum and sea-salt in the present study), while alum appeared in the fourth and the eighth position with doses of 40 mg/L, and 160 mg/L, respectively although optimum removal efficiencies were recorded with alum 160 mg/L (i.e. the eighth position).Hence, evaluation of monocriteria would have given unsatisfactory results.

4. Conclusions

The obtained results reveal the following conclusions:

- Direct chemical precipitation of wastewater improves the removal efficiencies to reach up to 87% of COD, 93% of BOD_5, 94% of TSS, 96% of T–P, and 20% of T–N as well as it greatly reduces the settling time in the primary treatment to about 30 min rather than about 2 h in the conventional primary sedimentation.
- Chemical precipitation removes about 50% of the organic load influent to the biological treatment in the conventional activated sludge systems. This enables to treat additional quantities of wastewater which may reach to double the designed capacity of WWTP.
- Sea-salt as a sole coagulant gives a vulnerable effect in the coagulation process due to its relatively low charge cation as well as it increases pH value of primary treated wastewater which may inhibit the action of micro-organisms in the consecutive biological treatment.
- The homogenous mixtures of alum and sea-salt were applied as coagulants to reduce cost of the treatment and resulted in satisfied values of removal efficiencies. Moreover, the least pH variation was recorded with the application of mixtures.
- Mixtures (1) (i.e. 67% aluminum + 33% sea-salt), and (2) (i.e. 50% aluminum + 50% sea-salt) as coagulants ranked the first, the second, and the third positions in AHP analysis. This indicates that the homogenous mixtures of coagulants give relatively better results than their individual components (i.e. alum and sea-salt in the present study).
- Evaluation of monocriteria would have given unsatisfactory results. This is evident in the appearance of alum with dose of 160 mg/L in the eighth position although optimum removal efficiencies were recorded with it.

References

[1] C.R. O'Melia, Coagulation in water and wastewater treatment, in: E.F. Gloyna, W.W. Echenfelder (Eds), Water Quality Improvement by Physical and Chemical Processes, University Texas Press, Austin, TX, 1970.

[2] H. Ødegaard, Chemical wastewater treatment – value for money, in: H. Hahn, R. Klute (Eds), Chemical Water and Wastewater Treatment, Springer Verlag, Berlin, 1989.

[3] Metcalf & Eddy, Inc., George Tchobanoglous, Franklin L Burton, H. David Stensel, Wastewater Engineering Treatment and Reuse, fourth ed., Mc Graw-Hill, New York, NY, 2003.

[4] Swedish Environmental Protection Agency, Cost Effective Methods, Final ed., 2003 (Corr. LH).

[5] I.G. Rashed, M.A. El-Komy, A.A. Al-Sarawy, H.F. Al-Gamal, Chemical treatment of sewage, The First Scientific Conference of the Egyptian Society for the Development of Fisheries Resources and Human Health, El Arish, Egypt, 1997.

[6] Environmental Protection Agency EPA, Wastewater Technology Fact Sheet Chemical Precipitation, Office of Water, Washington, DC, 2000.

[7] Zhou, Qianqian, Investigation on improving efficiency of pre-precipitation process at Sjölunda wastewater treatment plant, M.Sc. Water and Environmental Engineering, Chemical Engineering Department, Lund University, Sweden, 2009.

[8] S.S. Younis, N.M. Al Mansi, S.H. Fouad, Chemically assisted primary treatment of municipal wastewater, J. Environ. Manage.Health 9(5) (1998) 209–214.

[9] E. El-Bestawy, H. Hussien, H. Baghdadi, M.F. El-Saka, Comparison between biological and chemical treatment of wastewater containing nitrogen and phosphorus, J. Ind. Microbiol. Biotechnol. 32 (2005) 195–203.

[10] C.A. Kfouri, H.J. Kweon, Seawater as a coagulant substitute and the effects on disinfection in chemically enhanced primary wastewater treatment: A Case study of Paraty, Brazil

and Deer Island wastewater treatment plant, Boston, Master of Engineering in Civil and Environmental Engineering, Massachusetts Institute of Technology, 2003.

[11] S.V. Guansekara, Improvements on Municipal Wastewater Treatment by: Chemical Pre-precipitation with Ca^{+2}, Mg^{+2} and Acid Hydrolysis of Toilet Paper, M.Sc. Thesis, Royal Institute of Technology, Stockholm, 2011.

[12] M. Henze, P. Harremóes, J. Jansen, E. Arvin, Wastewater Treatment, Biological and Chemical processes, third ed., Springer, Heidelberg, 2002.

[13] A Aygun, T Yilmaz, Improvement of coagulation–flocculation process for treatment of detergent wastewater using coagulant aid, International Journal of Chemical and Environmental 1(2) (2010) 97–101.

[14] M.A. Ashmawy, M.S. Moussa, A.K. Ghoneim, A. Tammam, Enhancing efficiency of primary sedimentation in wastewater treatment plants with the application of Moringa Oleifera seeds and quick lime, J. Am. Sci. 8 (2012) 494–502.

[15] Giovanni De Feo, Sabino De Gisi, Mawrizio Galasso, Definition of a practical multi- criteria procedure selecting the best coagulant in a chemical assisted primary sedimentation process for the treatment of urban wastewater, J. Desalin. 230 (2008) 229–238.

[16] T.M. Saaty, Decision making with the analytic hierarchy process, Int. J. Serv. Sci. 1 (2008) 83–98.

[17] Standard Method, Standard Methods for the Examination of Water and Wastewater, 20th ed., American Public Health Association, Washington, DC, 1998.