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Selection of coagulant using jar test and analytic hierarchy process: A case study of Mazandaran textile wastewater

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Abstract. Textile factories are one of the industries which its wastewater treatment is a challenging issue, especially in developing countries and a conventional treatment cannot treat all its pollutants properly. Using chemical coagulants is a technique for physical and chemical primary treatment of the wastewater. We applied jar test for selection of suitable coagulant among the five coagulants including alum, calcium hydroxide, ferrous sulfate, ferrous chloride and barium chloride for the effluent of wastewater in Mazandran textile factory located in Mazandran Province, Iran. In addition, jar test, we also used analytic hierarchy process (AHP) method considering criteria which included coagulation cost, sensitivity to pH change, the amount of sludge generation and side effects for coagulation. The results of the jar test indicated that calcium hydroxide was proper among the coagulants which it removed 92.9% total suspended solid (TSS), 70% dye and 30% chemical oxygen demand. The AHP analysis presented that calcium hydroxide is more suitable than other coagulants considering five criteria.

Keywords: Mazandran textile factory; jar test; analytic hierarchy process (AHP)

1. Introduction

Protection of water quality of the river is a challenging issue.For keeping water quality to an acceptable level for different usage, all effluent discharges into the rivers should be treated to satisfy the standard which defined by the local water authority. Entering the effluent of wastewater from the textile factories into the surface water without proper treatment will cause emerge environmental problems such as oxygen reduction and algae growth. Also to discharge such wastewater to sewage network and domestic wastewater treatment, causes clogging of the network, disturbance to sedimentation units, reduction of oxygen in aeration tanks and disturbance on microorganism growing (Mahdavi 1998).

Jar test often used for physical and chemical wastewater treatment. Several researchers have

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been studied wastewater treatment using the jar test. Barredo-Damas *et al.* (2005) applied jar test before and after using ozone for treatment of wastewater of textile factories. Their result indicated removal of 57% COD and 95% turbidity. Bayramoglu *et al.* (2007) used electrical coagulation, including aluminum and iron electrode for treatment of wastewater from textile factory and assessed economic of the method. They determined both electrodes have similar effects on removal COD and turbidity. Kumar *et al.* (2008) achieved the commercial alum the most effective coagulant between various coagulants including aluminum potassium sulfate, poly-alumni chloride (PAC), $FeCl_3$ and $FeSO_4$. Their result indicated 58.57% COD and 74% dye removal at the pH of 4 using the coagulant dose of 5 kg/m^3. Bidhendi *et al.* (2007) investigated on COD, dye, TSS and turbidity removal from wastewater of textile factories. They determined that calcium hydroxide and other coagulations can remove dye and COD from textile wastewater. Gohari *et al.* (2009) studied the removal of dye from wastewater using magnesium chloride, calcium hydroxide and aluminum sulfate. They indicated 50% COD and 100% dye removal. Gohari *et al.* (2010) also applied two systems of pretreatment first including coagulation, flocculation and sedimentation and the second containing floating. They used three coagulation including, ferric chloride, aluminum sulfate and ferrous sulfate. The results described all the coagulation containing similar COD removal. Zengooei *et al.* (2016) investigated the coagulation and the flocculation process by poly-aluminum chloride (PAC) coagulant using modeling tools such as artificial neural networks and fuzzy regression in a water treatment plant in Iran. Their results showed that MLP networks have best Performance to simulate this process.

A Jar test is a time consuming method because several tests need to determine which coagulant is suitable for physical and chemical wastewater treatment. To reduce the times of testing and also considering other criteria, some researchers applied multiple-criteria decision-making or multiple-criteria decision analysis (MCDA). Aragones-Beltrana *et al.* (2009) applied analytic hierarchy process (AHP) and preference ranking organization method for enrichment evaluations (PROMETHEEs) to prioritize between a polymeric liquid chemical, $FeCl_3$ combined with an anionic polyacrylamide, and a combination of inorganic and organic coagulants (mainly ferric sulphate) and cationic coagulant. They stated that the application of both methods was a useful tool for prioritization of the coagulants. Karimi *et al.* (2010) conducted an investigation using AHP to identify which types of the wastewater treatment, including up flow anaerobic sludge bed (USAB), up flow anaerobic fixed bed (UAFB), anaerobic baffled reactor (ABR) and anaerobic lagoon was the best considering technical, economic, environmental and administrative criteria. They ranked 1 to 4 in a descending order of UAFB, ABR, UASB and anaerobic. Srdjevic *et al.* (2012) used AHP to prioritize between chemical treatment, evaporation, separated by the use of the membranes and biological treatment for treatment colored metals in Serbia. They used seven typical criteria for the wastewater treatment, including energy consumption, the price of the chemicals, effectiveness, simplicity of the process, the price of the facilities, ecological impact, and necessary educational level of the workers. Their results indicated ecological impact and energy consumption contained higher weight related to other criteria. Kalbar *et al.* (2012) used technique in order of preference by similarity to Ideal Solution (TOPSIS) to identify the most appropriate wastewater treatment. They concluded that the identification of appropriate waste water treatment alternatives was difficult under no scenario. Kalbar *et al.* (2013) conducted a study for types of wastewater treatment selection using AHP. They stated that the skilled people, mostly select natural treatment system. Nevertheless, pairwise comparison matrices based on skilled people recommended advanced technology for industrial wastewater treatment. Ilangkumaran *et al.* (2013) compared AHP under fuzzy environment, Preference Ranking Organization technique for

Enrichment Evaluation (PROMETHEE) and hierarchy Grey Relation Analysis (GRA) techniques for appropriate selection of wastewater treatment. They suggested that the fuzzy analytical hierarchy process (FAHP) is integrated with a preference ranking organization method for enrichment evaluation (PROMETHEE) technique and the FAHP is integrated with hierarchy Grey Relation Analysis (GRA) method.

Mazandaran textile factory is located in Ghaemshahr City, west of Seyahrud River, Mazandran Province, located on the southern coast of the Caspian sea, Iran. The geography coordinate is 36° 27′ 47″ N, 52° 51′ 36″ E. The production capacity of the factory is 5000 meters cotton and 800 kg hydrofoil cotton daily. The wastewater of the factory flow into the Sefid Rud River without proper treatment.

The first objective of the study was to select suitable coagulation for physical and chemical wastewater treatment of Mazandaran textile factory using the jar test. The second aim was to apply the Analytic Hierarchy Process (AHP) to identify the type of the proper coagulant among the alum, calcium hydroxide (lime), ferric chloride, ferrous sulfate and barium chloride considering cost, efficiency, sensitivity to pH changing, sludge generation and side effect criteria.

2. Materials and methods

We collected textile wastewater samples every five days during the summer and winter in 2014 and followed the procedure of testing according to examination of water and wastewater (2005). We carried out physical-chemical examination using multiple stirred Jar Test apparatus with 5 different coagulants with different pHs. The coagulants included alum, calcium hydroxide, ferric chloride, ferrous sulfate and barium chloride. We agitated textile wastewater and coagulants for 3 minutes with speed of 100 rpm. After that, the jar test was performed for each coagulants by changing pH to identify which pH reaches to a maximum total suspended solid (TSS) removal. Next, the testing carried out using the optimized pH from the first stage and again changing coagulants concentration of each coagulant to identify the optimized coagulant concentration which resulted in maximum TSS removal. All the tests were conducted for 15 minutes with speed of 30 rpm. At last, the flocculated wastewaters were precipitated for 30 minutes (ASTM 1995).

3. The analytic hierarchy process (AHP)

The AHP can solve multiple criteria decision making (MCDM) problem through a goal, criteria and alternative. The method developed by Saaty (1980).

The AHP method includes the following steps:

1- Define the objective which in our study was to select the appropriate coagulant.

2-Structure of the elements in groups of criteria, sub criteria and alternatives.

3-Make a paired comparison of the element and calculating consistency ratio.

4-Using eigenvector method to estimate the ratio scale and Eigenvalue for consistency index.

5-Evaluate alternative according to the weighting and final rank our criteria.

Saaty (2000) defined a mechanism for inconsistency in justification. Whether the consistency ratio is equal or less than 0.1, the judgment is acceptable. Otherwise the judgment should be reconsidered (Sabardast 2001). After achievement type and concentration of optimized coagulant experimentally, we applied the AHP technique considering efficiency, cost, and sensitivity to changing pH, side effect and sludge of the coagulants to determine optimized coagulant. We requested the significance of the each above parameters through sending the questionnaires to the wastewater treatment experts. They responded the questionnaires using the fundamental scale for paired comparison (Saaty 2008).

For calculation of AHP, we used Expert Choice software. The software receives quality data as indicated in First, we defined our objective of our analysis of the software and then defined criteria which first included cost, efficiency, sensitivity to pH changing, sludge generation and side effect. The side effect means the deteriorating effect of using coagulation such as using alum causes calcium hardness and corrosion on the equipment. The next step was paired comparison of the criteria. In the Expert Choice software is available three comparisons, including importance, preference and likelihood. In this paper, we applied the preference.

Table 1 The effluent characteristics of Mazandran textile wastewater

Time of sampling	Average temperature (C°)	Wastewater temperature (C°)	pH	BOD_5 (mg/l)	COD (mg/l)	TSS (mg/l)	Color (TCU[1])	TP (mg/l)	TN (mg/l)
January 14, 2014	-4	2	5.8	410	980	272	150	1.1	2.10
January 21, 2014	-2	3	8	373	750	278	155	3.1	12
February 3, 2014	1	5	5.8	355	1000	287	140	1	1.10
February 9, 2014	-11	1	5.8	425	1040	282	150	1.79	5.12
February 26, 2014	0	6	8	420	929	281	129	1.35	3.12
July 23, 2014	30	5.32	36.8	380	800	262	145	1.19	14
July 28, 2014	25	27	55.8	360	1150	253.5	140	1.05	3.14
August 1, 2014	5.24	5.26	5.9	430	1158	298	150	1	15
August 6, 2014	5.22	25	6.9	370	984	310	150	1.3	8.15
August 11, 2014	6.25	27	5.9	360	840	235	135	1.22	2.15
August 16, 2014	5.21	5.25	5.9	400	992	270	135	1.1	5.15
August 27, 2014	17	20	8.8	370	900	213	140	1	14.1
Mean	67.4	67.9	8.78	387.75	960.25	270.13	143.25	1.2	13.42
Standard deviation	947.14	526.11	0.6	27.6	125.76	26.66	7.94	0.22	1.97
Maximum	6.25	7.32	9.6	430	1158	310	155	1.79	15.8
Minimum	-11	1	8	355	750	213	129	1	10.1

4. Results and discussion

Table 1 indicates the characteristic of Mazandran textile waste. As illustrated in Table 1, the maximum values of BOD, COD, TSS, phosphate and nitrogen were 430, 1158, 310, 1.79 and 15.8 mg/l respectively.

The characteristics of wastewater for jar test were 355 mg/l, 1000 mg/l, 287 mg/l, 8.5 and 140 TCU for BOD, COD, TSS, pH and Dye, respectively.

The first step for selection of coagulation, we changed pH and measured TSS removal. Afterward, the pH, which contained the maximum removal of TSS was chosen as optimized pH. In the second stage, we changed the amount of coagulation with the optimized pH and determined the amount of coagulation which reached to maximum TSS removal. We conducted Jar Test using 1000 mg/l alum for different pH. Fig. 1 indicates the removal of TSS with different pH. As presented in Fig. 2, the maximum TSS removal was achieved using the optimized consuming of alum (1200 mg/l) for the fixed pH of 6. Fig. 3 presents the effects of changing pH of removal of TSS using 600 mg/l lime. We determined the TSS removal from the wastewater using different lime concentrations for the fixed pH of 6, and observed the minimum TSS when used 1000mg/l lime. Fig. 5 indicates variations of pH using 300mg/l ferric chloride in Jar test in the textile wastewater sample, the maximum TSS removal occurred at the pH of 2 and 4. We applied different ferric chloride concentrations for the TSS removal at pH2 and observed the TSS reached to 33.5 mg/l for using 400 mg/l of ferric chloride (Fig. 6). The same test with different ferric chloride concentrations for the TSS removal at pH4 was carried out and observed the TSS reached to 40.5mg/l for using 600 mg/l of ferric chloride (Fig. 7).

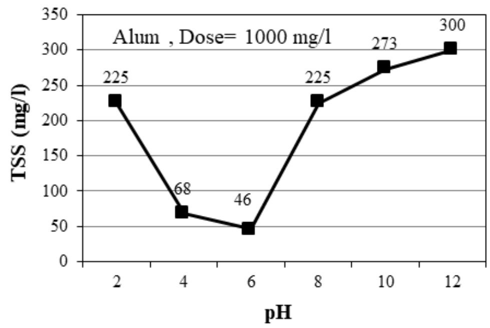

Fig. 1 The effect of changing pH on TSS removal using 1000 mg/1 Alum

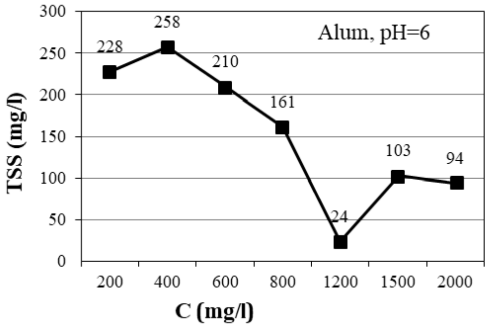

Fig. 2 The effect of changing alum concentration on TSS removal at pH=6

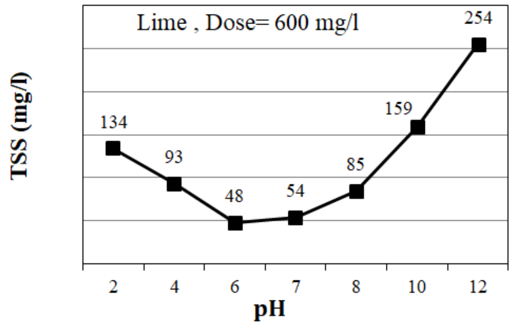

Fig. 3 The effect of changing pH on removal of TSS using 600 mg/1 lime

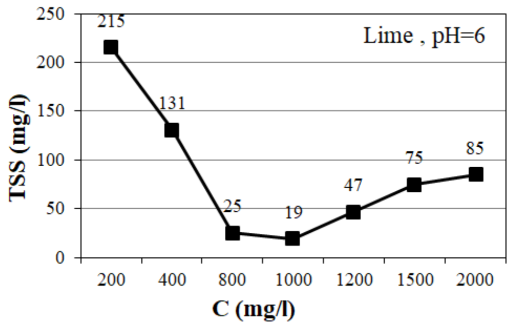

Fig. 4 The effects of changing lime concentration on TSS removal at pH=6 at TSS removal

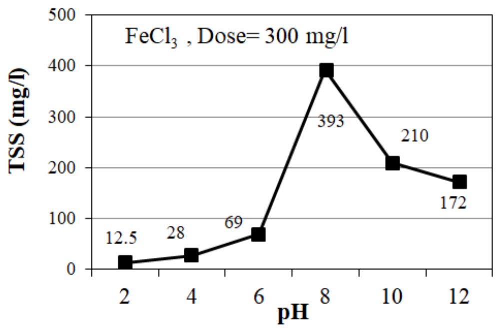

Fig. 5 The effects of changing pH on removal of TSS using 300 mg/l $FeCl_3$

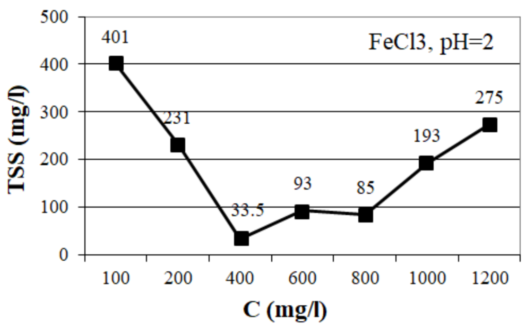

Fig. 6 The effects of changing $FeCl_3$ concentration on TSS removal at pH=2

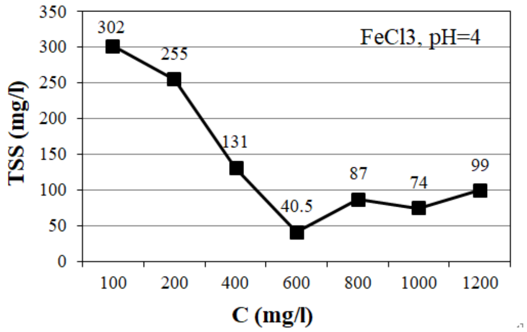

Fig. 7 The effects of changing $FeCl_3$ concentration on TSS removal at pH=4

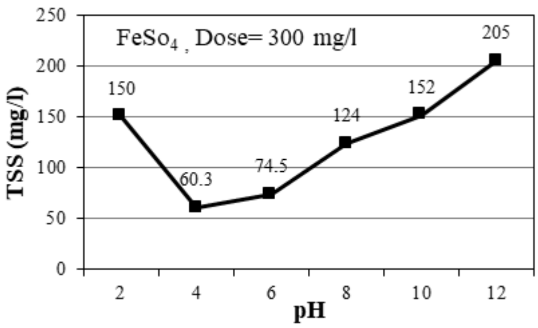

Fig. 8 The effect of changing pH on TSS removal using 300 mg/l FeSO4

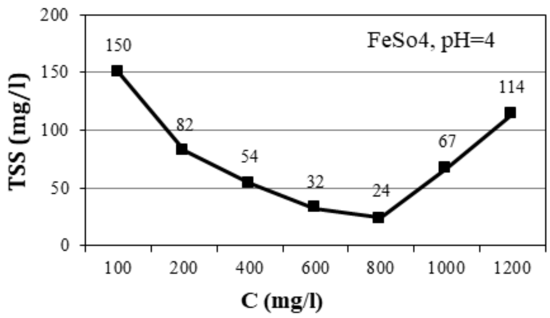

Fig. 9 The effect of changing FeSO4concentration on the TSS removal at pH=4

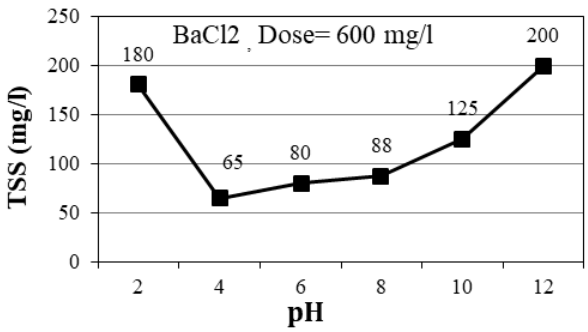

Fig. 10 The effect of changing pH 4 on TSS removal using 600 mg/l BaCl2

Using 300 mg/l ferrous sulfate in the Jar test of the textile wastewater sample with different pH, the maximum TSS removal occurred at pH4 (Fig. 8). We applied different ferrous sulfate concentrations for the TSS removal at pH4 and observed the TSS reached to 24 mg/l for using 800 mg/l of ferrous sulfate (Fig. 9). After that, we examined the Jar test using 600 mg/l barium chloride and observed maximum TSS removal at pH4 (Fig. 10). At the end, with different concentration of barium chloride, the maximum barium chloride occurred at 800 mg/1 containing pH4.

The optimization of the wastewater treatment experts associated with the importance of the five factors, including coagulation cost, sensitivity to pH changing, the amount of sludge generation and side effects for selecting of the coagulations was indicated in Fig. 12. Table 2 indicates the summary results of coagulation performance on the wastewater.

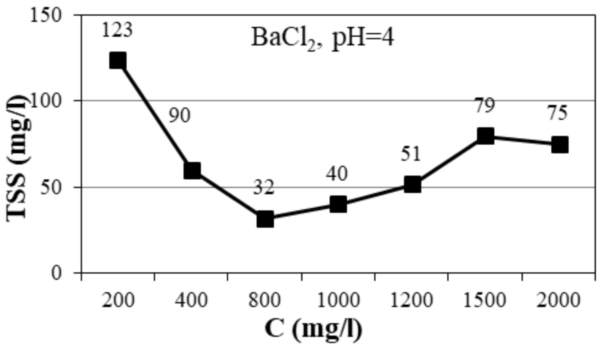

Fig. 11 The effect of changing $BaCl_2$ concentration on the TSS removal at pH=4

Table 2 The summary results of coagulation performance on the wastewater

Coagulation	TSS removal%	Minimums TSS (mg/l)	Optimized amount of coagulants (mg/l)	pH
Alum	91	24	1200	6
Lime	9.92	19	1000	6
$FeCl_3$	5.87	5.33	400	2
$FeCl_3$	85	5.40	600	4
$FeSO_4$	1.91	24	800	4
$BaCl_2$	14.88	32	800	4

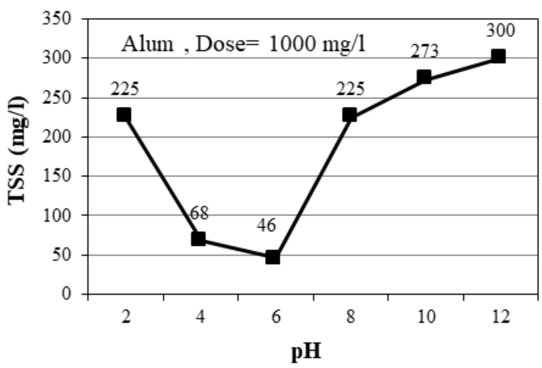

Fig. 12 The importance of the factors for coagulation selection

According to Fig. 12, we established five paired comparison tables. Table 3 indicates a matrix of paired comparisons of the coagulants according to the cost; the same matrix of paired comparisons was performed for the other factors; however, we illustrated one of them.

Table 3 A paired comparisons between the elements according to cost of the coagulants

	Alum	Lime	$FeCl_3$	$FeSO_4$	$Bacl_2$
Alum	1	1/5	1/3	3	1/2
Lime	-	1	3	9	5
$FeCl_3$	-	-	1	5	3
$FeSo_4$	-	-	-	1	1/5
$Bacl_2$	-	-	-	-	1

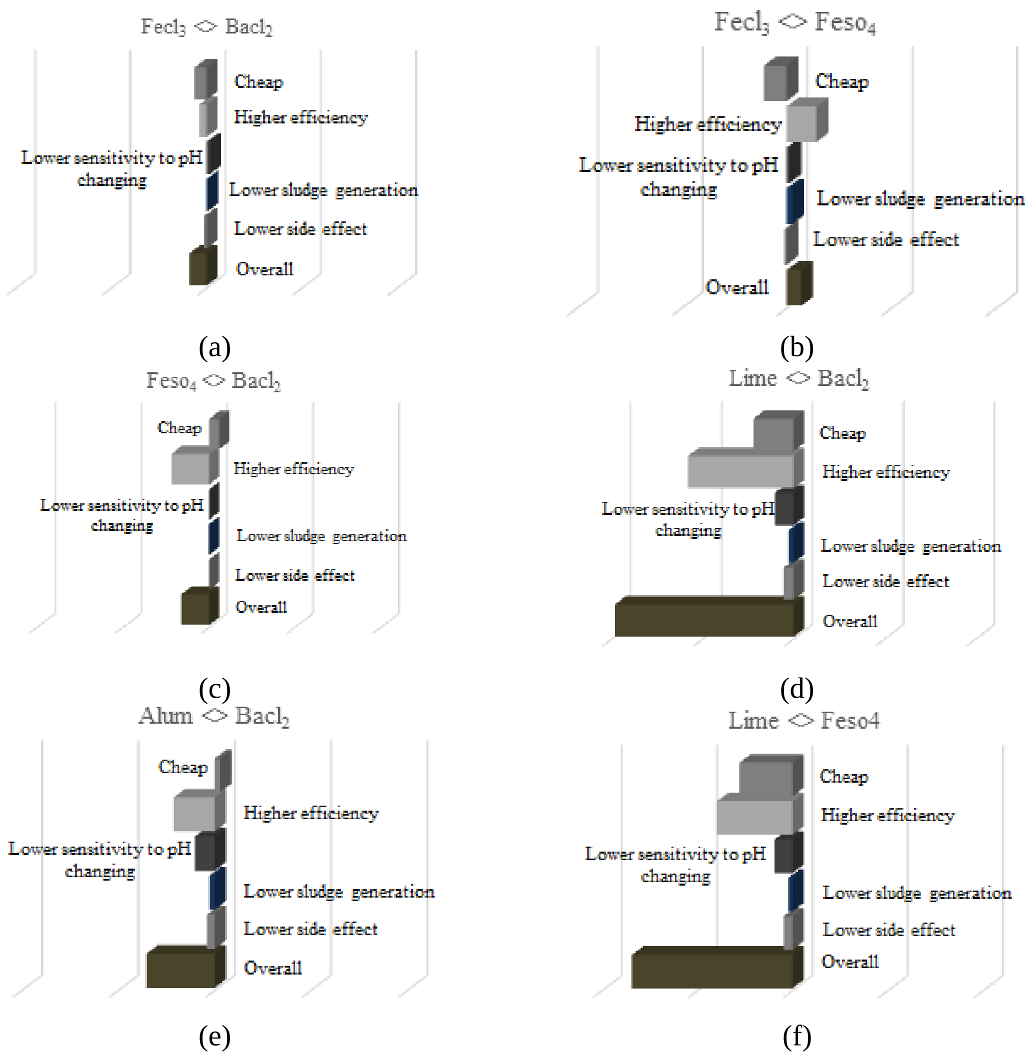

Fig. 13 The paired comparison of the five coagulants

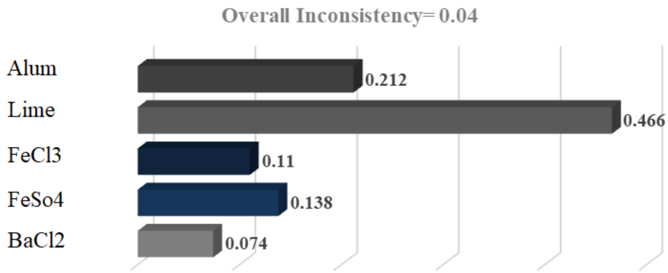

Fig. 14 The results of the priority of selection of the coagulants

Fig. 13 indicates weighted head to head of the coagulants considering cost, efficiency, sensitivity to pH changing, sludge generation and side effect criteria. As described in the Fig. 13, selection of lime is suitable than the alum considering cost and sludge generation. The lime is also proper for coagulant than selecting ferrous sulfate and Barium Chloride considering all the mentioned factors.

Fig. 14 indicates the final preference analysis and the inconsistency ratio. The inconsistency ratio was 0.04 which may present the logic of input data to the software. As presented in Fig. 14, lime contained 46.6% ratio considering coagulant cost, efficiency, sensitivity to pH changing, the amount of sludge generation and side effects. Therefore, lime coagulant in jar test could be the most suitable coagulant related to others. Comparing the AHP result including the five criteria with jar test results, which considered only removal of TSS, lime coagulant was the best for primary physical and chemical treatment of the textile factory.

We tested effluent of the wastewater with selected lime and observed a reduction of COD and dye to 650 mg/l and 42 TCU. This meant 35% COD and 70% dye removal. Therefore, flocculation, and sedimentation using the lime coagulant for primary treatment of the textile factory may be suitable.

5. Conclusions

Considering the results of our study, we summarized the following conclusions:

1- The chemical oxygen demand (COD), biochemical oxygen demand (BOD) and dye of the raw textile wastewater were 750-1158 mg/l, 355-433 mg/l and 129-155 TCU, respectively.

2- The jar test results indicated that the lime was the most suitable coagulant for TSS removal in comparison with alum, ferric chloride, ferrous sulfate and barium chloride.

3- The AHP demonstrated that the lime was the optimized coagulant in the following aspects: economy, efficiency, sensitivity to changing pH, sludge production and side effect criteria.

4- Lime coagulant removed 92.2% TSS from the textile wastewater at pH 6 and concentration of 1000mg/l.

5- The lime coagulant removed 35% COD and 70% dye from the textile wastewater.

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