Simultaneous Application of Electrochemical and Coagulation Processes in Surface Water Treatment

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Abstract: Background and Aim of the study: coagulants have been being used for long to treat surface water and reduction of their use can bring about great economic advantages. Various studies have been reported the acceptable effect of electrochemical process on turbidity elimination. Nonetheless, the effect of simultaneous application of these two processes has not been investigated yet. This study aims to investigate the effect of simultaneous application of electrochemical and coagulation processes on the reduction of coagulant use in surface water treatment. Materials and Methods: this study is experimental type which has been carried out on laboratory scale in a closed system. Water samples were weekly taken from Karaj river-Bilaghan basin during April and their optimum amount of Ferric Chloride ($FeCl_3$) and pH were determined by Jar test. Then, the simultaneous effects of electrochemical and coagulation processes was assessed. Electrochemical process was applied to samples for one minute using iron electrodes along with intense stirring. Turbidity of samples was measured according to the standard method. Results: the optimum amounts of Ferric Chloride and pH were found to be 50 $mg.l^{-1}$ and 8.5, respectively. After processing, the average turbidity of samples decreased from 9.43 NTU to 0.78 NTU. The simultaneous application of electrochemical process with an electrical current of 0.1 A along with the coagulation process using 25 $mg.l^{-1}$ and 37.5 $mg.l^{-1}$ of Ferric Chloride reduced the average turbidity by 89.19% and 90.22%, respectively. **Conclusion:** results showed that simultaneous application of electrochemical process with a current density of 0.315 $mA.cm^{-2}$ can reduce the concentration of coagulant by half of its optimum amount.

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Introduction

In water treatment facilities along with the determination of an appropriate type of coagulant to eliminate turbidity and organic compounds, it is also so important to find efficient methods which reduce the costs and chemicals use [1]. Currently, no. 1 and no. 2 water treatment facilities of Tehran can treat nearly 15 $m^3.sec^{-1}$ of Karaj river water. Untreated water undergoes a preliminary treatment at Bilaghan basin and is pre-chlorinated before running 30 kilometers towards treatment facilities. The untreated water, entering the mentioned treatment facilities, requires no complicated treatment processes and carries no heavy metals, taste or smell but it just gets turbid in the case of heavy rains and flooding [2, 3]. According to the Iranian standards, the acceptable level of turbidity for treated water is 1 NTU, while the water leaving these treatment facilities is well below this tolerance limit [2-5]. Use of coagulants such as Ferric Chloride, lime, Alum and so on is a necessity for precipitation of colloidal particles. Some of the disadvantages to coagulation method can be listed as extreme use of chemicals, problems with utilization and maintenance, the methods of injecting these materials into the treatment system, production of great amount of sludge and problems with their sewerage, and also extreme use of water. The mentioned treatment facilities use Ferric Chloride to treat the entering untreated water [6-8].

During recent years, a lot of attentions had been paid to development of the direct application of electricity in water treatment. The result is an ingenious method of water coagulation which is called electrocoagulation or electrochemical method. In this method DC electricity passes through two iron- and/or aluminum-made electrodes which are submerged in water. The ions leaving sacrificial electrodes pass through the electrolyte and separate undesirable contaminants through chemical reactions and precipitation and also coagulate colloidal materials as well. Then, the yielded materials are separated using electrolytic flotation or precipitation and filtration. Disinfection is also takes place as a result of anodic oxidation [9].

This process has recently been reported to efficiently reduce the turbidity and bacteriology indices of contaminated waters [10-16]. As an example study, Rabbani et al applied electrochemical process to contaminated water and managed to eliminate 100% of coliforms, 89.2% of turbidity and 91.11% of HPC [17]. In a study by Abuzaid et al, they have succeeded to eliminate 95 percent of turbidity by means of electrochemical process using iron electrodes and an electrical current of 1 A [18]. Kobya et al showed that electrocoagulation of turbid water with Fe-Al electrodes for about 30 minutes results in an elimination yield of 96.5% [19]. Electrocoagulation process is one the most efficient methods of water and waste water treatment because of its unique benefits such as its wide applicability for treatment of various types of waters and waste waters, simple system design, lower installation and utilization costs, requiring no specific chemicals, and quite less sludge production [1, 14, 15, 20]. On this basis, this study aims to investigate the effect of simultaneous application of electrochemical and coagulation processes on reduction of coagulant use in surface water treatment.

Materials and Methods

This is an experimental study of untreated water samples of Karaj River which was carried out on laboratory scale in a closed system with 4 replications. Untreated water samples were weekly taken from Bilaghan basin during a four-week period and analyzed in laboratory. To determine the optimum concentration of Ferric Chloride coagulant, Jar test was carried out on each sample in the concentration range of 3-60 mg.L^{-1}. Then, the optimum pH was investigated at the previously-determined optimum coagulant concentration by adjusting solution pH in the range of 3.5-7 and above 8 using acid and base [21]. Solution pHs were recorded by means of a digital pH meter. A more precise determination of the optimum coagulant concentration was carried out at the optimum pH in a concentration range about previously-determined concentration. The indicator of optimum concentration and pH was the residual turbidity after treatment which was measured in terms of NTU using a 2100P TURBIDIMETER. Jar test was done in the case of both intense stirring (80 rpm) for one minute and slow stirring (35 rpm) for 15 minutes. Then, to measure the residual turbidity, samples were given 20 minutes for precipitation and sampling was subsequently done beneath the solution surface.

After specifying the optimum coagulant concentration and pH, the effect of simultaneous application of coagulation and electrochemical processes was investigated. To achieve this, untreated water samples were treated at the optimum pH using a combination of optimum concentration multiples (multiplied by 1, 1.2, 1.4, and 3.4) and various current densities (0.1, 0.2, 0.3, 0.4, and 0.6 A). The electrochemical process was applied to samples for one minute using iron electrodes along with intense stirring. Finally, the effect of simultaneous use of electrochemical process and coagulant concentration on turbidity elimination level was statically analyzed using Two Way ANOVA model [22, 23].

Results

As mentioned above, the optimum concentration of Ferric Chloride coagulant was determined by performing Jar test in the concentration range of 3-60 mg.L^{-1} and without changing pH. Results are shown in Table 1.

Table 1. Residual turbidity of the water samples after treatment with coagulation process without pH adjustment

Sample 4 untreated sample) turbidity is 18.20 (NTU pH=7/4	Sample 3 (untreated sample turbidity is 5.72 NTU) pH=7/23	Sample 2 untreated sample) turbidity is 6.20 (NTU pH=7/76	Sample 1 (untreated sample turbidity is 7.59 NTU) pH=7/23	Residual Turbidity (NTU) / Concentration of Ferric chloride mg.L^{-1}
9/15	3/01	4/50	4/65	3
5/39	1/32	2/75	3/8	6
4/5	1/25	1/89	2/86	12
4/39	0/98	1/04	1/93	20
1/70	0/88	0/89	0/86	40
2/55	0/79	0/70	0/89	60

According to these results, the residual turbidity is the least in the case of using 40 mg.L^{-1} of coagulant. Thus, to specify the exact amount of optimum concentration, Jar test was done in a concentration range round about 40 mg.L^{-1}. The results are listed in table 2.

Table 2. Residual turbidity of the water samples after treatment with coagulation process in the concentration range round about previously-determined preliminary optimum coagulant concentration

Sample 4 (untreated sample turbidity is 18.20 NTU) pH=7/4	Sample 3 (untreated sample turbidity is 5.72 NTU) pH=7/23	Sample 2 (untreated sample turbidity is 6.20 NTU) pH=7/76	Sample 1 (untreated sample turbidity is 7.59 NTU) pH=7/23	Residual Turbidity (NTU) Concentration of Ferric chloride mg.L^{-1}
1/75	0/90	1/02	1/47	35
1/70	0/88	0/89	0/86	40
1/69	0/86	0/90	0/94	45
1/5	0/85	0/83	0/65	50
2/39	0/88	0/86	0/68	55
2/06	1/76	0/89	0/90	65
4/55	2/79	2/31	1/01	70

According to the results shown in tables 1 and 2, the optimum concentration of Ferric Chloride is 50 mg.L^{-1}, in the absence of pH adjustment. Next step was to determine the optimum pH at Ferric Chloride concentration of 50 mg.L^{-1}. Jar test was done again for various pHs and results are shown in table 3.

Table 3. Residual turbidity of the water samples after treatment with coagulation process along with pH adjustment

Sample 4) untreated sample turbidity is 18.20 NTU(	Sample 3 (untreated sample turbidity is 5.72 NTU)	Sample 2 untreated sample) turbidity is 6.20 (NTU	Sample 1 (untreated sample turbidity is 7.59 NTU)	Residual Turbidity (NTU) pH
11/95	6/50	5/04	5/37	4/5
8/29	5/26	3/80	4/8	5/5
2/27	1/15	1/63	2/15	6/5
1/5	0/85	0/83	0/65	7/5
0/98	0/76	0/81	0/60	8/5
1/55	0/79	1/21	0/71	9/5

According to the results obtained from Jar tests, the optimum concentration of Ferric Chloride is 50 mg.L^{-1}, while the optimum pH is 8.5.

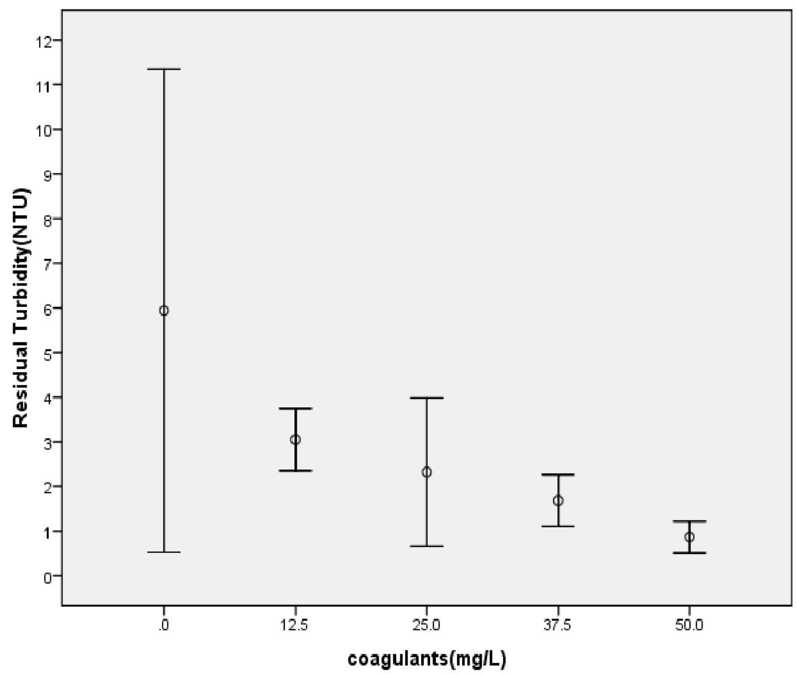

Figure 1. Illustrates the variation of residual turbidity with the concentration of used Ferric Chloride after chemical coagulation (without loading electrical current).

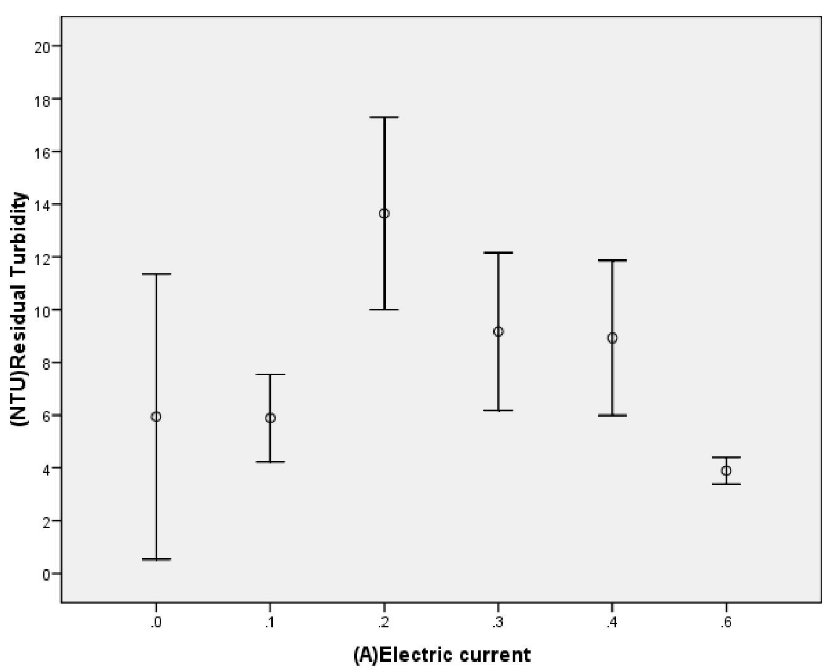

Figure 2. Illustrates the variation of residual turbidity with loaded electrical current after electrochemical process (in the absence of coagulant). Electrical currents were passed through solutions for one minute along with flash mixing.

Table 4 lists the results obtained for simultaneous application of chemical and electrochemical processes with different current densities and coagulant concentrations. These two processes were applied simultaneously and electrochemical treatment was carried out for the duration of one minute.

Table 4. The mean value and standard deviation of turbidity elimination percentage after simultaneous application of electrochemical and coagulation processes

p.value (ANOVA test)	0/6	0/4	0/3	0/2	0/1	صفر	Electrical current mA Coagulant Concentration Mg.L^{-1}	
<0/001	49/09±19/32	-17/25±25/01	-35/26±6/56	-53/76±41/62	22/16±7/93	43/28± 13/24		صفر
	0/995	<0/005	<0/001	<0/001	0/553	-	p.v	
0/553	47/61±17/52	42/91±19/02	47/61±17/52	58/79±14/03	77/38±12/63	64/43± 16/16		12/5
	0/999	0/196	0/395	0/976	0/626	-	p.v	
<0/001	52/60±13/57	37/90±5/83	54/98±7/98	73/39±9/09	89/19±1/91	73/64± 13/78		25
	<0/026	<0/001	<0/053	1/00	0/126	-	p.v	
<0/001	62/53±12/18	31/44±35/87	41/05±10/08	72/14±15/92	90/22±1/23	78/80± 11/95		37/5
	0/587	<0/007	<0/032	0/977	0/834	-	p.v	
<0/001	14/29±4/56	14/25±29/57	0/60±19/35	11/5±70/07	88/17±2/65	88/71±7/23		50
	<0/001	<0/001	<0/001	0/323	1/00	-	p.v	

The simultaneous application of electrochemical and chemical coagulation processes with different current densities and Ferric Chloride concentrations (as multiples of the optimum concentration) are illustrated in figure 3.

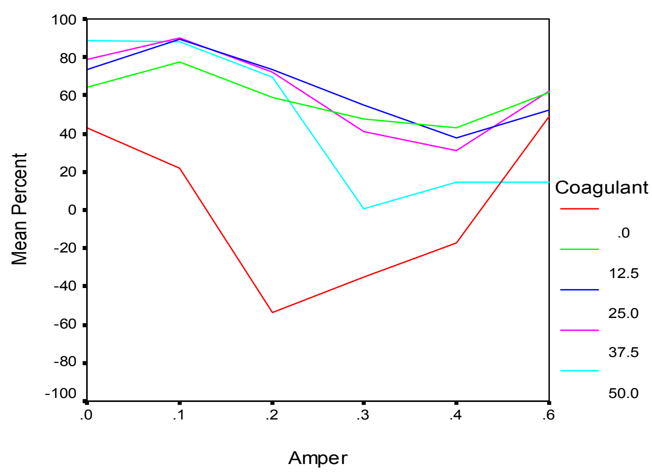

Figure 3. Turbidity elimination process with different current densities and Ferric Chloride concentrations

Discussion

Results obtained for chemical coagulation in the absence of electrochemical process (tables 1 and 2) show that at optimum concentration of 50 mg.L^{-1} and optimum pH of 8.5 the average residual turbidity has decreased from 9.43 NTU to 0.78 NTU with an elimination yield of 91.70%. There is a trivial difference between these findings and those reported in the study by AlaviMoghadam et al on the water entering the Jalaliyeh treatment facility of Tehran. The mentioned study demonstrates that 40 mg.L^{-1} of Ferric Chloride can decrease water sample turbidity from 11 NTU to 0.42 NTU with an elimination yield of 96.25%. This difference seems reasonable by considering the difference in sampling time and place and other conditions for two studies [24]. In addition, there is a good accordance between our results and those reported by Kohestanian et al which have demonstrated the yield of surface water turbidity elimination by Ferric Chloride to be in the range of 85 to 98 percent [25].

According to our findings, the minimum and the maximum amount of residual turbidity respectively belong to the application of 600 mA and 200 mA current densities for one minute through the electrochemical process (figure 2). In addition, comparison of figures 1 and 2 reveals that the application of just electrochemical process for one minute in the absence of any coagulant has very small effect on turbidity elimination because of the short reaction time. Rabbani et al have reported that electrochemical processing of contaminated water with a electrical current of 600 mA for 60 minutes can eliminate the water turbidity by 95.61% [17].

Furthermore, the obtained results demonstrate that the simultaneous application of electrochemical process with a electrical current of 100 mA along with using 37.5 $mg.L^{-1}$ of Ferric Chloride leads to the turbidity reduction by 90.22%, while it will be 89.19% in the case of using 25 $mg.L^{-1}$ of Ferric Chloride. Since this difference is not significant and in order to reduce coagulant use, the optimum concentration of Ferric Chloride is recommended to be considered as 25 $mg.L^{-1}$. Our study suggests a turbidity elimination yield of 89.19% which is in good accordance with the yield of 95% reported by Abuzaid et al for electrochemical process with iron electrodes and electrical current of 1 A [18]. The acquired yield is even better than the yield of 75% reported by Toshiya Uchibori et al [26].

Conclusion

This study investigated the effect of electrochemical process on coagulant use during treatment of the water sample taken from Karaj River which is the chief water supplier of Tehran's two chief water treatment facilities, Kan and Jalaliyeh. Results showed that coagulant concentration can be reduced by half of its optimum concentration in the case of applying electrochemical process with an electrical current of 0.1 A and current density of 0.315 $mA.cm^{-2}$. This means that addition of electrochemical process in flash mixing unit results in the reduction of coagulant use and thence brings about considerable economic advantages.

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