Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2017.0915

77 (2017) 215–220
May

Investigating the removal of residual iron from water through coagulation by means of phosphate compounds

Mohammad Hadi Dehghani[a,b,c,*], Reza Ghanbari[b]

[a]*Center for Air Pollution Research, Institute for Environmental Research, Tehran University of Medical Sciences, Tehran, Islamic Republic of Iran, Tel. 98 21 6695 4234; Fax: 98 21 6641 9984; email: hdehghani@tums.ac.ir*
[b]*Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Islamic Republic of Iran, Tel. 98 21 6695 4234; Fax: 98 21 6641 9984; email: hdehghani@tums.ac.ir*
[c]*Center for Solid Waste research, Institute for Environmental Research, Tehran University of Medical Sciences, Tehran, Islamic Republic of Iran, Tel. 98 21 6695 4234; Fax: 98 21 6641 9984; email: hdehghani@tums.ac.ir*

Received 1 May 2014; Accepted 5 June 2016

ABSTRACT

The removal of residual iron in conventional and enhanced coagulation process by use of phosphate compounds was investigated. Jar test was performed on sequences of rapid mixing, slow mixing and sedimentation. Addition of phosphate compounds was accomplished during rapid mixing. Phosphate compounds were added to the jars in concentrations of 0.5, 1, 1.5, 2, 2.5, 3 and 3.5 mg L^{-1}. Dosage of ferric chloride in conventional coagulation test was 10 mg L^{-1}, and the experiments took place in different temperatures (35°C, 22°C and 5°C) and pHs (8.5, 7.5, 6.5 and 5.5). Dosages of ferric chloride were 20, 30, 40 and 50 mg L^{-1} in enhanced coagulation tests, which applied in two pHs (5.5 and neutral pH of water). The results obtained showed that concentrations of residual iron in pH of 5.5, 6.5, 7.5 and 8.5 were 0.32, 0.15, 0.08 and 0.22 mg L^{-1}, respectively. Maximum removal of iron was 0.27 mg L^{-1}, which took place in pH 5.5. Maximum and minimum concentrations of residual phosphate were detected at pHs of 8.5 and 5.5, respectively. Concentration of iron reached its maximum (0.18 mg L^{-1}) in coagulant dosage of 40 mg L^{-1}. Maximum removal of iron in this stage (0.1 mg L^{-1}) happened in coagulant dosages of 30 and 40 mg L^{-1}. Residual iron concentrations in enhanced coagulation at pH of 5.5 were 0.31, 0.72, 0.93, 1.2 and 1.68 mg L^{-1}, which took place in coagulant dosages of 10, 20, 30, 40 and 50 mg L^{-1}, respectively. Maximum removal of residual iron was 0.35 mg L^{-1}, which happened in coagulant dosages of 50 mg L^{-1}.

Keywords: Water treatment; Conventional coagulation; Enhanced coagulation; Residual iron; Phosphate compounds

1. Introduction

Iron profusely is the fourth element and the second metal in lithosphere, which accounts for 5% of its total weight. Iron coming second to aluminum is the element generally found in soil and is the most important and usable element [1,2]. Iron form and concentration in water depends upon dissolved oxygen and pH. In groundwater where there is no oxygen or the oxygen is limited and the pH is approximately 6.5 to 8.5, iron is commonly found in the form of dissolved (Fe^{2+}), and its concentration reaches 50 mg L^{-1} at near pH 7. Iron is commonly found in the form of dissolved (Fe^{2+}), and its concentration in groundwater reaches 50 mg L^{-1} [4–6]. Divalent iron (Fe^{2+}) is very unstable, and when it is exposed to oxygen, it converts to trivalent iron (Fe^{3+}), which is very insoluble in alkaline and acidic water. As a result, trivalent iron (Fe^{3+}) precipitates in form of hydroxide [$Fe(OH)_3$] or oxyhydroxide (Fe_2OH), which are both color compounds [3–5].

In water distribution systems when the iron concentration in water exceeds 0.3 mg L^{-1}, conversion of ferrous (Fe^{2+}) to ferric (Fe^{3+}) causes stain on the cloths in washing

---

[*] Corresponding author.

1944-3994/1944-3986 © 2017 Desalination Publications. All rights reserved.

machines. Owing to the fact that ferric (Fe^{3+}) also clogs pipes and as a result of it, nuisance bacteria grow. Maximum concentration of iron prior to the entry to the UV reactor is 1 mg L^{-1} [4–6].

High concentration of iron in distribution system, which roots from application of iron-based coagulants in surface water treatment plants or from highly iron-concentrated groundwater intake, provides liable conditions for the growth of iron bacteria. Growth of these bacteria not only produces biological mass in water pipelines but also causes corrosion of cast iron, steel and galvanic pipes through reducing dissolved oxygen on the metal surface and releasing corrosive compounds such as organic acids, sulfur hydrogen and sulfuric acid gas formation from sulfate and other sulfur substances and finally participating in cathodic processes [7–10].

Iron concentration is much lower in surface water than groundwater. For this reason, WHO declared the mean concentration of iron in rivers 0.7 mg L^{-1} in 1996. Generally, iron concentration in drinking water is less than 0.3 mg L^{-1} but higher concentration can be found in areas where iron salts are used as coagulants in surface water treatment or where cast iron, steel or galvanic pipes are applied for water distribution. Iron concentration above 0.2 mg L^{-1} is not suitable for industrial applications [11–15].

Enhanced coagulation is the best available technology for the approach of water treatment objectives in terms of the amount of chlorine disinfection by-products. Enhanced coagulation has been used in most of the surface treatment plants. However, use of enhanced coagulation impetus great amount of iron ion to be applied in water. Therefore, studies have shifted their focus to find ways to eliminate iron from water [14–17].

In recent years, considerable interest has been shown on the efficacy of enhanced coagulation for water and wastewater treatment [14–19]. This article represents speculation of the possibility of residual iron removal from conventional and enhanced coagulation by means of phosphate compounds.

2. Materials and methods

Raw water synthetic samples were prepared for speculation and determination effects of interfering factors in iron removal, approaching the main objectives of study and repetitive tests. According to this fact that ferric chloride commonly is used as main coagulant in water treatment plants, this coagulant also was used in all tests. In all cases, standard methods guidelines were applied during experiments. This study, which was conducted for speculation of the possibility of residual iron removal from conventional and enhanced coagulation by means of phosphate compounds, was carried out in environmental health department of Tehran University's chemistry laboratory.

2.1. Chemicals and materials

Ferric chloride: Brown powder ferric chloride, whose degree of purity, solubility and molecular weight was 95%, 92.8% and 270.3 g $mole^{-1}$, respectively, was used. This solution was prepared daily in concentration of 1 g L^{-1} as $FeCl_3$ for jar tests.

Sodium orthophosphate powder: Sodium orthophosphate ($Na_2HPO_4.2H_2O$), whose molecular weight was 178.13 g $mole^{-1}$, was used. This solution was also prepared in concentration of 1 g L^{-1} as PO_4 during the experiment.

Sodium polyphosphate: Powder sodium polyphosphate, whose molecular weight was 666.42 g $mole^{-1}$, was used. This solution was also prepared only once in concentration of 1 g L^{-1} as PO_3 during the experiment.

For sample preparation, natural clay was used as follows: Firstly, the clay was passed through mesh 120 then 1.5 mg L^{-1} of this, weighted by scale and added in the water sample. The mixture then mixed for 10 min so as to homogenize. Solution was put away for 24 h and mixed again. After 30 min precipitation, the supernatant was used for the experiments.

2.2. Jar tests

Jar tests (coagulation, flocculation and sedimentation) were conducted by standard jar test instrument in room temperature. It should be noted that all jars and mixing paddles had been washed by HCl and then rinsed with deionized water. Phosphate compounds addition was done during rapid mixing and 1 min before or after ferric chloride coagulant injection. Phosphate compounds were injected into each jar at concentrations of 0.5, 1, 1.5, 2, 2.5, 3 and 3.5 mg L^{-1}. However, in all jar tests, no phosphate was added to one jar glass in order to residual iron in each condition stated. 10 mg L^{-1} ferric chloride doses for conventional and 20, 30, 40 and 50 mg L^{-1} ferric chloride doses for enhanced coagulation were used. All the analyses were performed according to the procedures outlined in standard methods [20].

2.3. Statistical analyses

Statistical methods including correlation, independent samples T-test and regression were used to analyze the performed studies. The data gathered was analyzed statistically by SPSS 11.5 and Excel software.

3. Results and discussion

3.1. The effect of sodium orthophosphate and sodium polyphosphate dosage increase

The effect of sodium orthophosphate and sodium polyphosphate dosage increase on iron decrease has been illustrated in Fig. 1. Orthophosphate has been able to decrease the amount of residual iron from 0.079 to 0.040 mg L^{-1}, whereas polyphosphate could decrease the amount of it up to the concentration of 0.069 mg L^{-1}.

This study shows that orthophosphate has been more effective in this stage, in removing the residual metal. Therefore, in this case also, the research objective was focused on using sodium orthophosphate compounds, in order to follow the research.

3.2. The effect of phosphate dosing location on coagulation with ferric chloride

The effect of phosphate dosing location on coagulation with ferric chloride was also investigated. The amounts of iron decrease vs. phosphate dosage variations have been shown in Fig. 2; in both dosing points, no significant

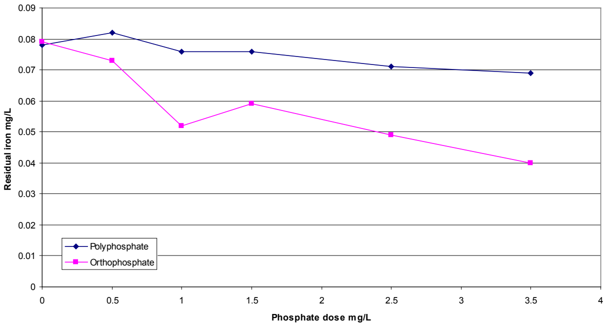

Fig. 1. The amount of decline in water iron content due to different dosages of orthophosphate and polyphosphate at natural pH of water.

difference is observed in the statistical data. In addition, the residual turbidities from both dosing points have been compared in Fig. 3. According to Fig. 3, if the dosing point is after the coagulant, the amount of iron decrease is a little more.

3.3. Study of the pH variation effect

The amounts of iron decrease at various pHs have been illustrated in Fig. 4. The amount of residual iron at pHs of 5.5, 6.5, 7.5 and 8.5 are 0.32, 0.15, 0.08 and 0.22 mg L^{-1}, respectively. The minimum iron concentration is observed at pH = 7.5 and the maximum is at pH = 5.5. At the three pHs except for pH = 5.5, when the phosphate dosage reaches 1 mg L^{-1}, the concentration on residual iron decreases to the standard limit. The maximum iron concentration decrease is at pH = 5.5, which is approximately 0.27 mg L^{-1}.

Trivariant regression analysis results for studying the effect of pH, phosphate dosage and temperature variations on the residual iron concentration show that there is a significant relationship between the residual metal concentration and factors including phosphate dosage, temperature and pH.

The amounts of the residual phosphate are given in Figs. 5 and 6. In this case also, the maximum amount of residual phosphate is at pH = 8.5, and the minimum is at pH = 5.5 and pH = 6.5. The residual phosphate at these pHs is only observed after increasing phosphate dosage to 1.5 mg L^{-1}. Phosphate removal percentage decreases at different pHs are also illustrated in Fig. 7. As it is seen in Fig. 7, phosphate removal percent decreases with increasing phosphate dosage. Phosphate removal percentage decreases with increasing phosphate dosage. For example, at pH = 8.5, when phosphate dosage is 0.5 mg L^{-1}, there is a 96% decline in phosphate concentration. Whereas in the case that phosphate dosage increases approximately to 3.5, phosphate removal percentage decreases to 58%. Therefore, the amount of the residual phosphate is mostly affected by the phosphate dosage, rather than the amount of pH.

3.4. Study of the effect of coagulant dosage increase at the natural water pH on the residual metal removal

The amount of iron decline in different ferric chloride dosages at the natural water pH is shown in Fig. 8. As it is seen in this figure, in all ferric chloride dosages below

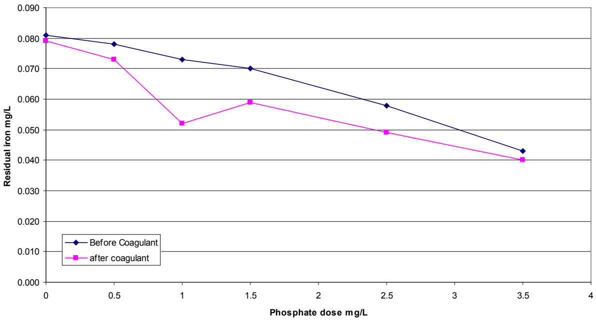

Fig. 2. The amount of decline in water iron content due to orthophosphate dosing point variation at natural pH of water.

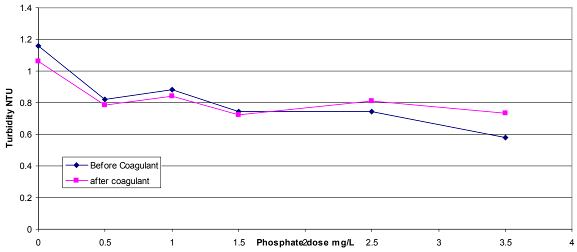

Fig. 3. Comparing water turbidities vs. different dosages of ferric chloride, in dosing point, before and after the coagulant.

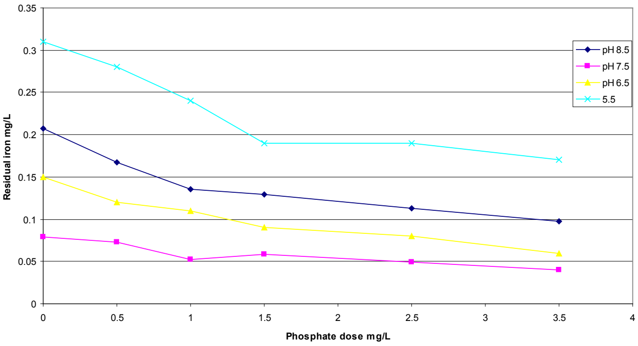

Fig. 4. The amount of decline in water iron vs. different dosages of orthophosphate, due to water pH variation.

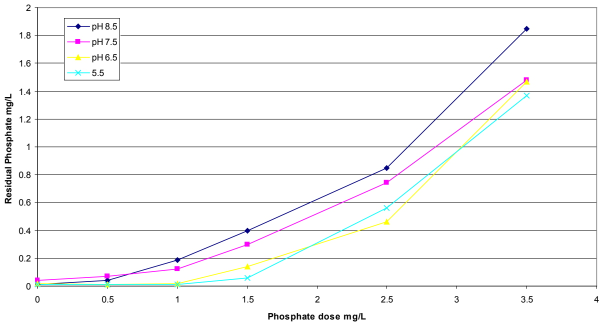

Fig. 5. The amount of water residual phosphate, in coagulation with ferric chloride vs. different dosages of orthophosphate, due to water pH variation.

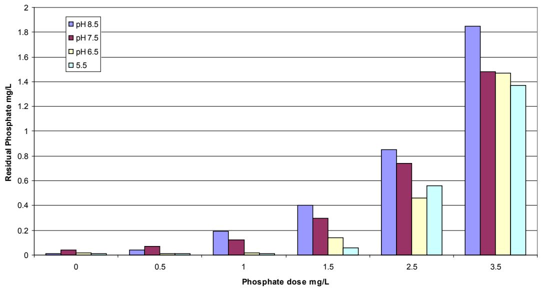

Fig. 6. Comparing the amounts of water residual phosphate, in coagulation with ferric chloride, vs. different dosages of orthophosphate, in coagulation with ferric chloride, vs. different dosages of orthophosphate, due to water pH variation.

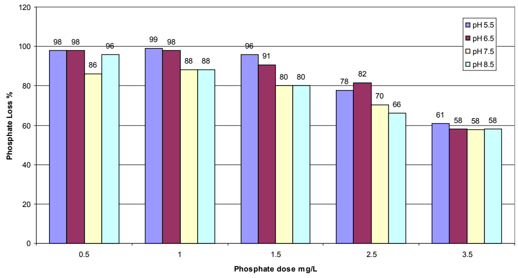

Fig. 7. Comparing phosphate removal percents, in coagulation with ferric chloride, vs. different dosages of orthophosphate, due to water pH variation.

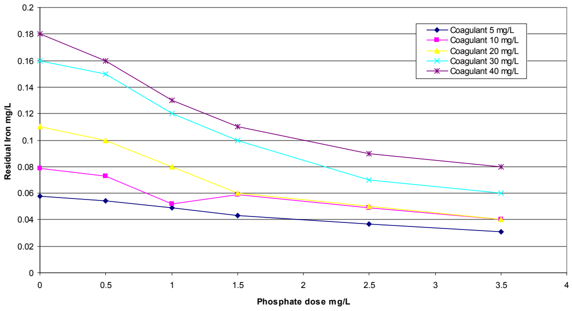

Fig. 8. The amount of decline in water iron vs. different dosages of orthophosphate, in different dosages of ferric chloride at natural pH of water.

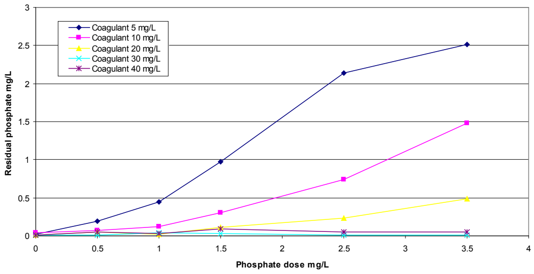

Fig. 9. The amount of water residual phosphate vs. different dosages orthophosphate, in various dosages of ferric chloride, at natural pH of water.

40 mg L^{-1}, the amount of the residual iron is less than the corresponding standards, even without phosphate dosing. The maximum iron concentration in these conditions is 0.18 mg L^{-1}, which is observed in a dose of 40 mg L^{-1} of ferric chloride. The maximum removal is observed in dosages 30 and 40 mg L^{-1} of ferric chloride, which approximately results in an iron concentration decline of 0.1 mg L^{-1}, and therefore, the iron concentration decreases to about 0.08 and 0.06 mg L^{-1}, respectively. The amount the residual metal is mostly affected by the consumptive coagulation concentration rather than the phosphate dosage concentration.

The amounts of the residual phosphate in different ferric chloride dosages are shown in Figs. 9 and 10. It is observed that the amount of the residual phosphate is above 0.5 mg L^{-1} only in dosages 5 and 15 mg L^{-1} of ferric chloride, and the amount of the residual phosphate is about 0.5 mg L^{-1} in a dose of 20 mg L^{-1} of ferric chloride only in dosed concentrations more than 2.5 mg L^{-1} of phosphate; the residual phosphate is about 0.5 mg L^{-1}. However, the residual phosphate is negligible, in dosages 30 and 40 mg L^{-1} of ferric chloride.

3.5. Study of the coagulant dosage effect at pH = 5.5

The residual iron concentration decline at pH = 5.5 in different ferric chloride dosages is given in Fig. 11.The amount of the residual iron at this pH value, without adding phosphate, is 0.31, 0.72, 0.93, 1.21 and 1.68 mg L^{-1} in dosages 10, 20, 30, 40 and 50 mg L^{-1} of ferric chloride, respectively. At this pH value, the amount of the residual iron decreases to the standard limit, only in a dose of 10 mg L^{-1}; the maximum iron removal at this pH value occurs in a dose of 50 mg L^{-1} of ferric chloride, which results in a decline of about 0.34 mg L^{-1}. The amount of residual metal is mostly affected

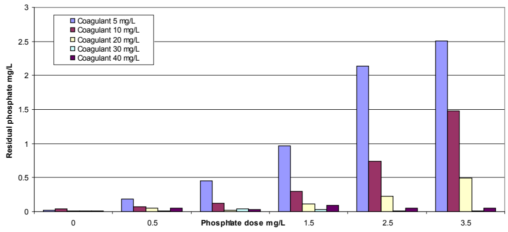

Fig. 10. Comparing the amounts of water residual phosphate vs. different dosages of orthophosphate in various dosages of ferric chloride at natural water pH.

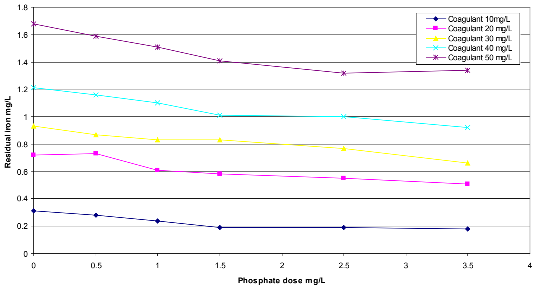

Fig. 11. The amount of iron decline from water vs. different dosages of orthophosphate, in various dosages of ferric chloride, at pH = 5.5.

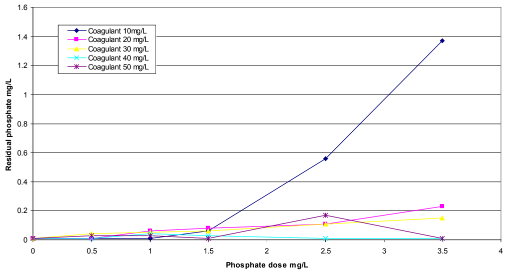

Fig. 12. The amount of water residual phosphate vs. different dosages of orthophosphate, in various dosages of ferric chloride, at pH = 5.5.

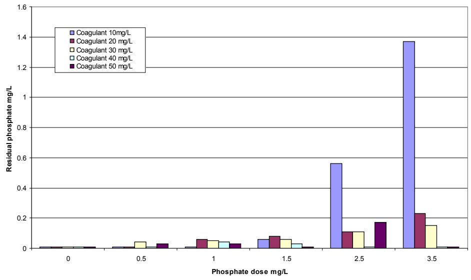

Fig. 13. Comparing the amounts of water residual phosphate vs. different dosages of orthophosphate, in various dosages of ferric chloride, at pH = 5.5.

by the consumptive coagulant concentration, rather than the phosphate dosage.

The amounts of the residual phosphate in different ferric chloride dosages are illustrated in Figs. 12 and 13. The residual phosphate is only observed in a 10 mg L^{-1} dosage of ferric chloride and dosed concentrations above 1.5 mg L^{-1} of phosphate, and in other cases, the residual phosphate increases to about 0.2 mg L^{-1}, only by approximately adding phosphate dosage up to 2.5 and 3.5 mg L^{-1}. This study shows that phosphate removal percentage is within 90%–100% in high dosages of ferric chloride. The amount of the residual phosphate is affected a little more by the phosphate dosage, rather than pH value.

3.6. Study of temperature effect

The amount of decline in water iron content vs. different orthophosphate dosages is different. The amount of the residual iron at temperatures of 5°C, 22°C and 35°C is 0.04, 0.08 and 0.22 mg L^{-1}, respectively. The amount of residual iron increases intensively, with rising temperature. As it is observed, the solution metal concentration increases intensively with temperature rise whereas it reaches beyond the determined standard, just at 35°C; the maximum amount of removal occurred at 35°C, which was about 0.25 mg L^{-1}. During this stage and in all cases, the solution iron concentration decreased to the standard limit, after phosphate dosing. The results of the effect of pH phosphate dosage and temperature variations on the residual iron concentration showed that there is a significant relationship between residual metal concentration and factors including the phosphate dosage, temperature and pH.

The results of the effect of water temperature and phosphate dosage variations on the residual phosphate concentration show that there is a significant relationship between the residual phosphate concentration and factors including water temperature and the phosphate dosage. On the other hand, it is clear that the amount of residual phosphate is a little affected by temperature and is much more affected by the phosphate dosage.

4. Conclusions

The effect of sodium orthophosphate and sodium polyphosphate dosage on residual iron removal shows that sodium orthophosphate was more effective than sodium polyphosphate in decreasing iron concentration. The efficacy of phosphate dosing location on residual iron removal indicated that the dosing point after the application of the coagulant increased iron removal a little more in comparison with its usage before coagulant addition; however, the data obtained from statistical analysis implied no significant disparity.

The results obtained also showed that increasing the temperature increased the concentrations of soluble metals and removal efficiency. Orthophosphate reduced the soluble metals to the standard levels in the all temperatures of this stage. Residual phosphates in this stage were not affected by temperature. Function of phosphate is acceptable, fast and efficient way of reducing the residual iron after enhanced coagulation from water.

Acknowledgment

This research has been supported by Tehran University of Medical Sciences (6142-27-03-86).

References

[1] AWWA, Principles and Practices of Water Supply Operations: Water Sources, 4th ed., 2010.
[2] J.K. Edzwald, Water Quality and Treatment: A Handbook on Drinking Water, 6th ed., AWWA and McGraw-Hill, 2011.
[3] F.G. Driscoll, Groundwater and Wells, 2nd ed., Johnson Screens, 1986.
[4] L.W. Mays, Water Quality and Treatment Handbook, 5th ed., AWWA, 1999.
[5] P.E. Zuane, Handbook of Drinking Water Quality, Van Norstrand Reinhold, New York, 1990.
[6] W.R. Knocke, J.V. Benschoten, The Use of Various Oxidants for Control of Iron and Manganese in Water Treatment Facilities, AWWARF, 1989.
[7] EPA, Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual, EPA 815-R-99-012, May 1999.
[8] G.C. Budd, A.F. Hess, H. Shorney-Darby, J.J. Neemann, C.M. Spencer, Coagulation applications for new treatment goals, J. Am. Water Works Assoc., 92 (2004) 102–113.
[9] A. Korchef, I. Kerkenia, M.B. Amor, S. Galland, F. Persin, Iron removal from aqueous solution by oxidation, precipitation and ultrafiltration, Desal. Water Treat., 9 (2009) 1–8.
[10] A.A. Zorpas, I. Voukalli, P. Loizia, Chemical treatment of polluted waste using different coagulants, Desal. Water Treat., 45 (2012) 291–296.
[11] I. Lou, S. Gong, X. Huang, Y. Liu, Coagulation optimization for low temperature and low turbidity source water using combined coagulants: a case study, Desal. Water Treatment, 46 (2012) 107–114.

[12] T. Meyn, J. Altmann, T. Leiknes, In-line coagulation prior to ceramic microfiltration for surface water treatment minimisation of flocculation pre-treatment, Desal. Water Treat., 42 (2012) 163–176.
[13] J.K. Edzwald, J.E. Tobiason, Enhanced coagulation: US requirements and a broader view, Water Sci. Technol., 40 (1999) 63–70.
[14] S. Shanawaz, Y. Yeomin, A. Gray, Y. Jaekyung, Determining effectiveness of conventional and coagulants through effective characterization schemes, Chemosphere, 57 (2004) 1115–1122.
[15] B.A. Carroll, M.J. Hawkes, Operation experiences of converting from aluminium to iron coagulation at water supply treatment works, Wa. Sci. Technol., 9 (1991) 353–358.
[16] K.J. Howe, M.M. Clark, Coagulation Pretreatment for Membrane Filtration, AWWA and American Water Works Research Foundation, Denver, 2003.
[17] G. Crozes, P. White, M. Marshall, Enhanced coagulation: its effect on NOM removal and chemical costs, J. Am. Water Works Assoc., 87 (1995) 78–89.
[18] C. Volk, K. Bell, E. Ibrahim, D. Verges, G. Amy, M.L. Chevallier, Impact of enhanced and optimized coagulation on removal of organic matter and its biodegradable fraction in drinking water, Water Res., 34 (2000) 3247–3257.
[19] M. Arnaldos, K. Pagilla, Effluent dissolved organic nitrogen and dissolved phosphorus removal by enhanced coagulation and microfiltration, Water Res., 44 (2010) 5306–5315.
[20] APHA, Standard Methods for the Examination of Water and Wastewater, 19th ed., American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC, USA, 2005.