Journal of Molecular Liquids 221 (2016) 673–684

Contents lists available at ScienceDirect

Journal of Molecular Liquids

journal homepage: www.elsevier.com/locate/molliq

Investigating the residual aluminum elimination from conventional and enhanced coagulation by phosphate compounds in wastewater treatment process

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ARTICLE INFO

Article history:
Received 26 May 2016
Accepted 14 June 2016
Available online 16 June 2016

Keywords:
Water treatment
Conventional coagulation
Enhanced coagulation
Residual aluminum
Phosphate compounds

ABSTRACT

Aluminum salts are important chemical materials which are extensively used next to in water treatment processes. High concentration of Al in drinking water may produce health problems. Post coagulant addition of phosphate compounds could reduce the concentrations of residual metals without the need of installing new unit processes in existing water treatment plants. Concentrations of residual metals in conventional coagulation were different in various pHs and minimum and maximum concentrations of Al were in pHs of 6.5 and 5.5. Maximum removal of Al took place in pH = 5.5 with 0.37 mg/l reduction. Maximum and minimum concentrations of residual phosphate were detected at pHs of 8.5 and 5.5 respectively. In natural pH concentrations of Al in enhanced coagulation had been increased versus coagulant dose increase (from 0.21 mg/l to 0.35 mg/l). Maximum removal of Al took place by alum dosage of 20 mg/l which reduce the concentration from 0.28 mg/l to 0.07 mg/l. Residual Al concentration in enhanced coagulation at pH of 5.5 increased from 0.55 mg/l to 2.4 mg/l with the increase of coagulant dosages from 10 to 50 mg/l. Maximum removal of residual Al happened in coagulant dosage of 50 mg/l. Temperature increases permanently increased the concentrations of soluble metals and consequently removal efficiency.

1. Introduction

Aluminum exists naturally in some of the water resource and is used as a coagulant in water treatment processes. In natural conditions, aluminum is converted to its insoluble form and separated from water. But some amounts of aluminum commonly remain in soluble form, so that its concentration is higher than that in raw water. High concentration of aluminum in water can cause adverse effects on human health [1–4]. Aluminum in raw and treated water in these four treatment plants was in its soluble form at first. Concentration of soluble aluminum in influent was partly low and generally increased after the treatment. Total aluminum concentration was >0.1 mg/l in finished water of all four treatment plants, consisting of about 10–80% soluble aluminum. Residual concentration of aluminum is affected by pH of coagulation, temperature, and pH of finished water. After treatment of water with alum, concentration of total recyclable aluminum will decrease, and total soluble aluminum and extractable soluble aluminum will increase. For raw water, in one hand, soluble aluminum is just a small portion of total aluminum, for finished water; on the other hand, almost all the total aluminum is soluble and completely extractable. Aluminum component may exist in finished water, as a residual from coagulation process with aluminum salts [5–7].

The results from other studies show that aluminum concentration varies from 0.014 mg/l in ground waters to 2.57 mg/l in surface waters, which are treated with alum. In the USA, aluminum concentration is reported to be in the range of 140–290 μg/l and 16–1170 μg/l in ground waters and surface waters, respectively. The concentration of this element in acidic water and the waters in forest areas in UK is reported to be 200–300 μg/l and 400–600 μg/l, respectively. It should be noted that acid rain can cause aluminum downwash from the land, eventually increasing its concentration in water resources [8–11].

Aluminum concentration in finished water with aluminum salt depends on primary concentration of this element in raw water, amount of coagulant used, pH, temperature, and presence of complexing agents. Aluminum is deposited in water distribution networks and leads to

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http://dx.doi.org/10.1016/j.molliq.2016.06.051
0167-7322/

scale formation. These deposits increase slowly along the distribution network, so aluminum concentration increases in water [12–14]. The result of investigation conducted [15] for assessing residual aluminum in distribution network in Borazjan suggests that the average aluminum concentration in drinking water in this area, which is due to alum used in Bandar Abbas treatment plant, was 170.2 μg/l with minimum concentration of 150 μg/l and maximum concentration of 180 μg/l.

According to other studies, it has been found that in most of treatment plants which use alum as a coagulant in treatment process, the residual aluminum concentration is in the range of 10–1300 μg/l. In addition, it is reported that aluminum concentration following the use of alum as a coagulant lies in the range of 10–2370 μg/l, which is more than that exists in raw water, so that leading to scale formation in distribution network [16–18]. Formmel et al. [19] investigated the effect of addition of phosphate compounds in rapid mixing in Michigun Lake to eliminate residual aluminum. Addition of orthophosphate in Bench–scale test reduced the residual aluminum concentration down to standard level of 350 μg/l. These tests included addition of Alum and phosphate and long time mixing of about 8 h. Filtrated samples showed that addition of orthophosphate lead to reduction of residual aluminum concentration in all the concentration (pHs of 7, 7.5, and 8.8, and temperature range of 4–31 °C). World health organization (WHO) has not recommended any guidelines for aluminum and only a concentration of 0.2 mg/l aluminum in drinking water is recommended to prevent color in distribution network.

The main objective of the present study is: Investigating effectiveness of phosphate compounds in removal of residual aluminum from conventional and enhanced coagulation in water treatment.

The specific objectives are as follows:

1. Determining the effect of phosphate on residual aluminum concentration from conventional coagulants in finished water
2. Determining the effect of phosphate dosages on residual aluminum from conventional coagulants in finished water
3. Determining the effect of water temperature on residual aluminum from conventional coagulants in finished water
4. Determining the effect of pH on residual aluminum from conventional coagulants in finished water

2. Materials and methods

This research is conducted in order to determine the possibility of residual aluminum elimination from conventional and enhanced coagulation by phosphate compounds. This research is an applied study and its result can be used to improve the quality of drinking water having residual metals due to metal coagulation. It is possible that some percentage of residual dissolved metals be eliminated without the requirement of adding another unit in the treatment plants using phosphate compounds. It implies that with spending minimum cost, a good efficiency in removal of residual dissolved metal is reachable.

In order to do the research and determining the effect of the factors involved in aluminum removal, achieving above mentioned objectives, and possibility of the tests repetition, synthesized water samples were used. Alum is generally used as the main coagulant agent in water treatment plants, so we used the same coagulant in this research. All the tests were carried out according to Standard Methods for Examination of Water and Wastewater (2012).

Aluminum sulfate (alum): powdered aluminum sulfate with a molecular weight of 666.42 g/mol was used. This solution was prepared during the tests with concentration of 1 g/l as $Al_2\ (SO_4)$ as the coagulant stock solution.

Sodium orthophosphate: Powdered sodium orthophosphate ($Na_2HPO_4 \cdot 2H_2O$) with a molecular weight of 178.13 g/mol was used. This solution was prepared once with concentration of 1 g/l as PO_4 and used for all the tests.

Sodium polyphosphate: Powdered sodium polyphosphate $[((Na_2(PO_3))_n]$with a molecular weight of 666.42 g/mol was used. This solution was prepared once with concentration of 1 g/l as PO_3.

2.1. Preparing synthetic raw water samples

Natural clay was used to make samples. The clay was first sieved and then 1.5 mg/l of it was weighted by a scale and poured into water sample and mixed for 10 min to become homogenous. The solution was left for 24 h and then was mixed again and used for the tests after 30 min sedimentation.

2.2. Jar test

Jar test (coagulation, flocculation, and sedimentation) was done in room temperature using a standard jar test device having six 1 l containers. Note that all the jars and mixing paddles were washed before each test with hydrochloric acid and rinsed with deionized water. Phosphate compounds were added during rapid mixing and 1 min before or after alum coagulant addition. Phosphate compounds were added to jar containers in concentrations of 0.5, 1, 1.5, 2, 2.5, 3 and 3.5 mg/l. However, in all the jar tests no phosphate was added to one of the jar containers to specify the amount of residual metal in each case. Dosage of 10 mg/l alum was used for conventional coagulation and doses of 20, 30, 40, and 50 mg/l alum were used for enhanced coagulation.

In this research, Jar tests were used for investigation of residual Al removal by use of phosphate compounds in conventional and enhanced coagulation and also for determination of affecting parameters. Jar tests (coagulation, flocculation and sedimentation) were done by a standard Jar instrument which was consisted of six jars (volume of each was 1 l). Jar tests were performed on sequences of rapid mixing (120 rpm in 2 min), slow mixing (20 rpm in 20 min) and sedimentation (30 min). All the containers had been washed and have been rinsed with acid and distilled water. Phosphate compounds were added to the jars in concentrations of 0.5, 1, 1.5, 2, 2.5, 3 and 3.5 mg/l. But in all of these tests, one jar remained phosphate free as the blank for investigating the true concentration of soluble metals in each condition. Dosages of alum in conventional coagulation test were 10 mg/l and these tests had been accomplished in different temperatures (35, 22 and 5 °C) and pHs (8.5, 7.5, 6.5 and 5.5). For enhanced coagulation tests, dosages of alum were 10, 20, 30, 40 and 50 mg/l which have been used in different pHs (5.5 and natural pH of water). All the samples had been filtered through 0.45 μm filters before analyses.

2.3. Statistical analyses

Different statistical analyses including correlation, independent samples *t*-test and regression were employed in SPSS software.

3. Results and discussion

3.1. Effect of increased dose of sodium orthophosphate and sodium polyphosphate

Effect of increased dose of sodium orthophosphate and sodium polyphosphate is shown in Fig. 1. As can be seen from the figure, polyphosphate just eliminates 0.4 mg/l of residual aluminum, while this amount for orthophosphate is 0.16 mg/l. This result is consistent with the previously obtained results [19–27], but the residual aluminum concentration in using polyphosphate was more than that reported by prior studies (The residual concentration in this study was 0.16 mg/l which was approximately two times higher than their results). This is mainly because of different chemical quality of water used in these two Studies. In present study, concentration of residual aluminum in usage of orthophosphate (0.16 mg/l) was higher than that observed i.e. 0.9 mg/l [19]. According to statistical analyzes, there is a statistically