REMOVAL OF ARSENIC AND IRON FROM GROUNDWATER BY OXIDATION-COAGULATION AT OPTIMIZED pH

ABSTRACT

This thesis describes a systematic laboratory and field study of arsenic and iron removal from contaminated groundwater by oxidation-coagulation at optimized pH (OCOP) technique. Sodium bicarbonate (NaHCO₃), potassium permanganate (KMnO₄) and ferric chloride (FeCl₃) were chosen as pH-conditioner, oxidant and coagulant, respectively. The thesis has been organized in four chapters dealing with different aspects of the study as follows:

1. Introduction: Narrates the background, motivation and the scope, objectives and plan of the present work.

2. Experimental: Describes the materials and the general experimental methods.

3. Results and Discussion: Presents the results, their interpretation, explanation and study of the mechanism involved in the removal process.

4. Conclusions: Summarizes the important findings and future scopes of the present investigation.

Chapter 1

1. Introduction

Chapter 1 contains the introduction part of the thesis. A detail analysis of arsenic contamination, its health impacts and mechanism of affect, the existing arsenic removal technologies, their merits and demerits are discussed in this chapter with reference to the literature. Since the removal of arsenic and iron is pH-dependent, different pH-conditioners viz., lime, ash, carbonate and bicarbonate salts of sodium and potassium are used for pH conditioning to facilitate removal of arsenic. Choosing of the suitable pH-conditioner for removal of arsenic with an appropriate dose is necessary to ensure maximum removal of arsenic without adding residual ions arising from the dose and to avoid readjustment of the final pH of the treated water. These facts lead us to think it worthwhile to carry out a systematic study of arsenic removal by oxidation-coagulation by KMnO₄ and FeCl₃ through optimization of pH.
Abstract

Iron in ferrous form usually coexists with arsenic in groundwater. The coexisting iron when removed by aerial oxidation also removes a part of the arsenic. We have chosen to carry out a pH-optimization for iron removal alone before taking up the works on pH-optimization for simultaneous removal of iron and arsenic, and the OCOP technique. The lacuna remaining in the area and the scope of the present topic of research has been discussed. The aims and objectives along with the strategy of the present work have been described towards the end of this chapter.

The main points considered for this investigation were to study the efficiency of different pH-conditioners with respect to dose and residence time, quantity of oxidant and coagulant required for the treatment, pH, influence of competing anions on removal rate, analysis of the various water quality parameters before and after treatment, analysis of the precipitate obtained after treatment through different analytical tools and the cost of the treatment per liter of water. The whole work was driven by an instinct to provide a viable solution to the arsenic affected poor rural people.

Chapter 2

2. Experimental

This chapter consists of the description of the materials and the methods applied in this study. The ashes were obtained from banana pseudostem which is still used for cooking as a substitute of edible soda by villagers of Assam, a North-Eastern state in India. All the other required chemicals were analytical grade quality, obtained from Merck and Sigma Aldrich and used as such. The procedure of batch experiments for removal of arsenic and iron has been described here. Also the methods used for physico-chemical analyses of the water were described in details.

Concentration of arsenic, iron and other heavy metal ions were determined by using a Perkin Elmer Atomic Absorption spectrophotometer or an Inductively Coupled Plasma Optical Emission spectrophotometer. The pH of the solutions was measured using a Orion multiparameter kit. The characterization of precipitate obtained after treatment was done by using FTIR, XRD, SEM and EDX analysis. The detailed description of the instruments along with methods has been included in this chapter.
Chapter 3

3. Results and Discussion

This chapter describes the results of the experiments, their interpretation, explanation and study of the mechanism involved in the removal process. For systematic organization, this chapter has been sub-divided into four major sections as follows.

3.1 pH-conditioning for removal of iron

As mentioned earlier, we have studied the effects of pH-conditioning on removal of iron from groundwater since iron usually coexists with arsenic and also influences the removal of arsenic. The results on the experiments on removal of iron by using bicarbonate and carbonate salts of sodium and potassium, and banana ash, and their 1:1 binary mixture as pH-conditioner have been discussed in this section. Results of the batch tests have been analysed to assess performance and optimize the process for iron removal by these pH-conditioners. The different parameters considered for this experiment were the quantity of ash or/salt required, the effect of residence time, the effluent water pH and effect of initial concentration of iron. Both distilled water containing iron and groundwater amended with iron have been used in the study. The bicarbonates, especially, that of potassium, have been found to be the most effective for removal of iron. The pH of the treated water remains in the acceptable range for drinking when the bicarbonates are used. The sludge produced after the treatment were analysed by using various analytical techniques, viz., FTIR, XRD, SEM-EDX and the mechanism involved in the treatment process have been discussed in detail in this section.

3.2 pH-conditioning for simultaneous removal of arsenate and iron

In the second section the results of the experiment on simultaneous removal of arsenate and iron by using lime, banana ash, bicarbonate and carbonate salts of sodium and potassium and their 1:1 binary mixture as pH-conditioner have been discussed in this section. The parameters considered for this experiment were similar to that of the previous section. The arsenic removal in presence of the pH conditioners has been found to increase in the order: banana ash < carbonates < bicarbonates < lime. However, only the bicarbonate salts provide the suitable pH condition for simultaneous removal of arsenate and iron ions. The potassium salts are more efficient than the corresponding sodium salts.
However, sodium bicarbonate has also been found to be useful. Lime is disadvantageous because it requires post-treatment correction of highly alkaline pH.

### 3.3 Arsenic and iron removal by oxidation-coagulation at optimized pH (OCOP) method

The results of the batch tests of simultaneous removal of iron and arsenic by OCOP method by using sodium bicarbonate as pH-conditioner, potassium permanganate as oxidant and ferric chloride as coagulant have been discussed in this section. The different parameters considered in this study were the effect of doses of pH-conditioner, oxidant and coagulant, pH of the effluent water, effects of initial concentration of dissolved arsenic and iron, and effect of the presence of coexisting competing anions. Based on these, the doses of the pH-conditioner, oxidant and the coagulant have been optimized. The sludge produced after the treatment were analysed by using various analytical techniques, viz., FTIR, XRD, SEM-EDX and the mechanism involved in the treatment process have been discussed. The sludge has also been examined with respect to leaching of arsenic and sludge-disposal.

### 3.4 Field trial of the OCOP method

User trial of the OCOP method with optimized doses of pH-conditioner, oxidant and coagulant was carried out in different arsenic affected areas in Assam. The doses used for water with arsenic along with iron less than 1 mg/L were: 0.1 g/L of NaHCO$_3$, 0.5 mg/L of KMnO$_4$ and 25 mg/L of FeCl$_3$ as solid powder, 5% and 25% stock solutions, respectively. For the water containing 1-5 mg/L iron ions a higher dose of 4 mg/L of KMnO$_4$ was used. For the water containing above 5 mg/L iron ions, we added KMnO$_4$ solution until it imparts a light pink colour to the water. The colour however disappears after coagulation.

Different types of low-cost units with different capacities were installed at household and small community levels. User trainings were conducted for application of the method as well as for collection of samples of treated water for further analysis. The field trial was conducted at all together 16 spots water sources which included 10 households with 10 L, 5 schools with 25 L and 1 school with 200 L capacity units. The results obtained after treatment of arsenic containing water with the OCOP technique has been described in this section. The initial concentration of arsenic and iron were in the ranges of 196.43-238.12 µg/L and 0.136-16.25 mg/L, respectively. In all cases, the final
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Concentration of arsenic and iron were found to be in the ranges of 3.57-9.21 µg/L and 0.064-0.360 mg/L, respectively. Arsenic removal was found to be better with lower concentration of co-existing iron.

Chapter 4

4. Conclusions and future scope

This is the concluding chapter of the thesis. It delineates the final remarks and future scope of this work. The bicarbonate salts of Na and K provide the best pH condition for removal of arsenate and iron ions. The bicarbonates retain the final pH within the acceptable range for drinking. Though, potassium bicarbonate has been found to be more efficient pH-conditioner than sodium bicarbonate, the later is more preferable due to its easy availability and familiarity among common people.

Removal of arsenic and iron by the OCOP method using NaHCO₃, KMnO₄ and FeCl₃ as pH-conditioner, oxidant and coagulant, respectively, is highly efficient for simultaneous removal of both arsenic and iron from groundwater. The results of the field trial including the potability of the treated water are promising. This together with high efficiency, low-cost, simplicity of operation, safety and environment-friendliness and option of non-requirement of electricity suggest that the OCOP method has a great potential for arsenic removal in rural areas where alternate arsenic-free water is not available.

Finally, the findings of the present work and the proven applicability of the present method of arsenic and iron removal open up scopes for future research and development works, viz., better management and utilization of the solid sludge, developing sophisticated domestic arsenic and iron removal units and field trial of the technique at large community water supply system. The present OCOP method can also be studied for removal of other heavy metals from groundwater.