Up to Date Development of Iron Removal Techniques from Groundwater

A. S. M. Z. Hasan[1], F. Khatun[2]

[1]*Professor, Department of Civil Engineering, RUET, Bangladesh (ziaruet@gmail.com)*
[2]*Postgraduate Student, Department of Civil Engineering, RUET, Bangladesh (famatoki@gmail.com)*

Abstract

Groundwater is the major source of water for all purposes in Bangladesh. However, at most of the places in Bangladesh it is severely affected by iron compared to Bangladesh, and WHO standard. The presence of iron in groundwater creates a nuisance such as producing insoluble rusty oxide-red, brown stains and streaks on laundry and plumbing fixtures. Furthermore, iron imparts a typical bitter astringent taste to the water. Finally, iron passing into the distribution system may promote the growth of micro-organisms. As millions of people of Bangladesh rely on groundwater sources for their daily domestic and other purposes, the treatment of groundwater is essential. Therefore, researchers are continuously trying to develop a sustainable method for the removal of iron from groundwater. Detailed literatures have been reviewed to know about the latest development of iron removal techniques from groundwater. The physical methods are electro-coagulation, oxidation-filtration, ultra-filtration, microfiltration, slow and rapid sand filtration, subsurface iron removal, ultrasound field application, adsorption/ absorption. The chemical methods are ion exchange, lime softening and coagulation while bioremediation, biofiltration and application of magnetotactic bacteria are under microbial treatment. These methods are effective to remove iron more than 95% from groundwater.

Keywords: *Groundwater; iron; contamination; treatment; recent development.*

1. Introduction

Iron is one of the most commonly found elements in groundwater (Qingfeng, et al., 2017). This component normally exists in water in various states: dissolvable state (Fe^{+2}), insoluble state (Fe^{+3}), bacterial state, and natural state (Chaturvedi and Dave, 2012). Iron is a beneficial element for human health which is required to form hemoglobin. An overdose of iron in the body can lead to severe health problems such as diabetes, anemia, lung and coronary disease, hemosiderosis (liver disease), heart diseases, nausea, gastrointestinal problems and potentially abortive effects on pregnancy (Swaminathan and Gerner-Smidt., 2007). Also it causes aesthetic problems if found in drinking water for example, giving reddish color, undesirable odor, turbidity and taste issues (Demir, 2016). The groundwater of the various districts of Bangladesh is severely polluted with iron. The iron contents in groundwater vary from 0.24 to 6.2 mg/L in Bangladesh presented in the map using Q-GIS software by Islam, et al. (2017). The mean value of iron was found to be 2.15 mg/L and among the recorded data 70% is higher than the mean value. It is obvious that situation is alarming and hence different techniques have been developed for the removal of iron from water. Therefore, the aim of this study is to review the development of iron removal techniques.

2. Different Iron Removal Techniques

The various methods of iron removal with their performance are discussed in the following sections.

2.1 Oxidation-Filtration

Oxidation-filtration is the most common technique used for iron removal. Before filtration, iron needed to be oxidized so that it can form insoluble complexes. Oxidizing agent enables oxidation that involves the transfer of electrons from the iron or other chemicals. Ferrous iron (Fe^{+2}) is oxidized to ferric iron (Fe^{+3}), which promptly produces the insoluble iron hydroxide complex $Fe(OH)_3$ (Vigneswaran and Visvanathan,1995). Then, by filtration, the iron particles are separated. There are different filtration media for the removal of iron including manganese greensand, anthracite-sand, Pebble-sand, and ceramic (EwaOkoniewska et al.,2007). Manganese greensand is the most well-known medium being used for removal of iron through filtration (Ellis et al.,2000). Anthracite-sand are different sorts of media accessible for expulsion of iron. At long last, macrolite, dissimilar to the other media discussed so far, isn't a normally happening material which at that point goes through preparing for iron expulsion purposes. Series of pebble and sand bed can be used for the removal of iron by filtration after oxidation. It is a cheap and easy technique having iron removal efficiency of 80–90%.

2.2 Slow and Rapid Sand Filtration

Slow sand filters (SSFs) are very useful for their ability to remove various impurities including microorganisms from water (Haig et al., 2014). Astari and Iqbal (2009) studied the efficiency of sand filters for water treatment using four different sand filter systems, wherein the best one (sand channel width, 115 cm; sand profundity, 50 cm; tallness of water, 50 cm; and flow rate, 45 L/h) could eliminate Fe ions from water with an expulsion proficiency of 91.5%. Demir (2016) focused on the ability of slow sand filters for Fe ion removal and found that 90–95% removal efficiencies were achieved with very low effluent concentrations (1–2 mg/L). Furthermore, rapid sand filtration works basically similarly as SSF however varies with respect to the size of the sand grains. Usually two types of RSF are typically used: rapid gravity and rapid pressure sand filters. An examination concerning the evacuation of Fe particles from drinking water demonstrated that the removal proficiency of Fe particles varies in the range of 88.8 and 99.8%. The most noteworthy evacuation proficiency was accomplished at an influent of 10 mg/L for Fe (Marsidi et al., 2018).

2.3 Adsorption

In adsorption-oxidation iron expulsion, the system is worked under anoxic condition stifling the oxidation of ferrous iron and iron is eliminated by adsorptive filtration. The research has proved the effectiveness of coal and carbonaceous shale as channel media in adsorptive filtration iron expulsion from groundwater by direct filtration (Sharma, 2001). The findings indicate that 83.8 % or 91.7 % of ferrous iron was adsorbed from groundwater by coal or carbonaceous shale (all iron 2.66 mg/L; ferrous iron 2.35 mg/L). Obviously, carbonaceous shale would be a more effective filter media in adsorptive filtration iron. The widely used adsorptive materials are activated carbon in the form of granular and powder (EwaOkoniewska et al., 2007). Granular activated carbon is a good adsorbent medium because of its high surface zone to volume proportion. One gram of a typical commercial activated carbon will have a surface area equivalent to 1000 m^2. This elevated activated carbon surface area causes a large number of contaminant molecules to accumulate. The specific capacity of a granular activated carbon to adsorb contaminant molecules is related to molecular surface attraction, the total surface area available per unit weight of carbon, and the concentration of contaminants in the wastewater stream.

2.4 Subsurface Iron Removal

Subsurface iron removal is a cost-effective innovation thatprovides safe drinking water in rural, decentralized applications (Halem et al., 2010). The principle of subsurface iron expulsion is that circulated air through water is intermittently infused into an anoxic aquifer through a tube well partially displacing the iron-containing groundwater. The infused water oxidizes adsorbed ferrous iron resulting in a surface area of ferric iron hydroxides for adsorption of soluble ferrous iron and oxyanions (Appelo and de Vet, 2003). Soluble ferrous iron is adsorbed to the ferric iron coated soil grains in the abstracted groundwater when the flow is reversed. When the iron oxyhydroxide surface is depleted, not any more iron (II) will be adsorbed and iron breakthrough will be observed in the produced water (Dzombak and Morel, 1990).

2.5 Electro-Coagulation (EC)

The idea of the electrocoagulation method is the in-situ generation of the coagulants as the sacrificial metallic anode dissolves because of the applied current, while the cathode produces hydrogen gas and it helps to float the pollutants (Essadki et al., 2009). Various materials, for example, steel (Genc and Bakirci, 2015), graphite (Gao et al., 2013), zinc (Vasudevan et al., 2012), and iron (Ye and Li, 2016), have been utilized as anodes in the EC reactors. It has been accounted for that iron and aluminum are the best and effective electrode materials (Chaturvedi and Dave, 2012). When aluminium (Al) is used as electrodes, the anode produces the Al^{3+} ions; these aluminiumcations instantly undergo more reactions to form different types of monomeric materials such as $Al(OH)^{2+}$ and polymeric species such as $Al_{13}O_4(OH)_{24}^{7+}$ which immediately coagulate to form flocs (Ghosh et al., 2008). It is believed that aluminium hydroxide flocs $Al(OH)_3$, are responsible for the adsorption and precipitation of the dissolved iron (Ghosh et al., 2008). This treatment process gives palatable, clear, colorless and odorless water and iron removal efficiency of EC reactor is 95–99% (Chaturvedi and Dave, 2012).

2.6 Ultrafiltration/Microfiltration

Ultrafiltration (UF) is a type of process of separation in which membranes are used with pore sizes ranging from 0.1 to 0.001 µm. In a UF membrane, the pore size is primarily responsible for assessing the form and size of removed contaminants. Suspended solids and high atomic weight solutes are retained, while solutes of water and low atomic weight pass through the layer. In terms of reverse osmosis, microfiltration or nanofiltration, ultrafiltration is not quite special, aside from the scale of the atoms it contains. According to Kamar et al. (2014) the primary removal mechanism in ultrafiltration is size exclusion, although the electrical charge and surface of the particles or membrane may affect the purification efficiency. Iron ions removal of 90% can be attained by using ultrafiltration.

2.7 Ion Exchange

Ion exchange includes the use of synthetic resins where the unwanted ions in the water are substituted for a pre-saturant ion in the solid phase. Iron that interacts with groundwater can respond with CO_2 to produce ferrous bicarbonate. Ferrous bicarbonate or clear water iron is soluble in water and is not visible. This sort of iron can be eliminated by standard softening resin since it is a positive-charged particle. The following reactions sums up the response that regularly happens with ion exchange resin (Keller, 2004).

$$2RNa + Fe(HCO_3)_2 + O_2 \rightarrow R_2Fe + 2NaHCO_3 \quad (1)$$

Two sodium molecules are delivered from the resin for every molecule of ferrous iron that is picked up by the resin. A high concentration of salt (8–26%) will invert this response as found in the following condition: $R_2Fe + 2NaCl \rightarrow 2RNa + FeC$. Frequent regenerations are followed to prevent the iron from precipitating to its insoluble form. This method is used only for small quantities of iron removal because there is a risk of rapid clogging (Khadse, et al., 2015).

2.8 Bioremediation

Bioremediation is the use of microorganism to remove contaminants through their metabolism. The biological treatment of groundwater is used to remove electron donors from water sources, providing (biologically) stable drinking water, which preclude bacterial re-growth during subsequent water distribution. The dissolved metal cations of ferrous iron belong also to the electron donors, which are common contaminants found in mostly in groundwater. The expulsion of iron is usually done by the application of chemical oxidation and filtration. However, because of the presence of some advantages over traditional physicochemical therapy, biological oxidation has recently gained increased significance and use. The oxidation of iron is accelerated by the presence of certain indigenous bacteria, the so-called iron oxidizing bacteria (Zouboulis and Katsoyiannis, 2005). Corral-Bobadilla et al., (2019) found 94% iron (II) removal from groundwater.

2.9 Ultrasound Field Application

Ultrasounds initiate numerous physicochemical phenomena in water, whose effect could be utilized in aiding some water treatment technologies, e.g. disinfection, coagulation or sorption on granular activated carbon (Duckhouse et al., 2003). Stegpniak et al. (2007) experimented on the influence of the ultrasounds of diversified intensity (22 and 24 kHz) on the content iron compounds in water. Variable operating parameters, such as the vibration intensity and the exposure time (1-5 min), were used for the study. Ultrasounds of the frequency 22 and 24 kHz initiate phenomena influencing iron(II) oxidation in water. The separation of the oxidized form Fe(III) enables the decrease of the general content of iron. The increase of the effects in the removal of iron from water is assumed with the elongation of the time of sonification up to 5 min and the vibration amplitude up to 54 μm. The effect of ultrasounds on the removal of iron compounds is also proved in natural water conditions. At greater ultrasound intensity, the oxidation of soluble iron-organic complexes from Fe(II) is more intensive. At the use of the ultrasounds of low intensity, more effective is destabilization and removal of colloidal iron compounds which influence water turbidity. The maximum iron removal efficiencies of the system with ultrasound were 80.7%.

3. Discussions

The methods of iron removal are divided into reagent and reagentless ones. The reagent methods are used when iron cannot be removed by other methods or their efficiency is low. The major reagentless methods of iron removal include aeration, filtration, electrocoagulation, bioremediation, and some others (Kitaeva, et al., 2019). Aeration, which consists in artificial saturation of water with oxygen to convert the Fe(II) ions into Fe(III) ones and, hence, transform the soluble forms of iron into insoluble ones that can be further filtered off, is the simplest reagentless method of iron removal from water (Machekhina, et al., 2015). Different types of aeration devices are used for example packed tower aerator, diffused-bubble aerator, spray aerator etc. After conversion of soluble Fe(II) ions into insoluble Fe(III) it is removed by different types of filtration units containing various filter media. Sand, anthracite, BIRM media, green sand, pebbles and sand and attached growth biomass can be used as filter media.

4. Conclusion

There are many methods are developed for the removal of iron from groundwater of which some are based on simple techniques and some are based on sophisticated modern techniques. Based on the review it can be mentioned that bioremediation would be the best solution and more attention needs to be paid on microbial growth to enhance the metabolic activities for iron removal. However, suitable method should be selected considering local conditions, availability, economic conditions, ease of operation, performance and so one.

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