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Review

Recent strategies for the removal of iron from water: A review

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ABSTRACT

Iron is the 4th most abundant element on Earth and is found naturally in the water in diverse forms. It is a vital mineral nutrient, which acts as a co-factor for many enzymes and plays role in the maintenance of energy metabolism. According to WHO standards, the permissible limit of iron in drinking water is 0.3 mg/L. However, the dumping of domestic and industrial wastes in the water bodies is responsible for elevated levels of iron in the water. The continuous consumption of such water with high iron content may lead to various health problems. Bad odor, unpleasant taste, red color of water and stains on laundry and plumbing fixtures are also some of the issues related with high iron content in water. A variety of techniques have been adapted for the remediation of iron from different water sources. This review summarizes the different approaches used worldwide till date for the removal of high iron content from water. These methods have been classified into 4 different categories: conventional strategies, biological strategies, membrane technology-based strategies and nanotechnology-based strategies. The conventional strategies involve 11 different remediation techniques for removing iron from water, which have different iron removal efficiencies. The review also classifies the diverse types of iron available in water based on its mineral form, solubility and chemical nature.

1. Introduction

Metals are the inorganic substances found naturally in the water bodies. An optimum concentration of some of these metals is required by different organisms for their proper growth and maintenance. Water acts as a major source for such metals. These metals enter into the water bodies naturally when rain water percolates through rocks, thereby dissolving trace quantities of metals into the water. This water comes into bigger water bodies, which are used by people for different purposes. Iron is one such metal found naturally in water. It ranks fourth among the most abundant elements on earth, while in earth's crust, it ranks second [1]. It is found in large quantities in rocks and soil systems around the world. It is a vital mineral nutrient, which plays role in the maintenance of energy metabolism. It is an important element in hemoglobin, myoglobin as well as in several types of enzymes. Low levels of iron in the body may cause iron deficiency, anemia, fatigue and increased susceptibility to different infections [2].

Water bodies receive iron either through geogenic sources or via dumping of domestic waste and industrial effluents [3]. The sources of iron in surface water are mainly pollution from iron and steel industries, mining and metal corrosion [4]. Apart from surface water, iron is also present in ground water. The major reason behind the presence of iron in groundwater is due to leaching from iron bearing rocks and minerals [5]. The concentration of iron in surface and ground water varies from 3 to 4 mg/L to 15 mg/L [6]. Its concentration in the groundwater of West Bengal, India was in the range of 2–10 mg/L [7]. Concentrations of iron up to 6 mg/L have been reported in the Ganga river near the Fazalpur industrial area in Moradabad district of Uttar Pradesh, India [8]. The groundwater in Assam, the eastern state of India is highly contaminated with elevated levels of iron [9–11]. However, the permissible limit for drinking water is 0.3 mg/L [12,13]. Initially, concentrations above this level, in drinking water may not have adverse health effects. However, continuous consumption of such water with elevated levels of iron may result in a condition called iron overload [14]. Excessive iron intake may lead to the impairment of hematopoiesis by destroying the progenitor cells as well as the microenvironment for hematopoiesis. If iron overload is left untreated, it may lead to hemochromatosis, which damages different organs of the body [15–20]. Initial symptoms include weight loss, joint pain and fatigue. Eye disorders such as retinitis, conjunctivitis and choroiditis, cancer and heart diseases are also some of the common health issues faced due to high concentration of iron in the water [21]. Apart from these health related problems, several others issues of high iron content in water have been reported. The metal imparts an odor, metallic taste and red

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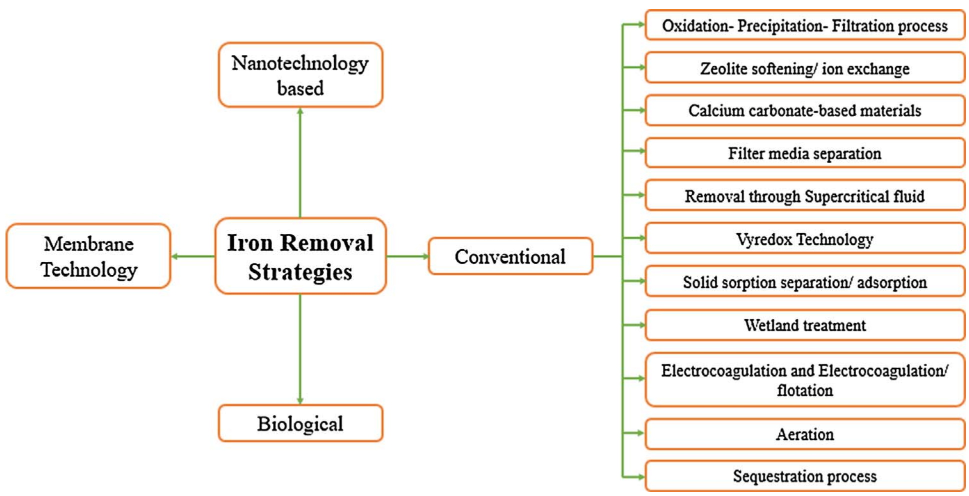

Fig. 1. Classification of strategies for Iron Removal.

color to the water at elevated concentrations [22]. It also causes stains and streaks on laundry and plumbing fixtures. Clogging of softeners and pipeline due to precipitation of iron may also create undesirable situations in the water distribution systems [23]. The higher concentrations of iron may also act as a substrate for certain bacteria. The surfaces of pipes are the most suitable habitat for such bacteria. These bacteria increase to such high population that they start clogging pipes and reduce the flow rate of water in the pipeline. It becomes very difficult to remove such bacterial colonies once they get established in the pipeline. Moreover, if the pipeline is made up of iron, punctures and leakages are some of the common problems reported [23,24]. When these bacteria die, bad odor and unpleasant taste are produced in the water mains [23].

This calls for the effective treatment of water in order to remove the elevated levels of iron and produce safe and clean water. A number of methods have been reported in the past for such purpose. This review article sorts these methods into 4 categories: conventional strategies, biological strategy, membrane technology-based strategy and nanotechnology-based strategy as shown in Fig. 1. The conventional strategies for iron removal have been further divided into different techniques such as oxidation-precipitation-filtration process, zeolite softening or ion exchange, limestone bed filtration, filter media separation, supercritical fluid extraction, Vyredox technology, solid sorption separation/adsorption, wetland treatment, electroflotation, aeration and sequestering or stabilization process. The article also summarizes the different forms of iron present in water, which have not been discussed in similar kind of previous articles. The incorporation of traditional methods for iron removal such as supercritical fluid extraction, Vyredox technology, wetland treatment and sequestration along with nanotechnology-based strategy provide a novelty to the article.

2. Forms of iron in water

Iron is present in a number of forms in water. These diverse forms can be broadly classified into different types based on the mineral form, solubility and chemical nature of iron [25]. The classification of different forms of iron present in water (Fig. 2) have been discussed as under:

2.1. Types of iron based on mineral form

Iron exists in different mineral forms in the water bodies. Broadly, the mineral forms of iron can be classified into 4 different categories [26] as shown in Fig. 2: oxides, silicates, carbonates and sulphides.

2.1.1. Oxides of iron in water

2.1.1.1. Hematite. The mineral form of iron (III) oxide, having the chemical formula as Fe_2O_3 is called hematite. It is usually present in areas having mineral hot springs or still standing water. Iron from the mineral gets precipitated out of water and collects in the form of layers at the bottom of springs, lakes or other standing water bodies.

2.1.1.2. Magnetite. The mineral form of iron (II, III) oxide, having the chemical formula as Fe_3O_4 is called magnetite. It is usually present in the lakes and sediments in marine areas in the form of detrital grains and as magneto-fossils.

2.1.1.3. Limonite. The mineral form of a combination of hydrated iron (III) oxide and hydroxide in variable composition, having chemical formula as $FeO(OH){\cdot}nH_2O$ is called limonite. The mineral is usually formed due to the hydration of other mineral forms, viz. magnetite and hematite. Limonite gets deposited in the run-off streams coming out from different mining operations.

2.1.2. Silicates of iron in water

2.1.2.1. Pyroxene. The mineral form of aluminum-silicon oxides with iron substituting for silicon or aluminum is called pyroxene. The general formula is $XY(Si, Al)_2O_6$ (where X represents Fe^{2+} and Y represents Fe^{3+}). The mineral is usually present in volcanic lavas and enters the water bodies when the lava goes into the water system.

2.1.2.2. Amphibole. The dark colored, inosilicate mineral form, having ions of iron present in the two chains of SiO_4 tetrahedra is called amphibole. These chains are connected at the vertices. It is most commonly found in metamorphic and igneous rocks and its entry in water bodies is usually due to rain water percolation.

2.1.2.3. Biotite. The phyllosilicate mineral form, having the general chemical formula as $K(Mg,Fe)_3AlSi_3O_{10}(F,OH)_2$ is called biotite. The mineral is a silicate sheet formed due to weak interactions between iron and potassium ions. Biotite, like amphibole, is also found in rocks (generally metamorphic and igneous), which goes into the water bodies upon mixing with rain water.

2.1.2.4. Olivines. The magnesium-iron silicate mineral form, having generalized chemical formula as $(Mg, Fe)_2SiO_4$ is called olivine. The mineral is one of the weakest mineral present, which causes its weathering, thereby ultimately getting mixed into the water body. In the presence of water, olivine changes into iddingsite, which is a combination of clay, iron oxide and ferrihydite [27].