

A REVIEW OF BIOLOGICAL IRON REMOVAL

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ABSTRACT

Soluble Fe(II) in ground water in Denmark is mostly removed conventionally by the simple process known as purely physico-chemical (or abiotic). By this process, the raw water is exposed to atmospheric oxygen to oxidise the iron from soluble Fe(II) to insoluble Fe(III) oxides, which is then removed by single or double filtration units, depending on the ground water quality.

Ground water containing iron complexed with organic and inorganic materials could be difficult to remove by the purely physico-chemical method. While humic acids could retard the oxidation of Fe(II), inorganic elements such as silicate could enhance the formation of highly dispersed colloidal iron particles which could easily go through the filter materials making it difficult to be removed.

Biological iron removal is known to overcome most of the problems associated with the application of conventional iron removal processes. Therefore, this script reviews pertinent literature on biological iron removal.

Keywords: Iron bacteria, Physico-chemical iron removal, Biological oxidation, Water treatment plants

INTRODUCTION

Physico-chemical iron removal (Abiotic iron removal)

The mechanism underlining the physico-chemical iron removal has always been considered to be the oxidation of soluble Fe(II), leading to the formation of flocs of iron(III) hydroxide precipitates, which is subsequently removed by sand filters. This process is termed as “oxidation- floc formation”, See equation 1



The possibility of iron(II) being adsorbed onto surfaces of coated filter media, proceeded by quick oxidation of the Fe(II) to Fe(III) hydroxides in the system has also been identified, known as the “adsorptive filtration” mechanism. Whichever of those

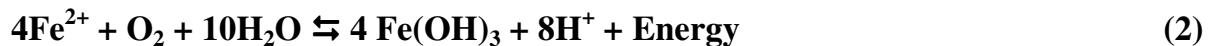
two processes that predominate in filters, they may occur concurrently during the deferrisation process, is not known. The addition of oxidants to the raw water becomes necessary on rare occasions in Denmark, where ground water contains contaminants that are difficult to be oxidized by simple aeration. When this happens, then oxidants such as ozone or potassium permanganate may be employed under permission from the Danish environmental authorities.

Biological iron removal

Ever since iron bacteria were discovered, the prospects of using it to remove iron from drinking water has been vigorously exploited by water treatment engineers, but the mechanism underlining the iron removal process by the iron bacteria is still not fully inferred. There are still controversies about whether the process of iron removal in sand filters could be either solely biological or iron oxidising bacteria play a supplementary role in the physico-chemical iron removal process under certain conditions. The main experimental difficulty in proving autotrophy by these iron bacteria is that the organisms grow and thrive well between the pH of about 5 to 9. At these pH values, iron Fe(II) is physico-chemically/ non-biologically oxidised to Fe(III), making it a difficult task to decide if the bacteria contributed to the oxidation of Fe(II). Nevertheless, it is now certain that the presence of biological phenomenon in the filters substantially reduces the iron concentration in the treated water by breaking the problem of the difficulty to remove Fe-organic or Fe-silicate complexes and also increase the rate of oxidation of Fe(II) to Fe(III).[1-4]

Metabolism of iron removal bacteria

The oxidation reaction of ferrous iron to ferric iron by biological means is similar to that of the physico-chemical reaction and it is as indicated in equation 2. It is known to be one of the most significant characteristics of iron oxidizing bacteria, but very little is known about the mechanism involved in initiating and perpetuating this exothermic biochemical iron oxidative processes in drinking water plants.



It is now certain that the iron oxidizing bacteria derive their essential energy requirements through a strictly chemolitho-trophic process.[5] This is an enzyme-mediated oxidation of Fe(II) with a concomitant fixation of carbon dioxide into an assimilable nutrient for the iron oxidizing bacteria . As a result, precipitation of Fe(III) salts occur either by enzymatic action of autotrophic bacteria (intracellular) or by catalytic action of polymers excreted by the bacteria sheath (extracellular). The original source of carbondioxide is principally from the groundwater where organic compounds in form of humic substances is transformed by anaerobic fermentation in ground water and by gravity transferred by water to e.g. 100 m deep below the ground

surface. Humic substances are present in groundwater either chelated with Fe(II) or existing solely in the anoxic zone. [1, 6, 7]

Several kinds of iron oxidizing bacteria may be involved in water treatment systems but in all cases, the biological oxidation process is seen as catalytic in nature, causing a rapid oxidation of insoluble ferric hydroxides found to be more compact or superior to the precipitates formed from other treatment processes.[8]

Biotic conditions for the precipitation of iron

A shift from abiotic to biotic precipitation is governed by the chemical and the physical properties of the water. The most important conditions for the biotic precipitation are enumerated at neutral or slightly acidic pH, a change from negative redox potential to redox potentials up to about 200-320 mV and oxygen levels changing from zero to 2-3 mg/L, together with considerable amount of CO₂. However, redox potential and pH are the main factors that determined whether biotic precipitation will take place or not. The stringent pH and Eh limits required by the iron bacteria describes them as very good example of gradient organism that develops under neither strongly reducing conditions nor in an fully oxidized milieu.[8]

Table 1 below compares three of the most important iron bacteria in terms of their characteristic features as well as conditions required for their growth and development.

Table 1: Comparison of conditions and features of Gallionella, Leptothrix and Sphaerotilus

	Gallionella	Leptothrix	Sphaerotilus
	Chemolithoautotrophic	Chemoheterotrophic	Chemoorganotroughs
Cell Shape and size	Kidney shape: Width: 0.5 – 0.7 μm Length: 0.8 – 1.8 μm . Gram negative cell walls	Rod Shape Width: 0.6 – 1.4 μm Length: 1.0 – 12.0 μm Gram negative cell walls	Rod shape Width: 1.2 – 2.4 μm . Length: 2.0 – 10 μm Gram negative cell walls
Sheaths/Stalk	Width: 2 nm Shape: Twisted Surface structure: Dissolves in reducing agents and weak acids	Width: 1.5 – 3 μm Shape: Hollow sometimes and straight Surface structure: Rough Detaches from the body intermittently	Width: Not specified Shape: Hollow sometimes and straight Surface structure: Smooth
Energy / Carbon Source	Carbon dioxide in form of principally HCO_3^-	Sugars, organic acids and glycerol	Carbon sources like sugars, organic acid. They also metabolize nitrogen compounds.
Type of iron produced	Ferrihydrite (Ferric hydroxide)	Ferrihydrite (Ferric hydroxide)	Ferrihydrite (Ferric hydroxide)
Living conditions	Anaerobic and microaerophilic Oxygen content: 0.1 – 3 mg/l increasing Temp: About 8 – 16°C Oxidation/Reduction Potential: negative -300 mV increasing Fe^{2+} content: 2 – 25 mg/l pH: 6 – 7.6	Slightly aerobic to aerobic Oxygen content: 1mg/l Temp: 10 – 40°C Oxidation/Reduction Potential: Not specified Fe^{2+} content: Not specified pH: 7.5	Anoxic and aerobic Oxygen content: <0.1 mg/l – full saturation oxygen saturation. Temp: About: 10 – 40°C Oxidation/Reduction Potential: Not specified Fe^{2+} content: Not necessary pH: 5.4 – 9

Søgaard et al. [8], Sharma et al. [4], and Mouchet [3] described the iron oxidizing bacteria as a gradient organism. This means that they possess a unique property of causing oxidation and precipitation of soluble Fe(II) at conditions which straddles the theoretical boundary between the field of Fe(II) solubility and the formation of Fe(III) precipitates, as defined by the thermodynamic analysis of the electrochemical equilibrium, Figure 1. They therefore thrive well under conditions that are neither completely reduced nor completely oxidized. In water treatment plants, the conditions could be manipulated and optimized by aerating or stripping off CO₂ from the ground water.

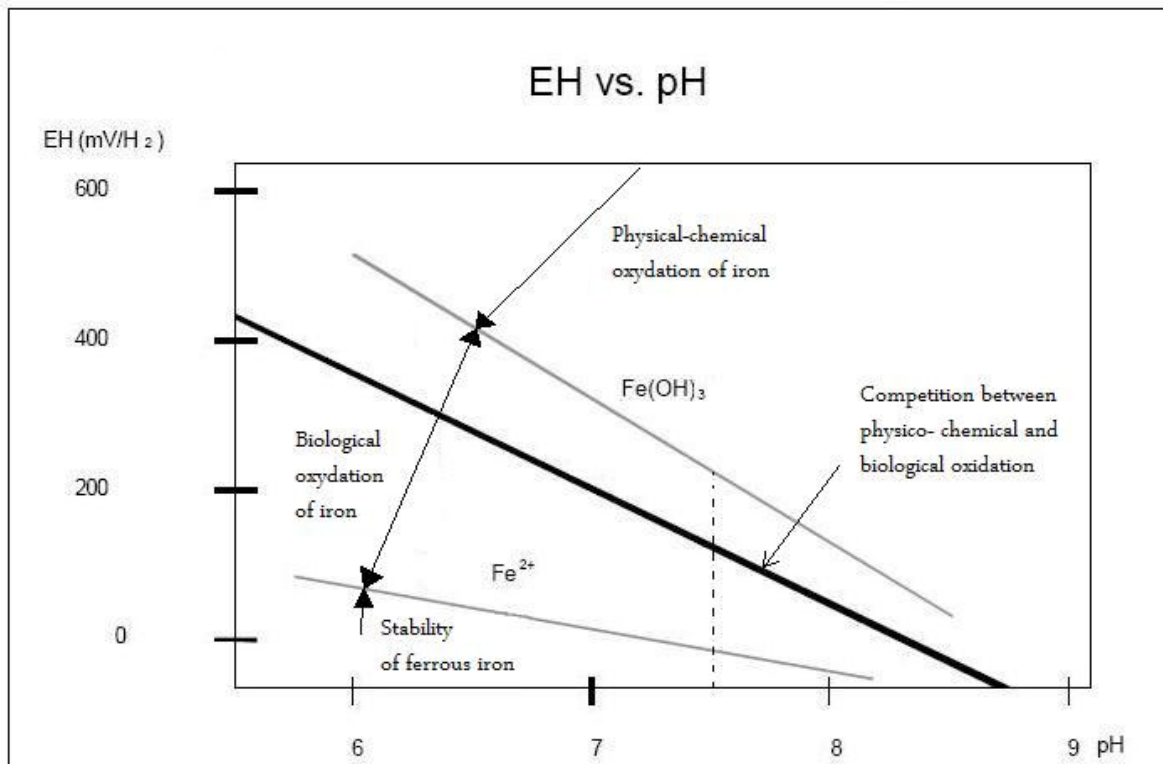


Figure 1: Field of activity of iron bacteria with respect to Eh – pH [3, 4]

Important iron removal bacteria and their morphology

Several bacteria genera and species are found in a variety of soils and aquatic habitats associated with iron. Microbiologists have subsequently investigated the physiology and the ultra structure of some of these unique micro-organisms and have published reviewed literature on them.[6, 9-12] Many iron bacteria could easily be identified directly by observation under the microscope due to their distinct characteristic sheath secretion. Examples of such bacteria are of the genus *Sphaerotilus* and *Leptothrix* group. Others like *Gallionella ferruginea* are recognised by their elongated helical or twisted stalks, composed of numerous intertwine micro fibrils but a non-stalk forming

strain has also been reported to exist.[13] Without the stalks, *Gallionella ferruginea* consist of a kidney-shaped mycoplasmodial cell body, which gives rigidity to the cell wall. On the other hand, the Eubacteria in the family Siderocapsacea, such as *Siderocapsa treubii*, *S. Major* etc might not have stalks or sheaths, making them extremely difficult to be identified.

Today, the exact function of the sheath does not remain obscure. Investigations of sludge samples from filters have revealed that massive growth of bacteria sheath have profound catalytic influence on the oxidation of iron (Søgaard). Researchers have also argued that the sheath has nutritional and ecological consequences for the iron bacteria. This is evident in their ability to grow in slow running water low in nutrients, where the present of sheath allow the bacteria to attach themselves to solid surfaces. Furthermore, the sheath defends the organism from predators and parasites.[14] Work done by Anderson and Pedersen [13] demonstrated that *G. ferruginea* stalks gives them the unique possibility to colonise and survive in habitats with high nutrients of iron, which produces toxic oxygen radical during chemical oxidation. Under such conditions, the iron is normally inaccessible to the bacteria without defence system against the oxidation of iron.

The research done by Balashova [15] to digest the stalk of *G. ferruginea* by proteolytic enzymes gives the strongest conviction that the sheaths are protein in nature. Till date, although it is known that the encrustation of the sheaths of iron precipitating bacteria is protein in nature. It is however found that besides proteins, they also contain big amounts of carbohydrates and smaller amounts of lipids.

CONCLUSION

The iron precipitating bacteria is now well known to be able to increase rates of precipitation of iron in drinking water treatment systems.

A clear metabolic reason for the huge amount of work in producing iron precipitating sheaths or stalks that these bacteria perform is still uncertain.

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