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Removal of Iron from Industrial Ground Water

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Abstract Iron is one of the most abundant element contained in the ground water. It is mostly present in the form of Iron (II), Iron (III) and metallic Iron in a negligeable quantity. When crossing the delivery network, a ground water may severely destroy it if any treatment is provided. The list of the treatment is very large: aeration, precipitation, insolubilization, cascading, filtration, reverse osmosis and adsorption.

Keywords: Ground Water, Iron (II), Iron (III), Physical-chemical Treatment, Biological Treatment

1. Introduction

Ground water is the most important form of water used for drinking, irrigation, and industrial purposes. This last point is the one which will focus our attention. Ground water is usually extracted through borehole and dispatched in the network pipe. The delivery water should first be analyzed to evaluate its harmfulness with respect to the installations. One key parameter to take into consideration is the Iron concentration.

The common forms of Iron in ground water are metal Iron (Fe), Ferrous Ion (Fe^{2+}) and Ferric oxide-hydroxide (Fe^{3+}). Fe^{2+} and Fe^{3+} are usually called Iron II and Iron III respectively. Iron II is generally soluble in an anoxic environment and colorless. In the presence of oxygen, Fe^{2+} forms Fe^{3+} which is insoluble with a rusty color. The presence of Iron in an industrial water may lead to corrosion of the delivery system, and straining of equipment, sanitations and laundry. So it is very important to remove it from water to an acceptable range.

2. Methods for removing Iron from ground water

The method to remove Iron from water are physical, chemical and biological.

Physical-chemical treatment

Aeration

Aeration consists of exposing water to the wind in order to oxidize Iron (II) into (Fe(OH)3. The key parameters to control to achieve this operation are the pH and the quantity of oxygen. Aeration is very effective for the oxidation of Iron II.

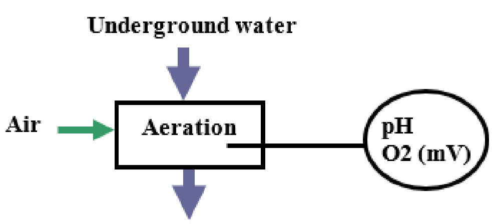

Figure 1. Aeration technique

The most common ways to perform aeration are cascading and air blowing.

Cascade aerator helps water to easily trap oxygen in the air. This system is optimal in case of nappe flow regime, presence of gravel on the Stair treads [4]. Air blowing is an injection of air using a device connected to bottom of water reservoir.

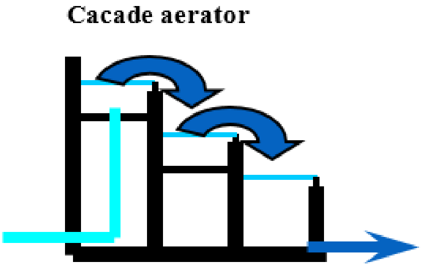

Figure 2. Illustration of Cascade technique

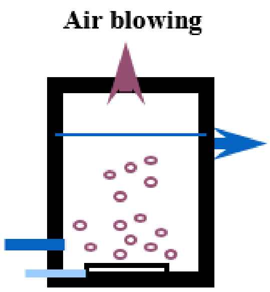

Figure 3. Illustration of Air blowing technique

Insolubilization and precipitation

This step generally follows the first one (aeration) and contribute to remove the extra quantity of Iron in water. It mainly consists of using chemical reactants such as Potassium permanganate ($KMnO_4$), Hydrogen peroxide (H_2O_2) and Ozone (O_3). The role of these agents called flocculants is to speed up the conversion of Iron into ($Fe(OH)_3$. The key parameter to control is the removal ratio of reactant with respect Iron.

On average, 1 g of $KMnO_4$ lead to the removal of 1.06 g of Iron, and 85%-96% of Iron II is removed using Hydrogen peroxide [4]. The removal efficiency is highly dependent on the pH and the contact time.

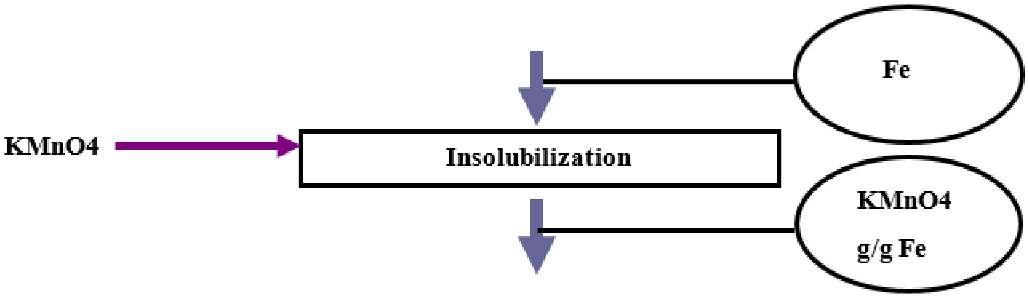

Figure 4. Illustration of Insolubilization technique

Lime ($Ca(OH)_2$) softening is used to remove Iron from water due to hardness reduction. The reaction of lime with ground water provoke the reduction of water hardness owing to Calcium carbonates ($CaCO_3$) and Magnesium Hydroxides ($Mg(OH)_2$) precipitation. According to [3], hardness removal from carbonate, calcium and magnesium rich water occurs as follow:

Carbonic acid neutralization:

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_{3(s)} + H_2O$$

For carbonate rich groundwater:

$$Ca^{2+} + 2HCO_3^- + Ca(OH)_2 \rightarrow 2CaCO_{3(s)} + 2H_2O$$

$$\mathbf{Mg^{2+} + 2HCO_3^- + Ca(OH)_2 \rightarrow MgCO_3 + CaCO_3 + 2H_2O}$$

$$\mathbf{MgCO_3 + Ca(OH)_2 \rightarrow Mg(OH)_{2(s)} + CaCO_{3(s)}}$$

For calcium rich ground water

$$\mathbf{Na_2CO_3 + Ca(OH)_2 \leftrightarrow CaCO_{3(s)} + 2NaOH}$$

$$\mathbf{Ca^{2+} + Na_2CO_3 \rightarrow CaCO_{3(s)} + 2Na^+}$$

For magnesium rich ground water:

$$\mathbf{Mg^{2+} + Ca(OH)_2 \rightarrow Mg(OH)_{2(s)} + Ca^{2+}}$$

$$\mathbf{Ca^{2+} + Na_2CO_3 \rightarrow CaCO_{3(s)} + 2Na^+}$$

When $CaCO_{3(s)}$ and $Mg(OH)_{2(s)}$ precipitate they carry Iron and contribute to its precipitation this is the so called co-precipitation.

Decantation

The objective of decantation is to eliminate the maximum insoluble compounds and to avoid the filters to get clogging too quickly. The key parameter to control at this stage is the water turbidity.

Filtration, reverse osmosis, Ion exchange and adsorption

The objective of this stage is to ensure the quality of the water in term of Iron and Turbidity content. The key parameter to control are turbidity and total discharge Head. The filter media of the filter can be made up of several compounds for instance, we can use rice straw, limestone and quartz sand [2,7]. After filtration, a dirty water should be collected for further treatment before dumping to the environment or reused if needed. The mechanism should be maintained currently to avoid clogging as we can see in Figure 5, washing air and water is required for this purpose.

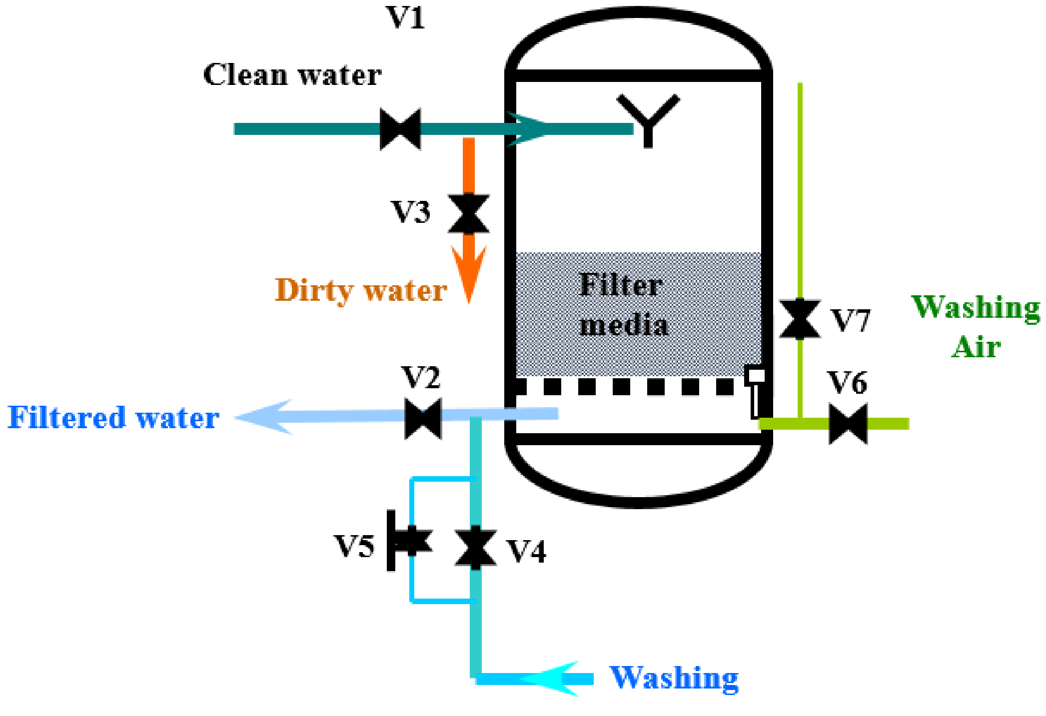

Figure 5. Illustration of filtration technique

During reverse osmosis, water passes through semipermeable membranes which retain soluble Iron. This technology work optimally when there are no solid forms into water to prevent clogging. As the oxidation of Iron rich water lead to $(Fe(OH)_3$ precipitation which may clog the membranes, reverse osmosis is very difficult to implement.

The removal of Iron ions using ion exchange consist of exchange Iron ions with less harmful ones. In the practice, it is very difficult to remove only Iron ions; so a resin containing both ions and cations are used to completely demineralize the water. The demineralized water is then mixed with the raw water to obtain the desired Iron concentration. Ion exchange is very sensitive to oxygen: in an oxic environment, formed precipitates may saturate the resin bed and block the process.

The adsorption is the bound of element in a solid interface [1], we currently referred to adsorbent such as porous ceramic, clay and limestone. The ultrasound associated to Porous ceramic increase the removal rate of Iron from water by 29.6% [6].

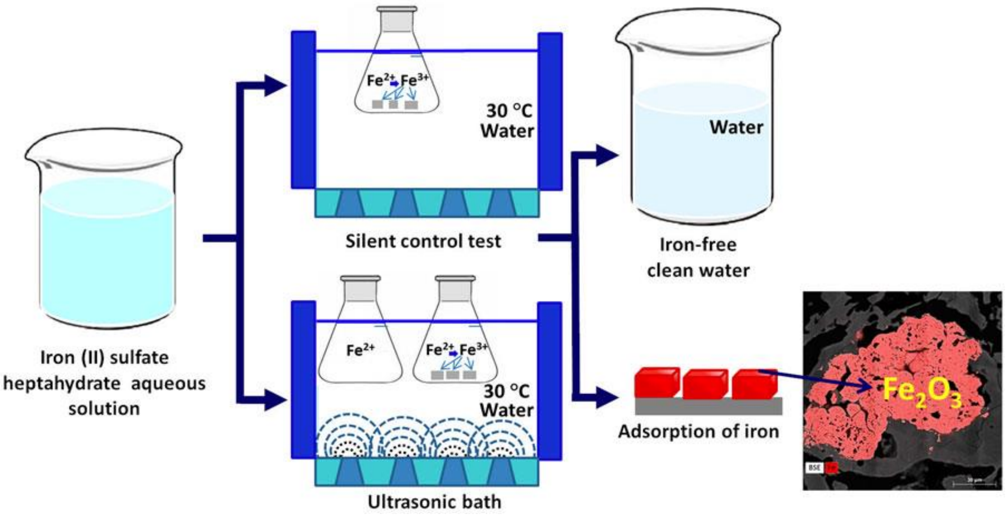

Figure 6. Ilustration of Adsorption with ultrasound technic [6].

Biological treatment

Bacteria are used to assimilate Iron (II) from water. According to [8], the treatment is done by the bacteria *Gallionella*, *Leptothrix, Crenothrix, Clonothrix, Sphaerotilus* and *Siderocapsa*. Meanwhile, high pH and oxygen concentration as well as the presence of hydrogen sulfide (H_2S), ammonium ion (NH_4^+), Zinc (Zn) and bleaching agents will negatively impact the action of the bacteria.

The implementation of a biological treatment starts with water aeration which will oxidize water thus remove a part of H_2S. The parameter to control is the air flow, pH and O_2 concentration. The main risk is an excessive clearance of CO_2 leading to high pH and ($Fe(OH)_3$ precipitation. The filtration closes this process.

Conclusion

This work aims to propose an overview of different technics used to remove Iron, Iron(II) and Iron (III) from industrial water: biological treatment and physical-chemical treatment. Each of these treatment has its own specificities, advantages and inconveniences. The user will decide based on the analysis of the raw water but also its capability: finance, technical skill and logistics.

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