Iron and Manganese Removal Handbook

Second Edition

American Water Works Association

4

Overview of Treatment Technologies

Several treatment methods may be used to remove iron and manganese from drinking water supplies. This chapter provides an overview of treatment options that should be considered for iron and manganese removal and includes guidance regarding selection of treatment methods for a particular application.

Over the past decade or so, advances in treatment technologies have allowed systems to be constructed in less space, produce fewer residuals, and treat multiple contaminants.

This chapter addresses two key questions:

1. Why consider new technologies?
2. When should traditional technologies be used?

A few years ago, a utility discovered that a well with elevated iron (10 mg/L) and manganese (0.5 mg/L) also showed evidence of surface water contamination. Traditional treatment methods would have included the use of clarification, oxidation, coagulation, and filtration. Instead, the utility was able to use an ultrafiltration (UF) membrane to accomplish the removal of the iron, manganese, and pathogens. No clarification or coagulation was needed. The use of membranes was—and in some cases still is—considered to be an innovative treatment technology. The use of membranes resulted in significant savings for the owner. Figure 4-1 describes the traditional and newer technologies that can be used to remove iron and manganese.

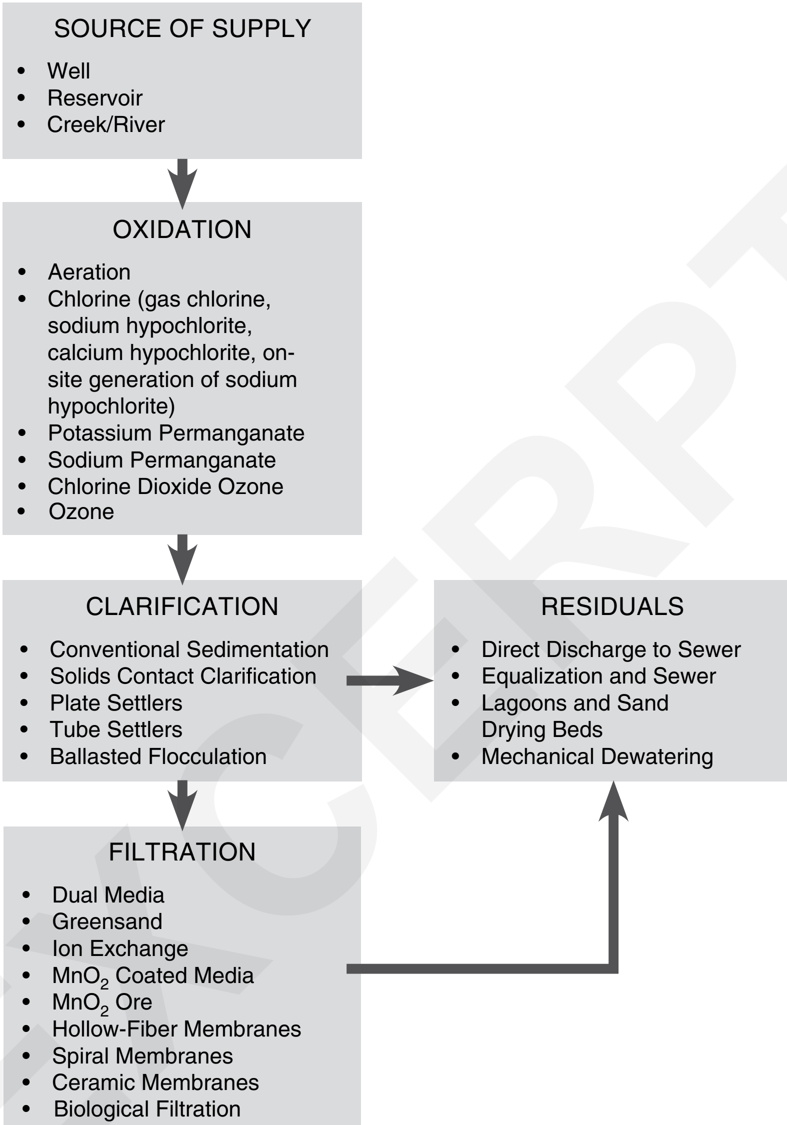

Figure 4-1 Technologies for iron and manganese removal
Source: Hatch Mott MacDonald

OVERVIEW OF TECHNOLOGIES

The treatment for iron and manganese typically involves multiple unit processes. The answer to the question "When should traditional technologies be used?" can be found in the properties of iron and manganese that are encountered in source waters.

As discussed in chapter 1, iron and manganese are often found in water supplies in their dissolved state. Traditional technologies involve converting these dissolved forms to a particulate form that can be clarified and filtered. The conversion from dissolved to particulate forms requires the use of an oxidant. Traditional forms of oxidation are well understood and can be successfully employed.

Conventional sedimentation and filtration technologies are well suited for the removal of particulate forms of iron and manganese. Traditional technologies are typically simple to operate and generally do not employ the use of proprietary treatment technologies.

Innovative technologies may be beneficial for small sites or in situations that have multiple contaminants. Nontraditional technologies may warrant consideration for systems with the following conditions:

- High concentrations of radionuclides
- Wells under the influence of surface water
- Wells with high iron/manganese and limited space
- Sites where disposal of residuals is problematic
- Sites where very high backwash volumes would impact water production

The nontraditional treatment methods for the removal of iron and manganese include the following:

- Ballasted flocculation
- Membrane filtrationBiological filtration

When selecting and designing a process for iron and manganese treatment, the quality of the source water should be analyzed comprehensively, because some contaminants can affect the operation of the system. For example, radiological contaminants may be removed by some types of filter media, but the media may become radioactive, resulting in safety concerns and increased cost for media disposal. In most cases, separate treatment for radiological contaminants may result in a lower life-cycle cost.

SEQUESTRATION

Sequestration is a form of treatment in which a chemical, known as a sequestrant, is added to groundwater. The chemical forms a bond with iron and manganese ions, allowing them to remain in solution. Sequestration for drinking water treatment of iron and manganese is generally limited to sources where the iron is less than 0.6 mg/L and the manganese is less than 0.1 mg/L. Sequestration of source water concentrations above these values may result in aesthetic issues in the distribution system and is generally not allowed by regulators.

OXIDATION, CLARIFICATION, FILTRATION

Most iron and manganese removal treatment processes incorporate oxidation to convert the dissolved forms of the metals to a solid, followed by a filtration process. When concentrations in the source water are above 8 to 10 mg/L combined iron and manganese, a clarification step is typically required prior to filtration. A combined iron and manganese concentration of 8 mg/L will generally result in a filter run time of less than 24 hours for sand/anthracite filters as well as greensand-type filters.

The clarification process reduces the amount of solids that must be removed by the filters, which results in longer filter run times before backwashing is required. Clarification may be achieved using any number of technologies, such as conventional sedimentation, plate or tube settlers, solids-contact clarifiers, dissolved air flotation, or ballasted flocculation. The type of filtration used in this treatment approach may be a conventional dual-media anthracite-and-sand filter, a mono-medium sand or anthracite filter, glauconite, manganese dioxide–coated sand media, or manganese dioxide ore.

OXIDATION, MANGANESE DIOXIDE–COATED MEDIA FILTRATION

Filtration using manganese dioxide–coated and ore-type catalytic media, such as manganese greensand, has historically been used for iron and manganese removal. In recent years advances have been made in the types of manganese dioxide media, allowing for higher loading rates and reducing backwash requirements.

Several different types of proprietary manganese dioxide–coated media filtration systems are available for iron and manganese removal. Although the mechanics vary, the basic treatment provided is oxidation of iron and manganese with the addition of chlorine or potassium permanganate followed by filtration of precipitates. Manganese dioxide coating on the filter media acts as a catalyst for the oxidation and reduction of iron and manganese.

Some of the proprietary media on the market include the following:

- Ferrosand® manganese greensand produced by Hungerford and Terry
- GreensandPlus™ synthetic manganese greensand produced by Hungerford & Terry
- LayneOx™ produced by Layne Christensen Company
- ANTHRA/SAND™ produced by WesTech

These media can be classified into two groups: manganese dioxide–coated sand and manganese dioxide ore. All these media are similar in that they use a combination of chemical oxidation and catalytic media to remove iron and manganese in water. Different proprietary media have different specific mechanics, loading rates, backwashing requirements, and removal efficiencies.

Design of the manganese dioxide–coated media systems is discussed in further detail in chapter 7.

OXIDATION, MEMBRANE FILTRATION

Membranes are often used for removal of turbidity and pathogens from surface water and groundwater under the direct influence (GUDI) of surface water. Membranes are also used for iron and manganese removal. Membrane treatment is often a viable option for GUDI wells that require treatment for iron and manganese. Membranes may be considered as a treatment option when the source water is non-GUDI groundwater, but typically are not the most cost-effective treatment solution in this situation.

Membrane systems operate by straining out particles that are larger than the pore size of the membrane. Microfilters are generally classified as having openings between 0.05 and 1.0 microns, whereas ultrafilters are generally classified as having openings between 0.005 and 0.05 microns. Dissolved iron and manganese converted to particulate form via conventional oxidation can be subsequently strained out on the membrane.

Several manufacturers of micro/ultrafilters have experience in treating water for iron and manganese. Each system uses a unique membrane and operates slightly differently in terms of backwashing and cleaning. Pressurized and immersed membrane systems are available.

BIOLOGICAL FILTRATION

Hydraulically, the biological filtration process operates similarly to a pressure filter in that raw water is pumped through a pressure vessel containing a granular media. However, unlike most other pressure filtration systems, which rely on the formation of a chemical precipitate and subsequent filtration, biological processes do not require any chemical oxidants.

Instead, conditions are established in the pressure vessel that foster the growth of bacteria. These bacteria oxidize the iron and manganese in the raw water, which is then retained within the filter in the form of dense precipitates. These precipitates are more compact than the amorphous precipitates formed during chemical oxidizing processes. Therefore the biological filter has a higher iron and manganese retention capacity (up to five times higher). The increased metal retention capacity allows the system to achieve long filter run times. Air is continuously injected into the raw water to provide the proper growth environment for the bacteria.

It is important to note that the required environmental conditions for biological iron removal are different than those for biological manganese removal. Therefore, where both iron and manganese are present, two stages of biological filtration are required: one for biological removal of iron and one for biological removal of manganese.

Biological filtration processes for removal of iron and manganese are proprietary patented systems manufactured by Infilco Degremont, Inc., marketed under the names Ferazur® and Mangazur®. Design of biological filtration systems is discussed in further detail in chapter 7.

RESIDUALS

All iron and manganese removal processes generate residuals. The requirements for residuals treatment will differ at each site depending on land available, the viability of disposal of waste to a sanitary sewer, the feasibility of recycling to the head of the plant, and other factors. The residuals generated by the treatment process and the options for treatment should be considered when selecting an iron and manganese removal process.

Some residuals treatment processes that may be considered include the following:

- Direct sewer discharge
- Equalization followed by sewer discharge
- Batch settling with decant recycle and solids discharge to sewer

- Equalization followed by treatment using plate settlers with decant recycle
- Lagoons
- Mechanical dewatering

Chapter 8 provides a discussion of residuals handling.

EVALUATION AND SELECTION CRITERIA FOR OPTIMUM TREATMENT

The process of evaluating and selecting a treatment option involves quantifying the iron and manganese concentrations in the source water, identifying other water parameters that require or impact treatment, and establishing the finished water quality goals.

Understanding the project constraints, such as site conditions, sewer availability, and regulatory acceptance will inform the selection process. Initial technologies should be screened for their potential feasibility and a subset of unit processes established for further evaluation. The evaluation generally consists of the preparation of concept-level designs for each option, including the development of a flow schematic, building floor plan, section, and site plan. These drawings are then used to develop construction, operating, and life-cycle costs.

In addition to the cost estimates, other factors should be considered. The technical and financial feasibility of a treatment option should be the primary criteria, but qualitative issues should also be weighed where more than one viable treatment option exists. Some qualitative considerations may include sustainability, operational flexibility, maintenance requirements, ease of integration into an existing facility, complexity of the process, track record of the proposed technology on similar applications, and location of service technicians.

The full list of qualitative issues that should be considered will vary from site to site and client to client. An example evaluation methodology (qualitative ranking matrix) is presented in Table 4-1. In order to develop a collaborative input/output for the qualitative analysis, the project team should consider completing the ranking matrix with the input of the owner and operations staff to establish the relative weight and rating components.

Table 4-1 Qualitative ranking matrix for determining suitability of an iron and manganese removal system

Criteria	Relative Weight (0–5)	Rating (1–5)	Weighted Rating
Overall system criteria			
Confidence in technology for iron and manganese removal			
Confidence of the technology for crenoform removal			
Equipment complexity—number of pumps and compressors			
Location of service technicians			
Operating costs			
Residuals			
Residuals generation as percent of overall plant output			
Impact of residuals recycling on plant performance			
Level of treatment required for residuals			
Ability to send residuals to sanitary sewer			
Operational criteria			
Level of operator attention required			
Ease of maintenance			
Experience in treatment chemicals used			
Ease of startup and shutdown of system			
Layout-related criteria			
Ease of integration with existing facilities			
Layout flexibility—restrictions on equipment location			
Total Weighted Rating			

TREATMENT SYSTEM DESIGN ELEMENTS AND WORK FLOW

The design of an iron and manganese treatment system begins with the process engineer defining the water quality and flow rate requirements of the system. This is followed by a conceptual evaluation phase and subsequent preparation of a basis of design report, which is followed by preparation of the design documents. The following sections present a suggested design sequence and description of the major design elements.

Conceptual Design

Define the concentration of contaminants in the raw water and develop minimum, average, and maximum concentrations. For surface water supplies, seasonal variations should be considered and data obtained. The concentration of all primary and secondary regulated contaminants should be obtained in order to ensure that all of the potential regulatory issues are addressed.

In addition to iron and manganese, analyses of the following constituents are also recommended, since they could impact the design and operation of the system:

- Hydrogen sulfide (H_2S)
- Silicon dioxide (SiO_2)
- Ammonia
- Radionuclides including radium, and uranium. Note that even if these values are below the MCL, some treatment media can remove these contaminants and the media may become radioactive.
- Contaminants that may be regulated by USEPA or are regulated by some states, e.g., perchlorate and methyl-*tert*-butyl-ether (M*t*BE)

In addition, for well water systems, a microscopic particulate analysis (MPA) should be conducted to assess if the groundwater is under the direct influence of surface water.

Define the treatment capacities of the system: minimum, average and maximum. Also establish any seasonal variations in capacity.

Define the treatment goals and regulatory requirements. For example:

- Is satisfying the secondary MCL acceptable, or are lower concentrations desirable?
- What are the regulatory requirements regarding loading rate? Is a waiver needed for the use of higher loading rates?

Define the site constraints including the following:

- Are there constraints on exposed vessels?
- Is the space site limited, requiring high-rate processes?

Define residuals-handling constraints including the following:

- Are sewers available, and do they appear to have sufficient capacity for iron and manganese liquid residuals?
- Is there sufficient space for sand drying beds?
- Are residuals required to be hauled off-site or recycled because of the lack of sewers?
- Is recycling of decanted residuals needed to minimize water consumption?

Based on these considerations, develop a set of treatment options for conceptual evaluation.

Perform a conceptual treatment evaluation that provides the following:

- Process floor plan showing overall equipment dimensions and orientation
- Site plan with concept contours and piping
- Estimate of electrical loads
- Capital, operating, and life-cycle costs based on process layouts
- Evaluation of noneconomic issues such as ease of operation and reliability

Discuss the evaluation with the owner, and provide a recommendation for final design.

Perform pilot testing if the process requires a loading rate higher than is permitted by regulations, if competing treatment technologies are being evaluated, or if there are site-specific water quality issues.

Detailed Design

Develop the basis of design report (BDR) that defines the design criteria for the treatment processes along with the design requirements for the support design disciplines (i.e., structural, architectural, electrical, etc.).

The BDR should include the following:

Design criteria

- Process and instrumentation diagram (P&ID). The equipment and piping portion of the P&ID should be included.
- A functional description of the control approach

- Process mechanical floor plan section completed to approximately 30 percent
- Site plan completed to approximately 30 percent
- A construction cost estimate

If permitted by regulatory agencies, consider submitting permit applications using the 30 percent drawings provided with the BDR. Discuss the BDR with the owner, and use it for development of the plans and specifications.

Design drawings

- Distribute the mechanical plan and section to other design disciplines and proceed with developing structural; architectural; plumbing; heating, ventilation and air conditioning (HVAC); and control design.
- Revise the process mechanical layout as needed.
- Develop technical specifications.
- Submit design drawings to the owner for review at the 60 percent, 90 percent, and 100 percent levels of design completion.

SUMMARY

The ultimate goal of an iron and manganese treatment system is to have a facility that does the following:

- Achieves the treatment objectives
- Is cost effective
- Is sustainable
- Allows for straightforward operation
- Is not complex and costly to maintain
- Enables comprehensive data collection along with the systems to analyze and interpret the data
- Is flexible enough to address future changes in regulations
- Will meet system needs with minimal upgrades for 20+ years

Satisfying these objectives will involve a project team consisting of design engineers, regulators, operators, and the owner. For the project to succeed especially in the long term, active participation of the owner and operators during the design is vital. These people have institutional knowledge regarding issues such as changes in source water quality, site conditions, and preferences regarding equipment operation and maintenance.

Throughout the design process, all the stakeholders should actively communicate by assessing and as necessary challenging the design decisions, equipment selection, and layout. Approaching the project design in a collaborative and open fashion will foster project success.